Appendix 11.4. Microtunnel Technical Note

TECHNICAL NOTE

Kilkenny Road Pumping Station to Mortarstown Wastewater Treatment Works

SUBJECT	PROJECT NO.	DATE
Tunnelling reference design	100111164	22 May 2026

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Document history

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2.1	Tunnel realignment following public consultation	J Lovell	J Piazza	R Weber	-	2025-12-14
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Client signoff

Client	Uisce Éireann		
Project	Kilkenny Road Pumping Station to Mortarstown Wastewater Treatment Works	**Project No.**	100111164
Client signature / date			

TECHNICAL NOTE

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Executive summary

A sewer pipe requires installation to accommodate gravity flows from Kilkenny Road Pumping Station (KRPS) to Mortarstown Wastewater Treatment Plant (WWTP). Due to a confluence on site constraints along the proposed alignment, the pipe is proposed for installation using trenchless construction. An assessment of construction method suitability and horizontal alignment constraints has proposed micro-tunnelling as a suitable method for construction of a tunnel to accommodate a 1.65 m I.D product pipe. Construction is proposed in three pipe jack drives, facilitated by a trench excavation at KRPS, a 15 m I.D shaft at the WWTP, and four intermediate shaft sites. At each site, permanent manholes will be required for maintenance access. To confirm the tunnel and shaft construction method suitability and determine the extent of any necessary mitigations, detailed ground investigation alongside the proposed tunnel alignment has been proposed.

1. Introduction

Uisce Éireann proposes to upgrade the Kilkenny Road Pumping Station (KRPS) and Mortarstown Wastewater Treatment Plant (WWTP) to suit the population growth of Carlow. Under current arrangements the town is served by Mortarstown WWTP located 2.2 km south of Carlow town centre on the eastern bank of the River Barrow and has incoming flows from KRPS approximately 1 km to the north. As part of capacity upgrades being made, a new gravity fed sewer is planned between the existing KRPS and a new pumping station at the adjacent to the inlet works at Mortarstown WWTP. The existing pumping infrastructure in KRPS and the existing rising mains between KRPS and WWTP will be decommissioned (Figure 1).

Figure 1 - Location plan of KRPS and Mortarstown WWTP

AtkinsRéalis has been instructed to propose a reference design for construction of the new reinforced concrete gravity sewer pipeline.

2. Scope

AtkinsRéalis undertook an initial assessment to assess the feasibility of WWTP tunnel construction options against industry requirements and standards. The high-level feasibility study concluded that:

- Wet segmental caisson construction is the preferred method of shaft construction based on the site geology and dimension requirements.
- Micro tunnel boring machine (MTBM) construction is the preferred method of tunnel construction based on the site geology consisting of gravel and clayey sand at tunnel level (see Section 3).
- The location of the intermediate shafts and manholes forms a key alignment and space-proofing constraint, so their number and size should be minimised.

The AtkinsRéalis Tunnel Option Review [1] provided the following recommendations for the next stage of the design:

- The construction risks should be reviewed and updated.
- Information on the location of utilities should be reviewed to confirm the vertical alignment of the pipeline.

The following aspects are included within the scope of this reference design:

- Review of Uisce Éireann's design standards
- Geotechnical desk study
- Outline design of the gravity main horizontal alignment
- Tunnel construction outline methodology
- Temporary works outline design
- Arrangement and sizing of permanent access structures
- Connection to the existing KRPS
- Examination of construction feasibility and risk

2.1 Uisce Éireann Standards

2.1.1 Gravity sewers

Requirements for the design of gravity sewers are set out in the Uisce Éireann Technical Standard for Wastewater Gravity Sewer (IW-TEC-800-01) [2]. The specific requirements for tunnelled sewers are summarised as follows:

- Sewer shall be located outside the zone of influence of any building.
- Curved sewers shall not be permitted, except in exceptional circumstances. The pipe joints shall not be pulled more than half the deviation specified by the manufacturers. ***This project has been assumed to constitute exceptional circumstances and is therefore exempted.***
- The roughness coefficient Ks for new wastewater pipes shall be 1.5 mm.
- Sewers shall not be laid through gardens unless no reasonable alternative exists.

2.1.2 Tunnel shafts

Requirements for vertical shafts constructed for tunnel construction and operation according to IW-TEC-800-01 [2] are as follows:

- The positions of shafts shall be determined by practical consideration such as minimising traffic disruption, avoidance of existing public utility services, etc.
- The minimum diameter of shafts shall be 2440 mm; this is necessary for operation and maintenance of the sewer system [2].
- Where a shaft is used for pumping machinery, the minimum shaft diameter is determined by the size and arrangement of equipment that is to be accommodated. A stepped shaft may be considered within a wider diameter shaft housing mechanical pumping plant.
- The preferred maximum spacing between manhole on tunnels should be limited to 200 m, but this may be increased with agreement from Uisce Éireann and subject to carrying out a risk analysis.
- Shafts should have full height clear of lift access for removal of stretchers, safety equipment and general maintenance.

2.1.3 Manholes

Requirements for the design and specification of manhole access shafts are outlined in the Code of Practice for Wastewater Infrastructure (IW-CDS-5030-03) [3]. These can be summarised as follows:

- Cast in situ concrete manholes should be employed at the following locations:
  - At every change of alignment or gradient.
  - In areas with a perched water table.
  - Adjacent to bodies of water like rivers or lakes.
  - Within zones identified by the Office of Public Works Catchment Flood Risk Assessment and Management (CFRAM) with a flood risk occurring once every ten years.

- Manholes exceeding a depth of 6 m necessitate a detailed design submission for approval by Uisce Éireann prior to construction. These manholes should incorporate intermediate landing platform(s) as part of an engineered access solution.
- When located within a road, sewers should be at least 1 m from the kerb and the outside of manholes at least 0.5 m from the kerb line.
- For man-entry sewers, consideration shall be given to the size of the access openings required by confined space entry teams.
- Manholes shall be located to avoid dangerous traffic locations where possible.

Air-sealed covers have not been specified as a requirement along the proposed gravity main.

2.2 Design assumptions

The design presented herein has been established to comply with the design requirements presented below.

- The sewer will:
  - Connect from KRPS to the proposed new inlet PS at Mortarstown WWTP.
  - Operate according to a gravity fed design.
  - Have internal diameter 1.65 m.
- Intermediate access manholes will:
  - Have an internal diameter of at least 5 m to provide safe access.
  - Ideally be spaced not more than 200 m apart, with any specific exemption to be sought for any exceedance (under grant of Uisce Éireann).
  - Be located off the Kilkenny Road carriageway wherever practicable, to avoid lane closure as much as possible. Full road closure has not been permitted.
- The location and level of the connection into KRPS are fixed due to the existing structure on this site and the hydraulic design requirements.
- The pipe invert level of the connection into the new inlet PS is fixed at 39.50 m AOD according to the hydraulic design requirements.
- The size of the new inlet PS shaft is fixed at 15 m internal diameter according to the space-proofed requirements of the pump station [4].
- Utmost consideration will be given to the River Barrow Special Area of Conservation (SAC) and the alluvial woodland near the KRPS site. No works to be implemented in the alluvial woodland area and tunnelling beneath this area should be avoided.
- Consideration will only be given to exercise compulsory purchasing powers if all alternative options have been considered and ruled out.
- Based on a review of Uisce Éireann requirements for gravity mains, it has been assumed that:
  - Flow shall either drain to the pumping station or be controlled upstream of the gravity main.
  - No specific provision for air ventilation is required for reference design consideration.

The reference design outlined in this note accords to these requirements and others specified in Uisce Éireann requirements, which are considered to supersede any previous conflicting requirements.

3. Geology

A detailed ground investigation (GI) at the Mortarstown WWTP site was carried out by Priority Geotechnical Limited as part of the wastewater network upgrade project. A second phase was completed in 2022 with intrusive investigations at Mortarstown WWTP and KRPS. Surveying along Kilkenny Road (R448) and Green Road / Carraig Abhainn, but no intrusive GI was undertaken along these roads.

The following activities were undertaken across both phases:

- Eight trial pits
- 11 cable percussion boreholes
- 10 rotary core holes
- 16 slit trenches
- GPR of treatment plants, Kilkenny Road and Green Road / Carraig Abhainn

A Geotechnical Interpretative Report (document no: 5161805DG0361 rev 0 - CIP5 Mortarstown Prelim GIR & GDR_Rev A) was provided following the Phase 2 GI [5].

For the proposed pipeline route from KRPS to Mortarstown WWTP, topsoil down to 0.50 m bgl was noted at the roadside verge. This overlies made ground described as loose silty sand down to 1.52 m bgl at its greatest extent. Slightly silty/clayey gravelly sand was encountered beneath the made ground and recorded to 2.40 m bgl, before loose slightly silty very gravelly sand was encountered. This sand layer is described as fine to coarse. Groundwater was encountered as a trickle at 2.60 m bgl within the loose sand.

The slit trenches did not reach the proposed invert level or founding level of the pipeline and therefore the in-situ ground conditions could not be confirmed at formation level of the pipeline. Tunnel axis level is expected to range from approx. 43 m AOD (3 m bgl) at the KRPS end to approx. 42 m AOD (8 m bgl) at the WWTP end. The interpreted ground conditions at these locations is described in Table 1 and Table 2, but additional GI should be required to confirm the ground conditions at tunnel depth alongside Kilkenny Road.

