Knostrop Sludge Treatment Facility Secondary Containment Assessment

June 2021

YorkshireWater

Stantec

Sign-Off Sheet

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1 Introduction

As part of the Industrial Emissions Directive (IED) permit application for Knostrop Sludge Treatment Facility (STF), Yorkshire Water (YW) has undertaken an assessment of the significance and potential environmental risks associated with a loss of containment of sludge containing process vessels. YW has also reviewed existing provisions and potential improvement options against Best Available Techniques (BAT) principles, in alignment with CIRIA 736[1].

Knostrop STF falls under the IED as a Part A(1) installation by virtue of exceeding the 100t/d throughput limit for anaerobic digestion (AD). The permit will cover sludge import, bulking and blending, sludge screening, sludge thickening, the storage of sludge in feed tanks, sludge digestion, biogas processing and utilisation, sludge dewatering, liquor treatment, and cake management (plus the associated Odour Control Unit (OCU)). This document focuses on the secondary containment aspects of the permit requirements, in particular the application of BAT, and should be viewed in parallel with the main permit application document, in particular Section II: Technical Description, Section III: Accident Risk Assessment and Section V: Site Condition Report.

1.1 Site details and planning permission

Figure 1 shows an arial view of Knostrop STF. Knostrop is a large STF and is situated in south-central Leeds, England. The site treats indigenous sludge from the co-located wastewater treatment works which serves a population of around 1.2 million people from the surrounding areas and it also receives imports of sludge from other YW sites.

Figure 1. Knostrop STF aerial view. Permit boundary in green. © Google, 2021

[1] CIRIA (2014) Containment systems for the prevention of pollution: Secondary, tertiary, and other measures for industrial and commercial premises (C736; 2014)

Figure 2 indicates the key activities at Knostrop STF via a process flow diagram. The key activities are the sludge import reception, sludge thickening plant, digestion, heat and power, dewatering, and liquor treatment operations and associated routes of gaseous, liquid, and solid materials and energy vectors. These processes are further discussed in Section 3.2.1.

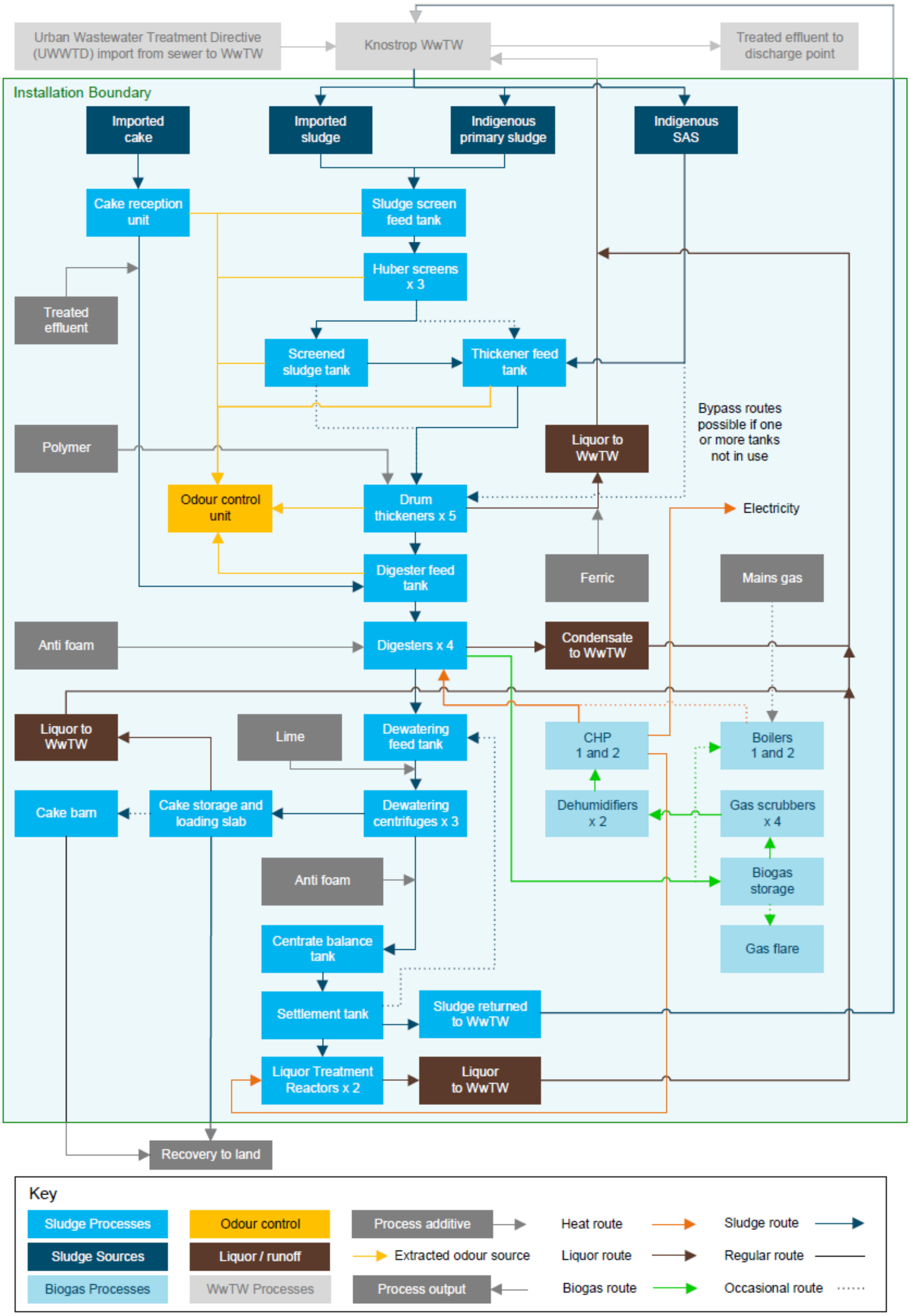


Figure 2. Process flow diagram Knostrop STF.

1.2 Overview

YW commissioned Stantec to assess existing provisions and potential improvement options for secondary containment at the site. Stantec have provided risk-based supporting evidence to accompany the permit application, which demonstrates the most appropriate solution(s) for IED BAT compliance using CIRIA 736 standards. To fully understand the requirement for secondary containment and to provide environmental protection at Knostrop, two different industry standard tools have been used, these are shown within the flow chart in Figure 3.

Firstly, the Anaerobic Digestion and Biogas Association (ADBA) secondary containment risk assessment tool has been applied to assets at Knostrop. The ADBA assessment tool provides a methodology for determining the specific design of secondary containment systems at a site, based on an assessment of sources, pathways and receptors which are at highest risk, and the types of control options which would provide protection. However, as an existing installation in continuous operation, retrospectively applying a standard secondary containment bund to all sludge tanks and containers presents significant technical, operational, safety and logistical challenges. It is also noted that the location of Knostrop STF within a wider wastewater treatment works (WwTW) presents opportunities in terms of utilising other existing YW assets as part of the pollution containment and prevention solution, and the ADBA tool does not have the flexibility to reflect this in the solutions it recommends.

Having regard to this limitation, a bespoke source, pathway, receptor approach has been developed by Stantec and applied to identify and risk assess the traditional bunding solutions favoured by the ADBA approach, as well as additional site-specific options for secondary containment. This has allowed the standard secondary containment bund wall indicated by ADBA to be assessed against several alternative options with the potential to provide an equivalent level of environmental protection. The identified options were then taken through a structured, risk-based assessment to identify the most appropriate secondary containment options.

Whilst these tools are discrete pieces of work, they come together to provide a detailed evidence base for intervention at Knostrop.

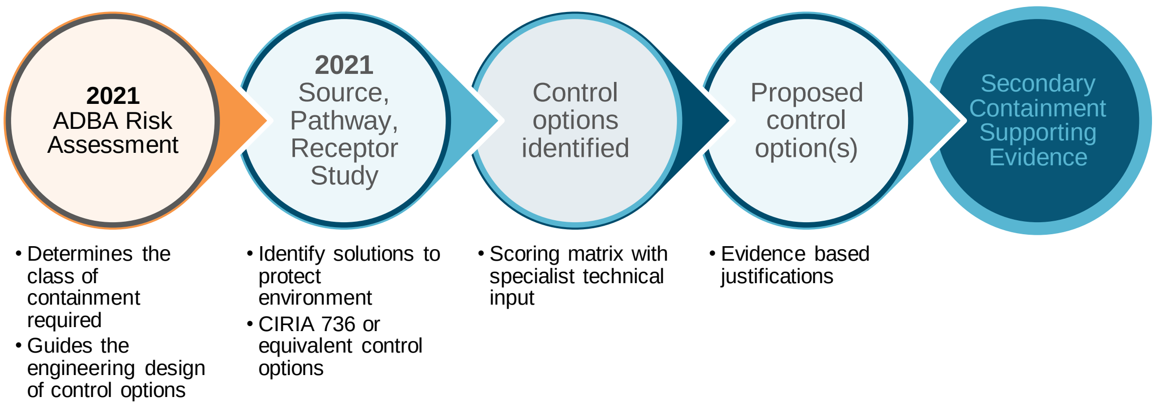


Figure 3. Flow chart showing the approach taken to provide secondary containment supporting evidence.

2 ADBA risk assessment tool findings

The ADBA Risk Assessment Tool is based on CIRIA 736 requirements for the prevention of pollution: including secondary and tertiary containment, and other measures for industrial and commercial premises. An assessment is presented in 0; the findings are summarised in this chapter.

2.1 Class of required secondary containment for Knostrop

To identify the class of containment deemed to provide sufficient environmental protection in the ADBA Risk Assessment, the tool uses a source, pathway, receptor model. This identifies hazards posed to the environment and assigns a class of containment based on the site hazard rating and likelihood of loss of primary containment. The approach is summarised in Figure 4.

