Irish Water

PROJECT:

Regional Biosolids Storage Facility for Greater Dublin

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SECTION 1: INTRODUCTION

1.1 Need for Storage Facility

The purpose of the Regional Biosolids Storage Facility (RBSF) is to store treated biosolids produced at the Ringsend Wastewater Treatment Plant (WwTP) and the WwTP for the Greater Dublin Drainage (GDD) Project. The *National Wastewater Sludge Management Plan* (Irish Water, 2016) (NWSMP) identifies reuse of treated wastewater sludges on land as the preferred outlet in the short to medium term. Constraints on land spreading due to seasonal factors require that biosolids must be stored at certain times of the year. The development of regional facilities for the storage of biosolids from wastewater treatment plants is recommended in the NWSMP. In relation to sludge storage in greater Dublin the NWSMP concluded:

"*In line with the approach taken to other facilities in this Plan, the development of Sludge Storage Facilities will no longer be considered solely on a per-plant or per-county basis. Where appropriate, Sludge Storage Facilities will be developed to serve a number of local plants and/or a wider regional need. In particular, the upgrade to the Ringsend WwTP sludge hub and the proposed GDD WwTP will result in a significant increase from current sludge volumes with a consequent increase in storage requirements. Therefore, a dedicated sludge storage facility should be developed in conjunction with the expansion of Ringsend to meet its requirements and take account of other future needs in the region"*.

Accordingly, the RBSF is being advanced in accordance with this requirement. The purpose of this report is to set out the basis for the proposed design and to describe the development for which planning permission is sought. The report should be read in conjunction with the accompanying drawings as listed in Appendix 1: List of Drawings

1.2 Biosolids Description

Organic and inorganic solids in the wastewater (both solid and dissolved) end up in a sludge which is subject to further separate treatment on the WwTP site. The sludge is treated to recover gas (the energy from which is used to run the plant), to reduce its volume, and to kill pathogens (bacteria and viruses). The treatment process results in 'biosolids', a biologically stable product with pathogens (viruses, bacteria) reduced to the extent that renders it safe for use in agriculture, and containing high levels of plant nutrients, e.g. nitrogen and phosphorus. The level of pathogen reduction from the treatment process is such that the treated sludge material can be transported and stored without any further health protection measures being necessary, subject however to compliance with all applicable waste regulations.

At the Ringsend WwTP the treated sludge is also dewatered or dried to give two final products for transport to storage: a wet 'cake' (26% dry solids) or a dry granular material (92% dry solids). Both materials are high in nutrients and are used as soil conditioners and organic fertilizers in agriculture. Both are generically termed 'biosolids', i.e. a fully treated sludge product which is biologically stable, has a low odour and is free of harmful pathogens. The cake material is known as *"biocake"* and the drier granular material is known as *"biofert"*.

Following the completion of the upgrade works at the Ringsend WwTP, the wastewater stream will provide for phosphorus recovery generating a product known as '*struvite*'. Like biocake and biofert, this material can be considered as a biosolid under the *"Code of Good Practice for the Use of Biosolids in Agriculture" (1999).*

Biosolids are described in the Code as rich in "*macro and micro nutrients required for healthy plant and animal growth. It contains Nitrogen, Phosphorus and Potassium. It can also provide Magnesium…."* Similarly, the recovered material will be utilised as a fertiliser or soil conditioner.

1.3 Proposed Site

1.3.1 Site Selection Process

Irish Water has concluded a site selection process to identify the most suitable location for a RBSF to serve Greater Dublin. The process involved three stages of non-statutory public consultation which facilitated engagement specifically on:

Stage 1. Methodology for Site Selection
Stage 2. Identification of Potentially Suitable Sites
Stage 3. Identification of Preferred Site

The proposed methodology by which a suitable RBSF site was selected was first set out in the Stage 1 report which was published by Irish Water in February 2017. That Report provided the background to the project and explained the proposed methodology for shortlisting potential suitable sites. A full public consultation process was conducted at each stage. As the selection process progressed a shortlist of potential sites was identified.

The sites and the further details of the methodology adopted in selecting them were provided in Stage 2 report published in May 2017. Finally, the publication of the Stage 3 Report in August 2017 identified the preferred site for the proposed RBSF at Newtown, Dublin 11 and the methodology adopted to identify it. The site location relative to the Ringsend and proposed GDD WwTPs is shown in Drawing Y17702-PL-001 and the transport routes from the respective facilities are shown in Figure 1-1.

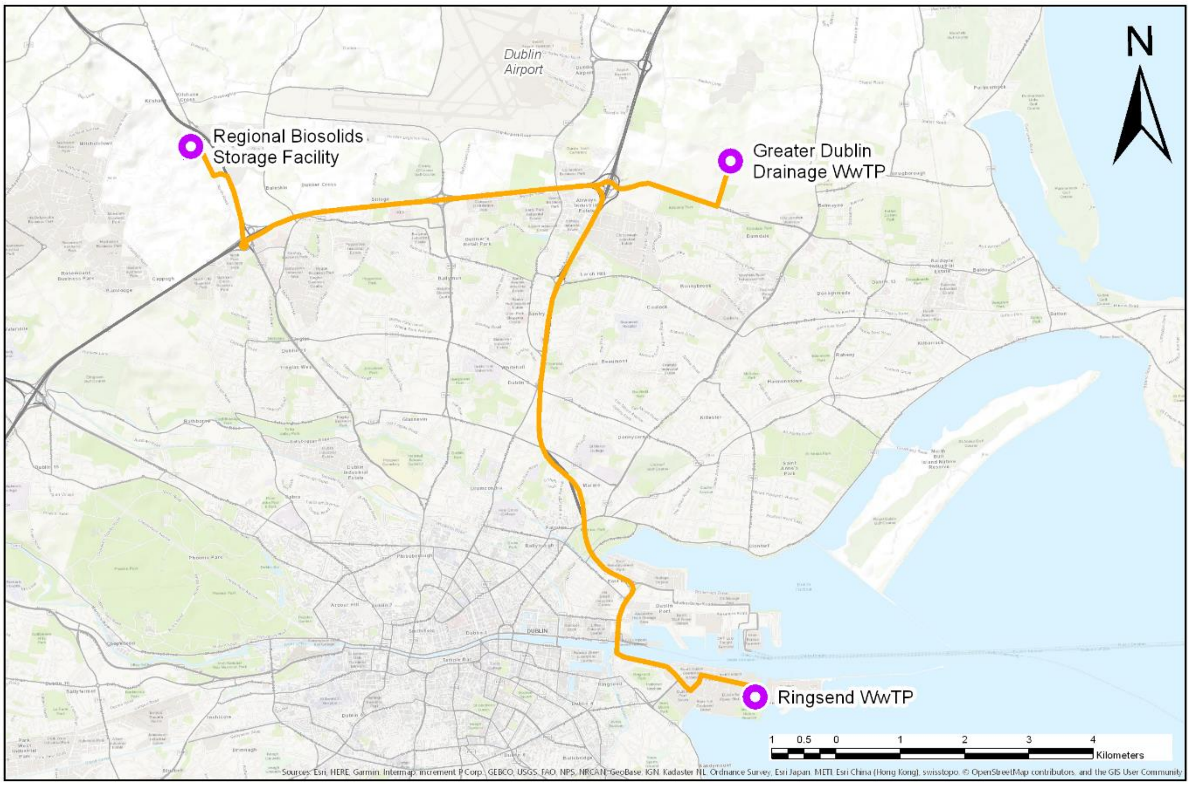

Figure 1-1 Transport Routes to the RBSF Site

Biosolids from Ringsend WwTP will be transported along Pigeon House Road, over the East Link bridge along East Wall road and via the Port Tunnel to Junction 3 on the M50 motorway. GDD WwTP biosolids will be transported from Clonshaugh along the N32 to Junction 3. Biosolids from both locations will arrive at the Newtown Site via the R135 having come off the M50 at junction 5 and travel a short distance on the N2.

1.3.2 Existing Development at Site

The proposed RBSF site is currently owned by Fingal County Council and has been partially developed for a previously planned waste recycling facility (ABP Reg. Ref. PL06F.EL.2045). The site location is shown on Drg. Y17702-PL-002 while the current site layout is shown on drawing Y17702-PL-003 and aerial views are presented in Figure 1-2 and Figure 1-3.

Figure 1-2 Existing Aerial Image of the RBSF site from the East

The site is accessed from the adjacent R135. Vehicles arriving to the site from the M50 approach from the south and turn left into the site. The road outside the site includes a clearly marked left turning slip lane for the site. Vehicles leaving the site turn left on to the R135 for all routes. The minimum visibility distances are available at the site entrance, verified with TII publication DN-GEO-03060.

The site comprises sections of grassland separated by a road network. The development works that were completed include a road network, boundary fencing, administrative buildings, drainage systems and other site services. An ESB 110 kV overhead transmission line and a 38kV underground cable both cross the southwestern corner of the site.

The site generally slopes from east to west. There is a difference of up to 3 m between the highest and lowest areas on the site. A tributary of the Huntstown Stream, which in turn is a tributary of the River Ward, flows along the western boundary of the site. The site naturally drains to this watercourse.

The planned development sought by Fingal County Council in 2005 under Section 175 of the Planning & Development Act 2000, as amended, comprised:

- A Construction and Demolition Waste Recovery Facility processing 75,000 tonnes per annum (tpa);
- A Biological Waste Treatment Facility treating 45,000 tpa of segregated domestic and commercial organic waste;
- A Waste Transfer Facility processing 65,000 tpa of municipal solid waste; and
- A Sludge Hub Centre treating 26,511 tpa of municipal sludge.

Figure 1-3 Existing Aerial Image of the RBSF site from the Southwest

Approval was granted for this development by An Bord Pleanala in April 2006 and some buildings, internal roads and services were constructed on the site in 2009. The partially developed site was secured and fenced off by the contractor and has remained unused since then.

The existing infrastructure on site was constructed as part of a Design and Build contract for the development of a waste recycling centre. Design information was submitted as part of the planning submission. This information and supplementary information was supplied by the consultants who acted on behalf of Fingal County Council for the planning application. Additional information was gathered from various site surveys. As the works were not fully completed, no “as-built” data was available.

SECTION 2: BIOSOLIDS PRODUCTION

2.1 Future Wastewater Design Capacity and Loads

The need for additional wastewater treatment capacity to serve the Greater Dublin Region was identified in the *Greater Dublin Strategic Drainage Study* (GDSDS) published in 2005. This study set out a vision for the future management of wastewater within Greater Dublin and was subsequently the subject of a *Strategic Environmental Assessment* (SEA) in 2008, following which it was incorporated into development plans. The GDSDS proposed that the capacity of Ringsend WwTP be maximised, within the existing site. The GDSDS also proposed the construction of a new wastewater treatment facility in north Dublin to cater for demand in excess of the Ringsend capacity. This facility is now known as the Greater Dublin Drainage (GDD) WwTP. A design horizon of 2040 has been chosen for the proposed RBSF to align with the NWSMP. The growth within the Ringsend catchment is projected to steadily rise to the 2040 design horizon.

Figure 2-1 Historic and Projected Loadings for the Ringsend Catchment (Carbonaceous Reduction)

In 2017 Irish Water carried out a review of current loadings on WwTPs in Greater Dublin as well as future growth in the region. This document titled *"Greater Dublin Drainage Strategy; Overview & future Strategic Needs"* (GDDS) is enclosed with this planning application for further information. This review examined 2016 Census data, CSO Regional Population Projections and a Demographic Study carried out in 2014 by Irish Water as part of the Water Supply Eastern and Midlands Region Project. The 2017 Review formed the basis for the most likely projected growth scenario within the Ringsend catchment, which is anticipated to be in region of 2.712m PE by the 2040 design horizon. This growth scenario provides a 20% allowance for headroom for industrial/ domestic growth which may be disproportional to the most likely scenario.

The projected loadings for the Ringsend catchment together with the required additional capacity are shown in Figure 2-1 which also shows the programmed capacity graph for the Ringsend WwTP. This graph, denoted in green, represents the projected population equivalent following the completion of the capacity upgrade by 2020/2021, which will provide for greater SS/BOD reduction capacity. Consequently, the WwTP's capacity upgrade will see a rise in capacity to a population equivalent of 2.4m for SS/BOD with follow on a programme of retrofitting new technology until 2028 to meet N/P requirements, subject to Planning Approval. The purple curve on Figure 2-2 shows the programmed capacity for phosphorus and nitrogen at the Ringsend WwTP.

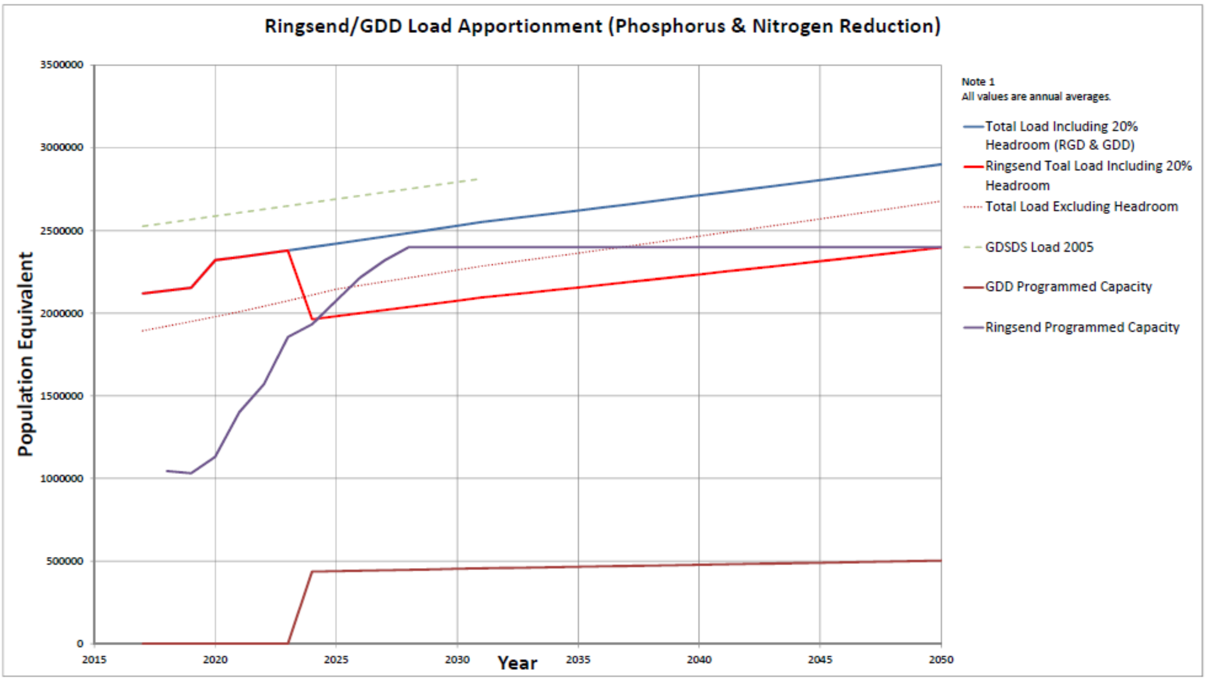

Figure 2-2 Historic and Projected Loadings for the Ringsend Catchment (P&N Reduction)

The loadings on the Ringsend catchment are projected to reach approximately 2.4 million PE by 2024 depending on the actual growth realised in the catchment. As well as the development of the treatment plant at Ringsend, Irish Water is separately progressing other projects for the provision of a the GDD wastewater treatment facility in north Dublin together with alterations to the drainage network to facilitate the required diversion of flows from the Ringsend catchment. The additional capacity is expected to be constructed by mid 2020s together with provisions for intercepting the Blanchardstown Catchment [9C] and part of the North Fringe [NF] Catchment and transferring these flows to the new WwTP. These alterations will accommodate the anticipated growth within the Ringsend catchment beyond 2024 and provide additional capacity within the Ringsend WwTP until it reaches its anticipated upgraded capacity of 2.4m PE by 2050. It is also anticipated that the GDD project will become operational in 2024 and will provide an additional capacity of 0.5m PE to accommodate this growth. As shown in Figure 2-1 by the 2040 design horizon, both Ringsend and GDD WwTPs will produce sludge equating to a design PE of 2.298m and 0.414m respectively. The remainder of the projected sludge arisings will be imports from smaller WwTPs in the Fingal area along with some septic tanks sludges with an equivalent PE of 0.21m PE.

2.2 Biosolids Production at Ringsend WwTP

The treatment of wastewater at Ringsend WwTP results in the production of primary sludge (PS) and surplus activated sludge (SAS). The following unit processes are currently used at the WwTP for the handling and treatment of both sludges.

- Thickening and Dewatering
- Storage
- Thermal Hydrolysis
- Anaerobic Digestion

- Thermal Drying

Arising from these treatment processes, two types of treated sludges, both granular and cake, are produced with a dry solids content typically of 92% and 26% respectively. Biosolids from Ringsend WwTP is currently transported a facility at Thornhill Co. Carlow for storage during the non-spread season. The Thornhill facility has a certificate from Carlow County Council for a maximum annual throughput of 25,000 tonnes of biosolids.

Following the upgrade of the wastewater process and provision of additional treatment capacity, the quantity of sludge generated at Ringsend will increase pro rata with loading and will also increase because of an improvement in the effluent quality. At present the average suspended solids in the treated effluent is approximately 52 mg/l and this is expected to improve to an average value of circa 20 mg/l with the development of additional capacity and introduction of Aerobic Granular Sludge (AGS) technology for the biological treatment stage of the wastewater. With the increase in efficiency and capacity at the Ringsend WwTP, it is anticipated the plant will produce approximately 27,375 tDS/annum of digested sludge at full capacity (i.e. 2.4m PE).

The inclusion of thermal drying within the in the sludge treatment process is a key factor in determining the volumes of material to be stored, as the space requirements for *biofert* is significantly less than that of *biocake*. For comparison, a tonne of dry solids requires a storage volume of 2.5m³ for biofert while biocake requires 3.8m³. Currently only two of the three dryer units are used at the one time, operating on a duty-duty-standby basis; this arrangement can cater for current sludge arisings. With relatively small investment the dryers can be reconfigured on a duty-duty-assist basis and this would mean that in the future, all Ringsend WwTP output would be biofert, except for occasional outage for maintenance situations.

Additionally, struvite will be produced at the Ringsend WwTP as a by-product to wastewater treatment process following the commissioning of the phosphorus recovery system at the beginning of 2021. This is a valuable fertiliser material which has proven commercial markets internationally. However, such markets have yet to be developed in Ireland. Irish Water has not yet procured the technology to be used for phosphorus recovery and there are several techniques now commercially available and proven to recover struvite. The product and P-recovery technique to be procured will have to meet a suitable standard to satisfy “end of waste” status through approvals from the Environmental Protection Agency.

The recovered material will also require REACH approval from the local competent authority (the Health and Safety Authority in Ireland). Irish Water may not be in a position to apply for end-of-waste approvals and/or REACH approvals until the P-recovery technique is selected as the standard to be attained and quality of product cannot be assessed unless specific techniques are known. This will clearly take some time and there will be a need for an alternative disposal route pending these approvals and there is a requirement to facilitate its reuse under traditional waste regulated channels of land-spreading in the interim. Accordingly, consideration needs to be given to the storage requirements arising therefrom.

2.3 Biosolids Production at GDD WwTP

Subject to achieving the necessary Planning Approvals, a Sludge Hub Centre (SHC) is proposed to be co-located with the GDD WwTP, in the eastern zone of the site, to provide sludge handling and treatment facilities for wastewater sludges generated at the plant. Wastewater sludges, also referred to as imported sludges, generated at other municipal wastewater treatment plants and private owners (i.e. septic tanks, domestic treatment systems) in the administrative area of Fingal will also be treated at the SHC. In accordance with Irish Water's NWSMP it is proposed to provide advanced anaerobic digestion treatment to the sludge to produce a 'biosolid' end product, which will be biocake only. Indicative unit treatment processes in the SHC include the following:

- Buffer tanks,
- Thickening and dewatering (centrifuges),
- Thermal hydrolysis (pasteurisation),
- Mesophilic anaerobic digestion.

The development will entail the construction of all the necessary buildings, tanks, ancillary structures and mechanical and electrical plant required to provide a treatment capacity of 18,500 tDS/annum for the 2050 design horizon. The treatment process will be designed to achieve a 50 percent reduction, yielding a digested sludge of 7,935 tDS/annum for the 2040 design horizon.

2.4 Storage Requirements

Irish Water is applying to An Bord Pleanála for planning approval for development of the RBSF based on a 20-year design horizon (up to 2040), which aligns with the NSWMP for land spreading in this period. The facility is required to store treated wastewater sludge from both Ringsend WwTP and the proposed SHC at GDD WwTP. Organic fertilisers, such as biosolids, are not permitted to be applied on land between mid-October and mid-January in the areas of the country where there is the most likely demand for biosolids to be stored at the RBSF. These rules are set out by the Department of Agriculture, Food and Marine to comply with the European Union's Nitrates Directive transposed into Irish law under *S.I. 31 of 2014*.

Sufficient storage capacity will be required at the RBSF to cater for a 4-month non-spread period. Irish Water will review the storage requirements within Greater Dublin in the medium to long term and develop the proposed RBSF further within the space provided on the selected site if and as required. Any further development would require planning consent before it could proceed. The Irish Water strategy to continue with thermal drying will also be a key driver in determining the storage requirements of the RBSF into the future. Having regard to the foregoing, three scenarios have been developed for RBSF design purposes as follows:

- High Volume Scenario: All biocake with no dryers in operation.
- Low Volume Scenario: Three dryers at Ringsend with biocake from GDD
- Most Likely Scenario: Two dryers at Ringsend with biocake for the remainder.

Each milestone year indicates a significant change to WwTP operations within the catchment and subsequently varying types of sludge production from each WwTP. The Ringsend WwTP is projected to reach full design capacity by 2028 while the GDD WwTP is expected to become operational in 2024.

This year is significant as the expected loading at Ringsend WwTP reduces to 2.017m PE due to the proposed diversions from the Ringsend catchment to the GDD WwTP. This has an impact in terms of sludge production as the SHC at GDD WwTP will not produce biofert as no thermal drying is proposed in the short term. Further, the imported sludges from the other Fingal plants will represent a step change in biosolids production.

The projected biosolids production, which includes 20% headroom, and likely storage volumes required are tabulated in Table 2-1 for 2021, 2024 and 2040 design horizons.

Table 2-1 Storage volume requirement for all scenarios

Year	Source	Loading including Headroom (PE) million	Total Treated Sludge (tDS/yr)	Biosolid	Annual Production (Tonnes)			Storage Volume (m³)		
					High Volume Scenario	Low Volume Scenario	Most Likely Scenario	High Volume Scenario	Low Volume Scenario	Most Likely Scenario
2021	Ringsend WwTP	2.338	26,668	Biofert	-	28,987	16,630	-	21,117	**12,116**
				Biocake	102,569	0	43,722	31,313	0	**13,348**
	Catchment Total	2.338	26,668		102,569	28,987	60,353	31,313	21,117	**25,463**
2024	Ringsend WwTP	2.017	23,006	Biofert	-	25,007	16,630	-	18,218	**12,116**
				Biocake	88,486	0	29,640	27,013	0	**9,049**
	GDD WwTP	0.382	4,880	Biofert	-	-	-	-	-	**-**
				Biocake	19,520	19,520	19,520	5,959	5,959	**5,959**
	Catchment Total	2.399	27,886		108,006	44,527	65,791	32,973	24,177	**27,123**
2040	Ringsend WwTP	2.298	26,212	Biofert	-	28,491	16,630	-	20,756	**12,116**
				Biocake	100,814	0	41,968	30,777	0	**12,812**
	GDD WwTP	0.414	5,289	Biofert	-	-	-	-	-	**-**
				Biocake	21,155	21,155	21,155	6,458	6,458	**6,458**
	Imported Sludges	0.207	2,644	Biocake	10,578	10,578	10,578	3,229	3,229	**3,229**
	Catchment Total	2.919	34,145		132,547	60,224	90,331	40,464	30,444	**34,615**

Notes:
1.Figures are rounded.
2.Biofert is 92% dry solids with a bulk density of 440kg/m³.
3.Biocake is 26% dry solids with a bulk density of 1050kg/m³.

The most likely scenario, presented in Table 2-1, is one in which the current thermal drying capabilities of the Ringsend WwTP producing biofert will continue in the short to medium term. The first phase of the SHC at the GDD WwTP will produce biocake from 2024 during the same term. The analysis herein and the projections developed assume that there is no change in technology in respect of sludge dewatering and biosolids production. It is to be expected that new methods and technological developments in dewatering plant will emerge over the lifetime of these plans. Such developments will provide the opportunity to reduce storage volume requirements, should these technologies prove to be viable on cost benefit analysis.

In the short term it is likely that struvite can be stored in separate segregated bays at the RBSF until market arrangements are firmly established. Unlike biocake and biofert, struvite will typically be bagged on the WwTP site to facilitate transfer to the fertiliser industry. However, in the interim situation, the product will be delivered in bulk to the RBSF. The annual quantities of struvite are expected to be in the region of 6,000 tonnes/year based on the average design load for the Ringsend WwTP. In comparison to biocake and biofert, struvite is a far denser material thus consuming less space with the RBSF. It is possible that struvite may need be stored at the RBSF until 2025 with the product being made available directly to the market thereafter. In terms of capacity, the RBSF is more than capable of safely accommodating the 1,600m^3 storage requirement during the non-spread season.

SECTION 3: STORAGE BUILDING D ESIGN

3.1 Operational Requirements

The RBSF will receive treated sludge from Ringsend WwTP and the proposed SHC at GDD WwTP in North Dublin. The facility will be operated by single/multiple contractors under the operations contract for these plants. If an interface between multiple contractors arises, this will be coordinated by a representative for Irish Water. A Certificate of Registration (COR) will be sought for the RBSF in accordance with the Waste Management (Registration of Sewage Sludge Facility) Regulations, 2010. The management of the proposed RBSF will adhere to the requirements set out by these regulations and implement actions within the operations contract to comply with same. A more detailed Operations Management Plan (OMP) will be submitted to Irish Water by the contractor on their appointment and will form part of the COR. Within the scope of works for any operations contract, a list of obligations will be included which will form the basis for the Contractor's OMP which will comply with the requirements of the local authority.

The deliveries from both sites to the RBSF will be scheduled to avoid queuing at the entrance to the facility so as not to cause a hazard on the adjacent public road. Deliveries will arrive at the RBSF site and be immediately directed to the entry weighbridge via the one-way traffic management system. The quantity and type of material contained in each HGV will be recorded at the entry weighbridge. Each HGV delivery will submit documentation to demonstrate both the quality and traceability of the material including the source and treatment which it has been subjected to.

These records shall be kept in accordance with COR for review by both the local authority and Irish Water. From the entry weighbridge, drivers will be directed to the appropriate storage building aided by internal road signage and road markings. In the event, that a storage building is unavailable the driver will be instructed to park in the HGV parking area at the northwest of the site and await instruction. During this time the driver will shut off the engine to avoid noise nuisance to those onsite and neighbouring properties. Once directed to a storage building, the driver will be instructed to tip the delivery within the building at the designated storage bay. Each storage bay will be numbered and clearly signed. Once the delivery is tipped, a loader vehicle will push the material into the designated bay. A record of the sludge imports and exports, origin and destination locations, together with the waste collection contractor's details for the materials stored in each bay will be kept by the operator.

It is envisaged 2 to 3 people will operate within the storage building at any one time. Operators will remain within the confines of the HGVs or loader, thus minimising requirement for pedestrian access to the building. Unloading and loading will take place within the building with closed doors to minimise noise and odour nuisance. Dedicated odour control units for the storage buildings will neutralise odours which will minimise any potential nuisance making it imperceptible at the site boundary. Details of an odour assessment for the RBSF can be found in Volume 4 of the EIAR. Once delivered, the empty HGV will be directed to the vehicle cleaning area for wheel washing to remove any adhered biosolids before leaving the site, being weighed on the exit weighbridge. During the spreading season, outgoing HGVs delivering biosolids to spread lands will be recorded at the exit weighbridge, while empty trucks will be weighed on arrival.