Table 1 - Geological information from rotary core RC11 drilled at the KRPS [5]

Top of strata level (m AOD)	Top of strata depth (m bgl)	Material	Compaction
46.4	0.0	Gravel (made ground)	*Anticipated geology at tunnel crown level*
43.3	3.1	Sandy gravel	Dense. *Anticipated geology at tunnel invert level.*
35.9	10.5	Gravel with boulders	Dense
33.9	12.5	Limestone	Solid

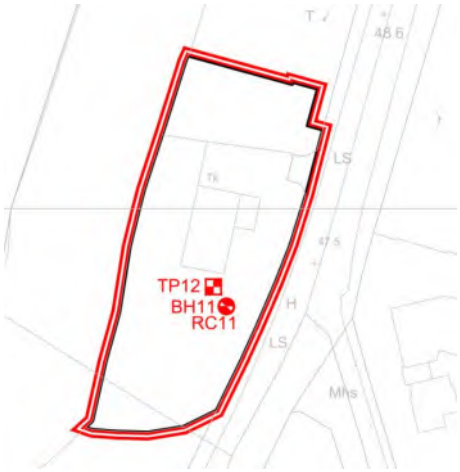

Figure 2 - Kilkenny Road Pumping Station GI locations

Table 2 – Geological information from rotary core RC06 drilled at Mortarstown WWTP [5]

Top of strata level (m AOD)	Top of strata depth (m bgl)	Material	Compaction
49.56	0.0	Sand	
48.06	1.5	Sand and boulders	
46.56	3.0	Boulders	Medium dense
45.06	4.5	Gravel and boulders	Dense
43.56	6.0	Clayey sand	Medium dense to loose. *Anticipated geology at tunnel level.*
40.56	9.0	Silty gravel	Loose to dense
33.06	16.5	Gravel with boulders to boulders	Dense

Figure 3 - Mortarstown WWTP GI locations

Based on the rotary core records included within the GIR [5], there is a medium to low likelihood of the tunnel alignment encountering limestone boulders up to 400 mm in diameter. However, the likelihood of encountering boulders may be higher elsewhere along the proposed alignment, so further ground investigation is required to confirm the overall risk level to be expected. Chiselling records from the cable percussion boreholes [5] indicate likely obstructions (e.g., cobbles) below 3 m bgl at the WWTP site. At the KRPS site, these obstructions are likely below 6 m bgl, presenting a potential risk to any deep piling works at this location.

The high groundwater level and proximity to the River Barrow means that water ingress into excavations presents another significant risk, although options to mitigate this are outlined in Section 5.

The existing investigations show that there are consistent strata along the tunnel alignment. However, additional GI is recommended before confirmation of the tunnel vertical alignment, clarify the risks, and mitigation of mixed-face ground including boulders. In accordance with the UK draft NA to EN 1997-2:2024, it is recommended as a minimum that at least one ground investigation is conducted per shaft location. This will reduce the uncertainty from interpolation of the ground conditions and provide information to enable shaft design and construction planning. This would also be minimally compliant with the current BS EN 1997-2:1997 which recommends ground investigation spacing of 20 to 200 m for pipeline and tunnels.

4. Alignment

4.1 Horizontal alignment

The factors constraining the horizontal alignment of the tunnel are described below and summarised in Figure 4.

- **Kilkenny Road (R448)** – the permissible site extent envelope (Figure 5) has been set to constrain the allowable extent of pipeline construction works to closely follow the alignment of this busy single-carriageway road for along most of its length, minimising the need to gain right-of-way on private property. In lieu of a temporary full road closure derogation provisioned by Carlow County Council Roads Department, the location and sizing of construction compounds has been designed to require only temporary partial (single lane) closure of the road during construction of the shafts and tunnel. These shaft sites have been positioned to ensure that access to the three properties along this stretch of Kilkenny Road can be maintained. Manhole access points are not permitted within the main carriageway but may be located within the adjacent cycle lane or footpath.
- **Permanent manhole access points** should be located away from the road when practicable to avoid future road closures when accessing and to reduce the extent of cyclic traffic loading on the manhole cover.
- **River Barrow Special Area of Conservation (SAC)** – the woodland between the river and the main road has a designated protected status. The permissible site extent envelope (Figure 5) has been set to delimit the greatest allowable extent of construction activity to ensure that the tunnel alignment avoids passing beneath the woodland, as stipulated in the project scope. Further, no construction compounds shall encroach upon this area.
- **Southern Gardens / Rath Abhainn** – the houses along this cul-de-sac may be at greatest risk of settlement if the proper controls and monitoring are not in place. For this reason, the horizontal tunnel alignment has been set to ensure that the horizontal distance between the tunnel and the houses is at least twice the tunnel depth below ground level.
- **Private property boundaries** – construction beneath the private greenfield sites between the WWTP and Rath Abhainn has been avoided, to minimise compulsory purchase requirements. This includes the private plot identified in Figure 4 for which an objection to any construction or tunnelling works was registered during the public consultation on 9 October 2025. The objection extends to a strip of land alongside Kilkenny Road which is owned by Carlow County Council but currently occupied by a private landowner.
- **Existing KRPS** – the connection point to the existing pump station is fixed.
- **Carlow southern relief road** – construction of an extension to the ring road is planned to commence after completion of the sewer pipeline. Therefore, tunnel construction sites need to avoid the area designated for road construction.
- The horizontal alignment as proposed will require the diversion of some **existing underground utilities.** These include Uisce Éireann clean water and wastewater pipes, cable, broadband, and Gas Network Ireland utilities that run alongside Kilkenny Road. The existing utilities as identified by GPR surveys are shown on the plans in drawings 5161805_EWE_DR_MOR_5520 to 5524.
- There are **trees and hedgerows** along the east side of Kilkenny Road. **Overhead wires** also pass close to KRPS. These may present an obstruction to crane operation, or roots may obstruct the construction of the intermediate shafts.

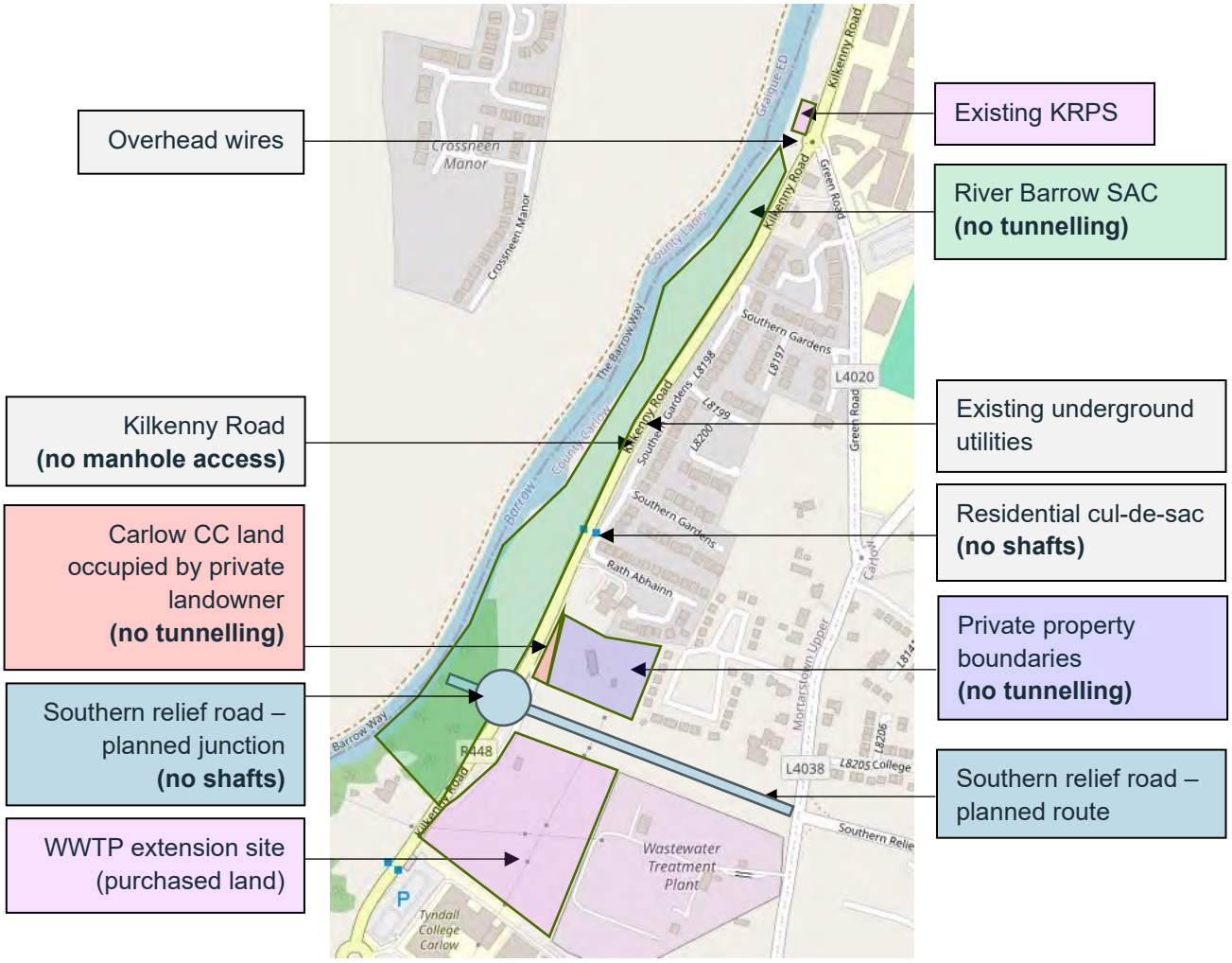

Figure 4 - Constraints for the horizontal alignment. Sketch not to scale

Based on the identified constraints, a red line envelope has been set to define the allowable extent of tunnelling. This is shown in drawings no. 5161805_EWE_DR_MOR_5120 to 5122 along with the subsequent horizontal alignment of the gravity main. Additional constraints remain within this envelope, including property boundaries and the planned relief road boundary. These mean that the use of a single straight drive between KRPS and the new inlet PS is not feasible.