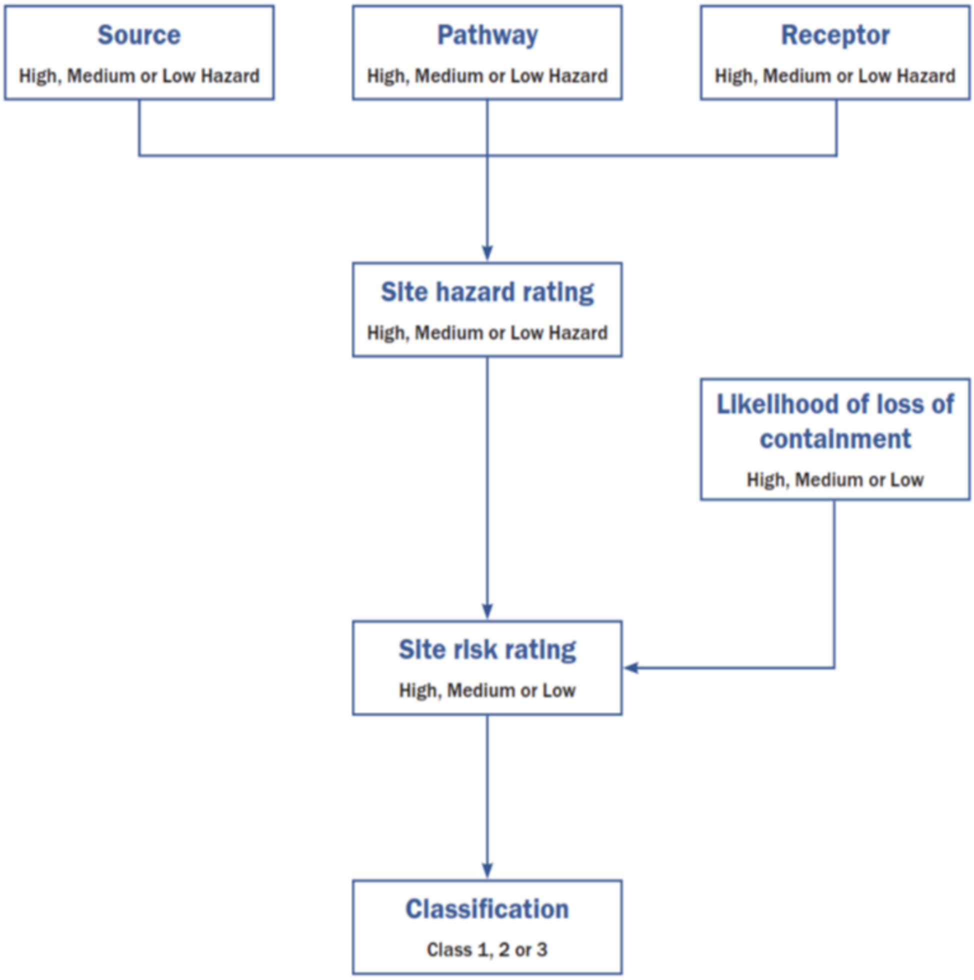


Figure 4. ADBA risk assessment classification flowchart.

The ADBA Risk Assessment Tool scored the source element as ‘High risk, the pathway element as ‘Medium risk’ and the receptor element as ‘High risk’ at Knostrop owing to the significant volumes of sewage sludge stored onsite and due to the potential for surface runoff and site drainage pathways to a sensitive receptor, the Wyke Beck. This gave Knostrop STF an overall a site hazard rating of ‘High Risk’. The likelihood of failure was ‘Low Risk’ due to the type of infrastructure involved and the mitigations at the site e.g., regular tank inspections and level sensors.

According to Table 4 within the ADBA tool (box 2.2 CIRIA 736), reproduced in Figure 5 below, the combination of a high site hazard rating and a low likelihood rating, gives the overall site risk as medium. The indicated class of secondary containment for **Knostrop STF was therefore deemed as being Class 2**.

Table 4: Overall site risk rating as defined by combining ratings of site hazard and probability of containment failure *(Box 2.2 CIRIA 736)*

Possible combination	Overall Risk Rating	Indicated class of secondary containment
HH, HM, OR MH	HIGH	Class 3
MM, HL, OR LH	MEDIUM	Class 2
LL, ML, OR LM	LOW	Class 1

Figure 5. ADBA classification matrix.

The ‘Knostrop STF ADBA Secondary Containment Risk Assessment’ contains detailed justification for this scoring and is included in 0.

The conclusion that ‘Class 2’ type secondary containment is indicated for the Knostrop site was taken forward to inform the next stage of the risk assessment, spill modelling and if necessary, the site-specific options appraisal carried out by Stantec in 2021 to support the permit application process (See Chapter 3).

3 Options appraisal

3.1 Objectives

The purpose of this stage of the assessment is to determine the significance and potential environmental risks associated with a loss of containment from sludge vessels within the Knostrop STF, and to review existing provisions and potential improvement options against BAT principles, including CIRIA 736. As described previously, this stage of the process is informed by the outputs of the ADBA tool, but also considers options which are outside the scope of the ADBA scoring system utilising a bespoke methodology which adopts source-pathway-receptor principles in a qualitative risk-based framework.

3.2 Sources in the anaerobic digestion area and dewatering areas

The sources of risk which have been identified at Knostrop are shown in Figure 6 below. These assets occupy two areas of the site, which are considered separately within this report:

- the anaerobic digestion facility (including a sludge import reception and indigenous sludge thickening operations) – 'Area A'.
- the dewatering and liquor treatment area (which also includes a dewatering feed tank that holds digested sludge) – 'Area B'.

A third permitted area located to the north-west currently contains no storage vessels and is outside the scope of this report.

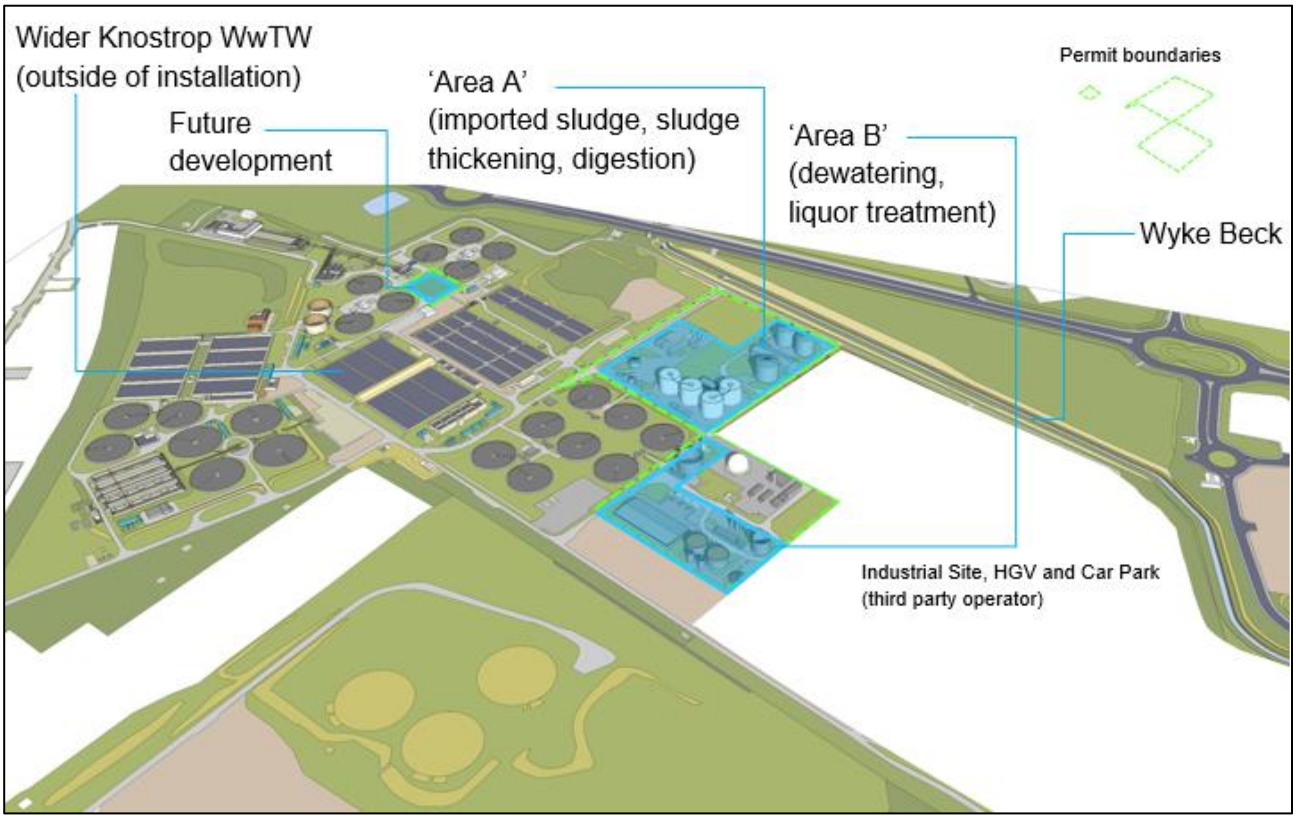


Figure 6. Knostrop sources of risk and site areas.

3.2.1 Bulk storage vessels (Area A)

A detailed discussion of risk sources and existing control and mitigation measures associated with Area A is provided below.

3.2.1.1 Sludge unloading area

Sewage sludges generated by smaller YW sewage works (with lower capacity or capability for treating sludges on-site) are imported to Knostrop STF for additional treatment. These sludges may be received in the form of thickened sludge, un-thickened sludge or undigested sludge cake and is delivered to site by tanker or tipper lorry.

The unloading processes are completed by tankers and/or tipper lorries controlled by approved YW supplier(s). Only appropriately authorised vehicles are able to discharge/unload at the site. This is controlled through the use of 'WaSP' loggers, valves on the discharge pipework will only open when a driver presents appropriate authentication to the system. The WaSP loggers record the source of the material, the time and date of delivery, the total volume discharged and average percentage dry solids of the load.

Sludge cake is delivered to the site by covered tipper lorry, the maximum load is typically 28 tonnes with unloading routinely taking up to 30 minutes. Sludge cake is tipped from enclosed wagons into one of two dedicated sludge cake reception units (Figure 7) which are fully enclosed when tipping operations are not taking place and have odour extraction routed to the Odour Control Unit (OCU). Sludge is moved from the tipping area via a conveyor belt which moves the sludge up and into a hopper. An enclosed screw conveyor then moves the sludge to the rewetting pump where final effluent is added (to a target of 6% dry solids) and pumped to the digester feed tank (5,376 m3 GRP coated steel). All above ground transfer lines are lagged and heated to reduce the risk of freezing and pipe rupture.

Figure 7. Cake unloading area and reception units.

3.2.1.2 Sludge screen feed tank (1 no.)

Primary sludge is pumped underground from the Knostrop WwTW to the sludge screen feed tank (Figure 8, 540 m^3 GRP coated steel with elevated concrete base and sloped floor to gravitate the sludge out onto the downstream sludge screens) where it combines with imported liquid sludge. Imported liquid sludge is delivered to site by tanker. The tanker unloads at the dedicated sludge import area and sludge is pumped, using vehicle mounted pumps and assisted by an in-line pump when necessary, to the sludge screen feed tank. Headspace air from this tank is routed to the Odour Control Unit (OCU).