All vehicles transporting biosolids material will be covered to prevent spillage of material and emission of odour. It is envisaged that approximately 6 people will be required to work at the RBSF site at any one time. As part of the OMP regular inspections will take place to assess the condition of the facility to avoid loss of material. These inspections will specifically monitor the integrity of the building structure. However, structural problems are not envisaged as measures will be incorporated at design stage to mitigate any potential structural degradation.

3.2 Storage Building Sizing

Two storage buildings will be located centrally onsite as shown in Drawing Y17702-PL-004. This location utilises the existing entrance on the site and will accommodate new internal circulation roads. The road will allow vehicular access to the storage buildings and for vehicles to travel past the buildings and around the site in a clockwise direction only. This avoids vehicles crossing lanes.

At the highest point, the roof level will be 15.2m above ground level. Powder coated steel entry and exit roller shutter doors for vehicles will be located at either end of each building to facilitate security. Internal to these doors fast acting automated doors will be installed to mitigate nuisance from noise and odour during operations. Separate self-closing doors will be provided for pedestrian access. Haulage vehicles bringing biosolids to and from the storage facility will access the buildings from the eastern end and will exit from the western end with only one-way traffic within the storage buildings.

A key element of the facility operations will be to provide for tipping of material within each storage building, to mitigate a possible dust or odour nuisance. As part of this mitigation a 10m wide service road will be provided within each storage building where operations can take place. An examination of technical data for the delivery vehicles indicates that a clearance height of 11.25m to the underside of the soffit/truss is required within each building to minimise the risk of structural damage.

Each building is proposed to be 105m long and 50m wide internally. The preliminary design incorporates 12 bays, each measuring 17m by 20m, to facilitate segregation of material. This may be subject to modification at detailed design stage to reflect operator's requirements. An indicative floor plan configuration is shown in Figure 3-1 while more details are shown in Drawing Y17702-PL-008. Depending on the material type, the storage volume in each bay can differ, mainly because of the stacking heights and material properties. While both materials are treated to the same bacteriological standard, the biofert material is more cohesive due to its lower moisture content following thermal drying.

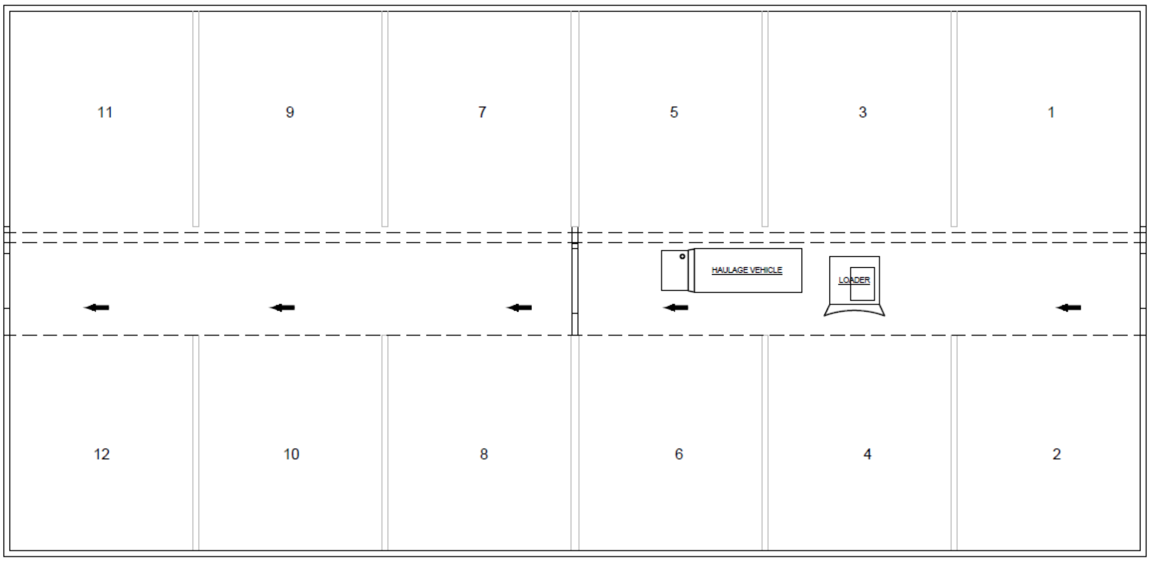

Figure 3-1 Typical Storage Building Floor Plan

A greater amount of biofert can be stored in one individual bay due to higher stacking heights of about 7m. A bay containing all biofert can hold 2,245m³ or 908 tDS of material. As biocake is far more saturated, the stacking heights are reduced to 3.5m. Consequently, a bay containing biocake can accommodate 1,090m³ or 297 tDS. A schematic of the available capacity for each bay is shown in Figure 3-2. It is proposed that precast concrete units will be used as barriers to close off full bays. These units will be moved as required by forklift and stored in the empty bays while not in use.

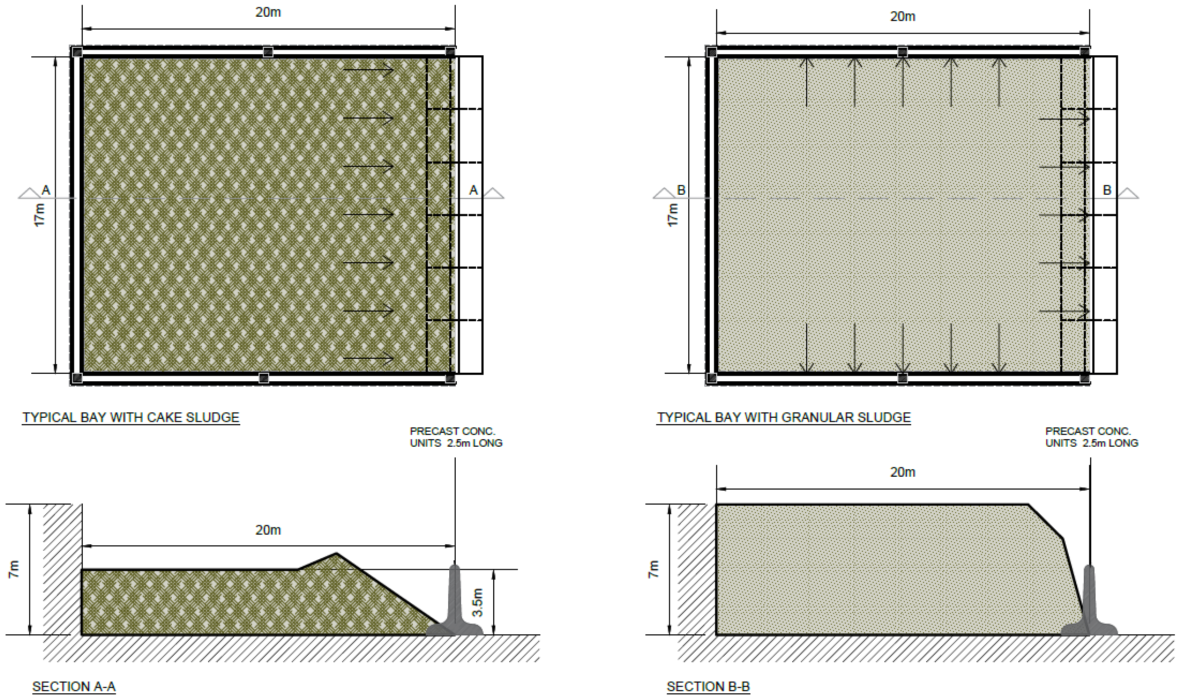

Figure 3-2 Plan of Typical Bay for Cake & Granular Sludge

Using this methodology, it is possible to project the future storage requirements under the different volume scenarios and these are shown in Table 3-1.

Table 3-1 Storage Bay Requirement for all Scenarios

Year	Population Equivalent (PE)m	Scenarios (No. of Bays)								
		High Volume			Low Volume			Most Likely		
		Biofert	Biocake	Total	Biofert	Biocake	Total	Biofert	Biocake	Total
2021	2.338	-	29	29	10	0	10	**6**	**13**	**19**
2024	2.399	-	31	31	9	6	15	**6**	**14**	**20**
2040	2.919	-	38	38	10	9	19	**6**	**21**	**27**

Based on the above staging for the most likely scenario, two buildings would be required by 2021 to accommodate 12,116m³ of biofert and 13,348m³ of biocake generated from the Ringsend WwTP. The existing facility at Thornhill may still be used by the DBO contractor up to the expiry of the operations contract in 2025 which would allow the construction of the second storage building to be postponed until the Thornhill facility is no longer in operation. For the 2040 scenario it is likely that technological advances and the combined use of 3 dryers will mean that 24 bays or two buildings will be sufficient for seasonal storage requirements.

As evident from Table 3-1, up to 4 bays will be free or Thornhill will be available up to 2024 for the storage of struvite during the non-spread season, as required. It is envisaged that a bay of struvite will have a capacity of 1,020m³ at a height of 3m.

3.3 Architectural Design

The architectural design of the storage buildings incorporates a curved roof. This roof profile results in a visual blurring of the buildings' roof apex. The roof is visually separated from the walls by a 'shadow band' and the footprint of the buildings is staggered. The slanting front façade of both buildings extends beyond the side walls of the building into the landscape. The external envelope will comprise insulated metal cladding panels, which will clad the entire perimeter of the building. As shown in the architectural Drawing's Y17702-PL-013 & 014, the colour of the panels will generally be grey and silver. This architectural design is provided to enhance the visual perception of the development from the most prominent views of the site. An architectural design statement prepared by Paul O'Toole Architects is enclosed with the planning application.

3.4 Structural Design

As ground conditions are favourable, it is proposed to use wide strip footings for the storage building. These will support reinforced concrete retaining wall up to 7m high. The floor will consist of a reinforced concrete slab on suitably compacted hardcore. As there is a general requirement for a clear span within the building and the architectural design calls for a curved roof. The roof structure is conceived as a curved lattice steel trusses at 6.25m centres. The will be supported on steel universal columns mounted on the retaining wall. A conceptual structural design is shown on Drawing Y17702-PL-008 & 010. This will be fully developed by structural engineers at detailed design stage.

3.5 Mechanical and Electrical Systems

A Building Management System (BMS) will be installed to facilitate management of the various systems throughout the RBSF. The main BMS panel for the system will be located in the Mechanical and Electrical (M&E) control room. The proposed systems to link into the BMS include the odour control system, security alarms, fire alarm system and roller shutter doors. A computer located in the administration building will facilitate dealing with day to day operations of the BMS (i.e. alarms and reporting). Power and control of the odour control system will be provided from the MCC panels in the M&E control room and link to the BMS. Cabling Containment will be provided for all power and control cabling within the storage buildings.

A Very Early Smoke Detection Apparatus (VESDA) Fire Detection System will be provided for each of storage buildings. This type of system is more suitable for this building and application than a standard addressable fire alarm system. The system will sample and monitor the air in each building to identify fire at an early stage of development. A process monitoring system (PMS) will be provided within each of the storage buildings. This system includes a thermal camera that will be provided for each bay to monitor material temperature and communicate over temperature to the BMS as required. The LED lighting installation within each building will be high bay corrosive proof lighting at high level. A lighting control system will be installed to ensure efficient management of the lighting system. Emergency lighting to IS3217: 2013 will be provided.

A steel roller shutter with internal fast acting inner door will be installed at each outer door. An internal fast acting door will be installed at the inner door opening. Control of all doors by fobs, handheld devices and underground loops will be finalized at detailed design stage.

A lightning protection system may be provided for the biosolid buildings. The detailed requirements for lightening protection will be developed once a risk assessment has been carried out by a specialist system supplier at detailed design stage.

3.6 Odour Control

An odour control system will be provided to reduce odour to an imperceptible level at the RBSF site. The system will involve extracting air at the rate of 2 changes per hour from within the storage buildings on a continuous basis. Fans located outside, between the storage buildings, will draw air though ducting to outside odour control units containing a proprietary organic filter media. The treated air will be emitted to the atmosphere through vertical stacks which will extend to a height of approximately 3m above the roof level of the storage buildings. Each building will be split into two zones so that each can be operated independently. Accordingly, there will be a total of four separate odour control units each with its own stack. The location of the stacks of shown in Drawing Y17702-PL-004 and outline details of the odour control units as shown in Drawing Y17702-PL-022.

3.7 Fire

There are some potential fire risks associated with storage of the biosolids in both the biofert and biocake forms. Previous studies carried out through academia indicated that the materials can potentially be self-combustible, self-heating or both. Michael Slattery and Associates (MSA), specialist fire consultants, were engaged during the design process to provide technical advice in respect of material analysis and fire safety compliance. As part of the initial review, consultation took place with the Dublin Fire Brigade Senior Fire Prevention Officer for the proposed location on 15th January 2018. Based on this meeting, MSA has outlined the relevant codes and guidance chosen for the design basis within the Fire Strategy Report attached in Appendix 2 and briefly described as follows:

- Relevant recommendations of BS 9999:2017 and TGD B supported where necessary by fire safety engineering analysis to justify deviations from these codes.
- Recommendations of relevant British and International design codes standards and specifications to the forms of construction or design of fire protection installations.

Biocake and biofert samples from Ringsend WwTP were sent to a specialist laboratory for testing. Material testing reports undertaken by BRE Global to determine the extent of the risk are also included with the MSA report. The isothermal heating risk for both materials is not an issue as the turnover time at the proposed facility will be substantially less than the time required to approach ignition temperatures (i.e. 249 days in the worst case for the biofert material). In the case of explosion risk potential for the biofert material is in the lowest Explosion Classification In fact the result of the testing on the biofert samples were noted to be very much at the lower end of the range. This has been discussed with the Fire Officer during consultations.

In relation to BS 9999, the buildings will be considered an 'A Type occupancy' (i.e. only persons familiar with the Buildings and awake will be present), with a Category 3 (Fast) fire growth rate in respect of the biofert dust explosion risk. Mitigation of this risk will be achieved by use of intrinsically safe equipment and electrical installations in the facility and provision of explosion relief in the building envelope, all of which will be addressed at detailed design stage.

As noted later in section 6.5, the existing water supply is insufficient for supplying the instantaneous demand required if a fire event was to occur. On this basis, firefighting water will be made available from a hydrant main system augmented by on site storage (i.e. fire protection holding tank) based on recommendation of NFPA 1142. The creation of 2 compartments within each building and considering the buildings as high hazard occupancies, then a firefighting water supply of 3,800 litres / min will be required with a total quantity of 880m³ based on NFPA 1142. A fire protection holding tank with a capacity of 914m³ will be provided which will be replenished from the public water mains.

3.8 Energy

Irish Water's commitments are designed to reflect the national target set out in the Public-Sector Energy Efficiency Strategy (DCCAE, 2017). As set out in "*The National Framework for Sustainable Development in Ireland – Our Sustainable Future*" energy efficiency is one of the key areas of opportunity in the transition to an innovative, low carbon and resource efficient society. Irish Water's Energy Policy sets aims to be *"33% more energy efficient in the abstraction, treatment, distribution, collection, treatment and the return to the environment of every cubic meter of water and wastewater against a 2009 baseline"*.

Irish Water has included Photovoltaic (PV) technology within the design to contribute clean renewable energy to the power requirement at the RBSF facility. This aligns with the existing energy management regime at Ringsend WwTP. By providing such technology, the project satisfies specific Development Plan objectives of the local authority in terms of a renewable energy contribution to the development. The application of roof mounted PV solar panels to an industrial/ warehouse structure is traditionally considered to maximise the potential power generation of such technology. This potential is maximised as the daytime operational hours of such industry correlates directly with periods of solar irradiance. Based on this evidence, Irish Water has chosen to include this technology as part of the overall planning application.

A feasibility study into the solar contribution potential was carried out by specialists as part of the initial design phase. This study will be re-examined at detailed design stage in order to capture rapid advances in solar technology, thus increasing efficiencies in the power output available from a single panel. This initial study considered a polycrystalline solar module with a peak power output of approximately 270W. Under this scenario a solar array of 1,545m² is required to provide a peak power output of 249.75kW. Irish Water proposes including this array within the area highlighted on Drawing Y17702-PL-004. A PVsyst (PV design software) model predicts an energy yield from such a system of 219,930kWh per annum, which equates to a carbon footprint reduction of 113,704kg of CO_2 per annum. It is anticipated the inclusion of PV technology will contribute upwards of 40% of the sites annual energy load.

Considering the buildings proximity to Dublin airport, a glint and glare study has been undertaken by Macroworks Ltd. in January 2018. (A copy assessment report will be submitted with the planning application for the RBSF). In summary the study concludes that there will be no adverse impacts. More specifically it states, *"Based on an in-depth analysis of receptors in the landscape (dwellings and routes) surrounding the proposed development and from the aviation receptors as recommended by the Federal Aviation Authority (FAA) technical guidance, we can determine no reason to suggest that there will be any adverse impacts from the solar development at Newtown as proposed."*

SECTION 4: ANCILLARY BUILDINGS

4.1 Administration & Welfare Building

An existing one-storey administration building (approximately 85 m^2 plan area) will be demolished. A new administration building will be constructed, to provide offices and welfare facilities for staff working at the facility. The building will contain an office, a meeting room, toilets, a changing/locker room, a kitchen/canteen and a washroom. The building details are shown in Drawing Y17702-PL-006. The overall dimensions of the one-story building will be 10m wide and 13m long. The height of the ridge will be approximately 4.1 m above ground level. The new building will incorporate a curved roof which is in keeping with the main storage buildings on site. The roof will be consisting of a galvanised steel cladding finished in metallic silver. The building will be constructed of blockwork with a combination of finishes consisting of profiled cladding on the upper section and a fair faced plaster on the lower section. The colours schemes for the proposed exterior are shown on Drawing Y17702-PL-006. A new parking area in front of the Administration and Welfare Building will be constructed and will provide 6 car parking spaces for staff and visitors, with an additional parking space designated for a person with ambulant disabilities. It is envisaged that this building will be used by RBSF staff and by HGV drivers for comfort and meal breaks.

4.2 Electricity Substation

Electricity Supply Board Networks (ESBN) were consulted regarding the existing substation and previous MIC. No connection was made to the existing substation. ESBN noted that the existing structure of the substation does not meet current ESBN requirements. The substation was constructed with smaller dimensions than current specifications. The existing electricity substation will be demolished. A new substation measuring 9.2m long, 9.2m wide and 2.91m high will be constructed to ESBN requirements to service site requirements. Details of this building are shown in Drawing Y17702-PL-006. Where feasible existing electrical ducting routes will be retained. An electrical supply will be brought to the M&E control room and onward to the electrical and mechanical equipment within the storage buildings. The M&E control room will be located between the storage buildings.

Based on the ESBN consultation, it was decided that the structure should designed to the latest ESBN specification. An initial loading design for the site, indicated an MIC of approximately 320kva would be required. ESBN also noted that for the proposed MIC a new customer room of similar size to the substation would be required as an addition to the substation building. The customer room will contain the ESB Meter, customer switches and panels. A dedicated keypad panel with key to the building inside, will be required external to the entrance so that ESBN personnel can gain access to the room at any time.

ESBN stated that a 400kva transformer will likely be installed to accommodate the load. The supply will come from a transformer to the West of the site with 6 No. cables running under the road and into the duct at the entrance door to the substation. It was agreed that all works (including all civil works) up to the ESB meter would be carried out by ESBN and their contractors. The substation structure is the responsibility of the Irish Water.

SECTION 5: TRANSPORTATION

5.1 Local Road Network

The proposed RBSF is located at Newtown, Dublin 11. It comprises approximately 11 hectares of partially developed land and is situated off the R135 road, on the western side of the N2 national road. It is approximately 1.6 km north of Junction 5 (Finglas) on the M50 motorway and 1.5 km west of Dublin Airport. The local road network near the site shown in Figure 5-1.

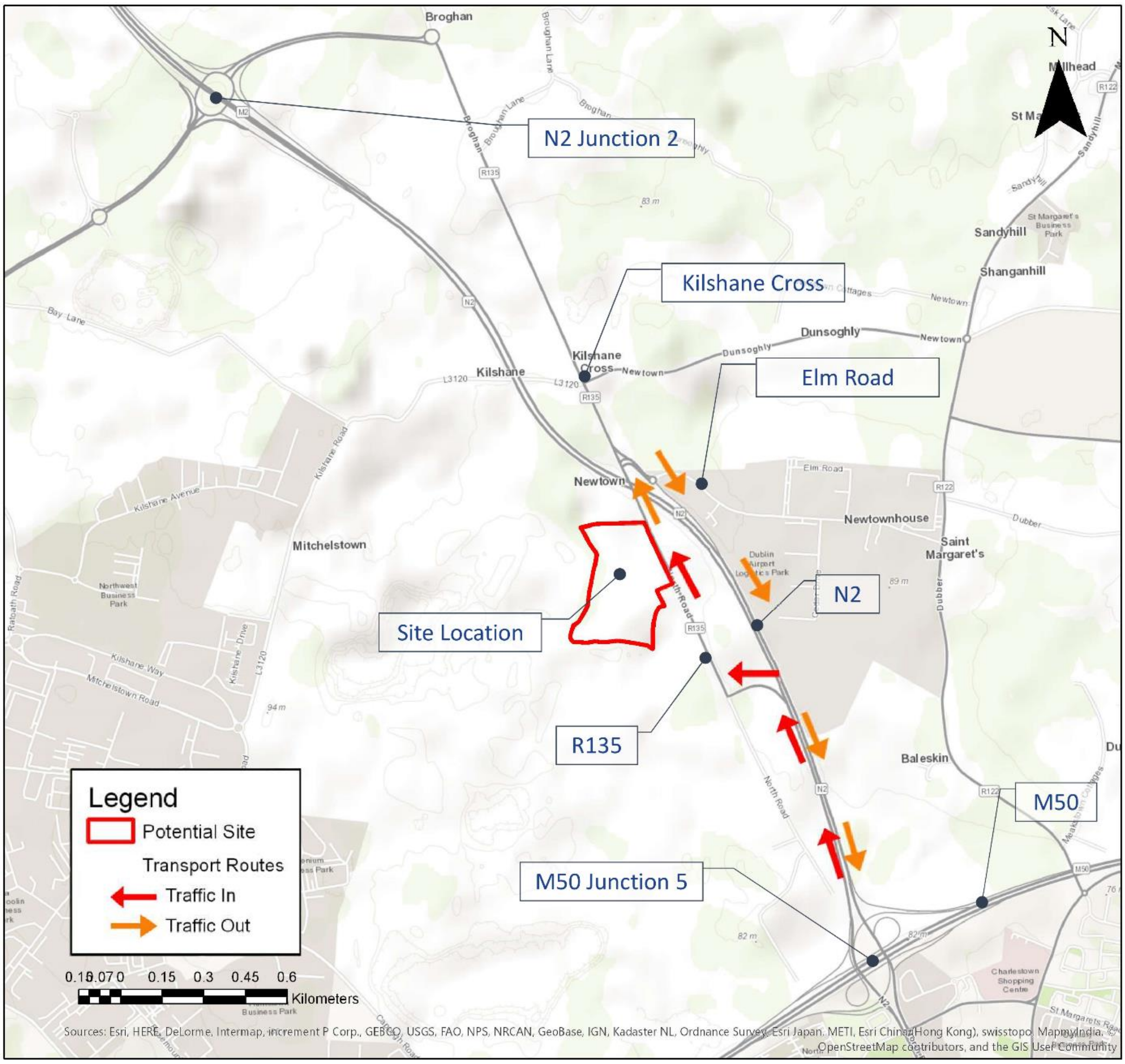

Figure 5-1 Local Road Network

The N2 National Road runs in a north/south direction from M50 junction 5 to the border with Northern Ireland near Aughnocloy, Co. Tyrone, via Ashbourne, Ardee and Monaghan Town. The N2 has a carriageway width of approximately 34.5 m, split evenly over two carriageways, each comprising three No. 3.65 m running lanes, 3.0 m hard-shoulder and 0.5 m central hard strip adjacent a 5.0 m central median. The R135 Regional Road is located to the east of the proposed site and runs in a north/south direction. The R135 has a carriageway width of 12.5 m and 60 kph speed limit within the study area.

5.2 Predicted Traffic Levels

To establish future year flows, traffic flow figures contained in the baseline model were factored up to the design years 2020, 2024, 2025 and 2040 using central growth rates contained within TII (NRA) Project Appraisal Guidelines: Unit 5.3 - Travel Demand Projections.

5.2.1 Total Trip Generation

Estimates of the total construction traffic and staff numbers associated with both phases for construction of the development were calculated on both buildings at storage capacity during the non-spread season. Information of the traffic leaving Thornhill was assessed for the 3 years, 2014-2016, to provide an indicative trend of the biofert and biocake demand. Based on this analysis a pattern of traffic to the spread lands was established for each month of the year. This pattern was modified to take account of the likely differing haulage patterns to reflect the different distances of the storage facility from the spread lands under the new scenario.

This pattern was then applied as a baseline for the distribution of the stored material from the RBSF to the spread lands for each of the proposed horizons (i.e. 2021, 2024, 2025 & 2040). The examination of existing information indicated March and September as peak traffic months. It is anticipated 17 trips per day will be required to deliver material to the RBSF from its sources based on the 2040 design horizon. During the spread season, for example in March - 59 trips will be required to the spread lands per operational day along with 11 deliveries from the source sites, equating to 70 daily trips.

Table 5-1 Predicted Daily Trip Generation for HGVs for Operations

Year	January	February	March	April	May	June	July	August	September	October	November	December
2021	5	4	28	**29**	5	5	5	11	18	9	5	5
2024	5	5	32	**30**	5	5	5	13	20	10	5	5
2025	14	15	**40**	39	12	12	15	40	38	18	11	12
2040	15	16	**70**	66	13	13	16	35	45	22	12	12

It is reasonable to assume these sludge quantities will continue on this basis until the operations have transitioned from the Thornhill facility. It is anticipated that HGV trips associated with the operation phase of the development will increase as the development approaches capacity in the design year 2040. A summary of the daily trip generation rates for the construction and operation phases are contained in Table 5-2.

Table 5-2 Daily Trip Generation Figures

Year	Construction Traffic				Operation Traffic			
	HGVs		Staff		HGVs		Staff	
	Arrivals	Departures	Arrivals	Departures	Arrivals	Departures	Arrivals	Departures
2020	25	25	30	30	-	-	-	-
2024	25	25	30	30	30	30	10	10
2025	-	-	-	-	40	40	10	10
2040	-	-	-	-	70	70	10	10

Light vehicular traffic associated with the proposed development is likely to be attracted to and distributed from the RBSF site in a similar proportion to the baseline traffic model. In this regard, the peak turn-in and turn-out flows calculated for the proposed development were distributed and assigned throughout the junctions considered in similar proportions to the overall traffic flows established as part of the baseline traffic model. HGVs associated with the proposed development will access the site the N2 northbound slip road and will return to the N2 via the N2 southbound slip road.

5.3 Current Traffic Levels

To determine current traffic behaviour in the vicinity of the site, classified traffic count surveys were carried out at the following locations:

- Location 1 – Kilshane Cross
- Location 2 – North Road (R135)/Elm Road junction
- Location 3 – Elm Road/N2 Southbound Link junction
- Location 4 – N2 Northbound Link/North Road (R135) junction
- Location 5 – N2 Mainline

The traffic count survey locations included the junctions most likely to be affected by the proposed project. Irish Traffic Surveys were commissioned to undertake the classified traffic counts between 7:00 am and 7:00 pm on Tuesday, 3 October 2017. The counts were designed to establish a 12-hour profile of traffic and trip patterns at each junction and to identify the critical peak hour periods of traffic flow through each junction. Full turning counts were recorded, and data was collected in 15-minute intervals. Additionally, TII Automatic Traffic Counter (ATC) TMU M02 000.0 N is located on the N2 in close proximity to the RBSF site between Junction 1 M50/N2 and Junction 2, Coldwinters.