Construction with linear drives avoids the issue of additional forces within the pipeline prevalent in arc trajectories. There is also no requirement for an onboard machine operator, bringing a safety benefit. Re-alignment of the MTBM will be required at each intermediate manhole. However, use of a curved trajectory could enable tunnelling to progress from Shaft C to Shaft E without requiring an additional jacking installation at Shaft D, via the arrangement of tunnelling drives shown in Figure 5. The minimum jacking radius for a tunnel at this diameter has been conservatively considered to be 1000 m, with the actual required radius comfortably above this at 5600 m. This could facilitate construction of the full tunnel length with three pipe jack drives.

Due to greater space constraints at Shaft E, it is proposed that this shaft should be used for MTBM reception after each adjacent drive. Shaft C and Shaft F are proposed as the MTBM launch and jacking sites. The use of these shafts for both upstream and downstream bores can be achieved via rotation of the jacking rig within the shaft, thus minimising the extent of temporary works otherwise required to lift out and move the rig between shafts. The proposed configuration is shown in Figure 5 and summarised in Table 3.

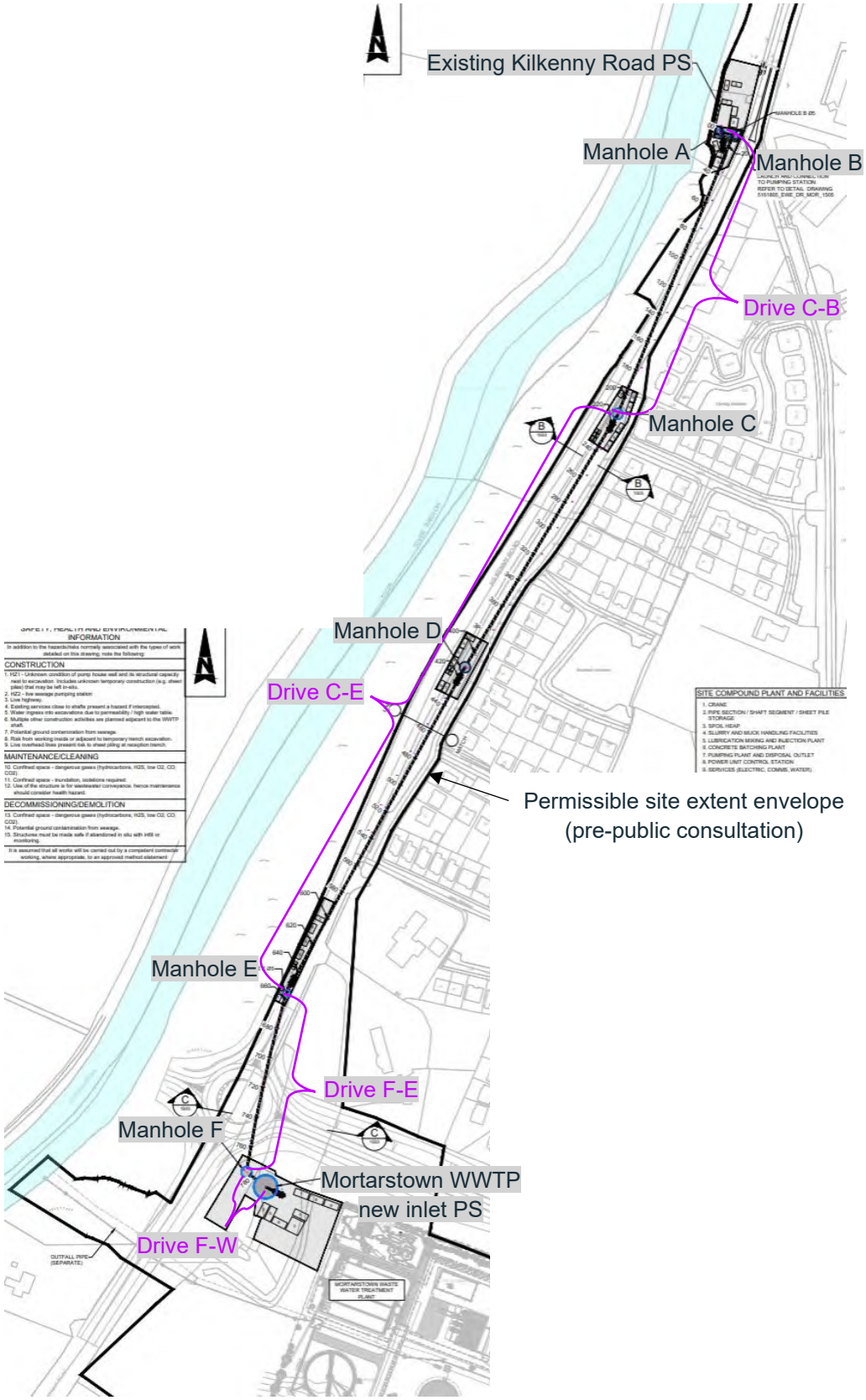

Figure 5 – Proposed tunnel and shaft alignment in plan, based on 5161805_EWE_DR_MOR_5120 to 5122

Table 3 – Proposed pipe jack tunnel construction drives

Drive ref.	Launch site	Reception site	Drive length (m)	Jacking radius (m)
F-W	Shaft at manhole F	New inlet PS	5	n/a (linear)
F-E	Shaft at manhole F	Shaft at manhole E	115	n/a (linear)
C-E	Shaft at manhole C	Shaft at manhole E	432	5600
C-B	Shaft at manhole C	KRPS trench	200	n/a (linear)

4.2 Vertical alignment

Proposed tunnel dimensions are summarised in Table 4. These indicative dimensions have been used to develop the reference design drawings, but the final dimension requirements should be determined by the Contractor following detailed design. Unless a separate internal protective lining is provided, the thickness of the concrete lining should be increased to account for additional cover to resist H_2S induced biochemical attack and abrasion over the design life of the sewer. The protective and/or sacrificial layer is shown indicatively pending calculation at the detailed design stage.

The hydraulic performance of the sewer has been determined separately by AtkinsRéalis Ireland and set out in the hydraulic design. Each drive has been aligned to maintain a constant vertical gradient of 1:800, to provide a safety margin above the self-cleansing flow requirement (min 1:1000).

Table 4 – Indicative sewer tunnel dimensions.

Jacking pipe internal diameter*	1.80 m
Jacking pipe structural thickness	175 mm
Additional lining thickness (for corrosion/abrasion resistance)	75 mm
Excavated diameter	2.15 m
Total sewer length from KRPS connection box to Mortarstown WWTP inlet shaft	785 m
Minimum gradient*	1:1000

Note: *Confirmed fixed values

5. Outline construction methodology

5.1 Sewer tunnel

The sewer product pipes have a hydraulic design requirement of 1.65 m internal diameter, which has been assumed to require 1.8 m I.D. pipes to account for the corrosion resistant interior lining as specified in the hydraulic design requirements. At this diameter, accounting for the fixed gradient requirements, AtkinsRéalis proposes the use of micro-tunnel construction by pipe jacking as the best suited approach for boring the pipeline.

Pipe jacking uses hydraulic jacks to drive purpose designed pipe sections through the ground concurrent with excavation at the face. Depending on the type of boring machine used, construction through a range of soil types can be possible, including cohesive soils, non-cohesive soils and mixed-faced conditions. The associated limitations on drive length and manoeuvrability have been accounted for in the design of the overall tunnel alignment.

Figure 6 - Example of a compact MTBM jacking operation from a shaft

The total drive length from KRPS to the new inlet PS will be 785 m. Guidance from the Pipe Jacking Association (PJA) [6] (reproduced in Table 5) indicates that pipe jack construction of a tunnel longer than 750 m carries at least a ‘medium’ risk, and that a maximum jacking drive of 500 m is preferable for the risk to remain ‘low’. This reference design therefore proposes to sub-divide the construction into three drives to reduce the maximum individual drive length to below 500 m. In line with the requirement for regularly spaced maintenance access shafts along the tunnel alignment, these shafts have been sized to serve the temporary purpose of jacking rig installation and TBM launch/reception.

Table 5 - PJA guidance on maximum drive lengths between shafts depending on tunnel diameter [6].

Excavation technique	Indicative risk	1.5 m tunnel I.D.	1.8 m tunnel I.D.
Pipe jack with remote operation machine	Low	<500 m	<750 m
	Medium	To 750 m	>750 m
Pipe jack with onboard machine operator	Low	300 m	750 m
Pipe jack with onboard machine operator & mechanical erector	Medium	250 m	500 m

Other tunnel construction methods have been ruled out due to unsuitability:

- Open cut trench excavation along the entire route is not suitable as this would require closure of Kilkenny Road for the full duration of the construction works.
- Segmental lining construction with a MTBM is not feasible at this small (1.65 m) diameter of tunnel. This option could typically only be considered if the tunnel diameter where to be increased to at least 2.4 m I.D.