Figure 8. Sludge unloading area and sludge screen feed tank.

Indigenous primary sludge and imported sludge is screened using three Huber Rotamat's enclosed rotating screens running duty/assist/standby (Figure 9). These enclosed rotating sludge screens reduce odour generation risk. Cake imports are not screened within the permitted installation. Screenings drop into a skip and are disposed of off-site. After screening, sludge is pumped via a covered sub-surface concrete sump, to the screened sludge tank (Figure 10, 3,855 m^3 GRP coated steel). Headspace air from this tank is also routed to the OCU.

Figure 9. Enclosed rotating sludge screens and skips.

Figure 10. Left: screened sludge tank, right: pipe lagging.

3.2.1.3 Sludge thickener feed tank (1 no.)

Indigenous Surplus Activated Sludge (SAS) is pumped underground from Knostrop WwTW to the thickener feed tank (Figure 11, 3,855 m^3 GRP coated steel), where it combines with the screened sludge before being pumped to the thickener building. Headspace air from the thickener feed tank is extracted and routed to the OCU. The tank contents are independently mixed (using air injection), powered by air compressors.

A number of bypass options are available at this point in the process, to allow for a single tank to be taken off-line for cleaning / general maintenance. These enable direct transfer of sludge from the screened sludge pumping station to the thickener feed tank, direct transfer from the screened sludge tank to the thickeners, or direct transfer of the incoming SAS to the thickeners. These options would be sub-optimal from a digester yield perspective but provide operational flexibility and enhanced process control.

Sludge from these tanks is transferred to the adjacent thickener building via the thickener feed pumps. Within the thickener building, liquid polymer, delivered in bulk by tanker (to 20,000 litre GRP tank) and by IBCs is first diluted with potable water (in a second 20,000 litre GRP coated steel tank) then mixed with final treated effluent as a carrier and introduced to the sludge via in-line injection. Both the bulk polymer storage tanks and mixing pumps are surrounded by a large below ground sump to provide secondary containment in the event of spills/leaks. Drainage of the sump bunds is controlled by a normally closed manually actuated valve, which returns bundwater to the WwTW for treatment. The sump is fitted with a high-level probe larmed to the PLC. The PLC includes level sensors to reduce risk of tank overtopping, which would result in contamination and potential odour generation.

After the injection of polymer, the sludge passes through a shear valve to break up the large pieces before transfer into individual flocculation tanks, collocated with each of the five thickener drums. The flocculation tanks give time for the sludge and polymer to mix prior to entry into the drum thickeners. Each of the five thickener drum units comprises of a single hopper serving two individual drums, operating on a 1 x duty/3 x assist/1 x standby basis. The polymer encourages separation of water and sludge as the thickened sludge is rotated in the drum to remove excess liquid. The drum thickeners have a cleaning-in-place (CIP) system installed, which utilises final treated effluent. Each thickener is subject to an automatic wash down on every shut down, and periodic manual washouts in the case of a pump failure. The internal area surrounding the drum thickeners is bunded.

The liquors are currently transferred via the filtrate pumping station to Knostrop WwTW. It is proposed to add a facility to dose these liquors with a ferric solution prior to their return to the WwTW, to reduce the concentration of phosphorous. This is likely to comprise of an additional storage vessel (capacity and type to be confirmed) and dosing facility. As the design is not finalised, spills in this area are outside the scope of this document.

Figure 11. Sludge thickener feed tank (first on the right).

3.2.1.4 Digester feed tank (1 no.)

The thickened sludge is then transferred to the digester feed tank (Figure 12, 5,376 m^3 GRP coated steel), where it is mixed. Air compressors provide tank mixing. Headspace air from these tanks is routed to the OCU.

Figure 12. Digester feed tank.

3.2.1.5 Digesters (4 No.)

Blended sludges are pumped using one of three hydraulically driven pumps from the digester feed tank to the anaerobic digesters (Figure 13, 4 no. 7,306 m^3 concrete tanks). The pump and compressors are located externally within a bunded area. Rainwater is periodically drained to the site system and returned to the WwTW. Any build-up of oil is removed by tanker to an appropriate facility. The anaerobic digesters operate independently in pairs, in a continuous process with sludge being added at the bottom of the tank, displacing treated sludge which leaves through discharge pipes at the top of the digester. Digester feed rates are in part determined by the dry solid component but typically 1,600 m^3 /day is achievable; this results in a 19-day retention time (greater than the 12-day minimum required by Hazard Analysis and Critical Control Points (HACCP) controls). The digesters are mixed by gas mixing systems, which utilise biogas from the headspace of each digester; the gas is compressed and then reintroduced using an array of mixing nozzles on the floor of the digester.

A hot water circuit provides heating to ensure optimum conditions for digester microbial activity, typically maintained at around 37.5°C. Mains water is heated to around 70°C by the CHPs. Boilers are available in the event that the CHP engines are off-line. This hot water then heats the digester using tube-in-tube, counter current heat exchangers. Sludge in the digesters is continually recirculated around the heat exchangers using pumps (duty / stand-by arrangement). A 3-way modulating valve on the water side controls the amount of hot water that passes into the heat exchanger, depending on the heat demands of the digesters.

Grit build up within digesters is a normal feature of operation, the digesters are cleaned out (including accumulated grit) every 10 years as part of the planned periodic inspection which also includes an internal and external inspection of tank integrity and replacement of instrumentation and gas mixing equipment as required.

An automatic anti-foam dosing system is in place to control digester foaming. This system uses a radar level probe in the digester headspace and compares this to the pressure level sensor at the bottom of the digester to determine the depth of foam. Upon detection of foam, final effluent is sprayed into the digester head space through nozzles in the digester roof. If this is not effective in breaking up the foam, a chemical anti-foam is mixed with final effluent and dosed into the headspace of the digester via the same spray nozzles. This system includes operator-adjustable dosing setpoints and failsafe systems; if the foam level continues to increase mixing systems are inhibited and if this continues the digester feed will be inhibited. Antifoam is stored in an 1m^3 IBC located within a GRP kiosk located adjacent to the incoming SAS pumping station to the north of the digestion compound.

The digestion plant operates under PLC and is largely automated. Furthermore, monitoring is undertaken to check that the digestion process is healthy and stable. This includes temperature, solids, volatiles, fatty acids and pH, as well as biogas quality.

Figure 13. Two of four digester units.

3.2.2 Bulk storage vessels (Area B)

Detailed discussion of risk sources and existing control and mitigation measures associated with Area B is provided below.

3.2.2.1 Dewatering Feed Tank

Sludge extracted from the digesters combines and is routed via an underground pipeline to a gravity fed dewatering feed tank (Figure 14, 5260 m^3 GRP coated steel) prior to onward processing. The tank is not enclosed and is mixed by a pump to introduce oxygen and prevent the anaerobic generation of methane.

In order to minimise the formation of struvite in downstream pipework and equipment, ferric sulphate is dosed in-line between the dewatering feed tank and the lime vessel feed pump. This reacts with the phosphorus in the sludge to reduce the level of phosphorus. This reduces availability of phosphorous to form struvite. From the dewatering feed tank digested sludge is fed to a lime vessel (13m^3 stainless steel) where lime is mixed with the sludge to increase the pH leading to additional pathogen reduction in the sludge. Powdered lime is supplied via an adjacent silo (81m^3 GRP) which is filled approximately fortnightly by tanker.

Limed digested sludge is then transferred to the dewatering plant where a polymer solution is injected into the sludge stream. Powdered polymer is stored within a storage silo prior to mixing with potable water within an adjacent polymer mixing tank. The sludge is then passed through one of three centrifuges where the sludge coagulates, and the supernatant liquor is removed by centrifugal forces.

This tank has high level sensors which automatically stop pumps transferring sludge into the tank if the set level is reached to avoid potential loss of containment. There is a concrete walkway around the tank, beyond this there is a mix of concrete and grassed areas. Surface water drains in the dewatering area return to the WwTW works via the liquor return pumping station.

Figure 14. Dewatering feed tank (green tank to the left).

3.2.2.2 Digested sludge treatment area (cake storage and loading pad)

The dewatered digested sludge cake is transferred via centreless screw conveyers from the centrifuges up over a push-wall and onto the cake pad, as shown in Figure 15. The whole area under the conveyer and adjacent sludge cake pad consists of engineered hardstanding with surface water runoff draining back to the WwTW for treatment.

Once on the cake pad, sludge cake is moved by mechanical loaders into a covered storage barn. Cake is typically stored for short periods and exported for land spreading in accordance with legislative requirements. Samples of digested cake are taken every 3 months and analysed for metals and pathogens to ensure HACCP standards are being met. pH analysis is conducted daily. Two quarantine bays are maintained should they be required.

Figure 15. Digested sludge cake storage and loading pad.

3.2.2.3 Liquor Treatment Plant (LTP)

Dewatered liquor drops from the centrifuges into a sump and is pumped to the centrate balance tank (Figure 16, uncovered, 2,212 m^3 GRP Steel). The centrate is dosed with antifoam in line. Before passing through a heat exchanger and then to a settlement tank (270 m^3 concrete, sub-surface) where solids are removed (Figure 17). The solids removed are either pumped to the Dewatering Feed Tank or to the Treated Liquors and Return Pumping Station for return to the WwTW.

Figure 16. Centrate balance tank (background) with dosing tanks (foreground).

Figure 17. LTP primary settlement tank.

Centrate is gravity fed to the Liquor Treatment Plant (LTP) pumping station, from where it is fed to two LTP reactor tanks (Figure 18, 2,230 m^3 steel coated GPR, uncovered). These tanks are seeded with anammox bacteria and are aerated and heated (via a heat exchanger powered by the CHP). The reaction process serves to remove centrate ammonia prior to discharge to the main WwTW for further treatment.

Figure 18. LTP reactor tanks.

3.2.3 Tank volumes

The volumes of the sludge tanks found in Area's A and B are summarised in Table 1.

Table 1. Sludge tanks at Knostrop STF and associated capacities and construction.