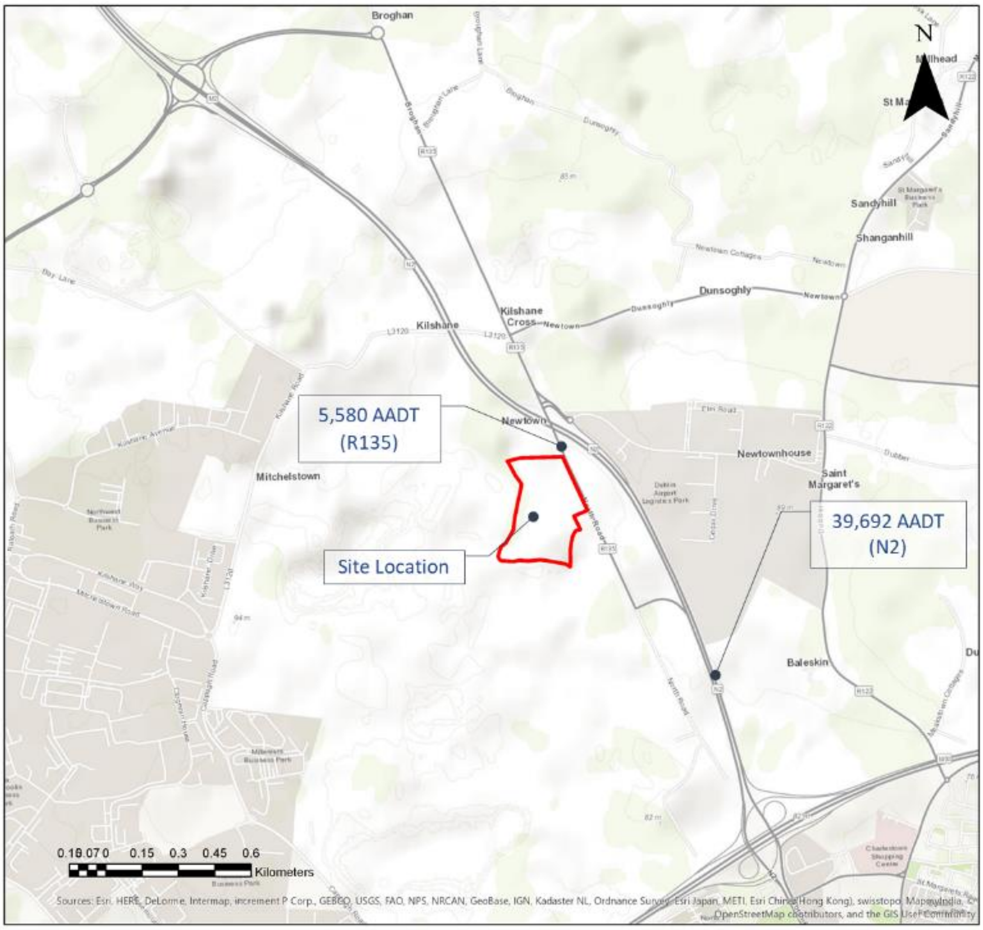

Figure 5-2: 2017 AADTs on Local Road Network

Project Appraisal Guidelines - Unit 16.1: Expansion Factors for Short Period Traffic Counts (TII/NRA) specifies a methodology to compute an AADT flow. Based on this, the AADT flows for the N2 and R135 are as detailed in Table 5-3.

Table 5-3 2017 AADTs Derived from Traffic Count Data

Link	12 Hour Flow (Vehicles)	AADT
N2	36,085	39,692
R135	5,073	5,580

It was found that the N2 AADT was 39,692 which is directly comparable to the AADT figures obtained from the TII ATC which estimated the AADT as 38,126 vehicles[1]. The calculated AADTs for the links identified are illustrated in Figure 5-2.

[1] Accessed on 20 December 2017.

5.3.1 Future Year Traffic Flows

The impact of the traffic flow resulting from the development was considered by assigning trips arising from the construction and operational phases of the development. The AADT for the pre and post development scenarios are presented in Table 5-4.

Table 5-4 Pre and Post Development AADT

Year	R135			N2		
	Pre-Development	Post Development	Percentage Increase	Pre-Development	Post Development	Percentage Increase
2017	5,580	-	-	39,692	-	-
2020	5,866	5,956	1.5	41,492	41,664	0.4
2024	6,272	6,364	1.4	44,028	44,200	0.4
2025	6,378	6,470	1.4	44,688	44,860	0.4
2040	7,522	7,614	1.2	50,732	50,904	0.3

5.3.2 Site Access and Egress Arrangements

Access to the site is provided via the existing entrance from the R135. A deceleration lane is currently provided for northbound vehicles on the R135 and a right-turn pocket is currently provided for southbound vehicles. Visibility in excess of 90 m, which is the desirable minimum distance commensurate to a 60 kph speed limit, is available to the left and right at the existing access. It is intended to maintain this access as part of the proposed layout. All alterations to the existing facility occur within the site and as such visibility is retained, as shown in Drawing Y17702-PL-014.

SECTION 6: SITE DEVELOPMENT

6.1 Demolition Works

A number of existing structures and sections of existing internal roads will need to be demolished as they are not suited to the proposed site layout design. The structures to be demolished include the security/weighbridge kiosk at the site entrance, the weighbridge kiosk near the eastern boundary, and the existing administration building. The existing electrical substation (not commissioned) will need to be re-built in order to meet current ESBN requirements. These buildings are identified on drawing Y17702-PL-003. These buildings are small relative to the scale of the proposed development at the RBSF site. Therefore, some of the material arising from the demolition works can be processed on site and reused in the proposed works. The demolition work is likely to be carried out by an excavator, using a specialist grab device if required.

Approximately 400 m of internal roads will be or removed. This will be carried out by pavement milling machines which will grind the road surface and convey the material to a nearby tipper truck. A high proportion of existing road surface and construction sublayers can be reused in the construction of the new roads on the site. If there is a surplus of reclaimed road surfacing material on the RBSF site it can be provided to a pavement contractor and re-used elsewhere.

The contractor may consider using the existing administration building as a temporary site office and sections of the existing roads as temporary haulage/construction routes. This would result in the demolition of the building and removal of roads occurring later in the programme.

6.2 Earthworks

A desk study (including information from previous site investigation data) as well as site-specific site investigations were undertaken to provide the data to compile the description of the existing environment. Details of site specific investigations at the site are summarised in Table 6-1. Information from the site investigations was used to create a general ground model for the site. This is shown in

Table **6-2** while a summary report of the 2017 site investigations.

It should be noted that there were several, less common strata encountered as part of the site investigation works. These included:

- Sand/ gravel deposits with strata thicknesses ranging between 0.3 – 1.6m.
- Silt with organics, generally described as very soft to firm grey/cream/blue sandy gravelly SILT with low organics. The thickness of this strata ranged between 0.1 – 1.9m and the top of the strata ranged from between 0.6 – 1.4m bgl.
- Made ground was encountered in several places, particularly at and around the existing road infrastructure on site. Made ground was also encountered in one trial pit beneath the topsoil and was described as slightly sandy slightly gravelly silt with broken clay pipe fragments.

Table 6-1: Site Investigation Summary

Contractor	SI Report References	Description of Investigation	Details of Investigation	Date of Works
TES Ltd. (with Glovers Site Investigations conducting boreholes and laboratory testing)	TES Ltd., Trial Pit and Borehole Logs for the Recycling Park at Kilshane Cross (2001) Glovers Site Investigations Ltd., Kilshane N2, Ground Investigation, Geotech Laboratory Test Results Report No. 4389 (January 2002)	Site investigations for Kilshane Cross Recycling Park	7 No. Trial pits 3 No. Boreholes (air rotary/odex drilling) Laboratory testing on soil samples	2001
Priority Geotechnical Ltd.	Priority Geotechnical Limited, Regional Biosolids Storage Facility, Site Investigation – Factual Report (Report No. P17148, 2018)	Regional Biosolids Storage Facility Site Investigations	11 No. Trial Pits 6 No. Slit Trenches 3 No. Rotary Coreholes 8 No. Cable Percussion Boreholes Laboratory testing on soil and rock samples	2017

Table 6-2: General Ground Model

Unit	Material	Description	Depth to Top of Unit (m bgl)	Range of Unit Thickness* (m)
1	Topsoil	Soft slightly gravelly SILT	0.0	0.2 – 0.8
2	Cohesive Glacial Tills	Soft – very stiff (slightly) sandy (slightly) gravelly CLAY, occasionally with low to medium cobble and boulder content Dark brown firm to stiff CLAY Soft to stiff slightly sandy, slightly to very gravelly SILT with low to medium cobble content and boulders noted in the 2001 SI	0.2 – 2.5	1.1 – 22.0 (Note: Definitive depths shown in the RC logs)
3	Bedrock	Strong, dark grey LIMESTONE, lightly to heavily weathered, moderately to very heavily fractured, with iron oxide staining and clay smearing	13.0 – 22.3	Unproven

*Note that the minimum and maximum thickness of each strata is unproven and represent the thicknesses encountered in the relevant SI points, which may not have reached the bottom of the strata.

As part of the RBSF development, excavation and removal of subsoils will be required to accommodate the foundations of the buildings and levelling of the site. Any soft and/or organic material is not considered suitable as a bearing stratum for foundations/roads and will require excavation. Unsuitable and surplus excavated material will be reused on the site for bunding and landscaping. There will be no rock excavation on the site.

Subsurface conditions underlying the proposed building footprints predominately comprise topsoil and cohesive glacial till overlying limestone bedrock at approximately 13.0 to 22.3m bgl. Strip or pad foundations are considered suitable for use under the buildings. The foundations will be founded below any soft and/or organic material.

The water table lies at least 16m below ground level (as measured from 3 No. standpipes installed across the site). As such, no temporary dewatering will be required in excavations for buildings, roads or services.

6.3 Surface Water Drainage

6.3.1 Existing Scenario

Design information for drainage was submitted as part of the 2005 planning submission. This information was supplied by the consultants, who acted on behalf of Fingal County Council for the planning application. The design rationale at the time appears to address the entire 15Ha of lands owned by Fingal CC. The site was divided into two catchments with a drainage network and discharge point for each. The existing design criteria and as-built layout could not be verified or reconciled. However, it appears the attenuation pond and tank were designed for return periods of 1 in a 10 year and 1 in a 20 year respectively although this could not be confirmed.

6.3.2 Pipeline Wayleave

The Coldwinters site located to the East of the RBSF site is currently drained to the St. Margaret's stream via a 450mm diameter surface water pipe. This pipe is contained within a 10m wayleave, a burden on Folio DN148148F, which traverses the RBSF site as shown on Drawing Y17702-PL-015. Irish Water propose to reroute this pipeline within the RBSF site to a new outfall downstream of the existing location. The diversion will facilitate the construction of the RBSF and have no impact on the existing surface water regime within the Coldwinters site. The proposed diversion is shown on Drawing Y17702-PL-015.

6.3.3 Proposed Surface Water Management

The proposed rationale for surface water design is to integrate the new area of development into the northern catchment and maintain much of the existing drainage infrastructure. The fundamental objective of the design is to comply with the GDSDS policy document for the entire site following the new development. Details of the surface water network and Sustainable Urban Drainage Systems (SuDS) for the proposed development are shown on Drawing's Y17702-PL-015 & 016.

An objective of the project is to maximise the existing infrastructure as part of a sustainable development. Therefore, the site has been subdivided into two catchment areas for surface water management. The first of these catchments, herein referred to as the "northern catchment", shall consist of all new development. The second catchment, herein referred to as the "southern catchment", shall consist of the existing road and footpaths within the proposed landscape area. Figure 6-1 shows the principle for subdividing the site into two separate catchments to manage surface water and noted as follows;

1. Northern Catchment (Shown in Purple) Area: 5.886 Ha;
2. Southern Catchment (Shown in Blue): 4.942 Ha;

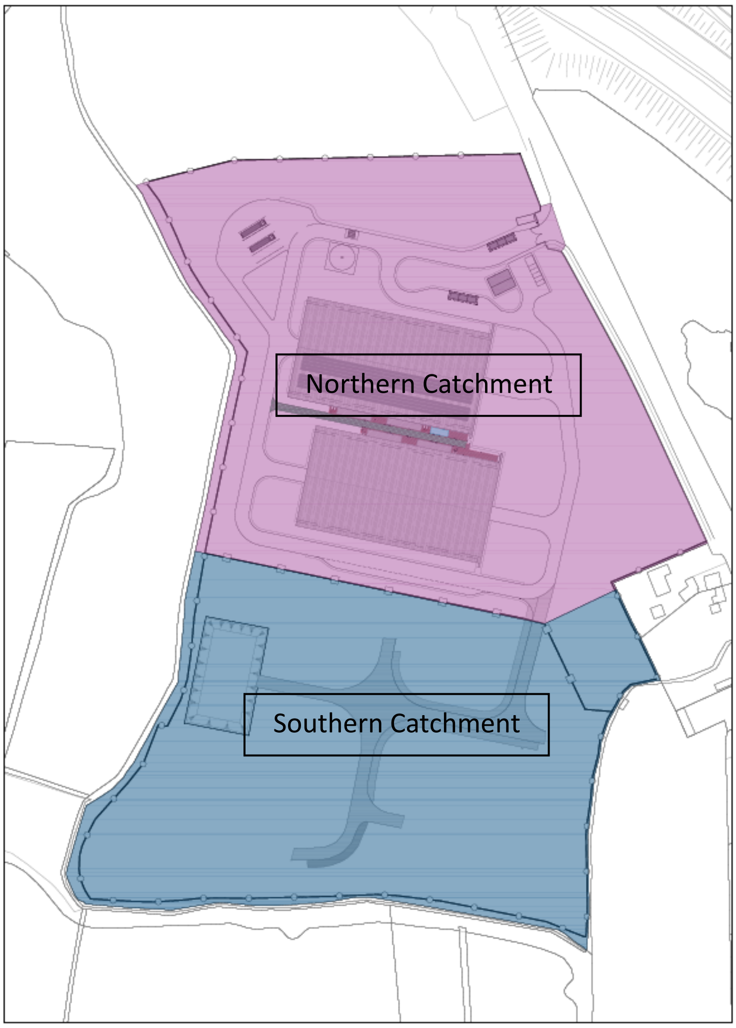

Figure 6-1 Surface Water Catchments

The limiting discharge rate from the northern catchment will be will calculated as Q_{BAR} with the application of growth curves, as long-term storage is provided, as per the GDSDS policy document. Based on the IH124 Q_{BAR} equation for small catchments and application of growth curves, a discharge rate of 32.6 l/s is estimated for the northern catchment. Considering the southern catchment to the south will remain unchanged and no long-term storage was previously provided within the surface water network, an allowable discharge rate of 2 l/s/ha has been applied equating to discharge rate of 9.88 l/s. Consequently, the overall catchment discharge rate equates to 42.48 l/s. A summary of discharge rates is shown in Table 6-3.

Table 6-3 Greenfield Run-Off Rates

Catchment	Total Area (Ha.)	Q_{BAR} (l/s)	Impermeable Area (Ha.)
Northern Catchment	5.886	32.6	2.611
Southern Catchment	4.942	9.88	0.5
Total	10.828	42.48	3.111

Consultation with the Dublin Airport Authority (DAA) was considered by the design team in terms of the proposed SuDS measures for the development to comply with GDSDS policy document. As the airport operator, DAA have a general concern with swales and retention ponds, due to the potential for areas of open water to develop, albeit on a temporary basis. DAA's experience is that any area of saturated or flooded grassland can rapidly attract bird activity. DAA state that ponds and wetlands, even if temporary, attract a variety of species known to be hazardous to aircraft, including gulls, herons, swans and geese. Even if a pond is proofed to prevent bird access, birds will continue to visit to check access. With this consultation in mind, the source control measures listed below in Table 6-4 have been adopted in the design.

The surface water run-off from the development, which includes both catchments, will pass through a treatment train of three SuDS devices. This treatment approach for surface water run off meets with the requirement of Volume 2, New Development, Greater Dublin Strategic Drainage Study. The SuDS strategy for the development provides a comprehensive approach to the management of surface water on the site including benefits for the SuDS triangle namely: water quality, water quantity and amenity/diversity. The treatment train approach has been adopted for the design of the surface water system for the development. This approach uses suitable SuDS measures in providing source control. The surface water treatment train is defined in *Appendix A, Glossary, Volume 3, Environmental Management* of the GDSDS. The SuDS measures under source control for the development are described separately below. The principal source control measures proposed for the development are shown in Table 6-4.

Table 6-4 Source Control Measures

Catchment	Source Control Measures	Location/ Treatment Area
Northern Catchment	Permeable Paving	Odour Control Buildings Service Area
	Dry Swales	Storage Buildings Roofs, Footpaths, Roads
	Reinforced Grass	Access Roads, Footpaths
	Stormtech System	Roofs, Footpaths, Roads
	Hydrocarbon Interceptor	Roofs, Footpaths, Roads
Southern Catchment	Attenuation Pond/Stormtech	Existing Roads & Footpaths
	Hydrocarbon Interceptor	Existing Roads & Footpaths

Rainfall run-off from road surfaces, footpaths and other impermeable areas within the northern catchment will be conveyed in a new drainage system which incorporates SuDS devices in as far as reasonably practical. Some of the existing drainage has been incorporated into the revised design for the northern catchment. Roof run-off will be conveyed via a series of rainwater down pipes into a rainwater harvesting system, discussed further in section 6.3.4. A maintenance access road between the buildings will be constructed of reinforced grass or a similar permeable pavement with no ground infiltration allowed. Dry swales (Refer to Figure 6-2) will convey run-off to a new storm attenuation tank with a capacity of 761m^3 in the northwest corner of the site.

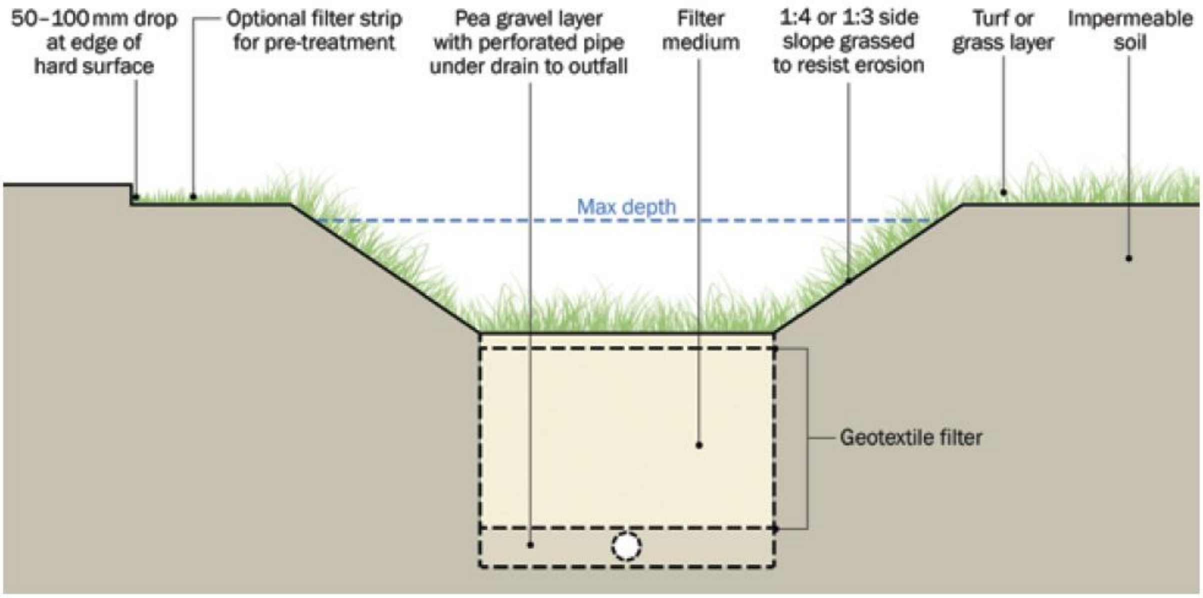

Figure 6-2 Typical Dry Swale (Figure 17.2 of SuDS Manual, C753 (CIRIA, 2015))

The flows will be attenuated in the Stormtech system or similar and will cater for the 100-year critical storm event. Each swale has been designed for approximate depth of 500mm as an aesthetically pleasing feature and shall not flood/ retain water once Section 17.12 of *SuDS Manual, C753 (CIRIA, 2015)* is adhered to for maintenance. A detailed analysis of the network for the northern catchment, which includes both existing and proposed pipework, for the 1, 30 and 100 year +10% critical storm event was conducted with the aid of Micro Drainage software. Based on the analysis, the Stormtech system will require an effective storage volume of 761m³ with an attenuated runoff rate of 32.6l/sec (refer to Appendix 3 for attenuation calculations and Micro Drainage analysis). The dry swales also include an allowance for long term storage (1 in a 100 year, 6hr event) within the system.

Dry swales will be lined with a geotextile membrane to mitigate against risk of pollution to ground water. In addition to this SuDS feature, grit traps will be provided in the sumps of road gullies. Furthermore, and oil/fuel separator will be provided prior to the connection to the proposed new attenuation tank to capture pollutants in run-off on roads and parking areas within the site. The dry swales will be constructed in accordance with details provided in the *SuDS Manual (C753) (CIRIA, 2015)*. Chambers and sewers will be in accordance with the Greater Dublin Region Code of Practice for Drainage Works (Dublin Region Local Authorities).

An emergency shut-off device will also be provided to prevent discharge to the stream in the event of a fuel spillage from a vehicle or runoff from the storage buildings due to firefighting water. The existing surface water system in the northern catchment will be decommissioned and removed. Minor alterations which includes upgrades to flow control devises and decommissioning of pipes will take place on the southern catchment. The existing flow control devices at the discharge locations will be upgraded to ensure the above discharge rates are achieved and hence the overall site will meet the requirements of GDSDS policy document.

The southern catchment of the site will continue to follow the existing surface water management regime via the existing network and attenuation pond. Considering the existing regime could not be verified, as noted above, the flow control device will be upgraded to comply with the GDSDS policy document. The existing pond has a storage capacity of approximately 2,100m³. A Microdrainage model has found upgrade of the flow control device will have no impact on the existing regime in the southern catchment.

6.3.4 Proposed Rainwater Harvesting System

Irish Water have a preferred strategic approach to incorporate water conservation designs for non-potable applications within their facilities where appropriate. The proposed design for the RBSF integrates rainwater harvesting as part of a water conservation strategy for the site. It is anticipated the daily demand for recycled water will be in the region of 42m³ by the 2040 design horizon, generated by the proposed wheel wash.

A rainwater harvesting system, which collects run off from the roofs of both storage buildings, has been designed to accommodate for the likely scenario. The roofs of the storage buildings equate to just over a hectare in area. Based on a design in accordance with Section 11.3 of *SuDS Manual (C753) (CIRIA, 2015)*, a rainwater storage tank of 520m³ would be required. There have been many technological advancements in recent times which could potentially integrate surface water management and water conservation systems.

Fundamentally, the Stormwater technology has the potential to utilise the rainwater harvesting storage in the event of a storm. The system continuously interprets Met Éireann weather forecasts along with site-specific characteristics. The tank automatically drains proportionally to the forecast rainfall, by opening an actuator valve, prior to significant rainfall events. The discharge off the site is maintained at the allowable rate (Greenfield runoff rate) at all times. Controlling the tank level in this way ensures the tanks are available for water attenuation when required but otherwise can act as rainwater harvesting systems.

The water fed for the wheel wash will utilise a programmable logic controller which prioritises the rainwater harvesting source to supplement the tank along with the recycled water. If in the event this recycled water is not available, the 150mm diameter water main will provide the additional volume.

6.3.5 Summary

In conclusion the following tasks have been concluded:

- A minimum three SuDS devices incorporated into design in accordance with GDSDS policy document.
- Surface water network designed, with the aid of Micro Drainage software, for no flooding for the 1, 30 and 100 year +10% critical storm event.
- Advice of DAA acknowledged and incorporated into design to mitigate ponding or potential for open water to develop.
- Existing surface water infrastructure to be maintained and integrated into the new system in as far as reasonably practical.
- Flow control devices at both outfalls to be upgraded to meet the above discharge rates.
- Water conservation included in the form of rainwater harvesting and wheel wash recycling system.

6.4 Wastewater Drainage

6.4.1 Existing Scenario

The existing foul drainage network currently drains to a pumping station in the southern part of the site. This station is connected to the public network via an existing rising main, which connects to a pumping station outside the site on the opposite side of the R135 public road.

6.4.2 Proposed Design

The proposed development will utilise the existing infrastructure as far as reasonably practical as part of value engineered solution which incorporates a sustainable approach. The existing sewers will be rerouted/ decommissioned to avoid clashes with the proposed building locations. These works will entail installation of new sewer sections, manhole construction and decommissioning of existing pipelines. These alterations are shown on Drawing Y17702-PL-017.

Wastewater is likely to be generated from 3 sources within the site, these are the storage buildings, wheel wash and administration building. Considering biosolids is to be stored at the site, any potential runoff from within the storage buildings or washdown area will contain nutrients. The storage buildings will collect wash down run off at the entrance and exit before diversion to the foul sewer network. It is anticipated run off will mainly occur in the event of washdown from within the storage buildings, which will be quite infrequent. The wheel wash will supply all unrecycled wash water on operation days and aligning with delivery movements. The administration building will contribute a small quantity of wastewater arising from employees and visitors on operation days. The estimated dry weather flows (DWF) are as follows:

6 employees * 150l/head/day	=	900l/day
Wheel wash unrecyclable water	=	42,000l/day
1DWF (900/24*3600)	=	0.496l/sec
6DWF (6*0.011l/sec)	=	2.98l/sec

Minor alterations to the existing pumping station will be required as the sump is sized to cater for a greater development. Due to the low dry weather flows associated with the RBSF development to reduce the sump size in the interim to maximise efficiency and avoid septicity.

The pumping station onsite will pump to the local authority pumping station, located on the adjacent public road, as per the previous planning permission and existing regime. Foul sewer construction shall comply with Fingal County Council and Irish Water’s requirements, specification and standard details.

6.5 Watermain Design

6.5.1 Existing Scenario

The existing site is currently serviced by a 150mm diameter, assumed uPVC, watermain based on the available design information. This main is supplied from a similar size public main in the adjacent R135. Based on information provided by the leakage and distribution department in FCC, the pressure head within the aforementioned main is considered to be 24-26m. This will be verified prior to the design phase, however no changes to the previous planning proposal are envisaged.

6.5.2 Proposed Design

The water demand onsite is considered relatively low except in the event of a fire occurring within the storage buildings. MSA, specialist fire consultants, were engaged to advise on regulations and statutory obligations to be adhered to as part of the design process. The proposed development will be supplied via the existing 150mm diameter watermain on site as shown on Drawing Y17702-PL-020. The preliminary daily water demand for the development is estimated as follows;

6 staff * 60l/head/day	= 360l/day
Wheel Wash (Total Required)	= 70 HGVs/day*1200l/min = 84,000l/day – (2040 horizon only)
Supplemented Water (Recycling)	= 84,000l/day * 0.5 = 42,000l/day
Total Demand	= 42,360l/day
Average Water Demand	= 42,360/day/24*3600= 0.49l/sec
Peak Water Demand	= 0.49l/sec*1.25*2.1 =1.3l/sec

For firefighting purposes, the watermain will be installed in accordance with the requirements of Technical Guidance Document B of the Building Regulations. Hydrants will be provided and located in accordance with Technical Guidance Document Part B of the Building Regulations. The design provides for 3 hydrants delivering 3,800 litres/ min to a fire. This delivery is based on the appropriate British Standard. Furthermore, one hydrant is required between 6 and 46m set back distance from every 1,000 sq. metres of building, this means a provision for 5 hydrants within the specified range for each building.

An Epanet model was set up to investigate the delivery of 3,800 l/min using the existing watermain, with amendments, over a 2-hour period. The model predicted velocities greater than the maximum 1.5m/s permitted by the “Design Guidelines for Modelling - Clean Water” published by Irish Water. Furthermore, head losses (approx. 20m) in this scenario also exceed recommended (3m/km of run) by the same document. The existing watermain will not provide a service in line with guidelines. High velocities should be avoided in a water supply system.

In view of this an above ground fire protection holding tank is proposed to store sufficient water, 880m³, onsite in the event of a fire. This will ultimately reduce velocities within the existing watermain and create a reliable fire water source to the fire brigade in event of fire. A separate fire water main will be available for the fire brigade to connect to the tank to eliminate the need for long hose lengths. This main will be fitted with hydrants to comply with the requirements of Technical Guidance Document B of the Building Regulations. The layout of the existing watermain, with minor alterations, and a separate 200mm diameter fire water main is shown on Drawing Y17702-PL-020.

Watermain works will be in accordance with Irish Water requirements, specifications and standard details. Pressure boosting, if required will be to the requirements of Fingal County Council and Irish Water. Design details for pressure boosting will be agreed with Irish Water and the local authority prior to development commencing on site. Water conservation measures will be in accordance with the relevant Bye-laws. During the construction stage, new emerging water conservation technologies will be considered and may be used subject to their efficiency and the approval of FCC and Irish Water.