5.1.1 Construction drives

Based on the above, for a 'low' risk pipe jack operation, two potential options for the micro-tunnelling configuration of a continuous drive from Shaft C to Shaft E have been considered:

1. **Single jacking station**. To construct the curved tunnel drive by jacking from a single launch site will require the inclusion of several inter jacks with an automatic lubrication system would need to be considered. It is recommended to install the intermediate access Shaft D before tunnelling to facilitate machine retooling, although this is not a requirement for this method of construction.
2. **Multiple jacking stations**. Requires construction of the intermediate Shaft D before tunnelling commences. An intermediate jacking station can be installed at the intermediate shaft to provide additional thrust for overcoming friction. This is recommended for the non-linear horizontal alignment and the maximum drive length near the upper limit of a typical 'low risk' drive. The space available at the Shaft D site is sufficient to facilitate this option, if selected.

The likelihood of encountering large boulders (greater than approx. 400 mm diameter) along the alignment should be determined, as these have the potential to jeopardise the viability of tunnel construction. Boulders of all sizes can also present a risk of significant cutter wear and blockage. The presence of intermediate shafts, which are required for maintenance access regardless of the construction configuration, presents the possibility of retooling machinery in response to cutter wear.

An alternative alignment with an increase in the maximum shaft spacing to 250 m was considered in the route optioneering and could be feasible. This option could avoid full closure of Kilkenny Road by relocating Shaft E onto a verge. However, the design of this alignment would be subject to further design, construction development, contractor involvement, and approval of derogations from Uisce Éireann of previously agreed spacing requirements.

With approval from Uisce Éireann to increase the permissible manhole access spacing beyond 200 m, this has facilitated the arrangement shown in Figure 5 whereby Shaft E is offset from the main carriageway of Kilkenny

Road. This avoids full closure of the road during construction, while also ensuring that future road closure will not be required in order to access the manhole for routine inspection and maintenance.

5.1.2 Micro-TBM selection

The chosen type of MTBM must be suitable for the ground conditions at tunnel level along the tunnel alignment.

AtkinsRéalis proposes use of a slurry MTBM for excavation and construction of the tunnel, based on a combination of tunnelling technology, dimension requirements (Section 2.2), spatial constraints (Section 4) and geology (including gravel, sand and clay as described in Section 3).

The geotechnical interpretative report issued by Priority Geotechnical Limited [5] identified ground conditions along the pipeline route ranging from loose silt to loose gravelly sand, beneath sandy gravelly clay. These conditions indicate that a slurry shield MTBM equipped with internal crushers could be a suitable tunnelling method for this range of ground conditions and the high groundwater table [7].

To operate a slurry MTBM, the main WWTP compound site should include space for installation of a slurry treatment plant. However, further information about the ground conditions combined with the application of appropriate soil conditioning agents could allow construction using an earth pressure balance MTBM to be considered. This would provide an opportunity to avoid the need for a slurry treatment plant.

Construction via MTBM requires excavation of an annular overbreak, which should be filled with grout to prevent settlement once pipe installation for each individual tunnel is complete. The allowable tolerance for joint levels between pipe sections must meet the hydraulic design requirements during detailed design specification of the pipe connections.

5.2 Access structures

For inspection and maintenance access, the design includes four intermediate manholes in addition to the launch and reception connection shafts. The maximum distance between manholes has been set at 200 m wherever practicable, to comply with the Uisce Éireann maintenance requirements. However, there is a deviation from this requirement applied between Manholes D and E due to the confluence of constraints governing the location of Manhole E. A maximum spacing of 240 m has resulted.

The layout of shafts is shown in drawings no. 5161805_EWE_DR_MOR_5120 to 5122. The indicative dimensions for launch, reception and intermediate shafts are outlined Table 6. Note that:

- It is recommended that the MTBM auxiliary power, control and utilities remain stationed at the launch sites for the duration of the tunnel construction to minimise land take and grid connection requirements at the intermediary manhole sites.
- The internal dimensions proposed for MTBM launch sites have been sized according to the space required for a typical jacking rig sized to accommodate 1.65 m I.D. pipes [8].
- Shaft excavation base levels have been indicatively set at 1 m below the sewer tunnel invert level to accommodate the assumed jacking space requirement. Sloped benching will be required to make up the required invert level. Final elevations of the shafts base will be decided by the detailed design for construction.

- The diameter of the new inlet PS shaft was determined by AtkinsRéalis Ireland within the separate Mortarstown WWTP SID Engineering Report (2026), according to the size and arrangement of the pumping equipment to be accommodated.
- The formation levels of shaft rings have been shown indicatively. Final toe levels remain subject to detailed design of the base slabs for resistance against uplift and support of the jacking rig.
- Structural support of the shaft lining is required at the tunnel breakthrough point. This involves sections of thickened concrete framing the tunnel eyes. The effect is a reduction in the shaft section area at breakthrough level.

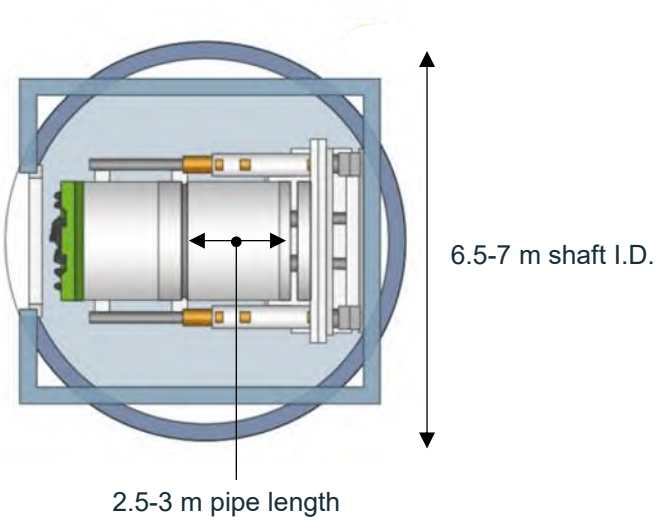

Figure 7 - Arrangement of a Herrenknecht compact jacking station

Table 6 – Proposed shaft/excavation dimensions

	KRPS trench	Shaft C	Shaft D	Shaft E	Shaft F	Mortarstown WWTP
Tunnel construction purpose	MTBM reception	MTBM launch	N/A	MTBM reception	MTBM launch	N/A
Permanent use	Manholes A & B	Manhole C	Manhole D	Manhole E	Manhole F	New inlet pumping station
Proposed construction method	Sheet piles	Segmental wet caisson	Segmental wet caisson	Segmental wet caisson	Segmental wet caisson	Collar ring pile wet caisson
Internal plan dimensions (m)	14 x 7	Ø 7	Ø 7	Ø 5	Ø 7	Ø 15
Indicative structural support thickness (mm)	600	225	225	200	225	500
Total shaft depth (m)	8.90	8.012	11.855	11.214	9.465	11.483
Ground level (m AOD)	46.98	47.684	51.117	49.978	47.983	49.983
Sewer invert level (m AOD)	41.10	40.672	40.262	39.764	39.518	39.50
Base level (m AOD)	38.08	39.672	39.262	38.764	38.518	35.53
Indicative compound site dimensions at shaft location (m)	150 x 30	50 x 15	50 x 15	80 x 9	120 x 50	

There are two options for the method of intermediate shaft construction:

1. **Wet caisson segmental lined** shaft construction is proposed as the preferred option. This method involves sinking a pre-cast caisson whilst the shaft is excavated. A head of water is maintained within the excavation, to prevent groundwater inflow by applying a small excess pressure onto the shaft base. When the shaft has reached through full depth a tremie concrete plug is cast into the bottom of the excavated shaft to temporarily seal the base and enable dewatering. A permanent cast in-situ base slab is then cast to provide the permanent seal. The approach has been assumed suitable based on the following:
   a. Pre-cast concrete segmental construction can be suitable for shafts greater than 2.4 m in diameter [7].
   b. The KRPS and WWTP sites have highly permeable geology (sandy gravel) combined with an elevated water table [5]. It has been assumed by interpolation that the geology along the tunnel alignment is similar in composition. With wet caisson construction, groundwater inflow can be excluded up to a depth of 50 m [7].
2. Alternatively, use of **sheet piling** may be considered for construction of the intermediate shafts, based on a **cast in-situ** structure with maximum shaft depth not exceeding 10 m bgl. This method carries certain heightened risks which make it potentially less suitable:
   a. With the current understanding of the ground conditions, this method will likely require ground treatment beneath the excavation level to enable a dry temporary excavation for construction of the permanent structure.
   b. The potential existence of boulder sized underground obstacles will make the sheet piling less feasible, so any boulders encountered should be excavated out to facilitate full depth pile installation.

The final construction method determined during detailed design should minimise ground movement to safeguard surface assets within the vicinity of each shaft.

5.2.1 New inlet PS / Shaft F

Detailed structural and spatial design of the new Mortarstown WWTP wet well / pump well shaft is not included in the scope of this reference design. Based on the preliminary designs for a 15 m diameter shaft, it is expected that the shaft and compound area will be sufficiently sized to allow for MTBM reception at this location prior to the installation of permanent structures within this shaft.

A proposed arrangement for the sewer connection into the new inlet PS is shown in Figure 8. The Mortarstown WWTP Specimen Design defines the pipe inlet invert level at a height of 4 m above the permanent base fill of the shaft.

For the alternative construction sequence whereby the new inlet PS shaft is used for MTBM launch, a temporary base level of approx. 39 m AOD would be required to install the jacking rig. The exact extent of additional excavation required below the sewer invert to install a jacking rig depends on the dimensions and operating requirements of the selected machine. A typical MTBM for this application weighs a maximum of 13 T, so this will either need to be supported on a steel temporary support structure or the shaft back filled to provide a temporary base at this level. By contrast, MTBM reception could be achievable without installation of a fixed support structure. Hence, the latter option had been assumed to offer a constructability benefit as well as reduced works sequencing constraint to the new inlet PS construction.