Tank	Area	Material	Size m^3 (each tank)	110% Size m^3	Constructed	Construction
1 no. sludge screen feed tank	A	Liquid	540	594	2018	GRP coated steel tank
1 no. screened sludge tank	A	Liquid	3,855	4,241	2018	GRP coated steel tank
1 no. sludge thickener feed tank	A	Liquid	3,855	4,241	2018	GRP coated steel tank
1 no. digester feed tanks	A	Liquid	5,376	5914	2018	GRP coated steel tank
4 no. digesters	A	Liquid	7,306	8,037	2018	Concrete
1 no. dewatering feed tank	B	Liquid	5,260	5,786	2018	GRP coated steel tank
1 no. centrate balance tank	B	Liquid	2,212	2,433	2018	GRP coated steel tank
1 no. LTP primary settlement tank	B	Liquid	270	297	2018	Concrete subsurface
2 no. liquor treatment tanks	B	Liquid	2,230	2,453	2018	GRP coated steel tank

3.2.4 Engineering and maintenance standards

YW maintain inhouse standards which define the types of assets that meet the requirements of their business, how they should be built and then maintained. In relation to Knostrop this covers:

- Design and construction of all assets, including selection of appropriately qualified design and build contractors.
- Procedures for inspection and testing of storage vessels, including internal and external inspections, thickness assessment and non-destructive testing.
- Regular inspections of above ground assets and associated pipework at defined intervals.
- Documented log of any actions arising as a result of these inspections.

YW's asset standards have been developed over many years and where relevant require compliance with Civil Engineering Specification for the Water Industry (CESWI) Seventh Edition March 2011 and the Water Industry Mechanical and Electrical Specifications (WIMES 9.02).

Contractors involved in the design/build of the Knostrop scheme were YW framework contractors, appointed following a rigorous EU tender process; this process involved an assessment of past experience, technical competency, design capability and quality procedures.

The combination of all of these measures significantly reduces the risk of a catastrophic tank failure, thus reducing the likelihood of secondary containment being required. Nonetheless, it is recognised that the risk of a catastrophic tank failure cannot be entirely eliminated, and external factors could always arise leading to very low likelihood, high consequence events (such as missile generation arising from other plant failure, domino effects or *force majeure*, for example an aircraft impact or terrorist attack).

3.3 Pathways

Pathways are the routes by which pollutants could potentially travel from a source to the point where they could cause damage, the receptor. The potential pathways in this assessment were determined via computation flow modelling using defined source spillage volumes. The modelling approach, limitations and spill volumes are outlined in the following sections, allowing the principal pathways to be identified.

3.3.1 Spill modelling

To model the potential impact of sludge spills to the environment from the various sludge treatment assets at Knostrop STF and defined credible pathways, YW has used PondSIM, a computational overland flow modelling tool. PondSIM can represent the flow of a liquid spill across an area of ground, taking account of local topography and flow restrictions (such as barriers). Applying this to the Knostrop site has allowed visualisation of the likely effects of a spill occurring within either of the key areas of the permitted installation.

3.3.1.1 Modelling limitations and uncertainties

As with any computational modelling tool, there are a number of assumptions required and associated modelling limitations and uncertainties:

- PondSIM is designed to model the overland flow of water; as such it is not able to account for the typically higher viscosities associated with sludge, which results in a larger modelled inundation extent than would be expected in reality.
- The model cannot allow for flow to drains and other subsurface features.
- Surge is not accounted for within the model. Instead, this will be allowed for by ensuring final designs consider CIRIA 736 recommendations, while recognising the loss of kinetic energy as viscous sludge travels over flat ground.
- The model assumes that no mitigation measures are put in place following an incident to curtail flow.
- The model assumes that the full modelled volume spills from a single point.
- Assets are treated as simple flow barriers in the model, which may result in deflections being observed where in reality flow would spread out.

Therefore, the modelled outputs are considered to be a worst-case inundation scenario resulting from sludge spills at Knostrop. Notwithstanding these limitations, the use of PondSIM is considered appropriate for the purpose intended in this study and allows for the rapid screening and assessment of asset risks to support prioritisation of risk mitigation.

To counter these limitations, worst-case assumptions were selected relating to the potential failure events, including spill volumes. These are discussed in 3.3.2.

3.3.2 Spill volumes

YW has followed CIRIA 736 guidance on spill volumes to be modelled i.e., values equivalent to the containment provided by bunded tanks have been used. For a single tank the volume should be calculated on the basis of 110 per cent of the capacity of that tank. For multi-tank installations, the containment volume should be calculated on the basis of 25 per cent of the total capacity of all the tanks in a common area (which is based on the assumption that it is unlikely that more than 25% of tanks will fail simultaneously), or 110 per cent of the largest tank, whichever is greatest.

In practice, this means that Area A would require containment sufficient to hold 25 per cent of the total stored volume to achieve equivalent protection to a traditional multi-tank bunded installation (Table 2, Scenario 1). In Area B, the dewatering tank is the largest contained volume by far (and exceeds the 25 per cent of the total volume of tanks in the area), therefore 110 per cent of this volume would need to be contained in an event of catastrophic failure (Table 2, Scenario 2). Furthermore, Scenario 3 is also included to provide a spill model that explores how the STF would perform when managing 110 per cent of every tank within Area's A and B to provide confidence in the site's containment capability. The LTP primary settlement tank was not included within Scenario 3 as the sludge is contained subsurface and even catastrophic failure of the walls would not result in a spill to surrounding land.

Table 2. Volume of material used in spill modelling scenarios.

Scenario	Capacity calculation	Material containment volume (m^3)	Modelling reference
1	25% total capacity of tanks within Area A	10,713	Figure 21
2	110% total capacity of the dewatering tank in Area B	5,786	Figure 22
3	110% total capacity of all tanks within Area A and B	60,260	Figure 23

3.3.3 Pathway identification

Table 3 lists the resulting pathways associated with tank failure at Knostrop determined using the PondSIM models. Full model results are presented in Section **Error! Reference source not found.**.

Table 3. Pathways from the key assets at Knostrop

Area	Tank	Pathways	Comments
A	Sludge screen feed tank (1 no.)	Overland run-off and infiltration through unsealed surfaces to: • Northeast of Area A. • Areas around the cake. reception unit.	Large amount of spill captured on existing site roads and hardstanding areas before reaching grass areas. Site drainage in these areas is connected to the main WwTW.
	Screened sludge tank (1 no.) Sludge thickener tank (1 no.) Digester Feed tank (1 no.)	Overland run-off and infiltration through unsealed surfaces to: • North of Area A. • Centre of Area A near the ODU. • Southeast adjacent to the heat and power site.	Spill will be captured on a mix of existing site roads, hardstanding and grassed areas. Site drainage in these areas is connected to the main WwTW. Additionally, the industrial car park zone will have a full retention interceptor installed. Management procedures for this area will be confirmed once construction is complete.
	Digesters (4 no.)	Overland run-off and infiltration through unsealed surfaces to: • Centre of Area A near the ODU. • North of Area A. • Southeast towards the car park.	Spill captured on existing site roads before reaching grass and permeable surface areas. Site drainage in these areas is connected to the main WwTW. Some sludge expected to reach the industrial car park zone, which will have a full retention interceptor installed. Management procedures for this area will be confirmed once construction is complete.

Area	Tank	Pathways	Comments
B	Dewatering feed tank (1 no.)	Overland run-off and infiltration through unsealed and sealed surfaces to: • North of Area B leading towards the car park. • West of Area B surrounding the cake barn. • Southeast onto grassed area	Spills captured on existing site roads, grass, and hardstanding areas. Site drainage in immediate area is connected to the main WwTW.
	Centrate balance tank (1 no.)	Overland run-off and infiltration through sealed surfaces to: • East of Area B surrounding the heat and power site. • West of Area B surrounding the cake barn. • South of Area B surrounding the LTP plant.	Spill captured on existing site roads and hardstanding areas. Site drainage in immediate area is returned to WwTW. Direct flow to adjacent WwTW area prevented by level change.

3.3.4 Planning permission

Planning consent is in place for 240,000m^2 of development directly adjacent to Knostrop STF. The development, called Gateway45 Leeds, is a commercial space for logistic and manufacturing schemes. Planning consent for the site was received in 2015, the commercial units which includes a parking zone are expected to be completed by the end of 2021. Figure 19 shows the planning development site drawing. The area closest to the STF will be HGV parking (shown in blue), this includes a full retention interceptor. Further away from the STF there is a car park with planned drainage schemes.

Modelling of this area has been completed using finished ground levels from the planning application and represents the best current view of potential pathways in this area. It is important to note that PondSIM does not capture flow to subsurface/remote storage such as the full retention interceptor, which is likely to hold a significant volume of sludge and minimise the extent of a spill.

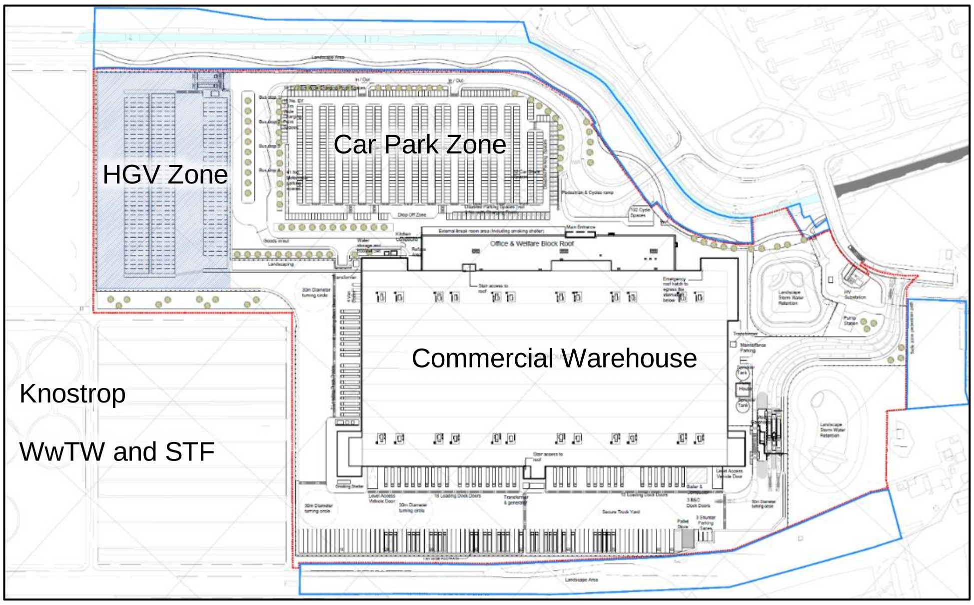


Figure 19. Gateway45, Leeds site layout adjacent to Knostrop STF.

3.4 Receptors

To complete the source pathway receptor model, a review of potentially sensitive receptors was conducted. These were identified based on engineering judgement and took account of potential flow paths which may take any cardinal direction. Figure 20 shows the receptors identified which could theoretically be impacted by a loss of containment of process vessels at Knostrop.