6.6 External Lighting Design

External lighting will be provided along the internal roads, pedestrian routes and around the buildings and other plant rooms. The basis of the preliminary design is provided Appendix 4. This will be subject to review at detailed design stage. Road-side lighting columns will be approximately 6m high and the lighting columns in the HGV parking area will be 8m high. A public lighting design for the RBSF and is shown on Drawing Y17702-PL-023. The design assumed that some of the existing underground electrical ducts could be reused. The public lighting design is based on using LED lighting, promoting onsite energy efficient systems. External lighting will be directed downwards, particularly at the northern end of the site. This is to ensure beam spread does not cover the proposed woodland planting in this area. The planting is provided for a foraging area for bats.

Appendix 1: List of Drawings

Drawing Number	Description
Y17702-PL-001	General Site Location Plan
Y17702-PL-002	Site Location Map
Y17702-PL-003	Existing Site Layout
Y17702-PL-004	Proposed Site Layout
Y17702-PL-005	Existing Buildings to be Demolished (Elevations & Plans)
Y17702-PL-006	Proposed Ancillary Buildings – Elevations, Plans & Typical Cross Sections
Y17702-PL-007	Storage Building A – Roof Plan & Elevations
Y17702-PL-008	Storage Building A – Plans & Cross Sections
Y17702-PL-009	Storage Building B – Roof Plan & Elevations
Y17702-PL-010	Storage Building A – Plans & Cross Sections
Y17702-PL-011	Landscape Layout
Y17702-PL-012	Contiguous Elevations
Y17702-PL-013	Proposed Road Layout & Markings
Y17702-PL-014	Junction Layout, Lamp Standard & Typical Road Details
Y17702-PL-015	Surface Water Drainage Layout
Y17702-PL-016	Surface Water Drainage Typical Details
Y17702-PL-017	Foul Drainage Layout
Y17702-PL-018	Foul Pumping Station – Plan & Section
Y17702-PL-019	Manhole, Trench Backfill and Bedding Typical Details
Y17702-PL-020	Watermain Layout
Y17702-PL-021	Watermain Typical Details
Y17702-PL-022	Odour Control Units Plan and Elevation
Y17702-PL-023	Electricity & External Lighting Layout
Y17702-PL-024	Site Development Details
Y17702-PL-025	Weighbridge Details and M&E Control Room Plan & Sections
Y17702-PL-026	Construction and Permanent Information Sign
Y17702-PL-027	Proposed Site Layout Overlaid with Services

Appendix 2: Strategic Fire Safety Report

Irish Water Sludge Storage Facility

Initial Fire Strategy©

Project Number > 16429
Reference > 16429R001

For Irish Water

/1 FIRE SAFETY STRATEGY

1.1 Basis of Compliance

Following an initial review of the options for Building Regulations Compliance at the proposed Facility and following a consultation with the Dublin Fire Brigade Senior Fire Prevention Officer for the proposed location on 15th January 2018, the following codes and guidance have been chosen as the basis for the design for this Facility.

- Relevant recommendations of BS 9999:2017 and TGDB supported where necessary by fire safety engineering analysis to justify deviations from these codes.
- Recommendations of relevant BS and IS design codes and specifications to the forms of construction or design of fire protection installations
- Fire Doorsets and Fire Resisting Construction BS 476 Parts 20-24 [1987] or equivalent EN standard
- Fire Detection and Alarm System IS3218: 2013
- Emergency Lighting IS3217: 2013
- In the case of the Fire Alarm and Detection Systems, the proposed installation to L3/M level of coverage to IS 3218:2013 exceeds the BS 9999 recommendation for such a building.
- Emergency Lighting to I.S. 3217:2013
- Travel distances and the number of escape routes will be as per the recommendations of TGD B / BS 9999.
- Water supplies firefighting will be from a hydrant main system augmented by on site storage based on recommendation of NFPA 1142. Based on the creation of 2 compartments per building and treating the building as high hazard occupancies (OCC No. = 4) in NFPA1142, then a fire fighting water supply of 3800 litres / min is required with a total quantity of 880m^3. A tank is to be provided with a reduced capacity based on the replenishment available from the public water mains.
- Access for fire appliances will meet the recommendations of TGD B / BS 9999.
- We note that FSC applications will be made in respect of each of the buildings in due course to Fingal County Council.

For compliance with the B5 Functional Requirement of the Building Regulations it is considered that the use of Section B5 of the TGD B in conjunction with the recommendations from Section 6 (Clauses 19 to 28) of BS 9999.

1.2 Purpose Group Classification by reference to TGD B

Proposed storage facility is considered to be Purpose Group 7(a) Hazardous.

An assessment of the risk has been undertaken on behalf of the client by the Building Research Establishments (BRE Global) into the risks pose by the materials to be stored at the facility. Their reports are appended.

The isothermal heating risk as referenced in the BRE Report P110360-1000 Issue 1 for both materials is not an issue as the turnover time at the proposed facility will be substantially less than the time required to approach ignition temperatures (i.e. 249 days in the worst case for the Biofert material).

In the case of explosion risk potential for the Biofert material BRE Report ref: P110380-1000 Issue 1 finds that the material is in the lowest Explosion Classification St.1 with K_{st} range 0-200 bar ms^{-1} In fact the result of the testing on the Biofert samples resulted in a K_{st} of 20 bar ms^{-1}, very much at the lower end of the range.

This has been discussed with the Fire Officer during our meeting.

In relation to BS 9999, the buildings will be considered an A Type occupancy (only persons familiar with the Buildings and awake will be present), with a Category 3 (Fast) fire growth rate in respect of the biofert dust explosion risk.

Mitigation of this risk will be achieved by use of intrinsically safe equipment and electrical installations in the facility and provision of explosion relief in the building envelope.

1.3 Conclusion

We note that the design proposed for the various buildings on site will be such that a Fire Safety Certificate will be granted by Fingal County Council in due course.

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BRE Global Client Report

Isothermal self-heating assessments

Prepared for: **Michael Slattery Associates**

Date: **24th January 2018**

Report Number: **P110380-1000 Issue: 1**

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Executive Summary

This report describes a series of isothermal heating tests to determine the self-heating properties of 'Biofert' dried sewage sludge and 'biocake' sewage sludge supplied by the client. This forms part of the testing work conducted by BRE Global on acceptance of BRE proposal P110380-1000.

Thermal Ignition Theory was first applied to problems of self-heating and spontaneous combustion in porous solids over thirty years ago. Since then the theory has been developed in many areas, some of which are particularly suited to industrial applications.

Data from the isothermal basket tests show the sewage sludges supplied by the client to be susceptible to self-ignition. Whether this will occur in practice depends upon the way in which they are stored and used.

The calculated critical ignition temperature for the Biofert material when stored in a silo 21m x 14m x 7.5m high is 36°C with a time to ignition estimated at 249 days.

The calculated critical ignition temperature for the Biocake material when stored in a silo 21m x 14m x 7.5m high is 87°C with a time to ignition estimated at 771 days.

Table of Contents

1 Introduction

This report describes a series of isothermal heating tests to determine the self-heating properties of 'Biofert' dried sewage sludge and 'Biocake' sewage sludge supplied to BRE Global by the client, Michael Slattery Associates (MSA). This forms part of the testing work conducted by BRE Global on acceptance of BRE proposal P110380-1000 dated 18th October 2017.

The purpose of this part of the work was to:

1. Conduct a detailed study of the sewage sludges and analyse the results in terms of thermal ignition theory,

2. Predict the likely circumstances which could lead to self-ignition storage, based upon thermal ignition theory.

This report describes the background to the thermal ignition theory, the test procedure used to determine self-heating behaviour and an analysis of the test results in terms of thermal ignition theory.

All tests were carried out at BRE Global during December 2017 and January 2018.

2 Experimental

2.1 Test Samples

The 'Biofert' sewage sludge material supplied to BRE Global by the client was a dried dusty product. The 'Biocake' was suppled as a wet sludge and was dried by BRE Global prior to testing.

2.2 Test Procedure

The test method followed was BS EN 15188:2007[1].

The material under test was placed in cubical wire mesh baskets of different sizes (sides 50mm, 75 mm, 100mm and 125mm). The baskets were each filled with the sample and levelled with a straight edge. The material was not compacted into the cube. The filled cube was then suspended in a mechanically ventilated oven pre-heated and thereafter maintained at a known temperature to within one per cent (measured in degrees Centigrade). A second, larger basket around the test basket provides a shield to restrict the influence of air circulation.

The centre temperature of the sample was monitored, together with the air temperature either side of the test basket, using 0.5 mm stainless steel sheathed chromel/alumel thermocouples. These were connected to a datalogger so that the self-heating process could be observed and recorded.

The materials showed two types of behaviour:

1 the central sample temperature rising by a relatively small amount (< 60°C) above the pre-set oven temperature and then gradually falling back to the oven temperature (sub-critical behaviour), and

2 the central sample temperature rising to high value of > 400°C indicating ignition (super-critical behaviour).

If the sample ignited, then the oven was reset to a lower temperature and a fresh sample tested. Conversely, if a sample failed to ignite the test was repeated with a fresh sample at a higher temperature. In this way, the minimum ambient temperature for ignition and maximum ambient for no ignition were determined for each cube size used to within 2°C of each other.

3 Results

3.1 General

Isothermal tests were conducted on the material to establish the critical ignition temperature for four series of cubic basket tests. The time for each test varied from a few hours to nearly a whole day depending upon whether ignition of the sample was achieved and the cube size. If ignition occurred, the sample was allowed to burn in the oven until either combustion was complete or a peak temperature had been reached. If no ignition occurred the test was continued until a peak temperature had been achieved and the material was cooling back to the oven temperature. A strong odour was detected if ignition occurred.

3.2 Biofert

Figures 1 and 2 show the temperature/time curves for typical super-critical (ignition) and sub-critical (non-ignition) behaviour. The temperature records show the test sample temperature increasing to the oven temperature and then exceeding this set temperature and rising to reach a peak of ~ 800°C for the super-critical condition but rising to less than 10°C above the set oven temperature for the sub-critical condition.

The results from the ignition tests are summarised in Table 1.

Table 1 Summary of test results

Sample name	Cube sizes (mm)	Critical temperature (°C)	Time to ignition (hr)
	50	160	1.6
	75	145	3.8
	100	135	6.9
Biofert sewage sludge	125	128	13.9

3.3 Biocake

Figures 4 and 5 show the temperature/time curves for typical super-critical (ignition) and sub-critical (non-ignition) behaviour. The temperature records show the test sample temperature increasing to the oven temperature and then exceeding this set temperature and rising to reach a peak of ~ 560°C for the super-critical condition but rising to less than 10°C above the set oven temperature for the sub-critical condition.

The results from the ignition tests are summarised in Table 2.

Table 2 Summary of test results

Sample name	Cube sizes (mm)	Critical temperature (°C)	Time to ignition (hr)
	25	227	1.9
	50	212	5.5
	75	195	6.9
Biocake sewage sludge	100	181	17.8

4 Data analysis and discussion

4.1 The Frank-Kamenetskii Parameter - δ

Biofert

To determine the Frank-Kamenetskii parameter for the sludge material, a plot of $\ln(\delta c T_R^2/r^2)$ against $1/T_R$ was drawn and a linear regression analysis of this data was performed. The ignition data used in the plot is given in Table 3.

Table 3 Ignition data

Cube half side r (m)	Critical Ignition Temperature (°C)	Time to ignition (hr)	Critical Ignition Temperature T_R (K)	$\ln(\delta_c T_R^2/r^2)$	$1/T_R$ (K^{-1})
0.0250	160	1.6	433	20.4435	2.309E-03
0.0375	145	3.8	418	19.5621	2.392E-03
0.0500	135	6.9	408	18.9383	2.451E-03
0.0625	128	13.9	401	18.4574	2.494E-03

Values for P and E/R in Equation (18) – see Appendix A - were derived from the graph in Figure 3. For this material the value of P is 45.27 and E/R is 10748.

The equation (18) can be rewritten using these values as;

$$\ln \frac{\delta T_R^2}{r^2} = 45.27 - \frac{10748}{T_R} \qquad \text{(i)}$$

The coefficient of correlation for the regression analysis was 0.9999.

A value for δ_c which is specific to the material is defined by correcting the value of δ_c for low activation energy. δ_c is corrected with Equation (8) in Appendix A, using values for $\delta_c(\varepsilon=0) = 2.52$ (i.e. for a cube, see Table 1A) and calculated from Equation (2) using E/R and the reference temperature = 293K. Hence the corrected value of $\delta_c = 2.59$.

Since the surface temperature was always close to the oven temperature, the $\alpha \prod \infty$ assumption is valid and no α correction was considered to be necessary. Also since the sub-critical temperature rises are moderate, no correction was necessary for reactant consumption.

The values of $\ln(\delta_c T_R^2/r^2)$ were recalculated using the corrected value for δ_c for the cubic geometry, and plotted against $1/T_R$, Figure 3. The values for P and E/R produced by the linear regression were substituted into Equation (i) to give the following expression;

$$\ln \frac{\delta T_R^2}{r^2} = 45.30 - \frac{10748}{T_R} \qquad \text{(ii)}$$

The coefficient of correlation for the linear regression was 0.9999.

Biocake

To determine the Frank-Kamenetskii parameter for the sludge material, a plot of $\ln(\delta c T_R^2/r^2)$ against $1/T_R$ was drawn and a linear regression analysis of this data was performed. The ignition data used in the plot is given in Table 4.

Table 4 Ignition data

Cube half side r (m)	Critical Ignition Temperature (°C)	Time to ignition (hr)	Critical Ignition Temperature T_R (K)	$\ln(\delta_c T_R^2/r^2)$	$1/T_R$ (K^{-1})
0.0125	227	1.9	500	22.1175	2.000E-03
0.0250	212	5.5	485	20.6703	2.062E-03
0.0375	195	6.9	468	19.7880	2.137E-03
0.0500	181	17.8	454	19.1519	2.203E-03

Values for P and E/R in Equation (18) – see Appendix A - were derived from the graph in Figure 6. For this material the value of P is 50.37 and E/R is 14254.

The equation can be rewritten using these values as;

$$\ln \frac{\delta T_R^2}{r^2} = 50.37 - \frac{14254}{T_R} \qquad \text{(iii)}$$

The coefficient of correlation for the regression analysis was 0.9578.

The corrected value of δ_c = 2.58.

The values of $\ln(\delta_c T_R^2/r^2)$ were recalculated using the corrected value for δ_c for the cubic geometry, and plotted against $1/T_R$, Figure 6. The values for P and E/R produced by the linear regression were substituted into Equation (iii) to give the following expression;

$$\ln \frac{\delta T_R^2}{r^2} = 50.39 - \frac{14254}{T_R} \qquad \text{(iv)}$$

The coefficient of correlation for the linear regression was 0.9578.

4.2 Estimates of Critical Pile Sizes and Ignition Temperatures

Using Equations (ii) and (iv) the size of pile required to lead to ignition of the material at any temperature can be calculated if a suitable value of δ_c for the pile geometry can be established.

The following calculations all assume high heat transfer at the pile surface. If this is not the case then δ_c must be corrected using the method given in Appendix A.

For Biofert equation (ii) can be rearranged to give a general form for δ, thus;

$$\delta = \exp(27.99)\ x\ \frac{r^2}{T_R^2}\ x\ \exp\left(-\frac{10748}{T_R}\right) \qquad \text{(v)}$$

For Biocake equation (iv) can be rearranged to give a general form for δ, thus;

$$\delta = \exp(50.39)\ x\ \frac{r^2}{T_R^2}\ x\ \exp\left(-\frac{14254}{T_R}\right) \qquad \text{(vi)}$$

By comparing values of δ obtained from the equations above with values calculated for δ_c from the expressions in Appendix Table 1, it can be established whether a system is super-critical at a particular temperature. If $\delta > \delta_c$ then the system is super-critical and will self-heat to ignition.

4.3 Sludge storage

The materials are stored in a silo of dimensions 21m x 14m x 7.5m high (maximum). A value for δ_c can be calculated using the equation in Table A1 for a rectangle:

$$\delta_c = 0.873\ (1 + r^2/l^2 + r^2/m^2) \qquad \text{(vii)}$$

Where sides are 2r, 2l, 2m and r < l, m.

This results in a value for δ_c of 1.27 when full.

Biofert

Thus using equation (vii) above, the critical temperature for the material is 36°C. Hence, if the material was stored at the volumes stated and at the critical temperature it would eventually self-heat resulting in ignition.

Biocake

Thus using equation (vii) above, the critical temperature for the material is 87°C. Hence, if the material was stored at the volumes stated and at the critical temperature it would eventually self-heat resulting in ignition.

4.4 Times to Ignition

The times to ignition can be estimated from Equations (viii) and (ix) thus;

$$t_i = M\, t_{ad} \left[\frac{\delta}{\delta_c} - 1 \right]^{-1/2} \qquad \text{(viii)}$$

where t_{ad} is the adiabatic time to ignition given by:

$$t_{ad} = \frac{RT_R^2}{E} \frac{C}{QA} \exp \frac{E}{RT_R} \qquad \text{(ix)}$$

Biofert

Using an approximate value for the bulk density of the material of 347 kg/m³ from the mass of material in a 125 mm cube, and typical values for the thermal conductivity (λ) and the specific heat (C) of powders of 0.05 W/m.K and 1200 J/kg.K respectively[17], QA can be obtained from Equation (19) in Appendix A.

Taking the experimentally derived values for E/R and P as above, QA = 6.31×10^{11}. Substituting these values into Equation (vi), the times to ignition t_{ad} can be estimated for the material. At the critical ignition temperature of 36°C the estimated time to ignition is 249 days.

Biocake

Using an approximate value for the bulk density of the material of 1047 kg/m³ from the mass of material in a 100 mm cube, and typical values for the thermal conductivity (λ) and the specific heat (C) of powders of 0.05 W/m.K and 1200 J/kg.K respectively, QA can be obtained from Equation (19) in Appendix A.

Taking the experimentally derived values for E/R and P as above, QA = 2.57×10^{13}. Substituting these values into Equation (vi), the times to ignition t_{ad} can be estimated for the material. At the critical ignition temperature of 87°C the estimated time to ignition is 771 days.

5 Conclusions

1. Biofert and Biocake sewage sludge samples supplied by the client were tested isothermally to determine its self-heating properties. From the critical ignition temperatures recorded both materials were found to be susceptible to self-ignition.
2. Thermal ignition theory has been used to correlate the results and a straight line for $\ln(\delta c T_R^2/r^2)$ versus $1/T_R$ has been found over the cube size range tested. Therefore, extrapolations for larger piles and different geometries may be made with confidence.
3. The critical ignition temperature of these materials when stored in a silo 21m x 14m x 7.5m high has been calculated to be 36°C with the time to ignition estimated to be 249 days for Biofert and 87°C and 771 days for Biocake.
4. Once the materials have ignited sustained combustion will continue until the fire is extinguished or the fuel has been consumed.

6 Recommendations

1. The risk of self-heating can be reduced by:
    - Ensure the material temperature, when stored in the volumes stated, is kept below the critical ignition temperatures stated.
    - Reduce the storage heights used.
    - Ensure the storage times are less than the estimated time to ignition.
2. If the physical nature of the product changes significantly, e.g. smaller particles, granules or changes to the proportion of dust, then the material would need to be re-tested.
3. If the chemical nature of the product changes then the material would need to be re-tested.

7 Nomenclature

Symbol	Definition	Units
A	Pre-exponential factor in Arrhenius equation	s^{-1}
a	Constant, Table 2	-
B	Dimensionless adiabatic temperature rise	-
b	Constant, Table 2	-
C	Specific Heat	$Jkg^{-1}K^{-1}$
c	Concentration	-
c_o	Oxygen Concentration by Volume	-
D	Diffusion Coefficient	m^2s^{-1}
D_o	Diffusion Coefficient at 0°C	-
E	Activation Energy	$Jmol^{-1}$
H	Heat Transfer Coefficient	$Wm^{-2}K^{-1}$
l	Length, Table 1	m
m	Length, Table 1	m
n	Order of Reaction	-
P	Constant, Equation 18/19	-
p	Porosity	-
Q	Heat of Reaction	Jkg^{-1}
Q_o	Heat of Reaction by Volume of Oxygen	Jm^{-3}
R	Universal Gas Constant	$Jmol^{-1}K^{-1}$
r	Characteristic Length	m

S	Surface Area	m²
T	Temperature	K
T_A	Ambient Temperature	K
T_i	Initial Temperature	K
T_R	Reference Temperature	K
t_{ad}	Adiabatic Time to Ignition, Equation (20)	s
t_f	Fourier Time, Equation (22)	s
t_i	Time to Ignition	s
V	Volume	m³
α	Biot Number, Equation 5	-
$\oplus$	Laplacien Operator	-
δ	Frank-Kamenetskii Parameter	-
δ_c	Critical Value of δ	-
ε	Small Parameter, Equation 2	-
θ	Dimensionless Temperature, Equation 4	-
ε_o	Maximum Subcritical Value of ε	-
ρ	Bulk Density	kgm^{-3}
λ	Thermal Conductivity	$Wm^{-1}K^{-1}$

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9 Figures

Biofert

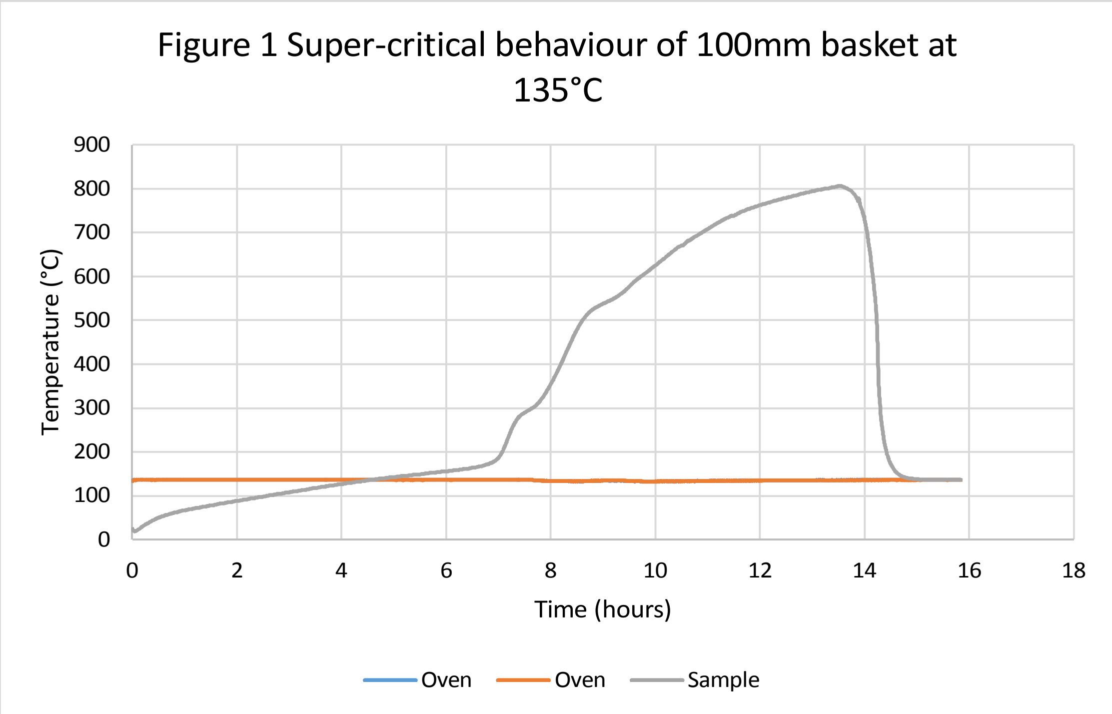


Figure 2 Sub-critical behaviour of 100mm basket at 134°C

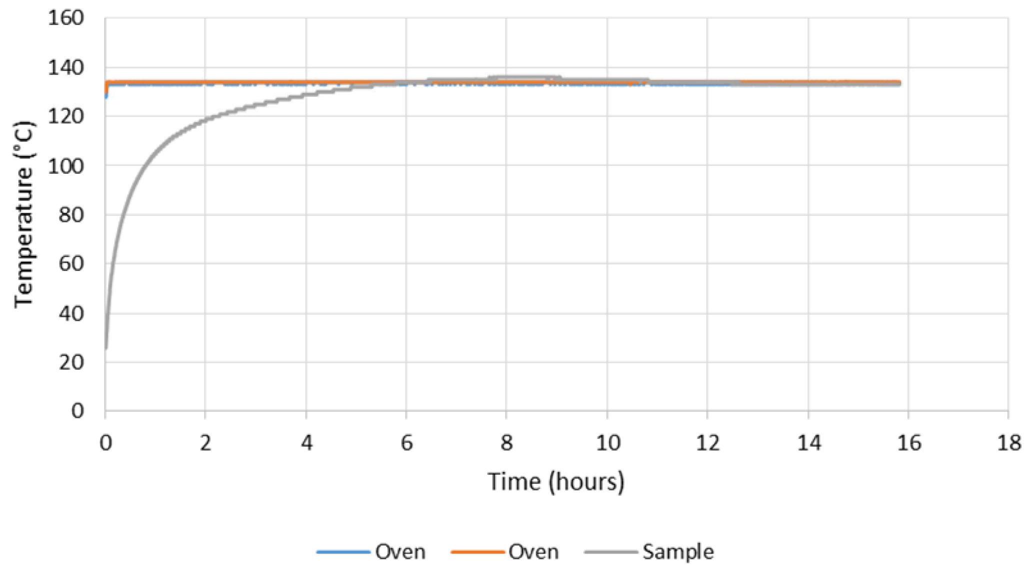
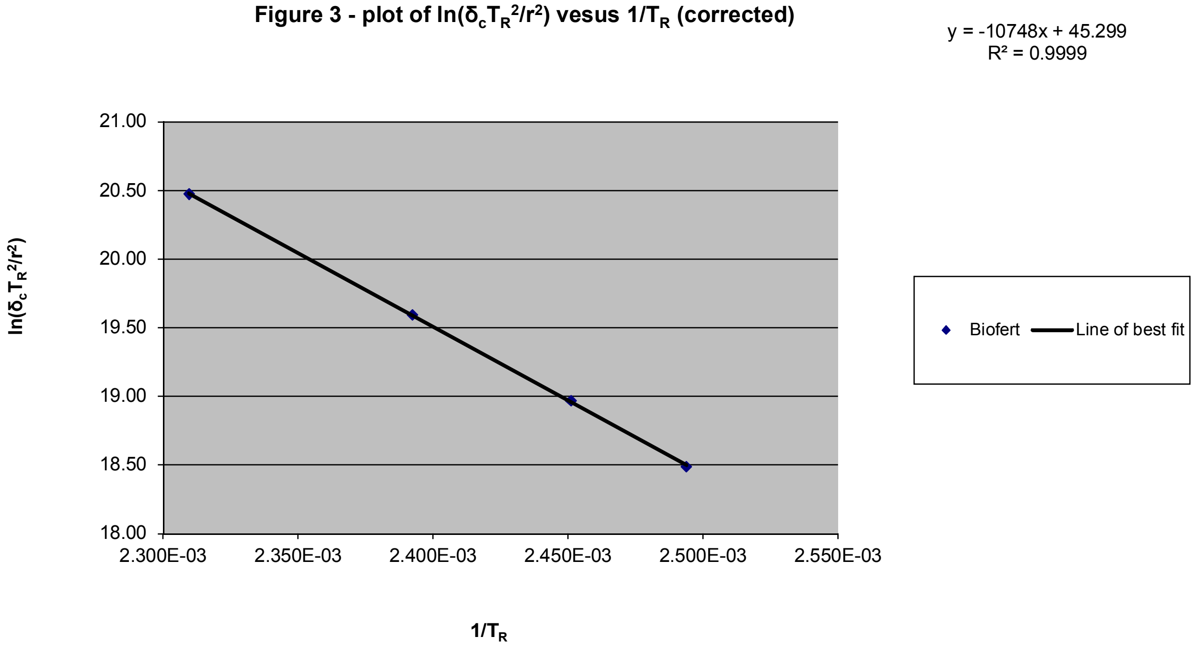


Figure 3 - plot of ln($\delta_c T_R^2/r^2$) vesus $1/T_R$ (corrected)