A wet caisson construction method is assumed for the new inlet PS structure; hence, it is not possible to excavate the shaft partially to reach the MTBM level and complete the tunnel drive before the completion of the shaft to its permanent depth with waterproof system fully installed. However, if an alternative shaft construction

method is chosen this may become an option. The exact construction sequence should be specified during detailed design.

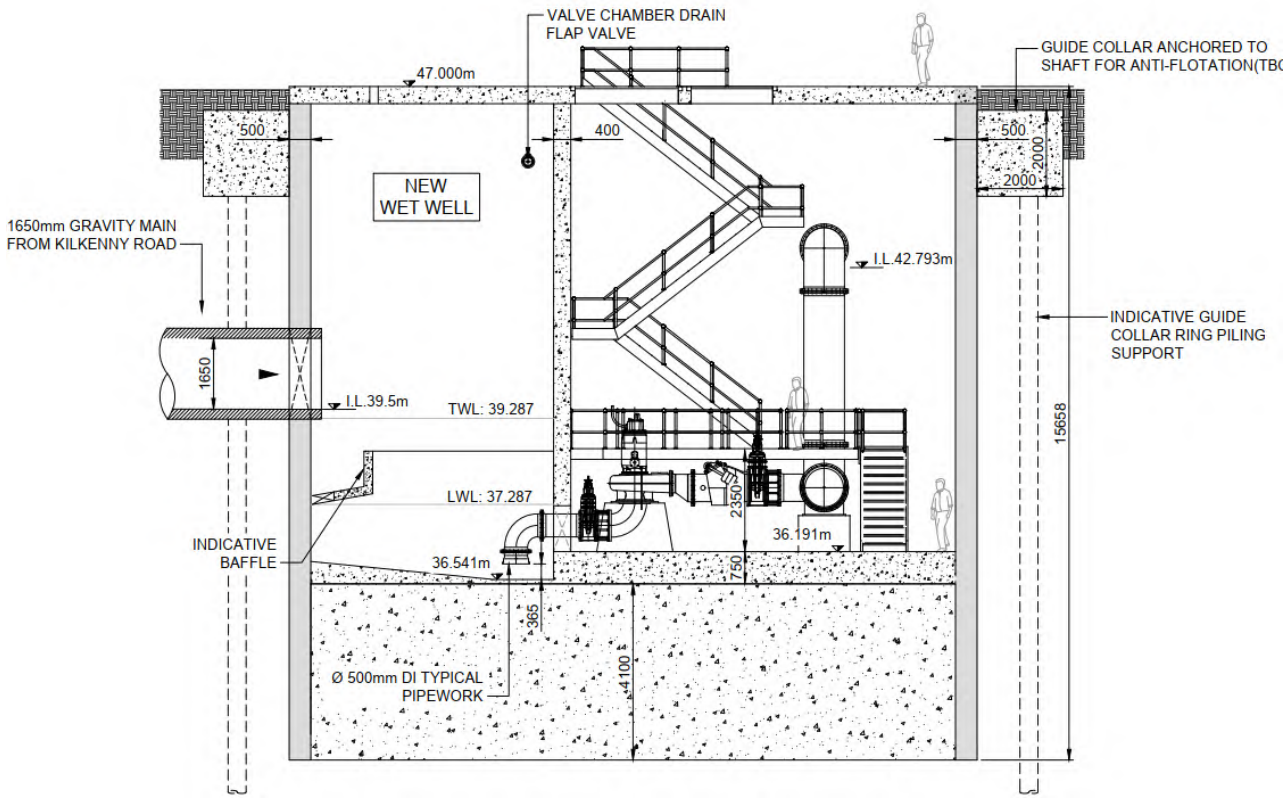

Figure 8 - New inlet works shaft at Mortarstown WWTP [4]

The use of Shaft F is required due to the constraints on the horizontal alignment resulting from the proposed bypass road junction and existing property boundaries to the east. Together, these inhibit a continuous linear tunnel alignment from Shaft E to the WWTP. Due to its proximity to the WWTP, Shaft F can be contained within the same compound site on land already owned by Uisce Éireann. Use of a full cut-and cover trenched connection into the new inlet PS has been considered unfavourable on account of the approx. 8 m depth of the tunnel at this location.

An indicative construction methodology relating only to construction of Shaft F and tunnel earth-retaining elements for the WWTP site is provided as below:

1. Construction of a jacking collar for hydraulic shaft sinking (or other preparatory work relevant to the chosen shaft construction).
2. Shaft excavation and segmental lining.
3. Installation of tremie concrete base seal.
4. Installation of jacking rig, thrust wall, MTBM and ancillary plant at Shaft F.
5. Lowering of pipe sections into the jacking rig during tunnel construction.

Indicative spatial requirements for the MTBM launch shaft site are outlined in Table 7 and shown in plan in Figure 9. These assumptions, based on the examples from other similar projects, have been used to determine the overall space requirements for the compound. Note that this is specific to the construction of the earth-

retaining structures. It does not include any requirements for the construction of internal structures and space provision for mechanical/electrical/plumbing systems has been assumed.

There are existing buried utilities along this section of the pipeline route which will require either temporary or permanent diversion to facilitate construction.

Table 7 - Services contained within the new inlet PS and Shaft F launch site compound

Name	Approx. area (m^2)
Shafts and jacking collars	150
Crane movement area (1)	800
Pipe section and shaft segment storage (2)	500
Slurry and muck handling facilities (4)	500
Pumping plant and disposal outlet (7)	100
Power unit control station (8)	100
Lubrication mixing and injection plant (6)	200
General stores and workshop (5)	200
Services: electric, comms, water (9)	200
Spoil storage (3)	1000
Total site area incl. access routes and exclusion zones	5000

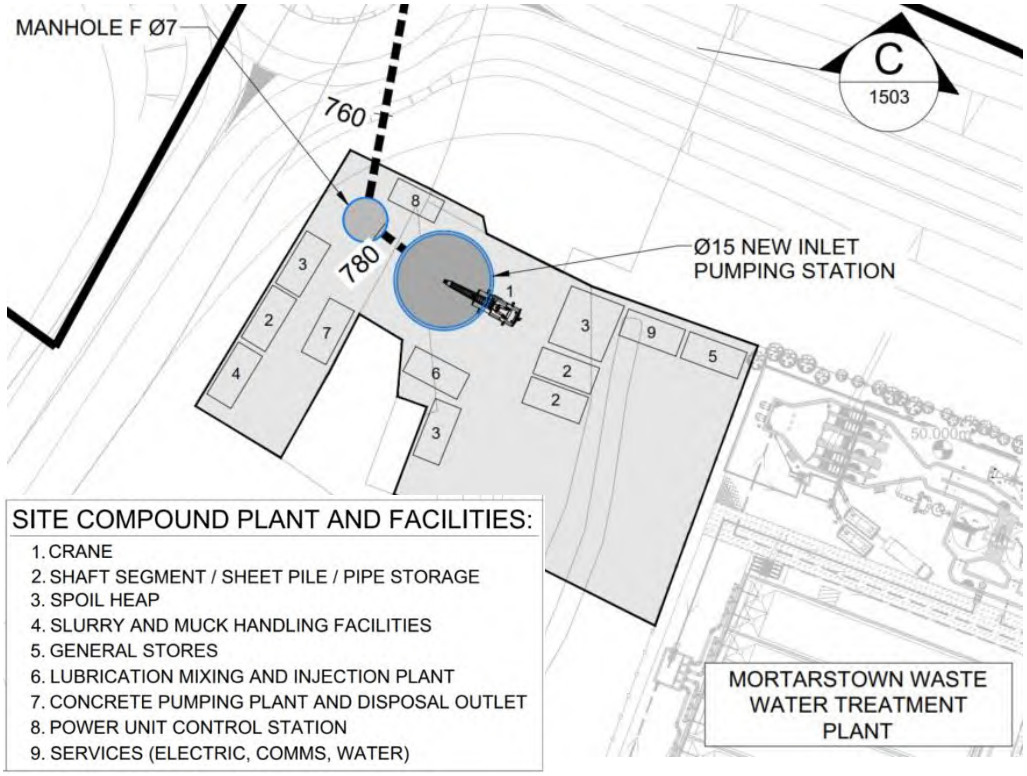

Figure 9 - Indicative plan arrangement at the new inlet PS / Shaft F site

5.2.2 Kilkenny Road Pumping Station

The following indicative activities are proposed at the existing KRPS site:

1. Driving of interlocking sheet piles on three sides. The fourth side will include support from the existing KRPS basement wall.*
2. Ground treatment below excavation depth to provide water cutoff
3. Pit excavation and soft eye installation.
4. Reception of the MTBM
5. Coring into existing wet well to form connection
6. Install pipe lengths and cast in-situ manhole shafts (x2).
7. Backfill trench and reinstate surface (leaving manhole cover access).

** Note: At this time, the nature of construction of the existing basement wall is unknown and will need to be determined to detail the connection between the temporary sheet piles as well as the breakthrough detail of the new pipe into the existing structure.*

Installation of soft-eye connection points is required to feed the pipeline into the existing wet well. A steel connecting pipe is proposed for this purpose.