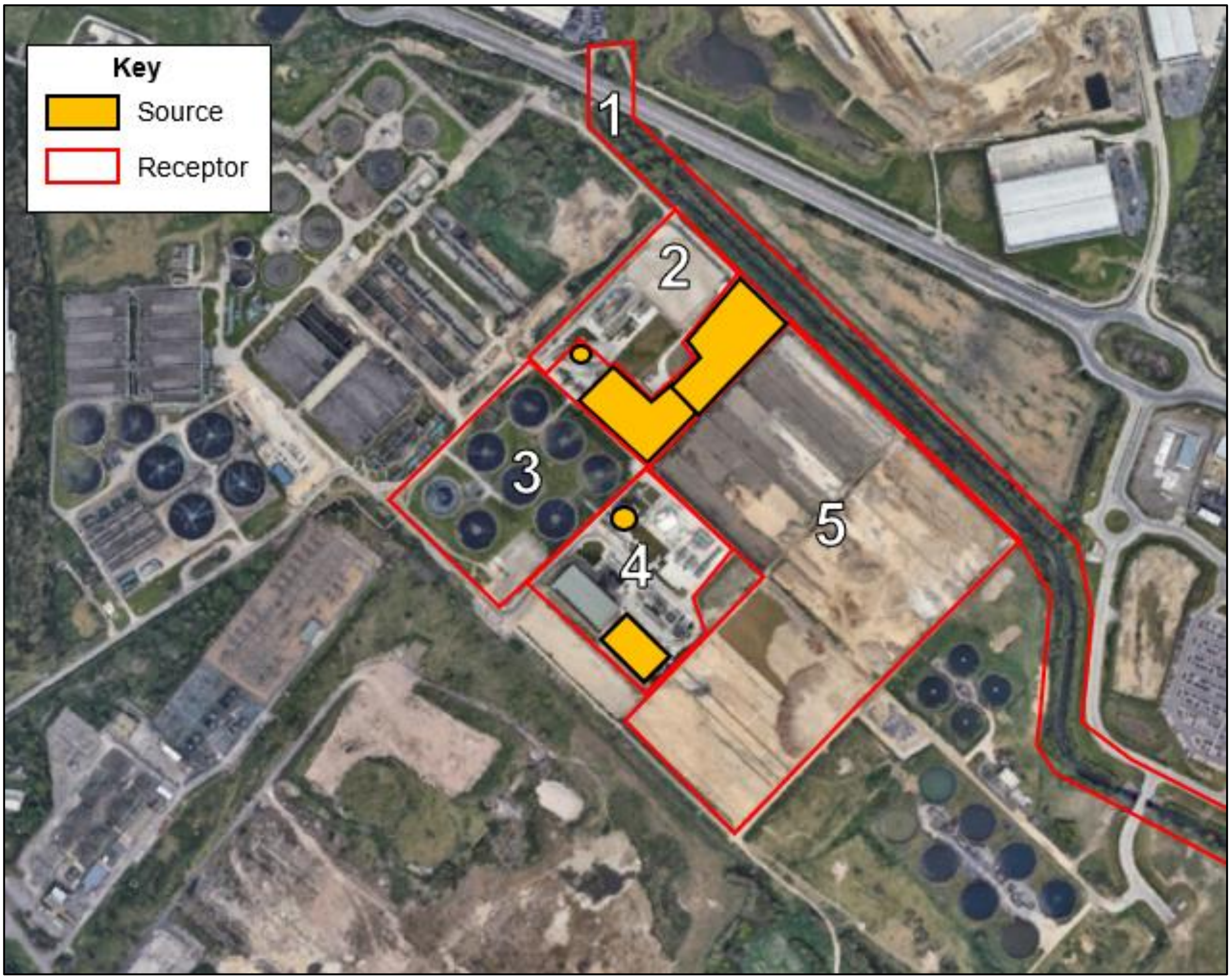


Figure 20. Map of local receptors at Knostrop. © Google, 2021

Table 4 lists the type of pathway potentially leading to each receptor e.g., indirect, such as via FSTs or permeable surfaces) or direct to the environment, e.g., a flow path into the Wyke Beck.

Table 4. Identified receptors and theoretical pathways prior to modelling.

Receptor No.	Receptor	Pathways to receptor (prior to modelling)	Pathway type
1	Wyke Beck (including adjacent habitats).	• No direct routes identified. • Through infiltration into unsealed surfaces.	Direct Indirect
2	Ground / groundwater - area to north of Area A.	• Overland run-off and infiltration through unsealed surfaces from Area A.	Direct
3	Ground / groundwater - area around final settlement tank west of STF site.	• Overland run-off and infiltration through unsealed surfaces from sludge screen feed and four digester tanks via the southwest grass area.	Direct

Receptor No.	Receptor	Pathways to receptor (prior to modelling)	Pathway type
4	Ground / groundwater - areas around dewatering and liquor treatment assets, including the heat and power area located northeast of Area B.	• Overland run-off and infiltration through unsealed surfaces from AD area via grass areas around effluent stream assets to North.	Direct
5	Ground / groundwater - areas around proposed planning permission for a car park - east of the WwTW.	• Overland run-off and infiltration through unsealed surfaces and barriers from Area A and B.	Direct

3.5 Source-pathway-receptor risk summary

The outcome of the source pathway receptor identification is summarised in Table 5.

Table 5. Source-pathway-receptor summary

Area	Source	Pathways	Receptors at risk
A	Sludge screen feed tank (1 no.)	Overland run-off and infiltration through mostly sealed surfaces to: • Northeast of Area A. • Areas around the cake reception unit.	• Receptor 1 – Wyke Beck • Receptor 2 – ground / ground water area north of Area A • Receptor 3 – Ground, unsealed grass bank on boundary of WwTW.
	Screened sludge tank (1 no.) Sludge thickener tank (1 no.) Digester Feed tank (1 no.)	Overland run-off and infiltration through unsealed surfaces to: • North of Area A. • Centre of Area A near the ODU. • Southeast adjacent to the heat and power site.	• Receptor 1 – Wyke Beck • Receptor 2 – ground / ground water area of Area A • Receptor 3 – Ground, unsealed grass bank on boundary of WwTW. • Receptor 5 – adjacent site drainage system
	Digesters (4 no.)	Overland run-off and infiltration through sealed surfaces to: • Centre of Area A near the ODU. • North of Area A. • Southeast towards the car park.	• Receptor 2 – ground / ground water area of Area A • Receptor 3 – Ground, unsealed grass bank on boundary of WwTW. • Receptor 5 – adjacent site
B	Dewatering feed tank (1 no.)	Overland run-off and infiltration through unsealed and sealed surfaces to: • North of Area B leading towards the car park. • West of Area B surrounding the cake barn.	• Receptor 3 –northeast of FST's • Receptor 4 – Ground, unsealed ground adjacent to tank. Ground, unsealed grass bank on boundary of WwTW. • Receptor 5 – adjacent site drainage system
	Centrate balance tank (1 no.)	Overland run-off and infiltration through sealed surfaces to: • East of Area B surrounding the heat and power site. • West of Area B surrounding the cake barn. • South of Area B surrounding the LTP plant.	• Receptor 4 – Ground, unsealed ground adjacent to tank. Ground, unsealed grass bank on boundary of WwTW. • Receptor 5 – adjacent site drainage system

3.6 Spill modelling results

This section presents the modelling outlining the potential unmitigated flow routes from the identified source, via surface pathways to the identified receptors as calculated by PondSIM.

The modelling assessment considered three scenarios. Scenario 1 (Figure 21) considered the effect of the simultaneous loss of containment at 25 per cent of the total volume of all tanks in Area A. Scenario 2 (Figure 22) considered the effect of the loss of containment of the largest tank, the Dewatering Feed Tank, at 110 per cent its volume in Area B. Finally, Scenario 3 (Figure 23) considered the effect of the simultaneous loss of containment at 110 per cent total volume of each of the tanks present in Area A and B and represents the absolute largest volume of possible spill, taking account of the modelling limitations discussed in 3.3.1 Spill modelling.

The implications of each scenario are considered in section 0.

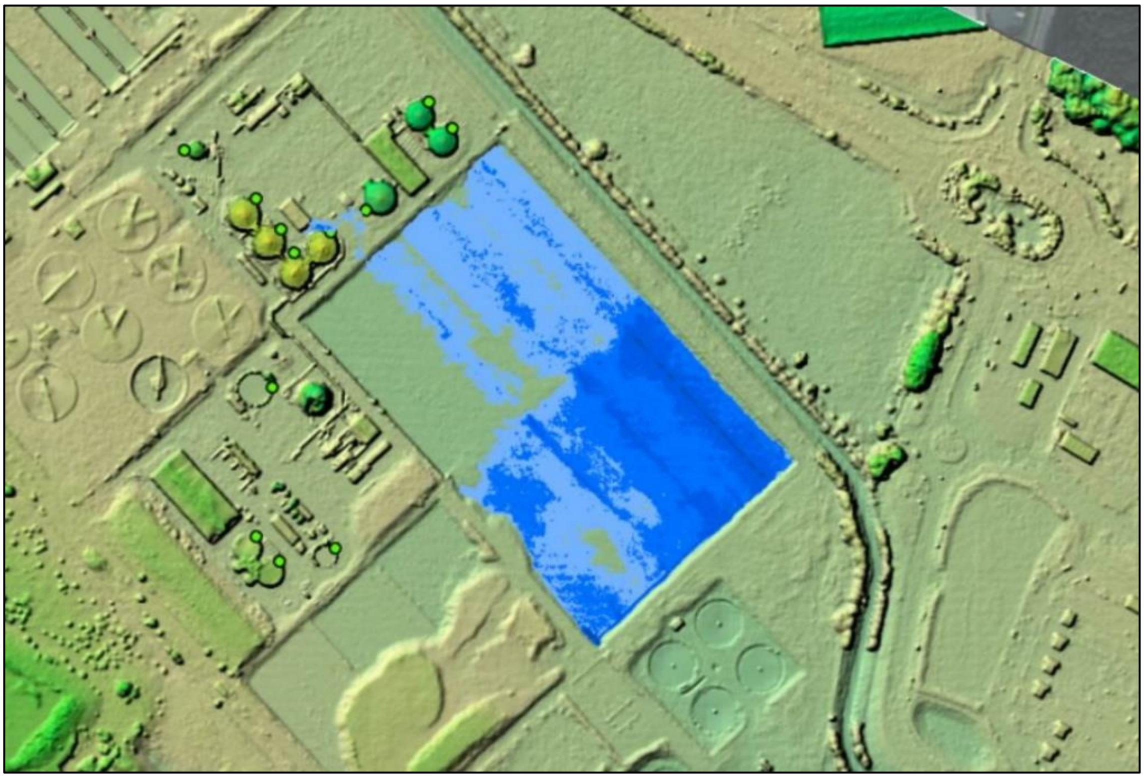


Figure 21. Scenario 1: Model output of spills from existing tanks in Area A (25% of total volume) within the permit area at Knostrop.