Biocake

Figure 4 Biocake Super-critical behaviour of 100mm basket at 181°C

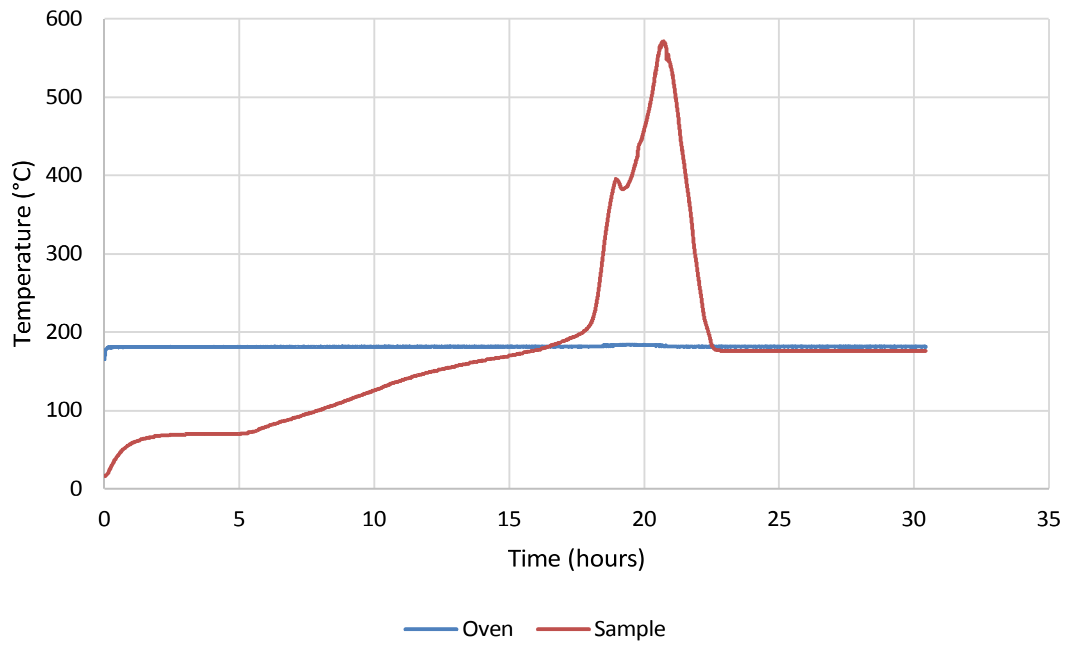
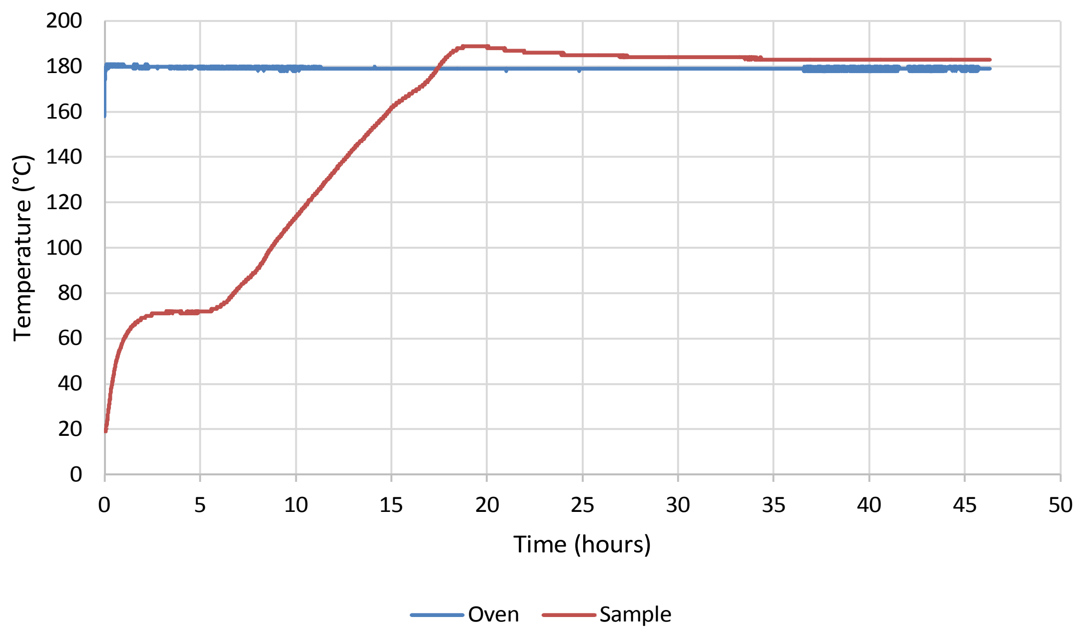


Figure 5 Biocake sub-critical behaviour of 100mm basket at 179°C



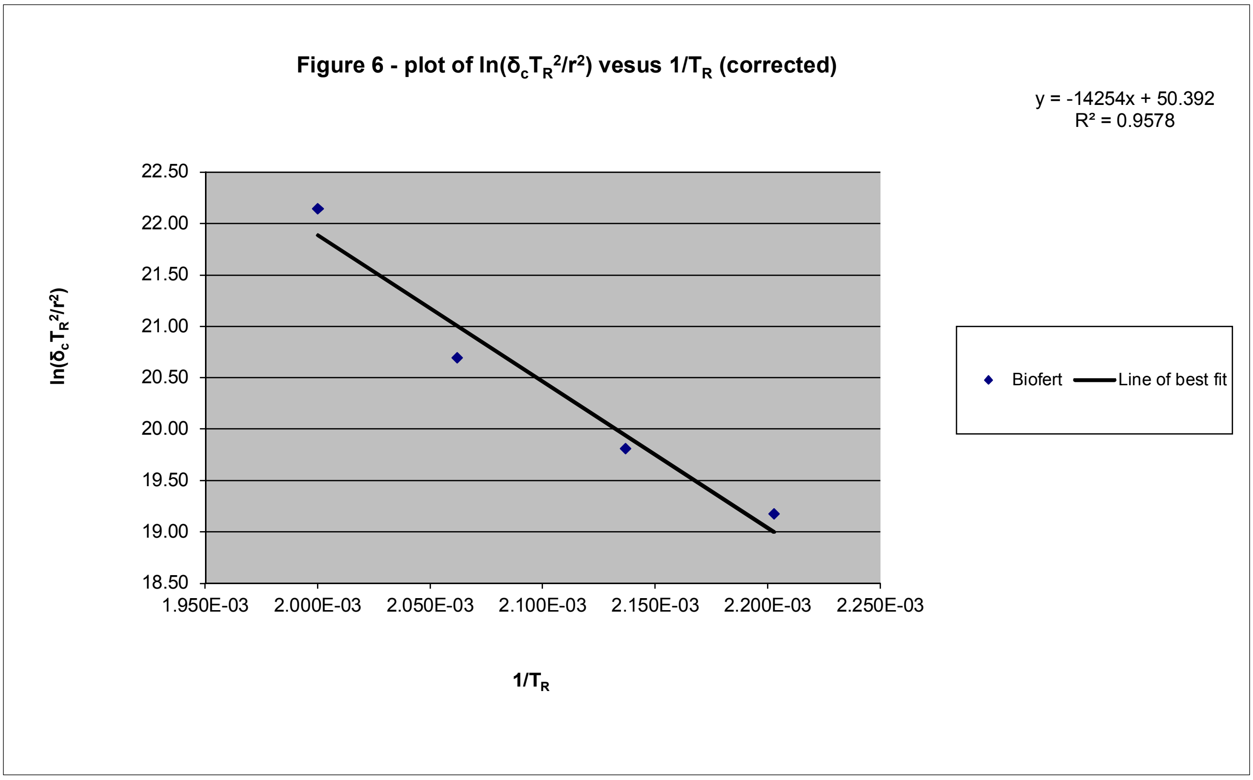


Figure 6 - plot of ln(δcTR2/r2) vesus 1/TR (corrected)
y = -14254x + 50.392
R² = 0.9578
22.50
22.00
21.50
21.00
20.50
20.00
19.50
19.00
18.50
1.950E-03
2.000E-03
2.050E-03
2.100E-03
2.150E-03
2.200E-03
2.250E-03
ln(δcTR2/r2)
1/TR
Biofert
Line of best fit

Appendix A Thermal Ignition Theory

Background

The term spontaneous combustion (or self-heating) is used to describe the culmination of a runaway temperature rise in a body of combustible material, arising as a result of heat generated by some process taking place within the body. The theoretical treatment which follows was developed to describe the ignition of explosives, propellants and unstable materials, and of liquid and gas systems. In such systems the reactants are essentially premixed.

Here we describe the application of the theory to accumulations of materials which can react exothermically with oxygen in the air, for this is the case when spontaneous fires start most unexpectedly. The approach described has been found useful in the study of self-ignition in bulk storage of material at relatively low temperatures and in smaller accumulations at higher temperatures.

The Critical Parameter δ_c

Whether a pile of material is liable to self-ignition or not, depends on the balance between the rate of heat generation within the pile and the rate at which heat is lost to the surroundings. Frank-Kamenetskii[3] highlighted the importance of a dimensionless group of terms δ, known as the Frank-Kamenetskii parameter, which is determined by the relevant physical and chemical properties of the material together with the size of the pile and a reference temperature. All these factors are important; more heat will be generated at elevated temperatures and by highly exothermic reactions, less heat is lost by large piles with poor thermal conductivity. Materials which are safe in one set of conditions may not necessarily be so in another.

For a given system, it is possible in general terms to determine a critical value for δ_c. This may be taken from literature, calculated from known methods or derived from first principles by solving the equations for the heat balance. If the evaluated value for δ is greater than δ_c then the system will self-ignite; the heat generated at all times exceeds that which is lost. The temperature rise is slow at first, and then rapid until ignition occurs.

If the calculated value of δ is less than the critical value, only moderate self-heating can occur. The theory predicts that the maximum temperature rise which can safely be sustained in a body is low, of the order of a few tens of degrees centigrade in practice, above this temperature self-heating to ignition will occur. The distinction between ignition and non-ignition is in principle sharp and arises as a consequence of the assumption in theory that the heat-generating reaction is highly sensitive to temperature. In general this is true and the distinction between sub-critical (non-ignition) and super-critical (ignition) states is also sharp in practice.

It is important to understand the assumptions of the theory in order to assess to what extent these are borne out in practice and under what circumstances corrections must be made.

The basic assumptions made by Frank-Kamenetskii are as follows:

(i) Heat is generated by a single reaction whose rate is not a function of time. The rate of reaction is assumed to be a function of Absolute temperature, T, according to the Arrhenius equation;

$$rate \propto \exp(-E/RT) \quad (1)$$

where E is the activation energy and R the universal gas constant.

(ii) The activation energy is sufficiently high for the condition;

$$\varepsilon = RT_R/E \gg 1 \qquad (2)$$

to hold. T_R is a reference temperature, typically taken to be ambient.

(iii) Heat transfer through the body is by conduction.

(iv) Heat transfer at the surface to the surroundings, by convection and radiation, is high, such that the surface temperature of the body is at ambient.

(v) The material is isotropic and homogeneous with physical properties that do not depend upon temperature.

These assumptions hold sufficiently well in many cases for predictions to be made on the basis of them. They rarely are so unrealistic so as to preclude useful estimates being made using the theory.

The foregoing assumptions allow the heat balances in the body which is simultaneously generating and losing heat to be written, subject to suitable boundary conditions, as;

$$\nabla^2\theta + \delta \exp\theta = 0 \qquad (3)$$

where θ is an approximate form of the Arrhenius Equation (1). θ is a dimensionless temperature given by;

$$\theta = \frac{E}{RT_R^2}(T - T_R) \qquad (4)$$

where T_R is a reference temperature. Suitable forms for the differential operator ∇ depend on the geometry of the body. The appropriate space variable is made dimensionless using a characteristic dimension, r, of the body.

Equation (3) has no time dependence and its solutions are steady state temperature profiles. If δ is made sufficiently large, no solutions can be found for Equation (3). At this transition, the value of δ is identified as the critical value for ignition in practice, δ_c. Solutions of the equation also yield a value θ_o, the maximum central temperature which may be attained at the critical value of δ. At $\delta > \delta_c$, the central temperature becomes (theoretically) infinite.

Critical Values of the Frank-Kamenetskii Parameter

Table 1A[4] gives values of the critical Frank-Kamenetskii parameter for a range of shapes, calculated on the basis of the assumptions for bodies exposed to a steady uniform ambient temperature. The reference temperature in all cases is ambient, and the characteristic dimension used in deriving δ_c is given.

Equation (3) is only amenable to exact solution for the simplest geometries and many of the values given in Table 1A are approximate. Where the values given are exact, this is indicated.

Table 1A. Values of δ_c for Various Geometries

Geometry	Dimensions	δ_c	θ_o
Infinite plane Layer	Thickness 2r	0.878*	1.12
Rectangular Box	side 2r, 2l, 2m r < l, m	$0.873\ (1+r^2/l^2+r^2/m^2)$	
Cube	sides 2r	2.52*	1.89
Infinitely long Cylinder	radius r	2.00*	1.39
Short cylinder	Radius r height 2l	$2.00 + 0.841\ (r^2/l^2)$	
Equicylinder	radius r height 2r	2.76*	1.78
Sphere	radius r	3.32*	1.61

* Exact value

The expressions and values given in Table 1A all yield δ_c to within a few per cent. As will be illustrated later, errors of this magnitude do not give rise to unacceptably large errors when applied to practical problems.

Ultimately if the required value cannot be found, then δ_c must be calculated by studying solutions to Equation (3). This equation may be solved numerically using standard procedures; the value of δ being increased until solutions fail to converge. This can give δ_c to any required degree of accuracy. Numerical approaches can dispense with many of the assumptions outlined above, to yield values highly specific to the problem.

Corrections to δc

General Remarks

The assumptions of the simple theory will generally not be met in practice and where the departures are significant or where particularly accurate values are required, corrections will have to be made to the value of δ_c. The corrections given below are those judged to be of greatest use for practical problems. The corrections are all approximations in themselves to a greater or lesser extent and in each case the range of values over which they hold and the expected accuracy are indicated.

The expressions given here are very often not the only ones which could be applied and in the literature others may be found which are better but perhaps less convenient to apply or which provide more valid results in certain limits. For typical values of the relevant parameters, errors of up to 10% in the determination of δ_c will give errors of about 1°C in the prediction of the critical temperature or 5% in critical size.

Finite Heat Transfer Coefficient

Assumption (iv) set the surface temperature of the body to ambient which implies a high heat transfer coefficient, H, at the surface. If H is not sufficiently large, the surface temperature will be above ambient.

It is important to correct δ_c for this failure as a low heat transfer coefficient will make ignition more likely, as heat losses are consequently reduced. Predictions made using uncorrected values of δ_c will therefore fail to err on the safe side. The way in which the rate of heat transfer from the surface affects the value of δ_c is embodied in a dimensionless group of numbers known as the Biot number, α, given by;

$$\alpha = \frac{Hr}{\lambda} \qquad (5)$$

where λ is the thermal conductivity and r is the characteristic dimension from Table 1A. The Biot number represents the ratio of external to internal heat transfers. If the thermal conductivity is low, the surface heat transfer coefficient high or the pile large then $\alpha \rightarrow \infty$ and no correction is necessary. The error in δ_c is about 2% when α = 100 and still less than 10% when α = 25.

If the thermal conductivity is high compared with the heat transfer coefficient at the surface then $\alpha \rightarrow 0$. The body is effectively at uniform internal temperature with a step to ambient temperature occurring at the surface. This is the Semenov condition and as this limit is approached δ_c is given, for all geometries, as;

$$\delta_c = \frac{\alpha}{e}\frac{Sr}{V} \qquad (6)$$

where S is the surface area and V the volume of the body. This expression is appropriate to low values of α. It overestimates δ_c by less than 3% when α = 0.1 and 10% when α = 0.3 [3].

Intermediate values of α use an expression by Barzykin et al[6] which is appropriate for all geometries;

$$\delta_c(\alpha) = \delta_c(\alpha \to \infty) \frac{\alpha}{2} \left(\sqrt{\alpha^2+4} - \alpha\right) \exp \frac{\left(\sqrt{\alpha^2+4} - \alpha - 2\right)}{\alpha} \qquad (7)$$

where δ_c $(\alpha \to \infty)$ is the value taken from Table 5.

This expression gives results which are within 2% of the exact results of Thomas[5] for α >2.

Low Activation Energy

In setting up Equation (3) it has been assumed that the quantity εθ is small. Since maximum values of θ are of the order of unity this is equivalent to the assumption that ε is small.

Typical values of E/R are of the order of 10^4 so that in most cases this assumption is correct. If correction for large values of ε is necessary, the following expression by Boddington, Gray and Harvey[7] may be used;

$$\delta_c(\varepsilon) = \delta_c(\varepsilon = 0)(1 + 1.07\varepsilon) \qquad (8)$$

This equation was derived from numerical results by Parks[6] and is valid for ε <0.05.

Reactions which are not sufficiently sensitive to temperature, i.e. low E/R, cannot exhibit self-ignition. There is a sharp cut off at definite values of ε, above which ignition will not be observed. These values vary slightly with geometry and Biot number but are in the region of ε = 0.25. Such large values of ε are very far from those normally encountered in practice.

Reactant Consumption

Assumption (i) assumes that the rate of the heat-generating reaction is a function of temperature only. In practice the reactants are inevitably depleted over a period of time and the reaction slows down as a consequence. The assumption is good if the reaction is sufficiently exothermic for negligible reactant consumption to have occurred at the point of ignition. The parameter which governs the effects of reactant consumption is the dimensionless adiabatic temperature rise, B, given as;

$$B = \frac{E}{RT_R^2} \frac{Q}{C} \qquad (9)$$

Highly exothermic reactions have high values of B, whilst a low heat of reaction gives a low value for B.

The correction to be applied also depends on the order of reaction, n, where rate of reaction depends on the reactant concentration, c, such;

$$rate\ of\ reaction \propto c^n \quad (10)$$

B and n for the reaction must be determined before correction can be made. For materials undergoing a simple reaction, it may be possible to obtain n and Q from the literature and to calculate B. In most cases, especially where natural materials are involved, the reaction responsible for self-heating is not a

$$\frac{\delta_c(B)}{\delta_c(\infty)} = \frac{1}{a + b(n/B)^{2/3}} \quad (11)$$

simple one. The heat of reaction is, in general, not the same as the heat of combustion of the material. Techniques for establishing Q will be covered later. These are not straightforward however and the evaluation of B is not easy in many cases. Assuming the values for B and n are available, the correction for a large B takes the form;

Tyler and Wesley[9] have obtained values for a and b for a range of values of ε (see Table 2A). If these values are used, Equation (11) reproduces numerically obtained values for δ_c to within 2% for B > 25, n = 1 and for B > 100, n = 2. For B = 25, n = 2 the error is about 10%.

Table 2A. Values of a and b as a Function of ε (Equation 11)

ε	a	b
0.000	1.000	2.28
0.025	0.973	2.35
0.050	0.944	2.41
0.075	0.916	2.49
0.100	0.895	2.56

Tyler and Wesley[9] do not examine the problem of B < 25 but these values have been studied under Semenov conditions. For large B Equation (11) may be used. For smaller B, Carter, Druce and Wake[10] suggest for a first order reaction (n=1);

This expression does have the advantage of including a dependence of δ_c on ε.

$$\frac{\delta_c(B,\varepsilon)}{\delta_c(\infty,0)} = \frac{(3-4\varepsilon)(1-4\varepsilon)}{e(1-2\varepsilon)(1-4\varepsilon-4/B)} \quad (12)$$

Under Semenov conditions, this expression predicts the numerical results of Adler and Enig[11] for ε = 0 to better than 7% for 100 > B > 25. The error increases to 14% when B = 10.

If the same correction is applied to values of δ_c under Frank-Kamenetskii conditions and compared with the numerical work of Tyler and Wesley[9], the error is probably no worse than under Semenov conditions and the above equation may be used. For more exact work at low values of B, a proportional correction to δ_c based on the numerical work of Adler and Enig[11] for Semenov conditions is probably quite accurate for Frank-Kamenetskii conditions.

The maximum central temperature attained by a system without ignition increases as B is decreased. For B > 100 Tyler and Wesley[7] found the following to hold for ε = 0;

$$\frac{\theta_o(B)}{\theta_o(\infty)} = 0.88 + 5.58\,(n/B\,)^{2/3} \quad (13)$$

The coefficients vary as ε is increased. As B decreases θ_o increases and the maximum temperature reached at ignition decreases. Ultimately, for B sufficiently small, the sub-critical temperature rise approaches the super-critical temperature rise and ignition cannot be recognised. Under such circumstances δ_c cannot be defined. In theory ignition is not possible if B < 4 for n = 1. In real systems, however, it appears that ignition may be observed at lower values of B.

Oxygen Diffusion

If a reaction proceeding in a porous body requires oxygen, then this must diffuse into the body from the surrounding atmosphere. The effects of oxygen diffusion are found to be governed by a parameter ϕ given by;

$$\phi = \frac{n\,\lambda\,T_R}{c_o\,Q_o\,D} \quad (14)$$

c_o is the concentration of oxygen in the voids by volume and Q_o is the heat of reaction by volume of oxygen. n is the order of reaction with respect to oxygen concentration. Frank-Kamenetskii theory assumes $\phi \ll 1$.

Takeno and Sato[12] show that as ϕ is increased δ_c increases, and therefore the system ignites less easily. Thus low concentrations of oxygen, low heats of reaction and low diffusivity increase δ_c.

The evaluation of ϕ in practice may present problems. Suitable values for Q_o may be found in literature, otherwise a method for measuring Q_o directly must be sought. The diffusion coefficient, D, depends on the porosity of the powder and the temperature. Bowes[4] suggests the following form;

$$D = D_o\,(T/273)^{1.75}\,p^{1.5} \quad (15)$$

where D_o is the diffusion coefficient for oxygen in free air at 0°C and p is the porosity (fraction of voids) in the material. For typical values the parameters in Equation (14), ϕ is frequently much less than unity and the correction to δ_c will not be necessary.

Hot Material

Thomas[13] has developed an approximate method for dealing with hot materials in cooler surroundings. It is included as it is especially useful in many industrial situations where hot material from processing may be stored in bags or bins. It is possible that instead of cooling to ambient the material may self-heat to ignition.

This analysis involves the use of a parameter θ_i where;

$$\theta_i = \frac{E}{RT_i^2}(T_i - T_a) \qquad (16)$$

where T_i is the initial temperature of the hot material. This parameter is then related to values of δ_c, which is defined with T_i as the reference temperature.

Values for δ_c including the dependence on α are given by Bowes[4], with a correction for an error in the original paper by Thomas[13]. The method suggested by Thomas is flexible and the derivation of $\delta_c(\theta_i)$ for other geometries is not too difficult in principle.

The analysis of Thomas assumes that $\varepsilon = 0$. Numerical results for the same type of problem and covering a range of values of ε are given by Gray and Scott[14]. Their formulation of the problem is rather different from that of Thomas however, with δ and θ being defined with ambient temperatures as reference.

As a result the curves of $\theta_i(\delta)$ become very steep in the region of small δ giving inaccurate predictions of θ_i in the region where critical initial temperature is well above ambient. In many cases this will be the region of practical interest. Otherwise the results of Gray and Scott[14] are useful, particularly for large ε.

Summary

The corrections given in the present section can be applied successively to a value of δ_c to obtain a suitable value for a given set of circumstances. On occasions this procedure will increase the errors somewhat. In most cases this will not matter greatly for practical purposes. It will be rare for all the corrections to be necessary in a particular case.

Practical Evaluation of the Frank-Kamenetskii Parameter

Direct Measurement of the Material Properties

To determine whether self-heating in a body is destined to culminate in ignition, the value of the parameter δ must be determined and compared to the value predicted above. The definition of the Frank-Kamenetskii parameter is;

$$\delta = \frac{E}{R}\frac{\rho Q}{\lambda}\frac{r^2}{T_R^2} A \exp\frac{-E}{RT_R} \qquad (17)$$

where T_R is a suitable reference temperature and r a characteristic dimension, defined as before.

In principle the parameters in the Equation (17) may be measured or taken from the literature and δ evaluated directly. Care is required in the choice of technique used to evaluate E, A and Q (together with n if a correction for B is applied). Such values are usually established using differential thermal analysis (DTA) or differential scanning calorimetry (DSC) possibly combined with thermo-gravimetric analysis (TGA).

These techniques work best on materials which exhibit a single reaction which behaves according to a simple rate law. Complications arise when the material is a naturally occurring compound with various possible decomposition routes. All that can be hoped for in practice is to obtain "effective" parameters which describe the reaction. It is important that an accurate and precise value for the effective activation energy, E, is obtained.

Because of the exponential dependence of δ on E, it is crucial to the success of the method that this parameter is determined with a high degree of reliability.

The direct evaluation of δ may not therefore be straightforward. However, if only small amounts of material are available, the methods mentioned above may be the most suitable and appropriate references should be consulted. Ohlemiller and Rogers[15] have calculated critical conditions numerically using reaction parameters determined as outlined above. The agreement with experiment is good. The analytical techniques used on the DSC and DTA curves to deduce E, A and Q were however quite sophisticated. These are described in detail by Rogers and Ohlemiller[16].

Indirect Evaluation

It is possible to obtain values for groups of parameters in Equation (17) by searching for critical behaviour under controlled ambient conditions. The theory predicts that material will either undergo moderate self-heating for $\delta < \delta_c$ or will ignite for $\delta > \delta_c$.

The critical condition is in principle very sharply defined and it proves to be in practice, except for materials with very low B values.

In searching for critical behaviour in a material, the parameters under the control of the experimenter are the size (r) and the ambient temperature (T_R). Thus the critical size may be determined for a given temperature or, more simply in practice the critical temperature may be determined for a known size. To see how this helps, Equation (17) is rewritten as;

$$\ln \frac{\delta T_R^2}{r^2} = P - \frac{E}{RT_R} \qquad (18)$$

where,

$$P = \ln\left\{ \frac{E}{R} \rho \frac{QA}{\lambda} \right\} \qquad (19)$$

If T_R and r are known for the critical case then the appropriate value of δ_c may be substituted in Equation (18).

A plot of $\ln(\delta_c T_R^2/r^2)$ against $1/T_R$ should yield a straight line of slope -E/R and intercept P. Once these two parameters are known δ can be calculated for any T_R and r from Equation (17).

Any system for which δ_c is known can be used in the experimental arrangement. In practice two types of set up have been found useful.

The first involves exposing a sample of material held in a wire mesh basket to a uniform temperature in an oven. The baskets might be cubes or short cylinders and appropriate values of δ_c would be taken from Table 1A. The central and surface temperatures are monitored by thermocouples.

An alternative method involves the determination of the critical temperature of a hot plate for a layer of known thickness of material upon it. The value of δc appropriate for this case is given by Beever[17]. The reference temperature in the definition of δ_c and θA is the hot plate temperature Tp. In practice layer thicknesses of 5 mm to 25 mm are used.

In order to calculate δ_c, which will be different for each layer thickness, α has to be estimated. The diameter of the layer must be at least six times its thickness in order for it to be assumed that it is of infinite extent. Tests of this type have been used for many years for the assessment of the ignition behaviour of dusts which are processed in hot environments, i.e. driers.

Times to Ignition

For many practical purposes it is not sufficient to know that a system is super-critical. It is usually important to have some idea of the time which will elapse before ignition occurs.

Very large piles of material, not much above critical, can have very long times to ignition. Because storage times are often appreciably less than the times to ignition, no hazard arises in practice.

Boddington, Feng and Gray[18,19] have derived an expression for time to ignition, t_i, for; systems not too far above critical

$$t_i = M\, t_{ad} \left[\frac{\delta}{\delta_c} - 1\right]^{-1/2} \quad (20)$$

where t_{ad} is the adiabatic time to ignition given by:

$$t_{ad} = \frac{RT_R^2}{E}\frac{C}{QA}\exp\frac{E}{RT_R} \quad (21)$$

The adiabatic time is the ignition time in the absence of any heat losses and is the shortest possible time in which a system could ignite. M is a constant which depends on the geometry and α. Some values for M are given in Table 3A and Boddington et al[16] indicate how M could be calculated for other conditions.