Constraints on the horizontal alignment (in particular, the SAC) inhibit a continuous linear tunnel alignment from Shaft C to the KRPS connection point. Permanent manhole access needs to be maintained wherever a pipe bend is installed, meaning that two manholes are required for the proposed dog-leg alignment.

TECHNICAL NOTE

A temporary trench excavation is proposed for reception of the ‘C-B’ MTBM drive and construction of the pipe connection into the existing KRPS wet well. The cut-and-cover method is proposed for the existing PS connection for the following reasons:

- Construction of this section of tunnel by manual tunnel digging beneath timber headings carries a greater safety risk than cut-and-cover construction.
- No existing utilities have been identified along this section of the pipeline route. This should be confirmed by the Contractor via a utility search.
- Sufficient space is required for extraction of the MTBM at this location. Use of an open trench allows for permanent manholes of only 5 m diameter to be installed, for inspection and maintenance access only.

The pipe invert is located approx. 6 m bgl at this location, meaning that a minimum excavation depth of 7 m has been assumed required. As shown in Figure 10, a short section of pipework requires installation within the trench to make the connection from the KRPS wet well chamber to the tunnelled gravity main. Construction of the manhole shafts is proposed as cast in-situ, as per Uisce Éireann requirements, and capped with precast slabs. Further detailing of the permanent access structures will be specified following agreement of the overall construction methodology. The outline arrangement currently proposed is shown in Figure 10, taken from 5161805_EWE_DR_MOR_5127.

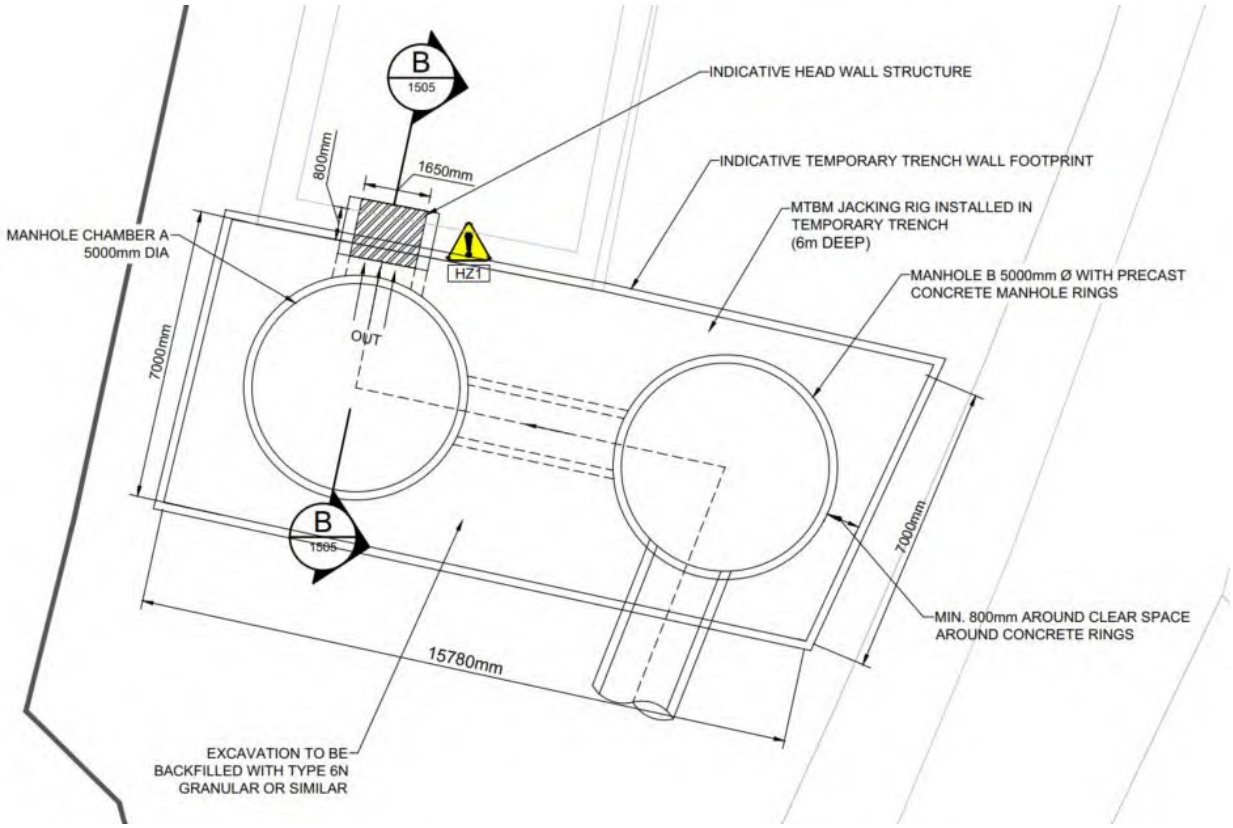

Figure 10 - KRPS proposed temporary trench arrangement plan

The low geological cohesion and a high groundwater table at this site are likely to require extensive prior ground treatment to mitigate the inherent construction risk.

TECHNICAL NOTE

Typical space requirement for plant and services located at the KRPS trench site are indicated in Table 8. The proposed works site as shown in Figure 11 has been arranged to avoid the environmentally sensitive area to the south and west.

Table 8 - Services contained within the KRPS launch site compound

Name	Approx. area (m^2)
Excavated area and sheet piles	100
Crane movement area (1)	250
Pile storage (2)	200
Spoil heap (3)	500
General stores and workshop (5)	200
Lubrication mixing and injection plant (6)	100
Concrete pumping plant and disposal outlet	200
Services: electric, comms, water (9)	200
Total site area incl. access routes and exclusion zones	2500

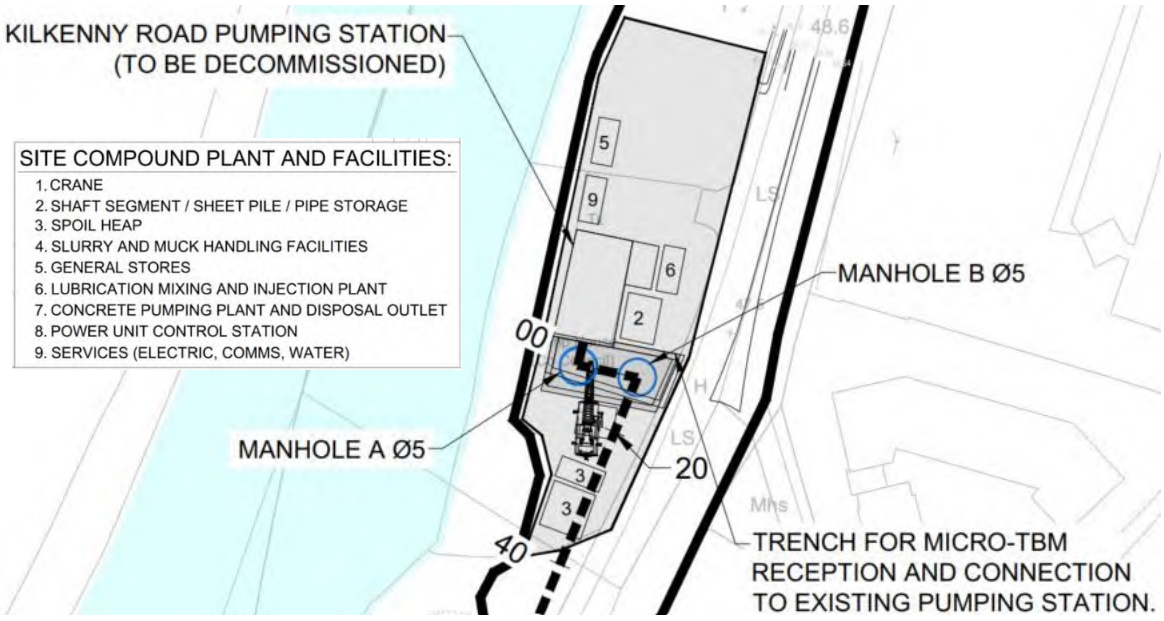

Figure 11 - Indicative plan arrangement at the KRPS trench excavation site.

To support the southwest wall of KRPS whilst the trench is open, temporary shoring is proposed in the form of waling beams. An example of this type of system is shown in Figure 12.

Figure 12 – Sheet pile trench box with waling beams example

There is a potential for differential settlement between the new gravity sewer and the existing KRPS. Mitigation could be provided by installing a rocker pipe at the soft eye connection with relative pipe movements accounted for in the detailed design of waterproof joints.

5.2.3 Launch Shaft C

Shaft C, like Shaft F, is located at a proposed change in horizontal trajectory along the alignment. It is proposed to use both of these structures for launch of the MTBM to complete the tunnel drives in alternate directions.

To drive the tunnel between Shafts C and E, the former is proposed for installation of a jacking rig to launch the MTBM. This is the most suitable configuration due to the greater availability of space for an enlarged construction compound (for jacking pipe storage) around Shaft C.

The following activities have been assumed for wet caisson construction:

1. Construction of a jacking collar for hydraulic shaft sinking (or other preparatory work relevant to the chosen shaft construction).
2. Shaft excavation and segmental lining.
3. Installation of tremie concrete base seal.
4. Installation of MTBM jacking frame and thrust wall.
5. MTBM launch and first drive completion.
6. MTBM pipework disconnected and jacking frame rotated inside shaft.
7. Second MTBM drive completed.
8. Completion of permanent shaft base slab and any benching.