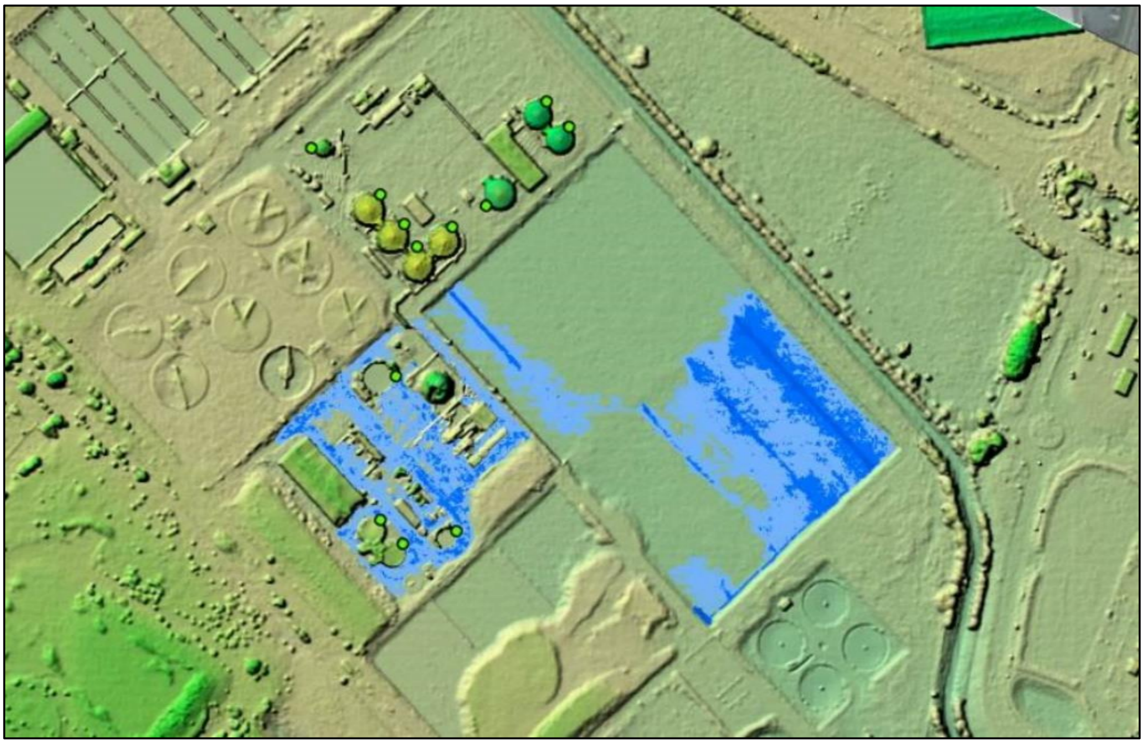


Figure 22. Scenario 2: Model output of spills from dewatering tank in Area B (110% of volume) within the permit area at Knostrop.

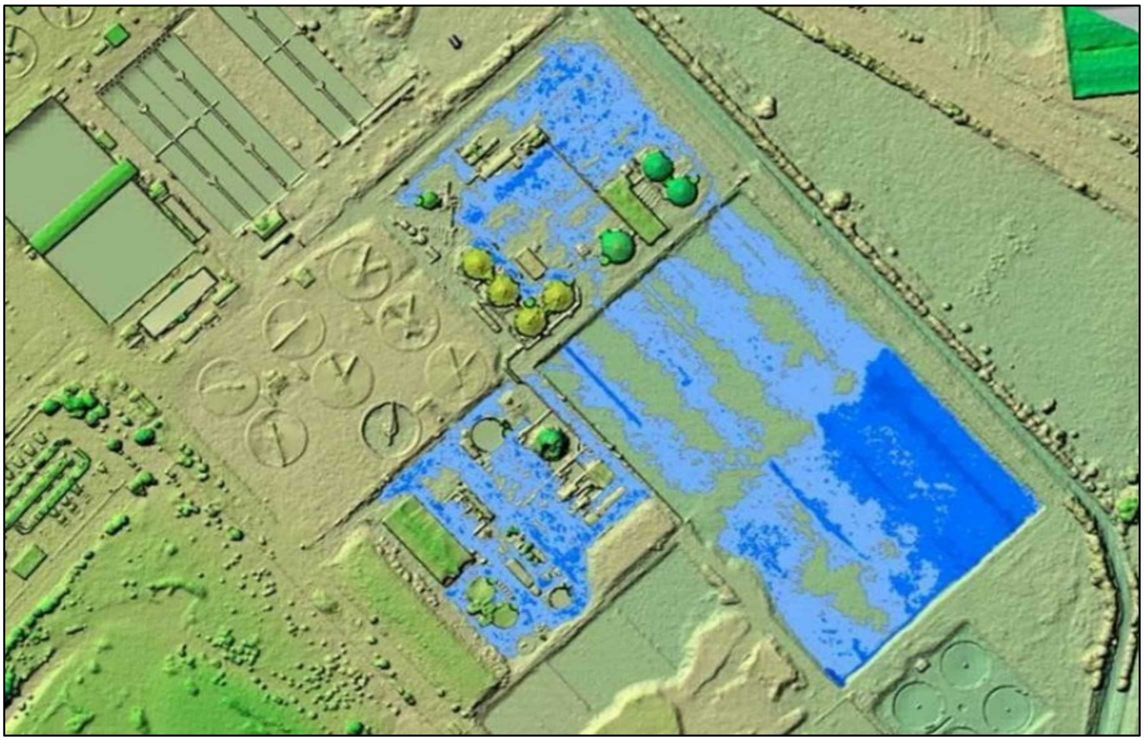


Figure 23. Scenario 3: Model output of spills from existing tanks in Area A and B (110% of each volume) within the permit area at Knostrop.

3.6.1 Environmental implications of spill scenarios

Figure 24 shows the potential for pooling of sludge within the section of permeable surface within Area A. This section is close to Wyke Beck, however surface drainage located within the imported sludge, sludge thickening, and digestion areas is connected to the main WwTW, preventing sludge transferring to receptors. Any significant sludge spill will be quickly removed in line with YW's accident management procedures, minimising the risk of transfer to groundwater.

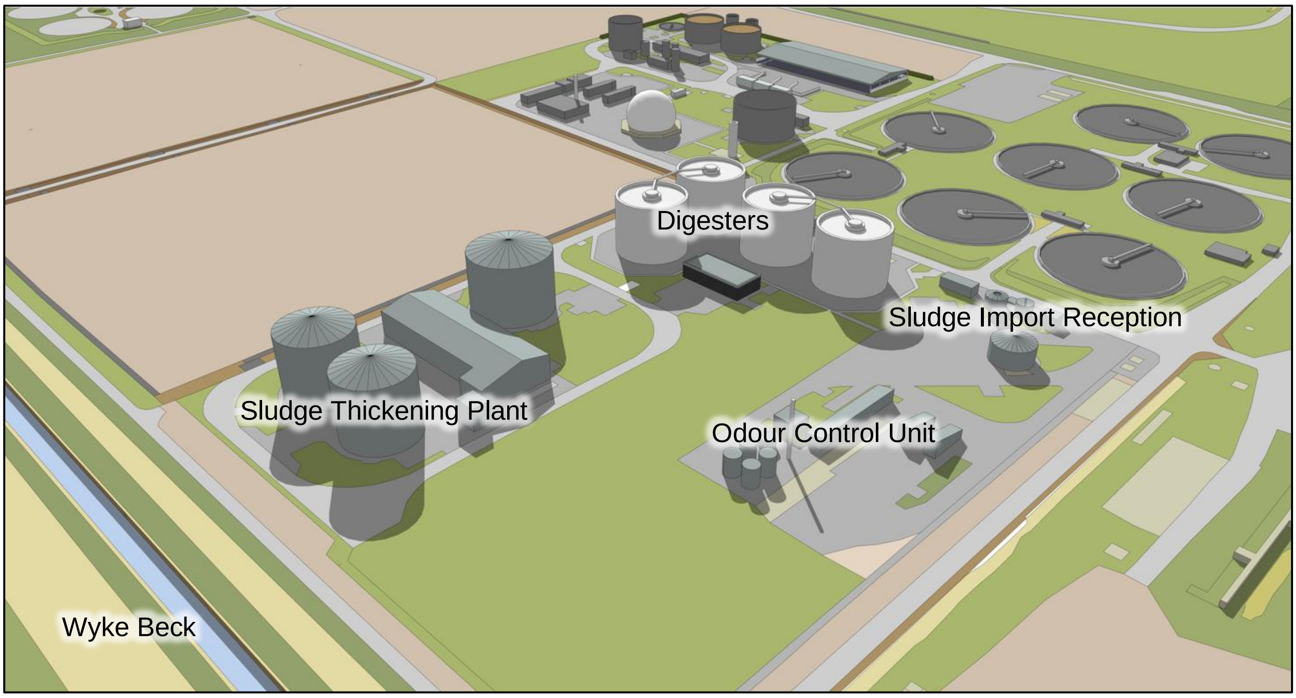


Figure 24. Section of permeable surface next to the imported sludge and sludge thickening areas.

Scenario 3 shows that under certain circumstances there is potential for significant pooling at the southeast section of the odour control unit, where most of the sludge is held on hardstanding impermeable surface next to the grassed area, as shown in Figure 25.