The variation in M is however not large and for most work an estimate based on the average value would be perfectly adequate. M also depends upon reactant consumption but Boddington et al[19] have shown that this variation is not large either.

Table 3A. Values for M in Equation (20)

$\alpha \rightarrow \infty$			$\alpha = 0$
∞ layer	**∞ cylinder**	**sphere**	**All geometries**
1.534	1.429	1.316	1.634

It can be seen from Equation (20) that the times tend to infinity under conditions which are close to critical and reduce sharply as δ is increased. The expression given predicts times to ignition well for $\delta/\delta_c < 2$ and better than 20% for $\delta/\delta_c < 3$.

In the evaluation of t_{ad}, the product QA may be estimated from P, Equation (19), if values can be obtained for λ and ρ. T_R is the critical value of the reference temperature.

By comparing Equation (21), with the definition of δ, Equation (17), it can be seen that;

$$\delta_c = \frac{t_F}{t_{ad}} \qquad (22)$$

where $t_F = \rho C r^2/\lambda$ is known as the Fourier time and is a characteristic cooling time for the system. Bowes[4] suggests the correlation $t_i \propto r^2$ for estimating times to ignition from experimental results. If Equation (22) is substituted into (19) it can be seen that this is true for a given value of $\delta/\delta c$. However in experimental work, the closeness of δ to the real value δc is never accurately known, and since times to ignition vary most steeply when δ is close to δc, Equation (20) is preferable for all but order-of-magnitude estimates.

Report Ends

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BRE Global Test Report

Explosion Indices Assessment on a Sample of “Biofert” Dried Sewage Sludge Dust

Prepared for: **Michael Slattery Associates**

Date: **20 December 2017**

Report Number: **P110380-1000 Issue: 1**

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Date 20 December 2017

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Table of Contents

1 Introduction

This report describes the explosion indices assessment undertaken on a sample of “Biofert” dried sewage sludge dust originating from Michael Slattery Associates.

The test undertaken was:

- Explosion indices (Maximum pressure and Kst)

Material tested:	“Biofert” dried sewage sludge dust
Manufacturer/supplier:	Michael Slattery Associates, 19 Windsor Place, Lower Pembroke Street, Dublin 2
Date sample received:	06 November 2017
Date sample tested:	04 – 18 December 217

2 Sample preparation

The sample was supplied as a coarse, agglomerated material. It was passed through a 1mm sieve prior to testing.

A particle size analysis was carried out on the sieved material using sieve analysis.

The moisture content of the material was assessed by placing a sample of known weight in an oven at 75°C for 24 hours, and calculating the percentage weight loss.

The results of these analyses are shown in Table 1 below.

Table 1 Particle size distribution and moisture content

Sample	>710μm	<710μm	<500μm	<300μm	<100μm	Median μm	Moisture %
	% volume						
“Biofert” dried sewage sludge dust	48.1	52.7	25.2	7.0	0.9	690	5.4

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3 Explosion indices test

3.1 Introduction

The measurement of the explosion severity that may be generated by an explosible powder is essential quantitative information for explosion protection, based on relief venting, suppression and containment. The test is described in BS EN 14034-1[1] and BS EN 14034-2[2]. The severity is characterised by two parameters, the maximum pressure P_{max} and the maximum rate of pressure rise $(dP/dt)_{max}$.

Values of K_{st} are derived from P_{max} and $(dP/dt)_{max}$. K_{st} values are also related to a broader explosion hazard classification which is used to rank groups of powder according to their K_{st} value. This is the St. Classification and Table 2 shows the relationship between K_{st} and St. Classification.

Table 2 St. Classification

K_{st} Bar m s^{-1}	**Explosion Classification**
0	St. 0
0 – 200	St. 1
200 – 300	St. 2
300	St. 3

Extensive work has been undertaken to relate the K_{st} value to the sizing of the explosion reliefs and suppression systems [3].

3.2 Test apparatus

The apparatus [3] consists of a spherical chamber with a volume of 20 litres and surrounded by a water jacket. Dust enters the sphere from a 0.6 litre pressurised storage chamber via a pneumatically operated outlet valve. The sample is injected by compressed air and a perforated deflector plate inside the chamber ensures uniform dispersion. The ignition source comprised of two pyrotechnic igniters with a total energy of 10 kJ located in the centre of the explosion chamber.

3.3 Test procedure

A known mass of dust is placed into the dust storage chamber. The sphere is then evacuated to 0.4 bar absolute. An automatic test sequence is initiated to pressurise the dust storage chamber to 21 bar absolute and activate the ignition source 60 ms after the dust had been dispersed. This procedure ensures that the explosion takes place at atmospheric pressure and at such a degree of turbulence that the explosion data obtained are compatible with that which would be obtained in a 1 m^3 vessel.

Explosion pressures are measured for a range of dust concentrations using piezo-electric pressure transducers. The values of explosion pressure, the rate of pressure rise are measured and the K_{st} value then computed from the pressure/time records. The values of the explosion pressures are corrected to correlate with the 1 m^3 vessel.

The maximum explosion pressure (P_{max}) and the K_{st} of the dust sample tested is defined as the mean values of the maximum values of each test series (total 3 series) over the concentration range close to the observed maxima.

The tests were conducted over the dust concentration ranges shown in Table 3 below.

3.4 Results

Table 3 Test results for "Biofert" dried sewage sludge dust

Concentration (kg/m^3)	Maximum pressure (bar g)	Rate of pressure rise dP/dt (bar/s)	K_{st} (bar m/s)
0.50	4.3	61	17
0.75	5.4	48	13
1.00	5.2	56	15
1.25	6.8	73	20
1.50	**7.1**	74	**20**
1.75	3.9	64	17
2.00	0.7	50	14
0.50	2.2	57	16
0.75	5.8	63	17
1.00	**5.7**	75	**20**
1.25	3.5	57	16
1.50	2.7	51	14
0.50	2.3	57	16
0.75	3.9	58	16
1.00	**6.1**	72	**20**
1.25	4.2	60	16
1.50	3.2	60	16

See Figures 1 and 2

Table 4 Summary of K_{st} test results

Sample	Moisture (% w/w)	P_{max} * (bar g)	K_{st} * (bar m/s)	St. Classification
"Biofert" dried sewage sludge dust	5.4	6.3	20	1

*average of the maxima shown in bold in Table 4 above

4 General remarks

Please note that the test results are valid for the particle size distribution and moisture content of the sample tested.

The dust tested represents an explosion hazard and we would advise that suitable measures should be taken to prevent and protect against the risk of an explosion.

If you require further information or advice regarding the use of this data you should contact BRE Global.

5 References

1. British Standards Institution. Determination of explosion characteristics of dust clouds – Part 1: Determination of the maximum explosion pressure P_{max} of dust clouds. British Standard BS EN 14034-1:2004 +.A1: 2011. London, BSI, 2004.

2. British Standards Institution. Determination of explosion characteristics of dust clouds – Part 2: Determination of the maximum rate of explosion pressure rise $(dp/dt)_{max}$ of dust clouds. British Standard BS EN 14034-2:2006 +.A1: 2011. London, BSI, 2006

3. Dust Explosion Prevention and Protection - A practical guide. Edited by John Barton. IChemE. 2002.

6 Figures

Figure 1

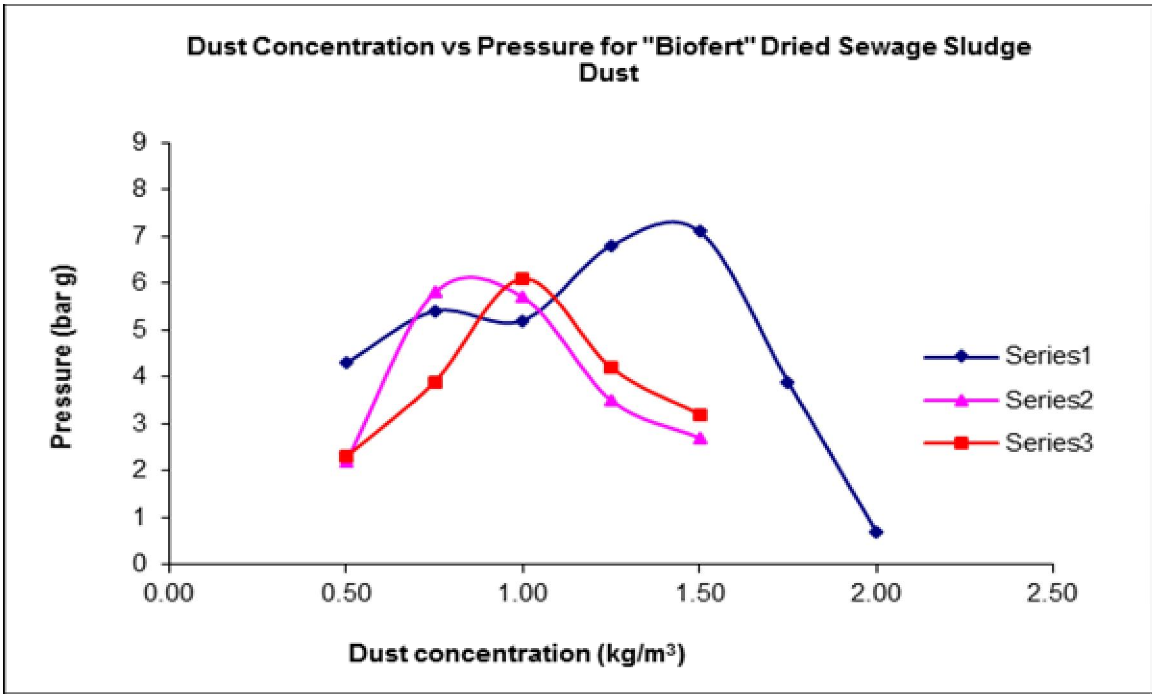
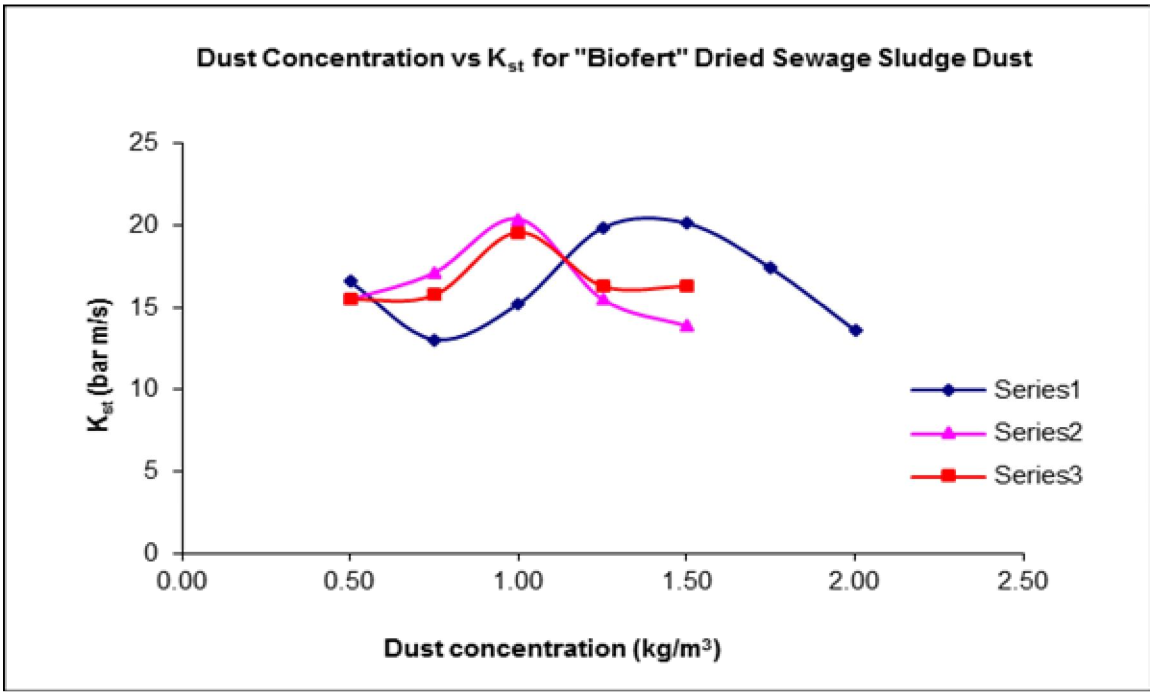


Figure 2



Report Ends

Appendix 3: Microdrainage Analysis

STORM SEWER DESIGN by the Modified Rational Method

Design Criteria for Storm

Pipe Sizes STANDARD Manhole Sizes STANDARD

FSR Rainfall Model - Scotland and Ireland

Return Period (years)	1	PIMP (%)	100
M5-60 (mm)	17.000	Add Flow / Climate Change (%)	0
Ratio R	0.300	Minimum Backdrop Height (m)	0.010
Maximum Rainfall (mm/hr)	50	Maximum Backdrop Height (m)	2.000
Maximum Time of Concentration (mins)	30	Min Design Depth for Optimisation (m)	0.300
Foul Sewage (l/s/ha)	0.000	Min Vel for Auto Design only (m/s)	1.00
Volumetric Runoff Coeff.	0.750	Min Slope for Optimisation (1:X)	900

Designed with Level Soffits

Time Area Diagram for Storm

Time (mins)	Area (ha)	Time (mins)	Area (ha)	Time (mins)	Area (ha)
0-4	0.414	4-8	1.882	8-12	0.315

Total Area Contributing (ha) = 2.611

Total Pipe Volume (m³) = 188.739

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S1.000	18.832	0.075	250.0	0.031	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S1.001	12.948	0.052	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S1.002	75.758	0.303	250.0	0.067	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S1.003	13.260	0.053	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S1.000	46.10	4.32	76.205	0.031	0.0	0.0	0.0	0.99	70.0	3.9
S1.001	45.30	4.54	76.130	0.031	0.0	0.0	0.0	0.99	70.0	3.9
S1.002	41.28	5.81	76.075	0.098	0.0	0.0	0.0	0.99	70.0	11.0
S1.003	40.67	6.03	75.770	0.098	0.0	0.0	0.0	0.99	70.0	11.0

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S1.004	6.752	0.027	250.0	0.014	0.00	0.0	0.600	o	300	Pipe/Conduit	
S1.005	26.677	0.107	250.0	0.020	0.00	0.0	0.600	o	300	Pipe/Conduit	
S1.006	31.406	0.126	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S1.007	88.354	0.353	250.0	0.035	0.00	0.0	0.600	o	300	Pipe/Conduit	
S1.008	14.177	0.057	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S2.000	77.028	0.308	250.0	0.032	4.00	0.0	0.600	o	300	Pipe/Conduit	
S2.001	45.182	0.181	250.0	0.055	0.00	0.0	0.600	o	300	Pipe/Conduit	
S2.002	9.050	0.036	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S2.003	17.895	0.072	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S3.000	21.065	0.084	250.0	0.020	4.00	0.0	0.600	o	300	Pipe/Conduit	
S2.004	17.608	0.070	250.0	0.020	0.00	0.0	0.600	o	300	Pipe/Conduit	
S4.000	21.065	0.084	250.0	0.019	4.00	0.0	0.600	o	300	Pipe/Conduit	
S2.005	26.563	0.106	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S5.000	54.736	0.219	250.0	0.078	4.00	0.0	0.600	o	300	Pipe/Conduit	

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S1.004	40.36	6.15	75.717	0.112	0.0	0.0	0.0	0.99	70.0	12.2
S1.005	39.21	6.60	75.690	0.132	0.0	0.0	0.0	0.99	70.0	14.0
S1.006	37.96	7.13	75.583	0.132	0.0	0.0	0.0	0.99	70.0	14.0
S1.007	34.91	8.61	75.458	0.167	0.0	0.0	0.0	0.99	70.0	15.8
S1.008	34.47	8.85	75.104	0.167	0.0	0.0	0.0	0.99	70.0	15.8
S2.000	42.79	5.30	75.955	0.032	0.0	0.0	0.0	0.99	70.0	3.7
S2.001	40.60	6.06	75.645	0.087	0.0	0.0	0.0	0.99	70.0	9.6
S2.002	40.20	6.21	75.464	0.087	0.0	0.0	0.0	0.99	70.0	9.6
S2.003	39.42	6.51	75.428	0.087	0.0	0.0	0.0	0.99	70.0	9.6
S3.000	45.96	4.35	75.440	0.020	0.0	0.0	0.0	0.99	70.0	2.5
S2.004	38.70	6.81	75.356	0.127	0.0	0.0	0.0	0.99	70.0	13.3
S4.000	45.96	4.35	75.350	0.019	0.0	0.0	0.0	0.99	70.0	2.4
S2.005	37.67	7.26	75.266	0.146	0.0	0.0	0.0	0.99	70.0	14.9
S5.000	43.98	4.92	75.600	0.078	0.0	0.0	0.0	0.99	70.0	9.3

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S5.001	54.736	0.219	250.0	0.037	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S2.006	26.475	0.106	249.8	0.022	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S1.009	18.972	0.076	250.0	0.007	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S1.010	28.794	0.115	250.4	0.030	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.000	72.811	0.291	250.0	0.025	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.001	11.308	0.045	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.002	55.073	0.220	250.0	0.035	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.003	25.822	0.103	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.004	11.086	0.044	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S7.000	8.189	0.033	248.2	0.061	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S7.001	2.971	0.012	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S7.002	4.195	0.017	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S6.005	19.074	0.076	251.0	0.024	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.000	11.417	0.046	250.0	0.041	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S5.001	41.19	5.84	75.380	0.115	0.0	0.0	0.0	0.99	70.0	12.8
S2.006	36.70	7.70	75.159	0.283	0.0	0.0	0.0	0.99	70.0	28.1
S1.009	33.91	9.17	75.047	0.457	0.0	0.0	0.0	0.99	70.0	42.0
S1.010	33.10	9.66	74.972	0.487	0.0	0.0	0.0	0.99	69.9	43.7
S6.000	43.01	5.23	76.100	0.025	0.0	0.0	0.0	0.99	70.0	2.9
S6.001	42.43	5.42	75.809	0.025	0.0	0.0	0.0	0.99	70.0	2.9
S6.002	39.85	6.34	75.764	0.060	0.0	0.0	0.0	0.99	70.0	6.5
S6.003	38.77	6.78	75.543	0.060	0.0	0.0	0.0	0.99	70.0	6.5
S6.004	38.33	6.97	75.440	0.060	0.0	0.0	0.0	0.99	70.0	6.5
S7.000	46.79	4.14	75.455	0.061	0.0	0.0	0.0	0.99	70.2	7.7
S7.001	46.60	4.19	75.422	0.061	0.0	0.0	0.0	0.99	70.0	7.7
S7.002	46.32	4.26	75.410	0.061	0.0	0.0	0.0	0.99	70.0	7.7
S6.005	37.59	7.29	75.393	0.145	0.0	0.0	0.0	0.99	69.8	14.8
S8.000	46.58	4.19	76.000	0.041	0.0	0.0	0.0	0.99	70.0	5.2

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S8.001	11.923	0.048	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.002	5.408	0.022	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S9.000	25.712	0.103	249.6	0.020	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S9.001	5.552	0.022	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.003	17.174	0.069	248.9	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S10.000	25.670	0.103	249.2	0.020	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S10.001	5.358	0.021	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.004	5.498	0.022	249.9	0.026	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.005	15.322	0.061	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.006	7.151	0.029	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.007	28.517	0.114	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S8.008	5.469	0.022	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S11.000	18.763	0.075	250.2	0.021	4.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S11.001	11.692	0.047	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒
S11.002	4.589	0.018	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	🔒

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S8.001	45.81	4.39	75.954	0.041	0.0	0.0	0.0	0.99	70.0	5.2
S8.002	45.48	4.48	75.907	0.041	0.0	0.0	0.0	0.99	70.0	5.2
S9.000	45.67	4.43	76.010	0.020	0.0	0.0	0.0	0.99	70.0	2.5
S9.001	45.33	4.53	75.905	0.020	0.0	0.0	0.0	0.99	70.0	2.5
S8.003	44.34	4.81	75.883	0.061	0.0	0.0	0.0	0.99	70.1	7.3
S10.000	45.67	4.43	75.940	0.020	0.0	0.0	0.0	0.99	70.1	2.5
S10.001	45.35	4.52	75.837	0.020	0.0	0.0	0.0	0.99	70.0	2.5
S8.004	44.03	4.91	75.814	0.107	0.0	0.0	0.0	0.99	70.0	12.8
S8.005	43.20	5.17	75.792	0.107	0.0	0.0	0.0	0.99	70.0	12.8
S8.006	42.83	5.29	75.731	0.107	0.0	0.0	0.0	0.99	70.0	12.8
S8.007	41.41	5.77	75.702	0.107	0.0	0.0	0.0	0.99	70.0	12.8
S8.008	41.15	5.86	75.588	0.107	0.0	0.0	0.0	0.99	70.0	12.8
S11.000	46.10	4.32	75.725	0.021	0.0	0.0	0.0	0.99	69.9	2.6
S11.001	45.38	4.51	75.650	0.021	0.0	0.0	0.0	0.99	70.0	2.6
S11.002	45.11	4.59	75.603	0.021	0.0	0.0	0.0	0.99	70.0	2.6

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S11.003	3.661	0.015	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S8.009	17.077	0.068	251.1	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S12.000	18.763	0.075	250.2	0.016	4.00	0.0	0.600	o	300	Pipe/Conduit	
S12.001	15.201	0.061	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S8.010	32.621	0.130	250.9	0.034	0.00	0.0	0.600	o	300	Pipe/Conduit	
S8.011	11.072	0.044	251.6	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S6.006	62.766	0.251	250.1	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S13.000	10.052	0.040	251.3	0.069	4.00	0.0	0.600	o	300	Pipe/Conduit	
S13.001	29.827	0.119	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S13.002	9.111	0.036	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S13.003	4.987	0.020	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S13.004	10.147	0.041	247.5	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S14.000	54.502	0.218	250.0	0.103	4.00	0.0	0.600	o	300	Pipe/Conduit	
S14.001	7.131	0.029	245.9	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S11.003	44.89	4.65	75.585	0.021	0.0	0.0	0.0	0.99	70.0	2.6
S8.009	40.37	6.15	75.566	0.128	0.0	0.0	0.0	0.99	69.8	14.0
S12.000	46.10	4.32	75.635	0.016	0.0	0.0	0.0	0.99	69.9	2.0
S12.001	45.17	4.57	75.560	0.016	0.0	0.0	0.0	0.99	70.0	2.0
S8.010	38.97	6.70	75.498	0.178	0.0	0.0	0.0	0.99	69.8	18.8
S8.011	38.52	6.88	75.368	0.178	0.0	0.0	0.0	0.99	69.7	18.8
S6.006	35.41	8.34	75.317	0.323	0.0	0.0	0.0	0.99	70.0	31.0
S13.000	46.67	4.17	75.325	0.069	0.0	0.0	0.0	0.99	69.8	8.7
S13.001	44.82	4.67	75.285	0.069	0.0	0.0	0.0	0.99	70.0	8.7
S13.002	44.30	4.83	75.165	0.069	0.0	0.0	0.0	0.99	70.0	8.7
S13.003	44.02	4.91	75.129	0.069	0.0	0.0	0.0	0.99	70.0	8.7
S13.004	43.47	5.08	75.109	0.069	0.0	0.0	0.0	0.99	70.3	8.7
S14.000	44.00	4.92	75.320	0.103	0.0	0.0	0.0	0.99	70.0	12.3
S14.001	43.61	5.04	75.100	0.103	0.0	0.0	0.0	1.00	70.6	12.3

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S6.007	53.781	0.154	349.2	0.000	0.00	0.0	0.600	o	375	Pipe/Conduit	
S15.000	22.086	0.088	251.0	0.100	4.00	0.0	0.600	o	300	Pipe/Conduit	
S15.001	6.271	0.025	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S15.002	6.271	0.025	250.8	0.066	0.00	0.0	0.600	o	300	Pipe/Conduit	
S15.003	69.855	0.279	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S15.004	16.200	0.065	249.2	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S15.005	8.402	0.034	247.1	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S16.000	17.591	0.070	251.3	0.187	4.00	0.0	0.600	o	300	Pipe/Conduit	
S15.006	4.581	0.018	254.5	0.036	0.00	0.0	0.600	o	300	Pipe/Conduit	
S15.007	15.025	0.060	250.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S17.000	54.341	0.201	270.0	0.155	4.00	0.0	0.600	o	300	Pipe/Conduit	
S17.001	54.260	0.201	270.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S17.002	53.567	0.198	270.0	0.155	0.00	0.0	0.600	o	300	Pipe/Conduit	
S18.000	54.301	0.201	270.0	0.155	4.00	0.0	0.600	o	300	Pipe/Conduit	

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S6.007	33.74	9.27	74.945	0.495	0.0	0.0	0.0	0.96	106.4	45.2
S15.000	45.89	4.37	75.465	0.100	0.0	0.0	0.0	0.99	69.8	12.4
S15.001	45.51	4.48	75.375	0.100	0.0	0.0	0.0	0.99	70.0	12.4
S15.002	45.13	4.58	75.350	0.166	0.0	0.0	0.0	0.99	69.8	20.3
S15.003	41.43	5.76	75.325	0.166	0.0	0.0	0.0	0.99	70.0	20.3
S15.004	40.67	6.03	75.045	0.166	0.0	0.0	0.0	0.99	70.1	20.3
S15.005	40.30	6.17	74.980	0.166	0.0	0.0	0.0	1.00	70.4	20.3
S16.000	46.17	4.30	75.015	0.187	0.0	0.0	0.0	0.99	69.8	23.4
S15.006	40.09	6.25	74.945	0.389	0.0	0.0	0.0	0.98	69.3	42.2
S15.007	39.44	6.50	74.925	0.389	0.0	0.0	0.0	0.99	70.0	42.2
S17.000	43.89	4.95	76.400	0.155	0.0	0.0	0.0	0.95	67.3	18.4
S17.001	41.03	5.90	76.199	0.155	0.0	0.0	0.0	0.95	67.3	18.4
S17.002	38.63	6.84	75.998	0.310	0.0	0.0	0.0	0.95	67.3	32.4
S18.000	43.89	4.95	76.125	0.155	0.0	0.0	0.0	0.95	67.3	18.4

Network Design Table for Storm

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type	Auto Design
S18.001	54.178	0.201	270.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S17.003	17.239	0.049	350.0	0.155	0.00	0.0	0.600	o	375	Pipe/Conduit	
S19.000	86.746	0.321	270.0	0.155	4.00	0.0	0.600	o	300	Pipe/Conduit	
S17.004	19.057	0.048	400.0	0.000	0.00	0.0	0.600	o	450	Pipe/Conduit	
S17.005	54.199	0.135	400.0	0.155	0.00	0.0	0.600	o	450	Pipe/Conduit	
S20.000	52.815	0.196	270.0	0.155	4.00	0.0	0.600	o	300	Pipe/Conduit	
S20.001	52.410	0.194	270.0	0.000	0.00	0.0	0.600	o	300	Pipe/Conduit	
S17.006	6.371	0.016	400.0	0.155	0.00	0.0	0.600	o	450	Pipe/Conduit	
S17.007	6.183	0.014	450.0	0.000	0.00	0.0	0.600	o	525	Pipe/Conduit	
S1.011	12.411	0.021	591.0	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit	
S1.012	52.641	0.088	598.2	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit	
S1.013	7.378	0.012	614.8	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit	
S1.014	8.108	0.014	579.1	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit	

Network Results Table

PN	Rain (mm/hr)	T.C. (mins)	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Foul (l/s)	Add Flow (l/s)	Vel (m/s)	Cap (l/s)	Flow (l/s)
S18.001	41.04	5.90	75.924	0.155	0.0	0.0	0.0	0.95	67.3	18.4
S17.003	37.93	7.14	75.650	0.620	0.0	0.0	0.0	0.96	106.3	63.7
S19.000	42.12	5.52	75.995	0.155	0.0	0.0	0.0	0.95	67.3	17.7
S17.004	37.23	7.45	75.525	0.775	0.0	0.0	0.0	1.01	160.7	78.1
S17.005	35.41	8.35	75.477	0.930	0.0	0.0	0.0	1.01	160.7	89.2
S20.000	43.97	4.92	75.885	0.155	0.0	0.0	0.0	0.95	67.3	18.5
S20.001	41.19	5.84	75.689	0.155	0.0	0.0	0.0	0.95	67.3	18.5
S17.006	35.21	8.45	75.342	1.240	0.0	0.0	0.0	1.01	160.7	118.2
S17.007	35.03	8.55	75.251	1.240	0.0	0.0	0.0	1.05	227.2	118.2
S1.011	32.77	9.86	74.564	2.611	0.0	0.0	0.0	0.99	281.2	231.7
S1.012	31.44	10.75	74.543	2.611	0.0	0.0	0.0	0.99	279.5	231.7
S1.013	31.26	10.88	74.455	2.611	0.0	0.0	0.0	0.97	275.6	231.7
S1.014	31.07	11.01	74.443	2.611	0.0	0.0	0.0	1.00	284.1	231.7