Figure 13 shows an indicative site layout for the MTBM launch site proposed at Shaft C. The arrangement of working and storage areas varies between each of the shaft sites due to the surface space constraints. It is proposed to site that all MTBM control and utility services to be arranged at the launch sites in order to

minimise the space requirement at other intermediate shaft sites. Indicative space requirements for the reception shaft are listed in Table 9.

Table 9 - Services contained within the Shaft C site compound

Name	Approx. area (m^2)
Shaft and jacking collar	50
Gantry/crane movement area[1] (1)	200
Pipe section storage (2)	150
Spoil heap (3)	200
General stores (5)	100
Services: electric, comms, water[2] (9)	100
Slurry and muck handling facilities (4)	500
Lubrication mixing and injection plant (6)	200
Pumping plant and disposal outlet (7)	100
Power unit control station	100
Total site area incl. access routes and exclusion zones	2500

[1] Due to the constrained space onsite and the proximity to a live road lane, use of a gantry lifting system may be preferable to a standard swing-crane.

[2] A supply of water will be required at each site. If water mains supply is not available, water tankers access to the sites will be required.

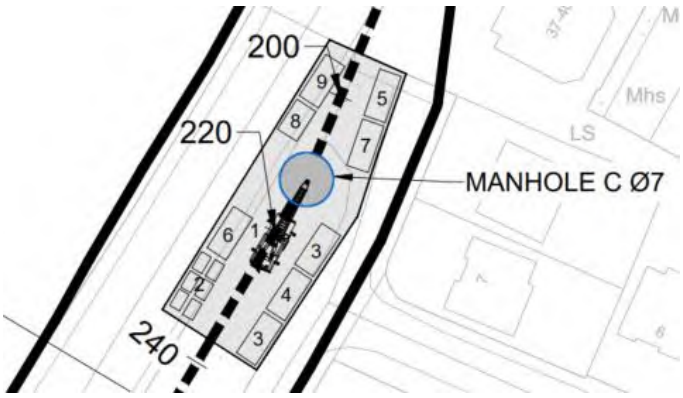

Figure 13 - Combined MTBM launch and reception site at Manhole C

5.2.4 Intermediate shafts

The space requirements for the compounds at Manholes D and E are less onerous than at the other sites, as there are fewer storage and service requirements for reception/intermediate shafts. The arrangement of working and storage areas varies between each of the shaft sites due to the surface space constraints. It is proposed to site all MTBM control and utility services at the launch sites in order to minimise the space requirement at the intermediate shaft sites.

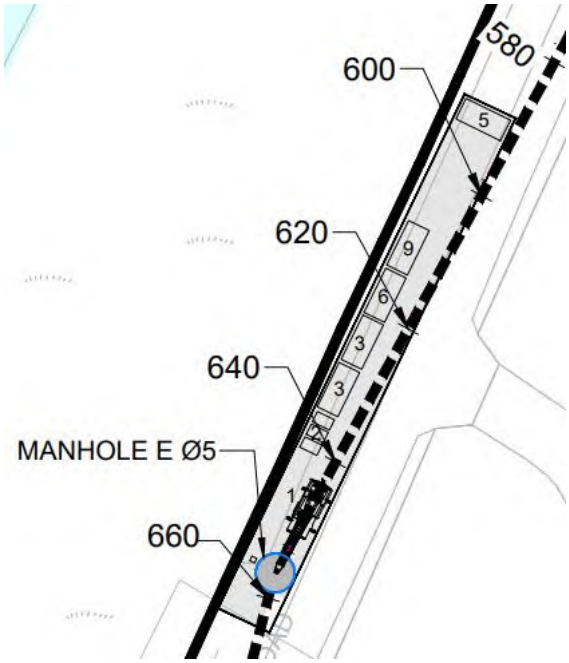

Figure 14 - Manhole E compound site indicative arrangement

Shaft D is not required for tunnel construction under this design but remains a requirement for inspection and maintenance access via a permanent manhole. Shaft construction prior to tunnelling is proposed as the preferred sequence, with the MTBM breaking through pre-installed soft-eyes to simplify the construction process and provide the opportunity to utilise these shafts for access during tunnelling for any maintenance and repairment. The site arrangement as shown in Figure 15 has been proposed according to a 7 m diameter manhole to facilitate the option to install intermediate jacking rigs, dependent on the jacking thrust requirements for the alignments as proposed. Alternatively, if the shaft is constructed after tunnelling has completed then there is an opportunity to reduce the manhole diameter to 5 m.

Figure 15 - Manhole D compound site indicative arrangement

5.2.5 Permanent manholes

The internal permanent structures to be installed within the KRPS trench are two manholes (A and B) with cut-and-cover pipe connection and an assumed steel connection into the existing pump station (see Figure 16 and

drawing no. 5161805_EWE_DR_MOR_5127). The proposed construction of the manhole shafts consisting of pre-cast caissons are required to be located at the alignment vertices in the trench. It is assumed that the trench will be backfilled upon completion of the tunnel and manholes to facilitate the removal of the sheet piles.

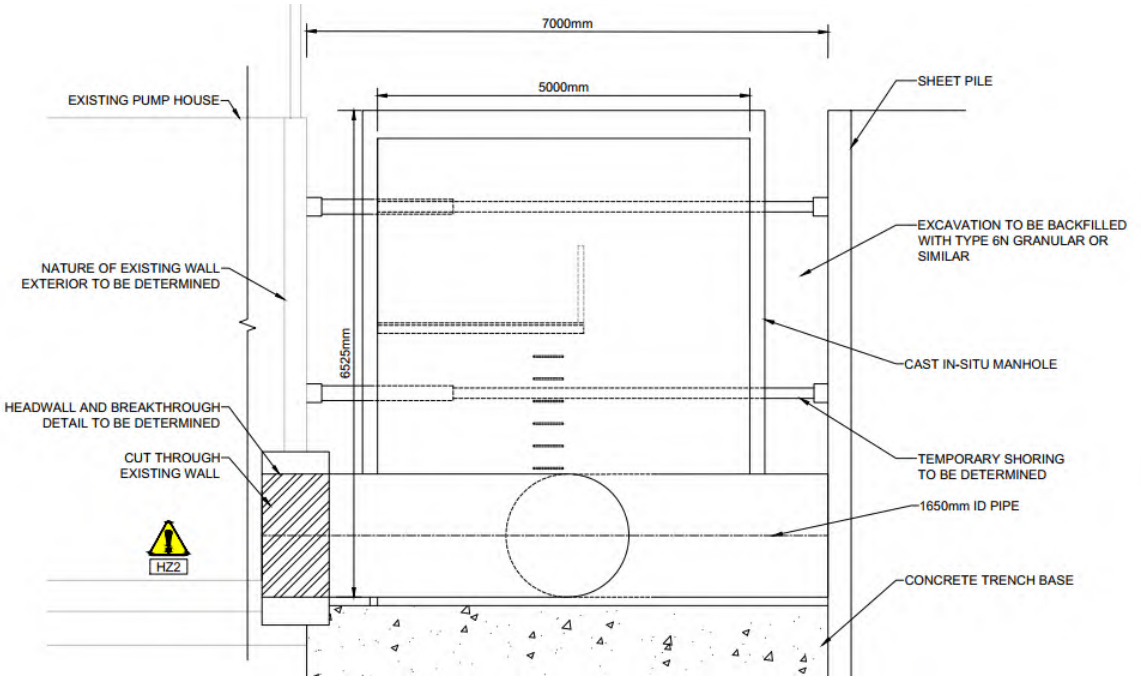

Figure 16 - Section showing proposed arrangement of Manhole A

Permanent manholes should also be installed inside Shafts C, D, E and F, with the proposed dimensions according to Table 6 and the Uisce Éireann standards. They should be capped and the original surface reinstated, leaving only the manhole access. Manholes are expected to be min. 675 x 675 mm to provide sufficient clear ladder access down to sewer invert level according to IW-CDS-5030-03. Where the sewer invert is greater than 6 m bgl, an intermediate landing platform should be installed between ladder runs.

Shaft bases should be benched to sewer invert level for maintenance of low flows and to aid inspections and maintenance. No allowance has been designed for installation of a sump or valve, as it is assumed that flow shall either drain to the pumping station or be controlled upstream of the gravity main. Based on a review of Uisce Éireann requirements for gravity mains, it has also been assumed that no specific provision for air ventilation is required for reference design considerations.

During detailed design, the cover of Manhole E should be specified to support regular vehicular loading as it is positioned within a cycle lane adjacent to the main carriageway. Similarly, Manhole F is located below an access road which is assumed to remain in regular use for traffic. This is expected to increase the thickness of the cover slab and access hatch. At Manholes A to D and F, regular vehicular loading is unlikely to be encountered. Covers should be designed to withstand potential explosions in case of ignition of methane from the wastewater system.

Space provision has been provided for installation of a second access point per manhole, if required for emergency access in accordance with Uisce Éireann's Access Strategy. Other operational emergency provisions that are recommended for installation at all shafts include a safety chain and stopboard.

6. Construction risks

The hazards identified within the risk assessment have been assigned a risk rating. Ratings have also been assigned for any control measures which are currently in place and any further control measures which will be required. A value for the likelihood of an incident occurring based on the hazard from 1 to 5 and a value for the severity / impact of the hazard from 1 to 5 have been assigned. The risk score for a hazard causing harm is calculated as likelihood x severity (or impact).