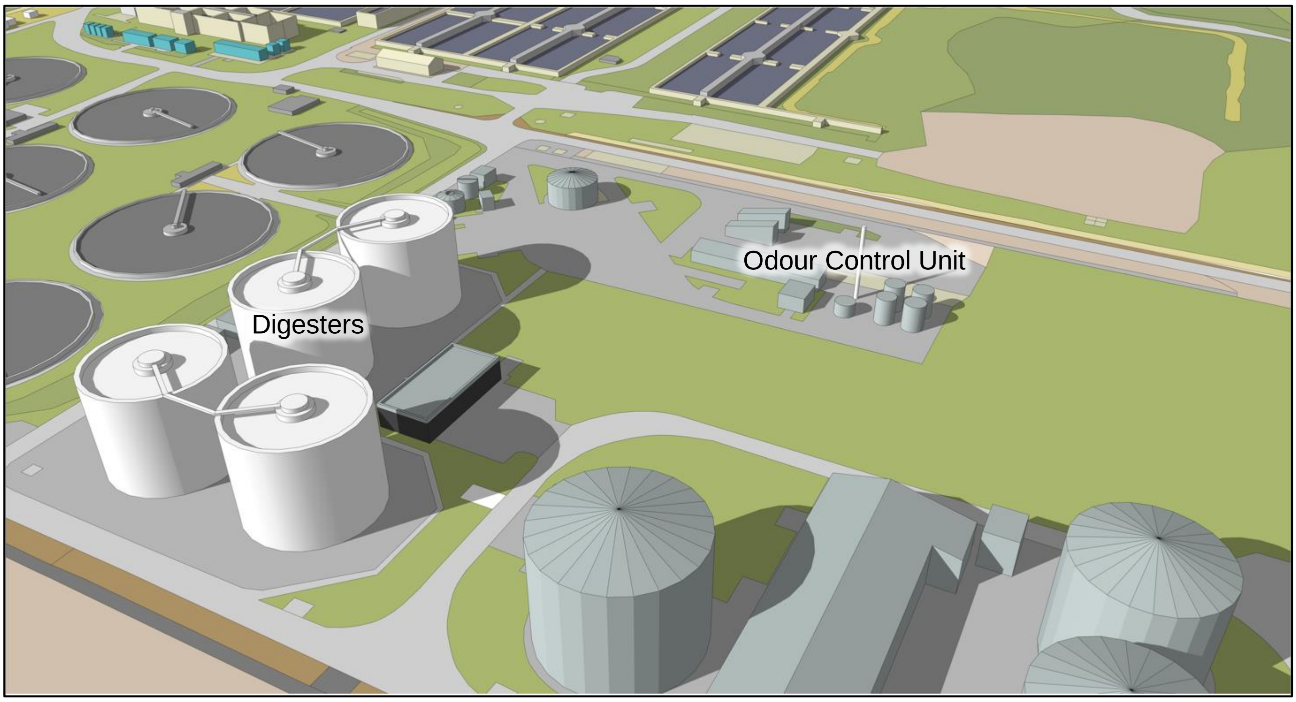


Figure 25. Grassed section next to odour control unit in Area A.

In Area B, whilst most of the dewatering and heat and power areas have the potential to be affected by sludge flooding, two inundation areas are identified. The first being south westerly flows outside of the cake storage barn (Figure 26) and in between the Liquor Treatment Plant and Heat and Power areas (Figure 27). Both these areas of flooding would occur on top of impermeable surfaces with drainage that is connected to the main WwTW.

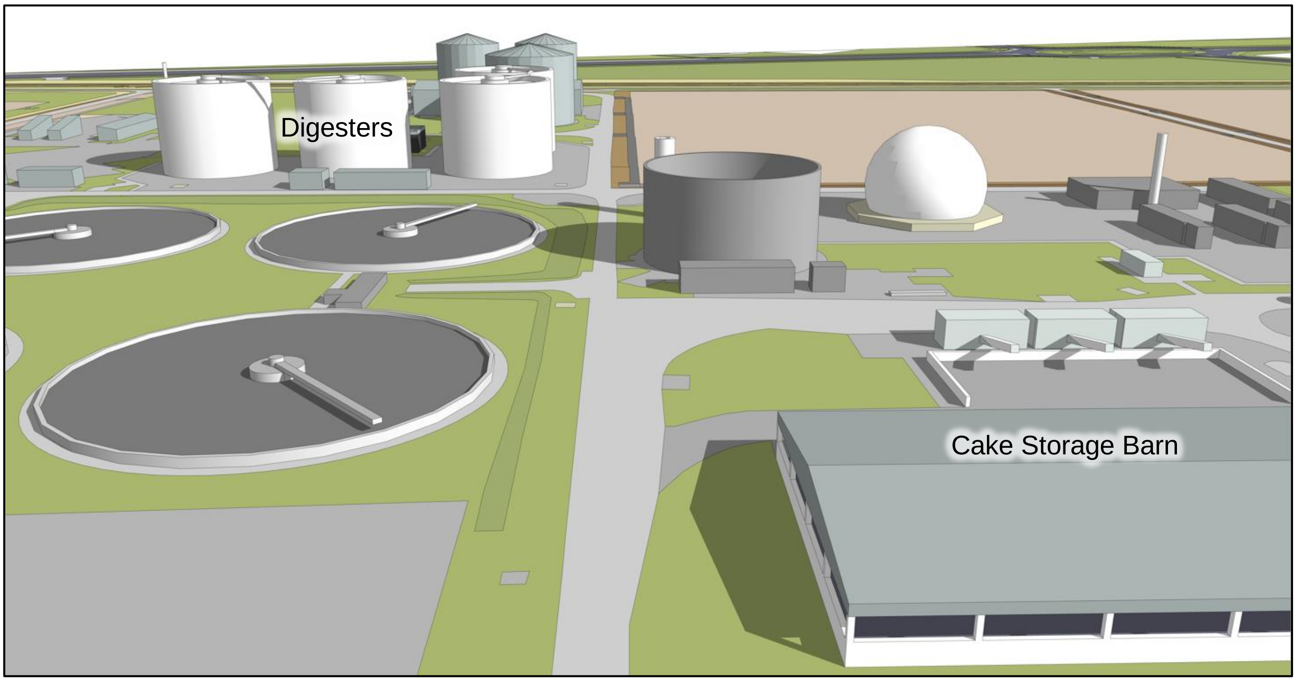


Figure 26. Road next to the sludge cake storage barn in Area B.

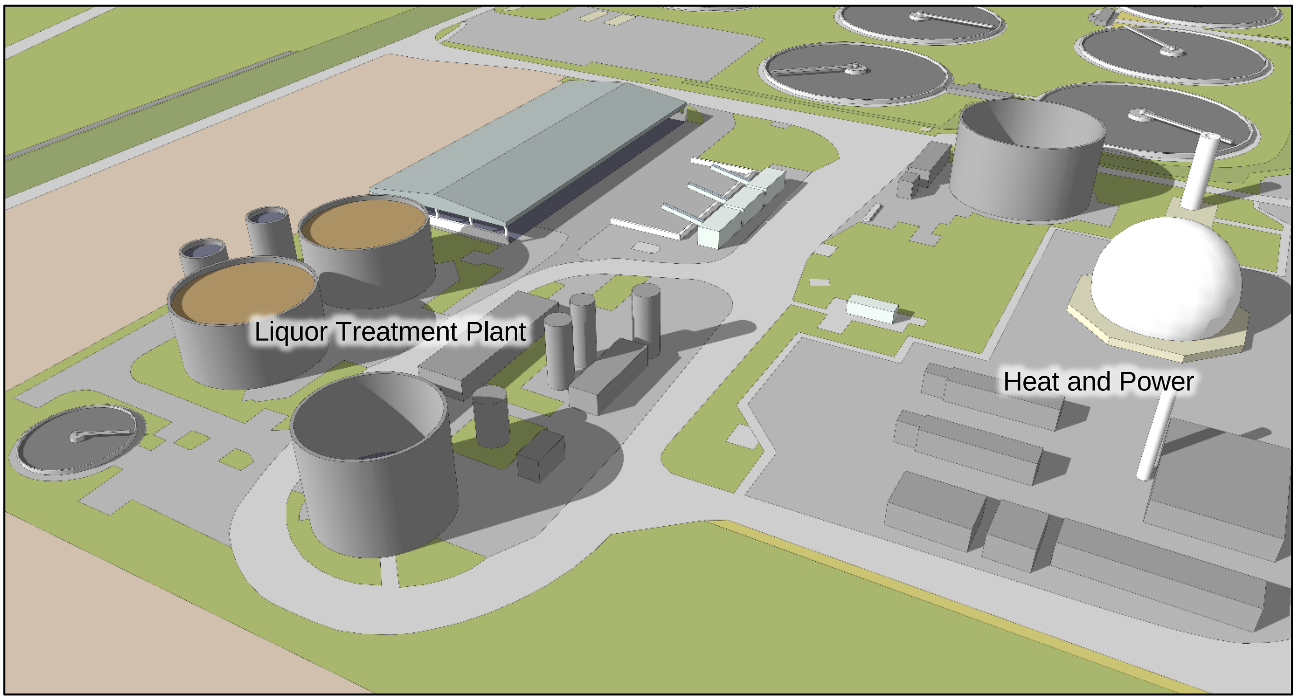


Figure 27. Liquor treatment plant and heat and power areas in Area B.

Figure 28 shows the area with the most potential significant depth of flooding, due to the flows accumulating from Area A and B. This section of impermeable ground is currently in development for the commercial warehouse HGV and car park zone. The surface water drainage layout for the HGV parking area closest to site includes a full retention interceptor designed to capture flows and remove oil, chemicals, and solids from the full flow of surface water to ensure they cannot contaminate the nearby environment. This facility will give YW time to respond to a spill and isolate the interceptor before flow can reach Wyke Beck.