Simulation Criteria for Storm

Volumetric Runoff Coeff	0.750	Additional Flow - % of Total Flow	0.000
Areal Reduction Factor	1.000	MADD Factor * 10m³/ha Storage	2.000
Hot Start (mins)	0	Inlet Coeffiecient	0.800
Hot Start Level (mm)	0	Flow per Person per Day (l/per/day)	0.000
Manhole Headloss Coeff (Global)	0.500	Run Time (mins)	60
Foul Sewage per hectare (l/s)	0.000	Output Interval (mins)	1

Number of Input Hydrographs	0	Number of Offline Controls	0	Number of Time/Area Diagrams	0
Number of Online Controls	1	Number of Storage Structures	1	Number of Real Time Controls	0

Synthetic Rainfall Details

Rainfall Model	FSR	Profile Type	Summer
Return Period (years)	1	Cv (Summer)	0.750
Region	Scotland and Ireland	Cv (Winter)	0.840
M5-60 (mm)	17.000	Storm Duration (mins)	30
Ratio R	0.300		

Online Controls for Storm

Hydro-Brake® Optimum Manhole: S2.2, DS/PN: S1.013, Volume (m³): 19.7

Unit Reference	MD-SHE-0222-3260-2600-3260
Design Head (m)	2.600
Design Flow (l/s)	32.6
Flush-Flo™	Calculated
Objective	Minimise upstream storage
Application	Surface
Sump Available	Yes
Diameter (mm)	222
Invert Level (m)	74.455
Minimum Outlet Pipe Diameter (mm)	300
Suggested Manhole Diameter (mm)	2100

Control Points	Head (m)	Flow (l/s)	Control Points	Head (m)	Flow (l/s)
Design Point (Calculated)	2.600	32.6	Kick-Flo®	1.575	25.6
Flush-Flo™	0.742	32.6	Mean Flow over Head Range	-	28.4

The hydrological calculations have been based on the Head/Discharge relationship for the Hydro-Brake® Optimum as specified. Should another type of control device other than a Hydro-Brake Optimum® be utilised then these storage routing calculations will be invalidated

Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)
0.100	7.5	1.200	31.0	3.000	34.9	7.000	52.5
0.200	22.0	1.400	28.9	3.500	37.6	7.500	54.3
0.300	28.5	1.600	25.8	4.000	40.1	8.000	56.0
0.400	30.5	1.800	27.3	4.500	42.4	8.500	57.7
0.500	31.7	2.000	28.7	5.000	44.6	9.000	59.3
0.600	32.3	2.200	30.1	5.500	46.7	9.500	60.9
0.800	32.5	2.400	31.3	6.000	48.7		
1.000	32.0	2.600	32.6	6.500	50.7		

Storage Structures for Storm

Cellular Storage Manhole: S2.2, DS/PN: S1.013

Invert Level (m) 74.456 Safety Factor 2.0
Infiltration Coefficient Base (m/hr) 0.00000 Porosity 0.60
Infiltration Coefficient Side (m/hr) 0.00000

Depth (m)	Area (m²)	Inf. Area (m²)	Depth (m)	Area (m²)	Inf. Area (m²)
0.000	745.8	745.8	1.800	0.0	960.6
1.700	745.8	960.6			

Summary of Critical Results by Maximum Level (Rank 1) for Storm

Simulation Criteria

Areal Reduction Factor 1.000 Additional Flow - % of Total Flow 0.000
Hot Start (mins) 0 MADD Factor * 10m³/ha Storage 2.000
Hot Start Level (mm) 0 Inlet Coeffiecient 0.800
Manhole Headloss Coeff (Global) 0.500 Flow per Person per Day (l/per/day) 0.000
Foul Sewage per hectare (l/s) 0.000

Number of Input Hydrographs 0 Number of Offline Controls 0 Number of Time/Area Diagrams 0
Number of Online Controls 1 Number of Storage Structures 1 Number of Real Time Controls 0

Synthetic Rainfall Details

Rainfall Model FSR Ratio R 0.300
Region Scotland and Ireland Cv (Summer) 0.750
M5-60 (mm) 17.000 Cv (Winter) 0.840

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440
Return Period(s) (years) 1, 30, 100
Climate Change (%) 10, 10, 10

PN	US/MH Name	Storm	Return Period	Climate Change	First (X) Surcharge	First (Y) Flood	First (Z) Overflow	Overflow Act.	Water Level (m)
S1.000	S3.8	15 Winter	100	+10%					76.303
S1.001	SD1	15 Winter	100	+10%					76.255
S1.002	S3.7	15 Winter	100	+10%					76.240
S1.003	SD2	360 Winter	100	+10%	100/240 Winter				76.121
S1.004	S3.6	360 Winter	100	+10%	100/180 Winter				76.120
S1.005	S3.5	360 Winter	100	+10%	100/180 Winter				76.119
S1.006	SD3	360 Winter	100	+10%	100/15 Winter				76.117
S1.007	S3.4	360 Winter	100	+10%	30/360 Winter				76.115
S1.008	S3.3	360 Winter	100	+10%	30/15 Summer				76.111
S2.000	S3.2e	360 Winter	100	+10%					76.120
S2.001	S3.2d	360 Winter	100	+10%	100/120 Winter				76.120
S2.002	SD4	360 Winter	100	+10%	30/360 Winter				76.118
S2.003	SD5	360 Winter	100	+10%	30/240 Winter				76.118
S3.000	S3.2l	360 Winter	100	+10%	30/240 Winter				76.117
S2.004	S3.2c	360 Winter	100	+10%	30/120 Winter				76.117
S4.000	S3.2h	360 Winter	100	+10%	30/120 Winter				76.115
S2.005	S3.2b	360 Winter	100	+10%	30/15 Winter				76.115

Summary of Critical Results by Maximum Level (Rank 1) for Storm

PN	US/MH Name	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
S1.000	S3.8	-0.202	0.000	0.21		12.5	OK	
S1.001	SD1	-0.175	0.000	0.22		12.6	OK	
S1.002	S3.7	-0.135	0.000	0.53		35.5	OK	
S1.003	SD2	0.051	0.000	0.10		6.0	SURCHARGED	
S1.004	S3.6	0.103	0.000	0.14		6.9	SURCHARGED	
S1.005	S3.5	0.129	0.000	0.13		8.1	SURCHARGED	
S1.006	SD3	0.234	0.000	0.12		8.0	SURCHARGED	
S1.007	S3.4	0.357	0.000	0.14		9.7	SURCHARGED	
S1.008	S3.3	0.706	0.000	0.12		6.8	SURCHARGED	
S2.000	S3.2e	-0.135	0.000	0.03		2.0	OK	
S2.001	S3.2d	0.175	0.000	0.08		5.3	SURCHARGED	
S2.002	SD4	0.354	0.000	0.09		5.1	SURCHARGED	
S2.003	SD5	0.390	0.000	0.08		5.0	SURCHARGED	
S3.000	S3.21	0.377	0.000	0.02		1.1	SURCHARGED	
S2.004	S3.2c	0.461	0.000	0.11		6.8	SURCHARGED	
S4.000	S3.2h	0.465	0.000	0.02		1.0	SURCHARGED	
S2.005	S3.2b	0.549	0.000	0.12		7.3	SURCHARGED	

Summary of Critical Results by Maximum Level (Rank 1) for Storm

PN	US/MH Name	Storm	Return Period	Climate Change	First (X) Surcharge	First (Y) Flood	First (Z) Overflow	Overflow Act.
S5.000	S3.2f	360 Winter	100	+10%	100/120 Winter			
S5.001	S3.2g	360 Winter	100	+10%	30/180 Winter			
S2.006	S3.2a	360 Winter	100	+10%	30/15 Summer			
S1.009	S3.2	360 Winter	100	+10%	30/15 Summer			
S1.010	S3.1	360 Winter	100	+10%	30/15 Summer			
S6.000	S2.9	15 Winter	100	+10%				
S6.001	SD6	360 Winter	100	+10%	100/360 Winter			
S6.002	S2.8	360 Winter	100	+10%	100/240 Winter			
S6.003	SD7	360 Winter	100	+10%	100/120 Winter			
S6.004	SD8	360 Winter	100	+10%	30/240 Winter			
S7.000	S2.7a	360 Winter	100	+10%	30/360 Winter			
S7.001	SD26	360 Winter	100	+10%	30/240 Winter			
S7.002	SD27	360 Winter	100	+10%	30/180 Winter			
S6.005	S2.7	360 Winter	100	+10%	30/180 Winter			
S8.000	S6.6	360 Winter	100	+10%				
S8.001	SD9	360 Winter	100	+10%				
S8.002	SD10	360 Winter	100	+10%				
S9.000	S6.5a	360 Winter	100	+10%				
S9.001	SD11	360 Winter	100	+10%				
S8.003	S6.5	360 Winter	100	+10%				
S10.000	SS6.4a	360 Winter	100	+10%				
S10.001	SD12	360 Winter	100	+10%				
S8.004	S6.4	360 Winter	100	+10%	100/360 Winter			
S8.005	SD13	360 Winter	100	+10%	100/240 Winter			
S8.006	SD14	360 Winter	100	+10%	100/180 Winter			
S8.007	SD15	360 Winter	100	+10%	100/180 Winter			
S8.008	SD16	360 Winter	100	+10%	100/120 Winter			
S11.000	S6.3a	360 Winter	100	+10%	100/180 Winter			
S11.001	SD17	360 Winter	100	+10%	100/120 Winter			
S11.002	SD18	360 Winter	100	+10%	100/120 Winter			
S11.003	SD19	360 Winter	100	+10%	100/120 Winter			
S8.009	S6.3	360 Winter	100	+10%	100/30 Winter			
S12.000	S6.2a	360 Winter	100	+10%	100/120 Winter			
S12.001	SD20	360 Winter	100	+10%	100/120 Winter			
S8.010	S6.2	360 Winter	100	+10%	100/15 Winter			
S8.011	S6.1	360 Winter	100	+10%	30/120 Winter			
S6.006	S2.6	360 Winter	100	+10%	30/120 Winter	30/600 Winter		
S13.000	S2.5b	360 Winter	100	+10%	30/120 Winter			
S13.001	SD22	360 Winter	100	+10%	30/120 Winter			
S13.002	SD23	360 Winter	100	+10%	30/15 Winter			
S13.003	SD24	360 Winter	100	+10%	30/15 Winter			
S13.004	S2.5a	360 Winter	100	+10%	30/15 Summer			
S14.000	S5.2	360 Winter	100	+10%	30/120 Winter			
S14.001	S5.1	360 Winter	100	+10%	30/15 Summer			

Summary of Critical Results by Maximum Level (Rank 1) for Storm

PN	US/MH Name	Water Level (m)	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
S5.000	S3.2f	76.117	0.217	0.000	0.07		4.8	SURCHARGED	
S5.001	S3.2g	76.115	0.435	0.000	0.10		6.4	SURCHARGED	
S2.006	S3.2a	76.113	0.653	0.000	0.20		12.6	SURCHARGED	
S1.009	S3.2	76.109	0.761	0.000	0.30		18.4	SURCHARGED	
S1.010	S3.1	76.103	0.831	0.000	0.30		18.7	SURCHARGED	
S6.000	S2.9	76.177	-0.223	0.000	0.14		9.3	OK	
S6.001	SD6	76.111	0.002	0.000	0.03		1.5	SURCHARGED	
S6.002	S2.8	76.110	0.047	0.000	0.06		3.7	SURCHARGED	
S6.003	SD7	76.110	0.267	0.000	0.06		3.6	SURCHARGED	
S6.004	SD8	76.109	0.369	0.000	0.06		3.4	SURCHARGED	
S7.000	S2.7a	76.110	0.355	0.000	0.07		3.6	SURCHARGED	
S7.001	SD26	76.109	0.387	0.000	0.07		3.5	SURCHARGED	
S7.002	SD27	76.109	0.399	0.000	0.07		3.4	SURCHARGED	
S6.005	S2.7	76.109	0.415	0.000	0.13		8.1	SURCHARGED	
S8.000	S6.6	76.118	-0.182	0.000	0.04		2.5	OK	
S8.001	SD9	76.118	-0.136	0.000	0.04		2.5	OK	
S8.002	SD10	76.118	-0.089	0.000	0.05		2.5	OK	
S9.000	S6.5a	76.117	-0.193	0.000	0.02		1.2	OK	
S9.001	SD11	76.117	-0.088	0.000	0.03		1.2	OK	
S8.003	S6.5	76.117	-0.065	0.000	0.06		3.7	OK	
S10.000	SS6.4a	76.117	-0.123	0.000	0.02		1.2	OK	
S10.001	SD12	76.117	-0.020	0.000	0.03		1.2	OK	
S8.004	S6.4	76.117	0.003	0.000	0.14		6.6	SURCHARGED	
S8.005	SD13	76.116	0.024	0.000	0.11		6.6	SURCHARGED	
S8.006	SD14	76.115	0.085	0.000	0.13		6.6	SURCHARGED	
S8.007	SD15	76.114	0.113	0.000	0.10		6.6	SURCHARGED	
S8.008	SD16	76.113	0.225	0.000	0.14		6.5	SURCHARGED	
S11.000	S6.3a	76.112	0.087	0.000	0.02		1.3	SURCHARGED	
S11.001	SD17	76.112	0.162	0.000	0.02		1.3	SURCHARGED	
S11.002	SD18	76.113	0.210	0.000	0.03		1.3	SURCHARGED	
S11.003	SD19	76.113	0.228	0.000	0.03		1.2	SURCHARGED	
S8.009	S6.3	76.112	0.247	0.000	0.13		7.6	SURCHARGED	
S12.000	S6.2a	76.111	0.176	0.000	0.02		1.0	SURCHARGED	
S12.001	SD20	76.111	0.251	0.000	0.02		0.9	SURCHARGED	
S8.010	S6.2	76.111	0.313	0.000	0.16		10.4	SURCHARGED	
S8.011	S6.1	76.108	0.441	0.000	0.17		9.6	SURCHARGED	
S6.006	S2.6	76.107	0.490	0.000	0.26		17.1	SURCHARGED	
S13.000	S2.5b	76.104	0.479	0.000	0.07		3.8	SURCHARGED	
S13.001	SD22	76.103	0.518	0.000	0.06		3.6	SURCHARGED	
S13.002	SD23	76.102	0.637	0.000	0.06		3.3	SURCHARGED	
S13.003	SD24	76.102	0.673	0.000	0.07		3.0	SURCHARGED	
S13.004	S2.5a	76.101	0.693	0.000	0.05		2.8	SURCHARGED	
S14.000	S5.2	76.103	0.483	0.000	0.09		5.7	SURCHARGED	

Summary of Critical Results by Maximum Level (Rank 1) for Storm

PN	US/MH Name	Water Level (m)	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
S14.001	S5.1	76.101	0.701	0.000	0.11		5.4	SURCHARGED	

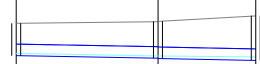
Summary of Critical Results by Maximum Level (Rank 1) for Storm

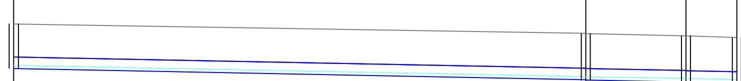
PN	US/MH Name	Storm	Return Period	Climate Change	First (X) Surcharge	First (Y) Flood	First (Z) Overflow	Overflow Act.	Water Level (m)
S6.007	S2.5	360 Winter	100	+10%	30/15 Summer				76.101
S15.000	S4.5	360 Winter	100	+10%	30/360 Winter				76.112
S15.001	SD21	360 Winter	100	+10%	30/180 Winter				76.110
S15.002	S4.4	360 Winter	100	+10%	30/120 Winter				76.110
S15.003	SD22	360 Winter	100	+10%	30/15 Winter				76.109
S15.004	S4.3	360 Winter	100	+10%	30/15 Summer				76.105
S15.005	S4.2	360 Winter	100	+10%	30/15 Summer				76.103
S16.000	S4.1a	360 Winter	100	+10%	30/15 Summer				76.104
S15.006	S4.1	360 Winter	100	+10%	30/15 Summer				76.102
S15.007	SD25	360 Winter	100	+10%	30/15 Summer				76.100
S17.000	SRW1.7	15 Winter	100	+10%	100/15 Summer				77.004
S17.001	SRW1.6	15 Winter	100	+10%	100/15 Summer				76.948
S17.002	SRW1.5	15 Winter	100	+10%	30/15 Summer				76.889
S18.000	SRW1.4b	15 Winter	100	+10%	100/15 Summer				76.784
S18.001	SRW1.4a	15 Winter	100	+10%	30/15 Summer				76.722
S17.003	SRW1.4	15 Winter	100	+10%	30/15 Summer				76.654
S19.000	SRW1.3a	15 Winter	100	+10%	100/15 Summer				76.621
S17.004	SRW1.3	15 Winter	100	+10%	30/15 Summer				76.525
S17.005	SRW1.2	15 Winter	100	+10%	30/15 Summer				76.423
S20.000	SRW1.1b	15 Winter	100	+10%	100/15 Summer				76.284
S20.001	SRW1.1a	15 Winter	100	+10%	100/15 Summer				76.215
S17.006	SRW1.1	15 Winter	100	+10%	30/15 Summer				76.130
S17.007	SRW1.0	360 Winter	100	+10%	100/15 Summer				76.097
S1.011	S2.4	360 Winter	100	+10%	30/15 Summer				76.096
S1.012	S2.3	360 Winter	100	+10%	1/720 Winter				76.091
S1.013	S2.2	360 Winter	100	+10%	1/180 Winter				76.082
S1.014	S2.1	720 Winter	100	+10%					74.794

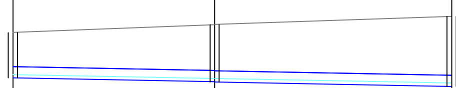
PN	US/MH Name	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
S6.007	S2.5	0.781	0.000	0.20		19.4	SURCHARGED	
S15.000	S4.5	0.347	0.000	0.10		5.9	SURCHARGED	
S15.001	SD21	0.435	0.000	0.11		5.7	SURCHARGED	
S15.002	S4.4	0.460	0.000	0.19		9.3	SURCHARGED	
S15.003	SD22	0.484	0.000	0.14		9.1	SURCHARGED	
S15.004	S4.3	0.760	0.000	0.13		7.9	SURCHARGED	
S15.005	S4.2	0.823	0.000	0.14		7.6	SURCHARGED	
S16.000	S4.1a	0.789	0.000	0.18		10.8	SURCHARGED	
S15.006	S4.1	0.857	0.000	0.41		19.6	SURCHARGED	
S15.007	SD25	0.875	0.000	0.33		19.4	SURCHARGED	
S17.000	SRW1.7	0.304	0.000	0.89		56.9	FLOOD RISK	

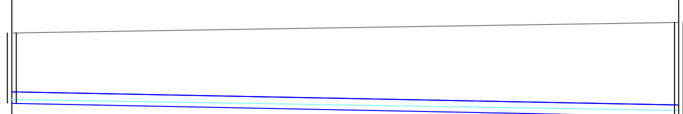
Summary of Critical Results by Maximum Level (Rank 1) for Storm

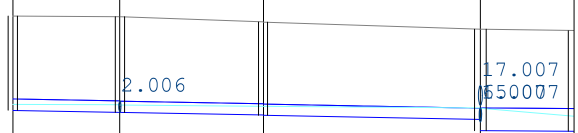
PN	US/MH Name	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
S17.001	SRW1.6	0.450	0.000	0.65		41.2	SURCHARGED	
S17.002	SRW1.5	0.591	0.000	1.07		68.2	SURCHARGED	
S18.000	SRW1.4b	0.359	0.000	0.88		56.0	SURCHARGED	
S18.001	SRW1.4a	0.498	0.000	0.59		37.7	SURCHARGED	
S17.003	SRW1.4	0.629	0.000	1.60		138.1	SURCHARGED	
S19.000	SRW1.3a	0.326	0.000	0.76		49.1	SURCHARGED	
S17.004	SRW1.3	0.550	0.000	1.43		180.3	SURCHARGED	
S17.005	SRW1.2	0.496	0.000	1.41		207.4	SURCHARGED	
S20.000	SRW1.1b	0.099	0.000	0.90		57.1	SURCHARGED	
S20.001	SRW1.1a	0.226	0.000	0.67		42.6	SURCHARGED	
S17.006	SRW1.1	0.338	0.000	2.60		278.7	SURCHARGED	
S17.007	SRW1.0	0.322	0.000	0.49		75.1	SURCHARGED	
S1.011	S2.4	0.932	0.000	0.94		125.8	SURCHARGED	
S1.012	S2.3	0.948	0.000	0.51		125.2	SURCHARGED	
S1.013	S2.2	1.027	0.000	0.18		32.5	SURCHARGED	
S1.014	S2.1	-0.249	0.000	0.19		32.5	OK	

MH Name		S3.8	SD1	S3.7
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S1.000	S1.001	
Dia (mm)		300	300	
Slope (1:X)		250.0	250.0	
Cover Level (m)		77.050	77.100	77.250
Invert Level (m)		76.205 76.130	76.130 76.078	
Length (m)		18.832	12.948	

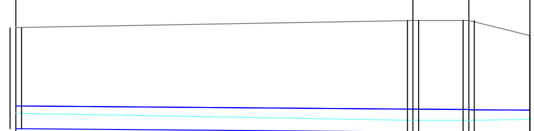
MH Name		S3.7	SD2		S3.5
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000					
PN		S1.002	S1.003		
Dia (mm)		300	300		
Slope (1:X)		250.0	250.0		
Cover Level (m)		77.250	77.000	76.940	76.890
Invert Level (m)		76.075 75.772	75.770 75.717	75.717	
Length (m)		75.758	13.260		

MH Name		S3.5	SD3	S3.4
Hor Scale 1000 Ver Scale 200 Datum (m)73.000				
PN		S1.005	S1.006	
Dia (mm)		300	300	
Slope (1:X)		250.0	250.0	
Cover Level (m)		76.890	77.100	77.320
Invert Level (m)		75.690 75.583	75.583 75.458	
Length (m)		26.677	31.406	

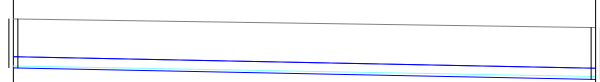
MH Name		S3.4	S3.3
Hor Scale 1000 Ver Scale 200 Datum (m)73.000			
PN		S1.007	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.320	77.600
Invert Level (m)		75.458 75.104	
Length (m)		88.354	



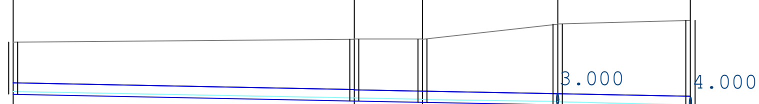
MH Name		S3.3	S3.2	S3.1	S2.4	S2.3
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000						
PN		S1.008	S1.009	S1.010	S1.011	
Dia (mm)		300	300	300	600	
Slope (1:X)		250.0	250.0	250.4	591.0	
Cover Level (m)		77.600	77.580	77.440	77.250	77.210
Invert Level (m)		75.104 75.047	75.047 74.972	74.972 74.857	74.564 74.543	
Length (m)		14.177	18.972	28.794	12.411	



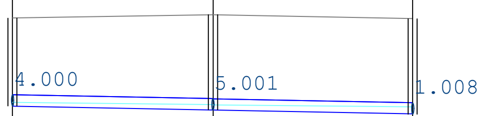
MH Name		S2.3			SP1
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000					
PN		S1.012			
Dia (mm)		600			
Slope (1:X)		598.2			
Cover Level (m)		77.210	77.400	77.400	77.000
Invert Level (m)		74.543 74.455	74.455 74.443	74.443 74.429	
Length (m)		52.641			

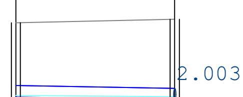


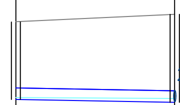
MH Name		S3.2e	S3.2d
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S2.000	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.250	77.020
Invert Level (m)		75.955 75.647	
Length (m)		77.028	

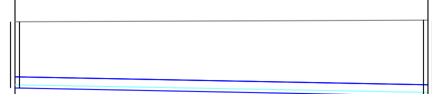


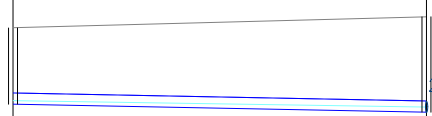
MH Name		S3.2d		SD5	S3.2c	S3.2b
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000						
PN		S2.001		S2.003	S2.004	
Dia (mm)		300		300	300	
Slope (1:X)		250.0		250.0	250.0	
Cover Level (m)		77.020	77.100	77.100	77.500	77.600
Invert Level (m)		75.645 75.464	75.464 75.428	75.428 75.356	75.356 75.285	
Length (m)		45.182		17.895	17.608	

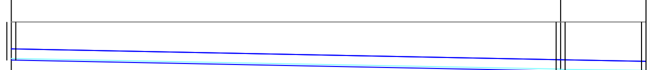
MH Name		S3.2b	S3.2a	S3.2
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S2.005	S2.006	
Dia (mm)		300	300	
Slope (1:X)		250.0	249.8	
Cover Level (m)		77.600	77.690	77.580
Invert Level (m)		75.266 75.159	75.159 75.053	
Length (m)		26.563	26.475	

MH Name		S3.2l	S3.2c
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S3.000	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.400	77.500
Invert Level (m)		75.440 75.356	
Length (m)		21.065	

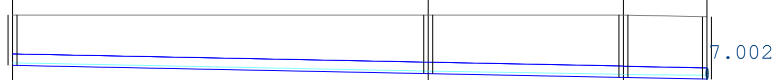
MH Name		S3.2h	S3.2b
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S4.000	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.400	77.600
Invert Level (m)		75.350 / 75.266	
Length (m)		21.065	

MH Name		S3.2f	S3.2g
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S5.000	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.350	77.400
Invert Level (m)		75.600 / 75.381	
Length (m)		54.736	

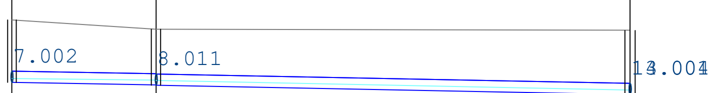
MH Name		S3.2g	S3.2a
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S5.001	
Dia (mm)		300	
Slope (1:X)		250.0	
Cover Level (m)		77.400	77.690
Invert Level (m)		75.380 75.161	
Length (m)		54.736	

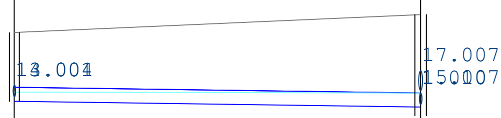
MH Name		S2.9		S2.8
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S6.000		
Dia (mm)		300		
Slope (1:X)		250.0		
Cover Level (m)		77.100	77.100	77.100
Invert Level (m)		76.100 75.809	75.809 75.764	
Length (m)		72.811		

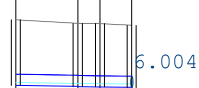
MH Name		S2.8	SD7		S2.7
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000					
PN		S6.002	S6.003		
Dia (mm)		300	300		
Slope (1:X)		250.0	250.0		
Cover Level (m)		77.100	77.100	77.100	77.050
Invert Level (m)		75.764 / 75.543	75.543 / 75.440	75.440 / 75.396	
Length (m)		55.073	25.822		

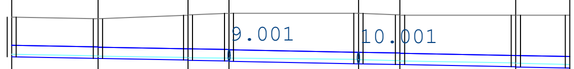


MH Name		S2.7	S2.6	S2.5
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN		S6.005	S6.006	
Dia (mm)		300	300	
Slope (1:X)		251.0	250.1	
Cover Level (m)		77.050	76.800	76.770
Invert Level (m)		75.393 / 75.317	75.317 / 75.066	
Length (m)		19.074	62.766	

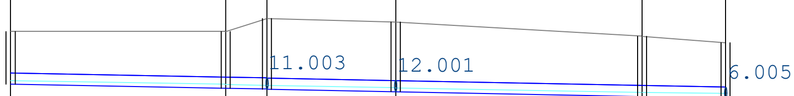


MH Name		S2.5	S2.4
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000			
PN		S6.007	
Dia (mm)		375	
Slope (1:X)		349.2	
Cover Level (m)		76.770	77.250
Invert Level (m)		74.945	74.791
Length (m)		53.781	

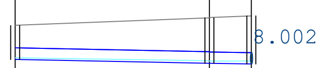
MH Name					S2.7
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000					
PN					
Dia (mm)					
Slope (1:X)					
Cover Level (m)		77.200		77.100	77.050
Invert Level (m)		75.455 75.422		75.410	
Length (m)					

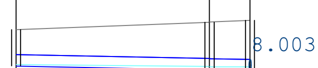


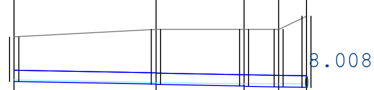
MH Name					S6.5		SD13		SD15
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000									
PN					S8.003		S8.005		
Dia (mm)					300		300		
Slope (1:X)					248.9		250.0		
Cover Level (m)		77.050	77.000	77.100	77.150	77.150	77.100	77.100	77.100
Invert Level (m)		76.000 75.954	75.954 75.907	75.907	75.883 75.814	75.814	75.792 75.731	75.731	
Length (m)					17.174		15.322		

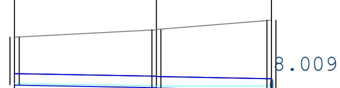


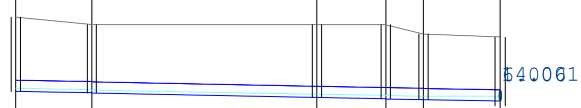
MH Name		SD15		S6.3	S6.2		S2.6
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000							
PN		S8.007		S8.009	S8.010		
Dia (mm)		300		300	300		
Slope (1:X)		250.0		251.1	250.9		
Cover Level (m)		77.100	77.100	77.450	77.350	76.970	76.800
Invert Level (m)		75.702 75.588	75.588	75.566 75.498	75.498 75.368	75.368 75.324	
Length (m)		28.517		17.077	32.621		

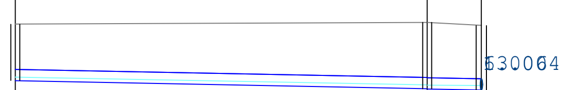
MH Name		S6.5a		S6.5
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S9.000		
Dia (mm)		300		
Slope (1:X)		249.6		
Cover Level (m)		76.900	77.100	77.150
Invert Level (m)		76.010 75.907	75.905	
Length (m)		25.712		

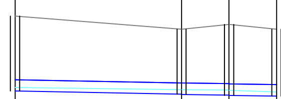
MH Name		SS6.4a		S6.4
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S10.000		
Dia (mm)		300		
Slope (1:X)		249.2		
Cover Level (m)		76.900	77.100	77.150
Invert Level (m)		75.940 75.837	75.837	
Length (m)		25.670		

MH Name		S6.3a				S6.3
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000						
PN		S11.000				
Dia (mm)		300				
Slope (1:X)		250.2				
Cover Level (m)		76.900	77.100	77.100	77.100	77.450
Invert Level (m)		75.725 / 75.650	75.650 / 75.603	75.603	75.585	
Length (m)		18.763				

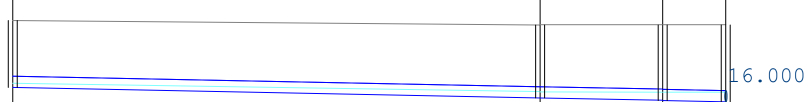
MH Name		S6.2a	SD20	S6.2
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S12.000	S12.001	
Dia (mm)		300	300	
Slope (1:X)		250.2	250.0	
Cover Level (m)		76.900	77.100	77.350
Invert Level (m)		75.635 / 75.560	75.560 / 75.499	
Length (m)		18.763	15.201	

MH Name			SD22				S2.5
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000							
PN			S13.001				
Dia (mm)			300				
Slope (1:X)			250.0				
Cover Level (m)		77.300	77.100	77.100	77.100	76.850	76.770
Invert Level (m)		75.325 75.285	75.285 75.166	75.165 75.129	75.129	75.109 75.068	
Length (m)			29.827				

MH Name		S5.2		S2.5
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN		S14.000		
Dia (mm)		300		
Slope (1:X)		250.0		
Cover Level (m)		76.800	76.850	76.770
Invert Level (m)		75.320 75.102	75.100	
Length (m)		54.502		



MH Name		S4.5			SD22
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000					
PN		S15.000			
Dia (mm)		300			
Slope (1:X)		251.0			
Cover Level (m)		77.450	77.100	77.230	77.100
Invert Level (m)		75.465 75.377	75.375	75.350	
Length (m)		22.086			



MH Name		SD22	S4.3		S4.1
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000					
PN		S15.003	S15.004		
Dia (mm)		300	300		
Slope (1:X)		250.0	249.2		
Cover Level (m)		77.100	76.980	76.980	76.980
Invert Level (m)		75.325 75.046	75.045 74.980	74.980 74.946	
Length (m)		69.855	16.200		

J.B. Barry & Partners Ltd		Page 15
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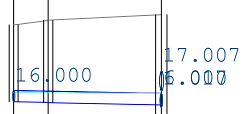
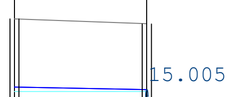
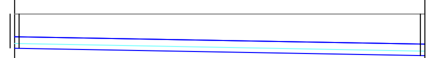
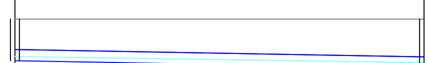


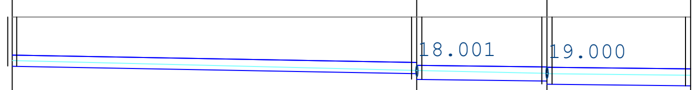
MH Name			SD25	S2.4
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN			S15.007	
Dia (mm)			300	
Slope (1:X)			250.0	
Cover Level (m)		76.980	77.100	77.250
Invert Level (m)		74.945	74.925 / 74.865	
Length (m)			15.025	

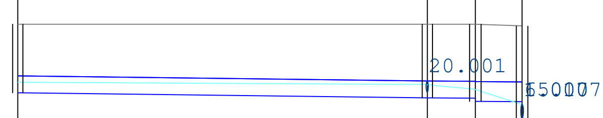


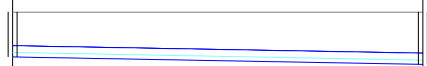
MH Name		S4.1a	S4.1
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000			
PN		S16.000	
Dia (mm)		300	
Slope (1:X)		251.3	
Cover Level (m)		77.115	76.980
Invert Level (m)		75.015 / 74.945	
Length (m)		17.591	

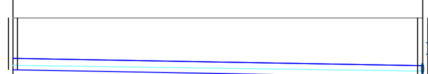
MH Name		SRW1.7		SRW1.6
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S17.000		
Dia (mm)		300		
Slope (1:X)		270.0		
Cover Level (m)		77.300		77.300
Invert Level (m)		76.400	76.199	
Length (m)		54.341		

MH Name		SRW1.6		SRW1.5
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S17.001		
Dia (mm)		300		
Slope (1:X)		270.0		
Cover Level (m)		77.300		77.300
Invert Level (m)		76.199	75.998	
Length (m)		54.260		

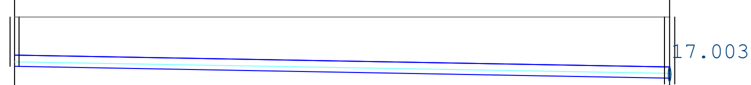
MH Name		SRW1.5	SRW1.4	SRW1.3	SRW1.2
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000					
PN		S17.002	S17.003	S17.004	
Dia (mm)		300	375	450	
Slope (1:X)		270.0	350.0	400.0	
Cover Level (m)		77.300	77.300	77.300	77.300
Invert Level (m)		75.998 75.799	75.650 75.601	75.525 75.477	
Length (m)		53.567	17.239	19.057	

MH Name		SRW1.2			S2.4
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000					
PN		S17.005			
Dia (mm)		450			
Slope (1:X)		400.0			
Cover Level (m)		77.300	77.300	77.300	77.250
Invert Level (m)		75.477 75.342	75.342	75.251	
Length (m)		54.199			

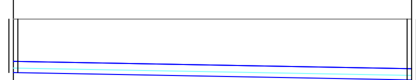
MH Name		SRW1.4b	SRW1.4a
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		S18.000	
Dia (mm)		300	
Slope (1:X)		270.0	
Cover Level (m)		77.300	77.300
Invert Level (m)		76.125 / 75.924	
Length (m)		54.301	

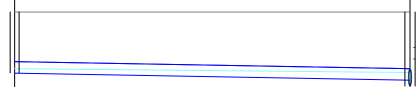
MH Name		SRW1.4a	SRW1.4
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			17.002
PN		S18.001	
Dia (mm)		300	
Slope (1:X)		270.0	
Cover Level (m)		77.300	77.300
Invert Level (m)		75.924 / 75.723	
Length (m)		54.178	

MH Name		SRW1.3a		SRW1.3
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S19.000		
Dia (mm)		300		
Slope (1:X)		270.0		
Cover Level (m)		77.300		77.300
Invert Level (m)		75.995	75.674	
Length (m)		86.746		



MH Name		SRW1.1b		SRW1.1a
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000				
PN		S20.000		
Dia (mm)		300		
Slope (1:X)		270.0		
Cover Level (m)		77.300		77.300
Invert Level (m)		75.885	75.689	
Length (m)		52.815		



MH Name		SRW1.1a	SRW1.1
Hor Scale 1000 Ver Scale 200 Datum (m)73.000			17.005
PN		S20.001	
Dia (mm)		300	
Slope (1:X)		270.0	
Cover Level (m)		77.300	77.300
Invert Level (m)		75.689 75.495	
Length (m)		52.410	

Existing Network Details for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

PN	Length (m)	Fall (m)	Slope (1:X)	I.Area (ha)	T.E. (mins)	Base Flow (l/s)	k (mm)	HYD SECT	DIA (mm)	Section Type
E1.000	39.820	0.488	81.6	0.084	4.00	0.0	0.600	o	300	Pipe/Conduit
E1.001	13.470	0.070	192.4	0.049	0.00	0.0	0.600	o	300	Pipe/Conduit
E1.002	61.770	0.300	205.9	0.156	0.00	0.0	0.600	o	450	Pipe/Conduit
E2.000	24.130	0.890	27.1	0.041	4.00	0.0	0.600	o	450	Pipe/Conduit
E2.001	73.510	0.980	75.0	0.074	0.00	0.0	0.600	o	600	Pipe/Conduit
E1.003	72.530	0.080	906.6	0.095	0.00	0.0	0.600	o	600	Pipe/Conduit
E1.004	19.890	0.040	497.2	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit
E1.005	16.210	0.030	540.3	0.000	0.00	0.0	0.600	o	600	Pipe/Conduit
E1.006	11.230	0.030	374.3	0.000	0.00	0.0	0.600	o	225	Pipe/Conduit

Network Results Table

PN	US/IL (m)	Σ I.Area (ha)	Σ Base Flow (l/s)	Vel (m/s)	Cap (l/s)
E1.000	75.638	0.084	0.0	1.74	123.1
E1.001	75.150	0.133	0.0	1.13	79.9
E1.002	75.080	0.289	0.0	1.41	224.7
E2.000	76.650	0.041	0.0	3.92	622.9
E2.001	75.760	0.115	0.0	2.81	795.6
E1.003	74.780	0.499	0.0	0.80	226.4
E1.004	74.700	0.499	0.0	1.09	306.8
E1.005	74.660	0.499	0.0	1.04	294.2
E1.006	74.630	0.499	0.0	0.67	26.6

Surcharged Outfall Details for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Outfall Pipe Number	Outfall Name	C. Level (m)	I. Level (m)	Min I. Level (m)	D,L (mm)	W (mm)
E1.006	EP2	77.000	74.600	0.000	1200	0

Datum (m) 0.400 Offset (mins) 0

Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)
15	74.960	30	74.960	45	74.960	60	74.960	75	74.960	90	74.960

Surcharged Outfall Details for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)	Time (mins)	Depth (m)
105	74.960	330	74.960	555	74.960	780	74.960	1005	74.960	1230	74.960
120	74.960	345	74.960	570	74.960	795	74.960	1020	74.960	1245	74.960
135	74.960	360	74.960	585	74.960	810	74.960	1035	74.960	1260	74.960
150	74.960	375	74.960	600	74.960	825	74.960	1050	74.960	1275	74.960
165	74.960	390	74.960	615	74.960	840	74.960	1065	74.960	1290	74.960
180	74.960	405	74.960	630	74.960	855	74.960	1080	74.960	1305	74.960
195	74.960	420	74.960	645	74.960	870	74.960	1095	74.960	1320	74.960
210	74.960	435	74.960	660	74.960	885	74.960	1110	74.960	1335	74.960
225	74.960	450	74.960	675	74.960	900	74.960	1125	74.960	1350	74.960
240	74.960	465	74.960	690	74.960	915	74.960	1140	74.960	1365	74.960
255	74.960	480	74.960	705	74.960	930	74.960	1155	74.960	1380	74.960
270	74.960	495	74.960	720	74.960	945	74.960	1170	74.960	1395	74.960
285	74.960	510	74.960	735	74.960	960	74.960	1185	74.960	1410	74.960
300	74.960	525	74.960	750	74.960	975	74.960	1200	74.960	1425	74.960
315	74.960	540	74.960	765	74.960	990	74.960	1215	74.960	1440	74.960

Simulation Criteria for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Volumetric Runoff Coeff	0.750	Additional Flow - % of Total Flow	0.000
Areal Reduction Factor	1.000	MADD Factor * 10m³/ha Storage	2.000
Hot Start (mins)	0	Inlet Coeffiecient	0.800
Hot Start Level (mm)	0	Flow per Person per Day (l/per/day)	0.000
Manhole Headloss Coeff (Global)	0.500	Run Time (mins)	60
Foul Sewage per hectare (l/s)	0.000	Output Interval (mins)	1

Number of Input Hydrographs	0	Number of Offline Controls	0	Number of Time/Area Diagrams	0
Number of Online Controls	1	Number of Storage Structures	1	Number of Real Time Controls	0

Synthetic Rainfall Details

Rainfall Model	FSR	Profile Type	Summer
Return Period (years)	100	Cv (Summer)	0.750
Region	Scotland and Ireland	Cv (Winter)	0.840
M5-60 (mm)	17.000	Storm Duration (mins)	15
Ratio R	0.300		

Online Controls for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Hydro-Brake® Manhole: EOUTLET, DS/PN: E1.006, Volume (m^3): 5.9

Design Head (m) 1.100 Hydro-Brake® Type Md6 SW Only Invert Level (m) 74.630
Design Flow (l/s) 9.9 Diameter (mm) 128

Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)	Depth (m)	Flow (l/s)
0.100	4.1	1.200	10.3	3.000	16.2	7.000	24.7
0.200	8.3	1.400	11.1	3.500	17.5	7.500	25.6
0.300	8.8	1.600	11.8	4.000	18.7	8.000	26.4
0.400	8.5	1.800	12.5	4.500	19.8	8.500	27.3
0.500	8.2	2.000	13.2	5.000	20.9	9.000	28.0
0.600	8.1	2.200	13.9	5.500	21.9	9.500	28.8
0.800	8.6	2.400	14.5	6.000	22.9		
1.000	9.4	2.600	15.1	6.500	23.8		

Storage Structures for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Tank or Pond Manhole: EOUTLET, DS/PN: E1.006

Invert Level (m) 74.660

Depth (m)	Area (m²)	Depth (m)	Area (m²)	Depth (m)	Area (m²)	Depth (m)	Area (m²)
0.000	1200.0	1.400	2100.0	2.800	2100.0	4.200	2100.0
0.200	1350.0	1.600	2100.0	3.000	2100.0	4.400	2100.0
0.400	1500.0	1.800	2100.0	3.200	2100.0	4.600	2100.0
0.600	1650.0	2.000	2100.0	3.400	2100.0	4.800	2100.0
0.800	1800.0	2.200	2100.0	3.600	2100.0	5.000	2100.0
1.000	1950.0	2.400	2100.0	3.800	2100.0		
1.200	2100.0	2.600	2100.0	4.000	2100.0		

Summary of Critical Results by Maximum Level (Rank 1) for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

Simulation Criteria

Areal Reduction Factor 1.000 Additional Flow - % of Total Flow 0.000
Hot Start (mins) 0 MADD Factor * 10m³/ha Storage 2.000
Hot Start Level (mm) 0 Inlet Coeffiecient 0.800
Manhole Headloss Coeff (Global) 0.500 Flow per Person per Day (l/per/day) 0.000
Foul Sewage per hectare (l/s) 0.000

Number of Input Hydrographs 0 Number of Offline Controls 0 Number of Time/Area Diagrams 0
Number of Online Controls 1 Number of Storage Structures 1 Number of Real Time Controls 0

Synthetic Rainfall Details

Rainfall Model FSR Ratio R 0.300
Region Scotland and Ireland Cv (Summer) 0.750
M5-60 (mm) 17.000 Cv (Winter) 0.840

Margin for Flood Risk Warning (mm) 300.0 DVD Status OFF
Analysis Timestep Fine Inertia Status OFF
DTS Status ON

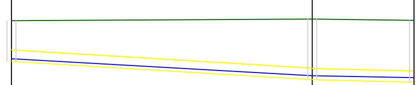
Profile(s) Summer and Winter
Duration(s) (mins) 15, 30, 60, 120, 180, 240, 360, 480, 600, 720, 960, 1440
Return Period(s) (years) 1, 30, 100
Climate Change (%) 10, 10, 10

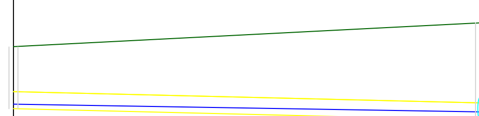
PN	US/MH Name	Storm	Return Period	Climate Change	First (X) Surcharge	First (Y) Flood	First (Z) Overflow	Overflow Act.
E1.000	EEX S1.6	15 Winter	100	+10%				
E1.001	EEX S1.5	15 Winter	100	+10%				
E1.002	EEX S1.4	15 Winter	100	+10%				
E2.000	EEX S1.3b	15 Winter	100	+10%				
E2.001	EEX S1.3a	15 Winter	100	+10%				
E1.003	EEX S1.3	15 Winter	100	+10%				
E1.004	EINLET	15 Winter	100	+10%				
E1.005	EPOND	15 Winter	100	+10%				
E1.006	EOUTLET	1440 Winter	100	+10%	30/720 Winter			

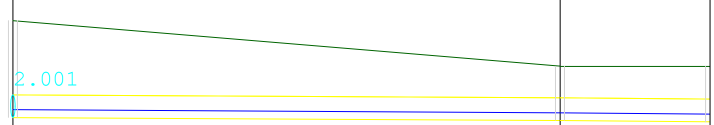
PN	US/MH Name	Water Level (m)	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
E1.000	EEX S1.6	75.750	-0.188	0.000	0.30		33.9	OK	

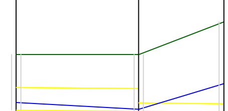
Summary of Critical Results by Maximum Level (Rank 1) for Y17702 EX SWS DAA (South Catchment)_REVA.SIM

PN	US/MH Name	Water Level (m)	Surcharged Depth (m)	Flooded Volume (m³)	Flow / Cap.	Overflow (l/s)	Pipe Flow (l/s)	Status	Level Exceeded
E1.001	EEX S1.5	75.368	-0.082	0.000	0.81		53.0	OK	
E1.002	EEX S1.4	75.322	-0.208	0.000	0.53		110.8	OK	
E2.000	EEX S1.3b	76.702	-0.398	0.000	0.03		16.6	OK	
E2.001	EEX S1.3a	75.859	-0.501	0.000	0.06		46.3	OK	
E1.003	EEX S1.3	75.218	-0.162	0.000	0.78		161.2	OK	
E1.004	EINLET	75.121	-0.179	0.000	0.67		137.6	OK	
E1.005	EPOND	75.081	-0.179	0.000	0.83		136.3	OK	
E1.006	EOUTLET	74.945	0.090	0.000	0.44		8.8	SURCHARGED	

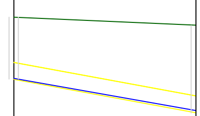
MH Name		EEX S1.6	EEX S1.5	EEX S1.4
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN		E1.000	E1.001	
Dia (mm)		300	300	
Slope (1:X)		81.6	192.4	
Cover Level (m)		76.700	76.750	76.710
Invert Level (m)		75.638 75.150	75.150 75.080	
Length (m)		39.820	13.470	

MH Name		EEX S1.4	EEX S1.3
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000			
PN		E1.002	
Dia (mm)		450	
Slope (1:X)		205.9	
Cover Level (m)		76.710	77.340
Invert Level (m)		75.080 74.780	
Length (m)		61.770	

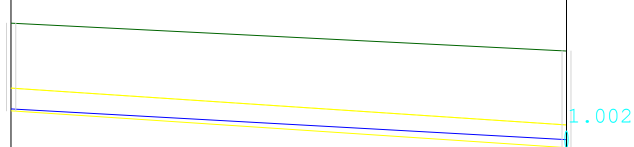
MH Name		EEX S1.3	EINLET	EPOND
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN		E1.003	E1.004	
Dia (mm)		600	600	
Slope (1:X)		906.6	497.2	
Cover Level (m)		77.340	76.130	76.130
Invert Level (m)		74.780 74.700	74.700 74.660	
Length (m)		72.530	19.890	

MH Name		EPOND		EP2
Hor Scale 1000 Ver Scale 200 Datum (m) 72.000				
PN		E1.005		
Dia (mm)		600		
Slope (1:X)		540.3		
Cover Level (m)		76.130	76.130	77.000
Invert Level (m)		74.660 74.630	74.630 74.600	
Length (m)		16.210		

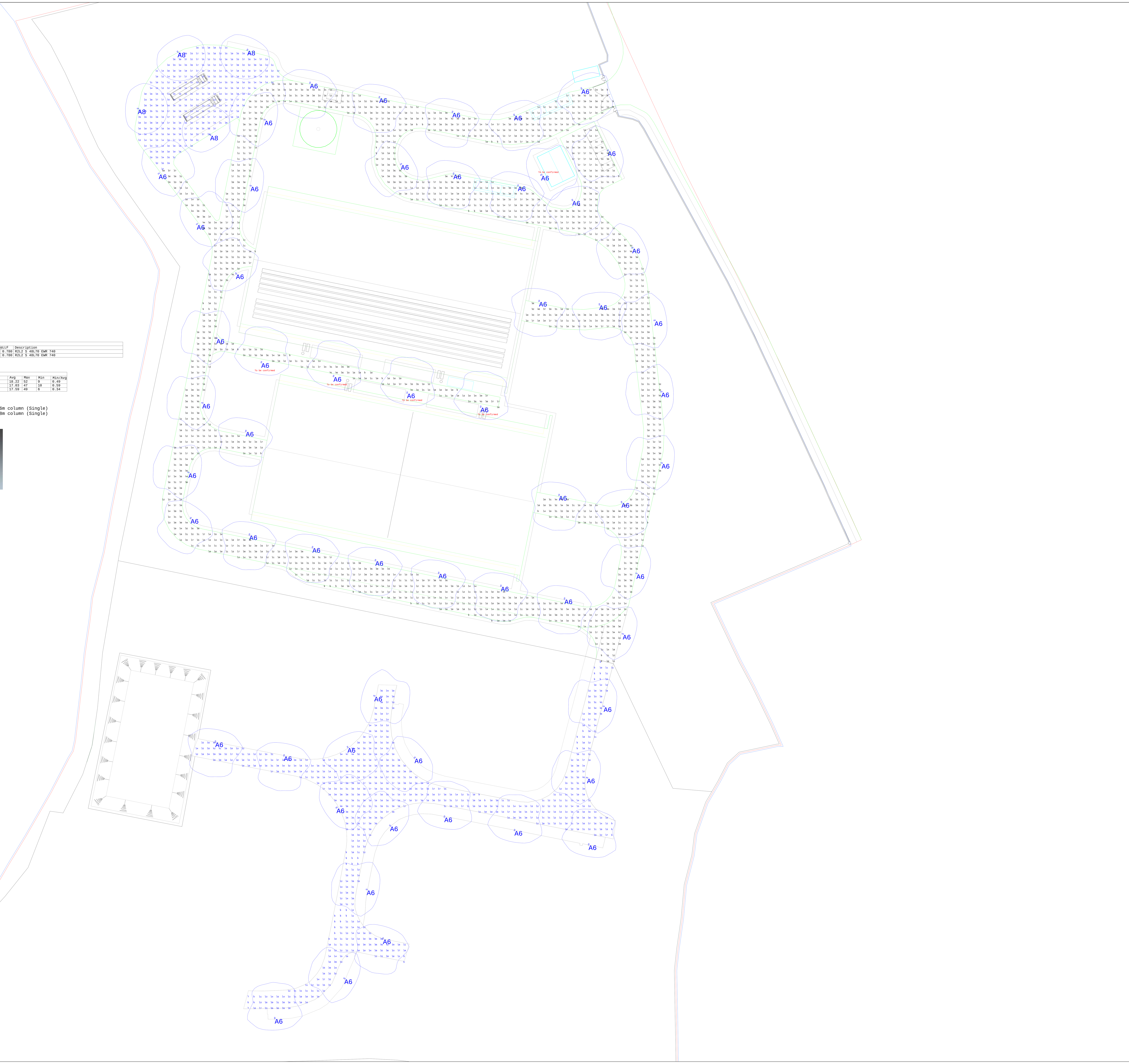
MH Name		EEX S1.3b	EEX S1.3a
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		E2.000	
Dia (mm)		450	
Slope (1:X)		27.1	
Cover Level (m)		78.300	78.080
Invert Level (m)		76.650	75.760
Length (m)		24.130	



MH Name		EEX S1.3a	EEX S1.3
Hor Scale 1000 Ver Scale 200 Datum (m) 73.000			
PN		E2.001	
Dia (mm)		600	
Slope (1:X)		75.0	
Cover Level (m)		78.080	77.340
Invert Level (m)		75.760	74.780
Length (m)		73.510	



Appendix 4: External Lighting Design



Luminaire Schedule						
Symbol	Qty	Label	Arrangement	Total Lamp Lumens	LLF	Description
	57	A6	SINGLE	11927	0.780	R2L2 S 48L70 EWR 740
	4	A8	SINGLE	11927	0.780	R2L2 S 48L70 EWR 740

Calculation Summary						
Label	CalcType	Units	Avg	Max	Min	Min/Avg
1 Roadway Upper	Illuminance	Lux	18.22	52	9	0.49
1A Lorry Park Upper	Illuminance	Lux	17.03	47	10	0.59
2 Roadway Lower	Illuminance	Lux	17.59	49	6	0.34

Ref A6 - Mounted on 6m column (Single)
Ref A8 - Mounted on 8m column (Single)

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This design drawing is for a lighting scheme which has been prepared for the client in collaboration with the client and other stakeholders, and is based upon the per-construction information provided. The lighting scheme should only be installed and maintained by competent persons and in accordance with the design drawings, applicable installation instructions and all applicable laws. No changes should be made to the design of the lighting scheme without formal written approval in advance from ZG Lighting (UK) Limited, to ensure that any risks to health, safety and welfare from any proposed changes can be identified and properly assessed.

No.	Date	Revision
R1	24.04.18	Revised site layout

Project Title: Bio Solids Dublin

Area: External Lighting

Client: JB Consulting

Scale: 1:500 @ A0	Project Number: 0001943051
Date: 24.04.18	Rev Number: R1
Drawn By: A Crutchley	Checked By:

Drawing Number: 0001943051-EX-R1-240418

Drawing Status: For Approval

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