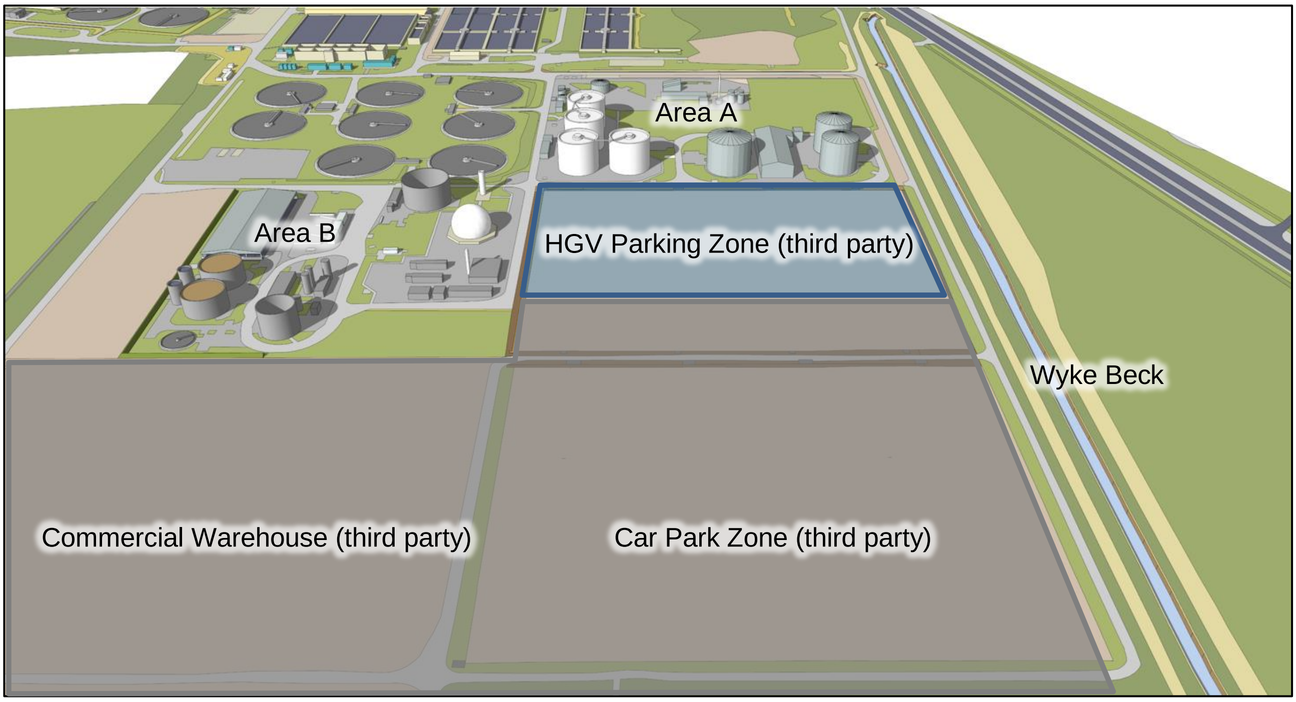


Figure 28. Gateway45 planned industrial site, HGV and car parking areas.

3.7 Control options

The spill modelling demonstrates in all 3 scenarios that no spills are predicted to affect Wyke Beck or any other sensitive receptors. On this basis there is no requirement for secondary containment solutions to be developed for the site.

This conclusion is based on the majority of spills modelled flowing to impermeable surfaces with drainage to the WwTW, or onto permeable surfaces with effective clean-up procedures – within the WwTW boundary. It is also based on the assumption that the implementation of the neighbouring facility is as expected and indicated on the planning drawings and that provision will enable containment of any spillage within the interceptors. It will be a requirement to develop appropriate emergency response plans with the facility operator in order to ensure that any significant loss of containment can be adequately managed, and risks mitigated beyond the installation boundary.

3.8 Surge

The catastrophic collapse of a tank would lead to a rapid release of sludge. As is normal for fast moving liquids, the sludge will tend to flow over obstacles. CIRIA 736 provides guidance on the height of bund wall that is required to ensure surge flow does not pass containment walls. This guidance is particularly relevant where the bund wall is close to, or downhill from, the vessels for which it is providing containment. As flow travels across flat ground, it will lose speed and the risk from surge will rapidly decrease. This is particularly true with a relatively viscous liquid such as sewage sludge.

At Knostrop, there are existing raised areas of ground, particularly located along the Wyke Beck at the north-eastern boundary. Figure 29 shows existing raised areas of ground in green and associated image viewpoints. These will provide both containment and protection of the Wyke Beck and the wider WwTW against surge.

Figure 29. Existing areas of raised ground situated between Areas A and B, and the Wyke Beck and WwTW.

3.9 Spills to unsealed areas

YW considers that in the case of Knostrop, a sludge spill onto an unmade grass or gravel area could form part of an acceptable control option. This decision is based on the following factors:

- YW's engineering standards and ongoing maintenance plans ensure that asset health issues associated with tanks are rare, and if they were to occur, are dealt with promptly.
- Catastrophic failure of a tank, or multiple tanks, is a high consequence but extremely rare event.
- Knostrop is either manned, or when not, monitored by the Service Delivery Centre on a 24/7 basis using CCTV and critical process alarms. A significant spill would be identified quickly, and the spill management procedure initiated, ensuring a rapid clean up. SCADA controls would also, via a number of surrogate metrics, such as levels, transfer, pump and valve status, provide rapid process control indications of certain loss of containment scenarios.
- YW has a fleet of sludge tankers across their region which form part of the operational response to sludge spills at present and could therefore be utilised rapidly in the event of a spill at Knostrop.
- Made ground exists beneath all areas of the site, associated with historical sewage and sludge treatment. Legacy mine workings are also present, and associated remediation (grouting) has been undertaken in some areas.
- Any loss of sewage sludge to unsurfaced ground shall be cleaned up rapidly to minimise the potential for environmental impact.
- Increasing the area of hardstanding would reduce rainwater dispersal through infiltration and increase the amount of rainwater flow collected and returned to the WwTW through surface water drainage. The large amount of concrete that would be required would also incur high capital and carbon costs. This runs counter to general environmental goals and YW's specific aim of achieving net zero carbon emissions by 2030.

4 Conclusions and recommendations

This study has considered the risks associated with credible loss of containment scenarios in each of the two main working areas of the Knostrop STF installation through the adoption of the widely used source-pathway-receptor model. A computational modelling study has been undertaken, which adopted conservative assumptions in order to address known limitations of this type of modelling tool. This enabled the potential effects of a substantial, unmitigated loss of containment to be considered; this has shown that further mitigation is not required to achieve a comparable level of protection of the identified sensitive receptors (the metric of compliance being an equivalence to a traditional 25 / 110 per cent capacity secondary containment bund in line with CIRIA 736 via the ADBA study).

Whilst no additional secondary containment solutions are required for the site, YW understand the following factors and current mitigation measures should be maintained to ensure adequate protection to the environment:

- Current controls
    - Continuation of the measures already in place to minimise the likelihood of catastrophic failure of sludge vessels, through the use of stringent technical standards, SCADA technologies and regular visual inspections.
- Existing infrastructure
    - Site drains are able to return liquid to the inlet works for treatment, providing containment and flow mitigation.
    - The sludge cake storage and loading pad has been engineered to drain liquid contents which returns to the inlet works of the WwTW, acting as remote containment.
    - In some areas spills, leaks and catastrophic pipe failures the site surfacing and drainage would transfer liquid to the WwTW, which would contain and minimise potential effects of loss of containment.
    - Proposals for development of the adjacent area for industrial use include provision for the collection of potentially contaminated surface water on areas potentially affected by loss of containment from the installation. The implementation of these control measures, and the associated operational practises and emergency response measures will be reviewed once the development is complete.
- Likelihood
    - Whilst the potential for catastrophic tank failure can never be wholly mitigated when sites are operated with large tank inventories, the likelihood of substantial failure is very low, as evidenced by YW's own track record of operating sludge storage/treatment vessels across its asset base.
    - In support of likelihood of failure YW has reviewed actual failure data. YW has over 40 years of experience in operating AD plants and STF's. YW has 14 AD sites, 5 of these sites have Environmental Permits. Within this time YW has not experienced the catastrophic collapse of a storage vessel.
    - YW has found from experience that 'failures' of concrete tanks are generally associated with ancillaries such as joints, waterstops, seals, etc, rather than any inherent defect with the actual civil structure. YW has experienced one incident of note, and this was at Hull STF digester number 5. This example is a case in point; the release of sludge that occurred was caused by the failure of a 'link seal' mechanical coupling that should have provided a watertight seal around the outside of a mixer pipe intrusion. In comparison with a catastrophic collapse scenario, this resulted in relatively controlled spill of small volume.
- Environmental impact
    - Receptors in the area must be protected from the effects of major sludge spills to reduce pollution and impacts to biodiversity.
    - The carbon impact of creating entirely impermeable containment areas would be significant and counter to YW's aim of achieving net zero carbon emissions by 2030.

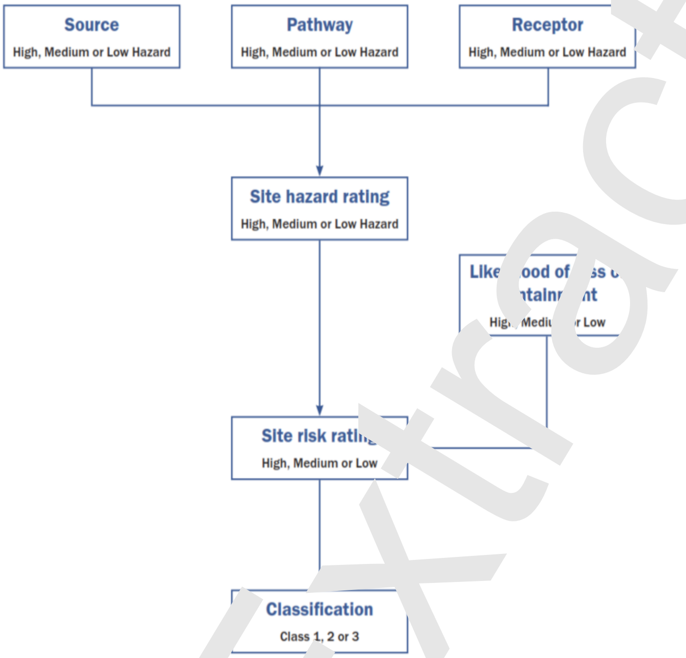
Appendices

Appendix 1 - ADBA assessment tool

Although this tool works as a standalone tool, we recommend you read this first: ADBA CIRIA736 Bund Classification Assessment

There are 5 steps to follow:

1) Identify the hazard posed to the environment by the inventory of materials held on the site and the location of the site
   a. Categorise the source
   b. Identify the pathways
   c. Identify the receptor
2) The Site Hazard Rating is derived by this tool from the combination of the hazards assessed above
3) Calculate the likelihood of a loss of primary containment event occurring
4) The combination of the Site Hazard Rating and the likelihood of a loss of containment occuring gives the site risk rating and required secondary containment classification
5) From the class of containment needed, identify suitable designs from the 'Standard Containment Designs' sheet



Additional Guidance

As detailed in section 2.4 of CIRIA C7[illegible]ining an overall hazard rating for the site is largely subjective, and assessing the combined effe[illegible]s a judgement based on knowledge, experience and the degree of confidence in the information available.

Section 2.4 of CIRIA C736 states: *"where there is uncertainty about the correct categorisation of any of the individual source, pathway or receptor hazard ratings, it may be appropriate to move the overall site hazard category to the next higher rating".*

The worksheets in this spreadsheet are protected to prevent inadvertant damage to the tool. To remove the protection, the password is CIRIA736

Screenshot from spreadsheet containing full assessment. Full document included as part of permit submission.