SEVERITY or IMPACT (S)						
	5 CATASTROPHIC	5	10	15	20	25
	4 MAJOR	4	8	12	16	20
	3 SERIOUS	3	6	9	12	15
	2 MODERATE	2	4	6	8	10
	1 MINOR	1	2	3	4	5
		1 RARE	2 UNLIKELY	3 POSSIBLE	4 LIKELY	5 ALMOST CERTAIN
		LIKELIHOOD (L)				

Risk score (R)

High – rating 15 or more

Further action is essential to control and/or lower the level of risk. Exposure to the identified hazard is prohibited or severely restricted

Medium – rating 8 to 12

Requires review of the equipment, activities, system of work within the workplace with the aim of lowering the risk to the next level.

Low – rating 1 to 6

Usually, no further action will be required except for monitoring to ensure the risk does not change and controls remain in place. However, if it is possible to reduce the risk levels still further, by using controls that are “reasonably practicable”, then this should be done.

Table 10 - Design risks

Ref	Construction Risk	L	S	R	Response/Control Measure	L	S	R
1	MTBM launch operations at KRPS may be restricted by medium voltage overhead lines.	5	4	20	While height restriction may be required, it is recommended to conduct a site survey before construction begins to confirm if the medium voltage overhead line may impose any potential risk to the construction process. If so then utility diversion may need consideration.	1	4	4
2	Reception shaft construction operations may be restricted by medium voltage overhead lines.	4	4	16	While height restriction may be required, it is recommended to conduct a site survey before construction begins to confirm if the medium voltage overhead line may impose any potential risk to the construction process. If so then utility diversion may need consideration.	1	4	4
3	Clashes with known underground utilities	5	2	10	Utilities to be diverted away from shaft construction locations. Predominantly a requirement at the location of Manholes E and F.	5	1	5
4	Clashes with underground utilities or service foundations of unknown elevation.	3	5	15	The exact location and depth of all Gas Network Ireland underground utilities and ESB underground cables should be confirmed before construction. If an unforeseen clash is encountered during construction, further utility diversion may be required.	1	3	3
5	Encountering larger boulders (>400 mm) during tunnel boring	4	4	16	Suitability of the vertical alignment to be confirmed against further GI. Choice of tunnelling method to consider the risk of larger (>400 mm) boulders.	3	3	9

Ref	Construction Risk	L	S	R	Response/Control Measure	L	S	R
6	Encountering boulders during shaft sinking	5	4	20	Shaft construction via the wet segmental caisson method should allow for any boulders encountered during the sinking process to be excavated.	5	2	10
7	Groundwater ingress through shaft base during construction.	5	4	20	Temporary sealing of excavation base should be implemented during construction. Proposed construction methodologies involve pre-installation of impermeable shaft walls (e.g., sheet piles) prior to excavation. The base of the excavation is to be sealed either prior to excavation (i.e. pre-installed ground treatment below the excavation level e.g., jet grouting, permeation grouting or neutrogel) or after underwater excavation using a tremie concrete placed plug. Dewatering pumping may also be considered, however based on current understanding of the ground conditions this is unlikely to be a sufficient measure to achieve a dry excavation on its own.	2	2	4
8	Uplift of shaft base	3	3	9	Shear connection to be provided between base slab and shaft walls. Uplift checks to be conducted during detailed design.	2	2	4
9	Ground movement and settlement impacting the road and/or nearby buildings	4	4	16	Ground settlement and its impact on assets to be assessed during detailed design. Monitoring and protection measures (inclinometers, extensometers, piezometers, monitoring targets) to be implemented if required. Horizontal alignment has been set to avoid property boundaries.	2	4	8
10	Unforeseen ground conditions	4	4	16	A more comprehensive ground investigation utilizing methods such as borehole or rotary core sampling is recommended along the tunnel alignment. This will provide a better understanding of the soil condition in this area and help mitigate the potential for unforeseen soil conditions.	3	2	6

TECHNICAL NOTE

Ref	Construction Risk	L	S	R	Response/Control Measure	L	S	R
11	Excavations encountering underground utilities of unknown depth.	4	4	16	Underground utilities should be confirmed on site using techniques such as ground penetrating radar and / or exploratory excavations prior to commencing shaft and tunnel construction. This includes confirmation of the utility type, size and horizontal and vertical alignment.	2	3	6
12	Vehicle collision	3	5	15	Lane closure with physical barriers to entry is proposed to prevent any form of road accident into the deep excavation along the road. Exclusion zone to extend 1 m from shafts in all directions. Reduced speed limit (ideally 30 km/h) to be enforced where works occupy part of the main road.	2	3	6
13	Sinkholes	3	4	12	Loose cohesionless ground at the tunnel face extending to the ground surface represents a risk for uncontrolled face collapse and a sink hole developing. This risk of this occurring can be reduced by vigilance during construction, maintaining slurry pressure and continuously monitoring excavation volumes passing through the machine. Surface watch when MTBM is passing critical locations (e.g. under roads) may also severity of impact by enable fast mitigative reaction (e.g. stop traffic). Risk assessment and emergency action plan to be developed during construction planning.	2	3	6
14	Damage to the Special Area of Conservation (SAC)	4	3	12	The red line envelope has been set to exclude tunnelling underneath this area. Contractor to ensure measures such as fixed hoardings and impermeable barriers are installed to prevent impingement on the SAC.	2	3	6
15	Unknown construction of the KRPS basement structure	3	4	12	A comprehensive records source check and/or additional trial pits investigations required to confirm the nature of the construction of the original KRPS basement structure and the nature and likelihood of any temporary support	2	3	6

Ref	Construction Risk	L	S	R	Response/Control Measure	L	S	R
					measures left in the ground on the outside face. Such detail will be important for ensuring an adequate seal between the temporary excavation support for the new construction and the existing structure as well as appropriately planning the adjacent excavation and breakthrough works into the existing wet well.			
16	Vibration and progressive load imposition from MTBM on granular soil causing vertical tilting of the MTBM trajectory.	3	3	9	Ground treatment should be considered behind the launch/reception shaft eyes to reinforce the soil against vibrational or differential loading deformation.	2	2	4
17	Pipe jack construction program at risk of delay due to non-continuous working schedule and/or noise limit hours	3	2	6	To be confirmed or agreed with local and environmental authorities.	2	2	4
18	Visual/reputational impact of slurry leakage impacting the SAC/river	3	2	6	Option for use of and EPB MTBM outlined. Alignment set to avoid tunnelling beneath the SAC.	2	1	2
19	Damage to tunnel caused by subsequent construction of intermediate shaft for Manhole D.	4	2	8	Contractor agreement on the preferred approach to be sought. Reference design considers pre-installation of all intermediate shafts as beneficial in facilitating tunnel access during construction and potential use for intermediate jacking stations.	2	2	4

7. Conclusion

A horizontal tunnel alignment has been proposed based on a review of constraints between the KRPS and Mortarstown WWTP sites and an assessment of construction method compatibility. The main constraints were identified as Kilkenny Rd, the SAC adjacent to the River Barrow, and the properties along Southern Gardens. Avoidance of the jacking rig installation beneath the road has been prioritised. However, installation of a construction shaft within the road has been determined to be unavoidable based on the currently imposed constraints. The vertical tunnel alignment is set by the constraints of the hydraulic design.

The proposed design utilises a trench adjacent to KRPS with two intermediate shafts for MTBM launch, for tunnel construction via three main pipe jacking drives plus a short drive into the WWTP wet well. An additional intermediate shaft is required for housing of a permanent access manhole. Contractor involvement is required to assure the compatibility of these shafts' connections with the tunnel, dependent on the construction sequence selected. Detailed design should be undertaken to confirm that the required jacking forces are achievable with the proposed alignment and working spaces.

The key outcomes for further engagement are:

- Single lane closure of Kilkenny Road is required for the construction of Manholes C, D and E. This will require liaison with the road authority to arrange and understand any limitations on the allowable duration or extent of closure.
- Manholes E and F, which have been located to avoid tunnelling beneath private property, are situated adjacent to the site earmarked for construction of the southern relief road junction. Any modification to the currently planned arrangement of this road construction should be communicated to ensure that this does not result in a clash with the proposed manhole construction.
- The suitability of maintenance access shaft spacing of up to 240 m should be confirmed and agreed upon by Uisce Éireann.
- Diversion of utilities will be required where these clash with the shaft locations alignment as shown in 5161805_EWE_DR_MOR_5520 to 5524. The detailed tunnel design should consider the wayleave and allowable settlement requirements of each utility owner.

In order to improve the understanding of geological risks associated with the tunnel and shaft construction, it is recommended that further ground investigation shall be carried out along the proposed sewer alignment. This should aim to increase the extent of borehole data available across the site, improve the ground risks management strategy and reduce the likelihood of encountering unexpected underground obstacles. The GI should:

- Improve the understanding of the groundwater conditions at the site to inform the development of a safe ground treatment or shaft dewatering strategy, as well as to aid the choice of MTBM.
- Confirm the expected depths, distribution and size of the boulders/cobbles along the tunnel alignment, to fully understand the potential risks to construction arising from the large boulders (greater than one third of the tunnel outer diameter).
- Be scoped appropriately and consider the potentials of using geophysical techniques to support the intrusive ground investigation where there is a risk of encountering obstructions may lead to boreholes refusal.

The full tunnel specimen design drawings set is included in Appendix E of the SID Engineering Report.

8. References

[1] AtkinsRealis, “Kilkenny Road Pumping Station to Mortarstown Wastewater Treatment Works: Tunnel Option Review,” 2023.

[2] Uisce Éireann, “IW-TEC-800-01 Technical Standard: Wastewater Gravity Sewers,” 2018.

[3] Uisce Éireann, “IW-CDS-5030-03 Code of Practice for Wastewater Infrastructure,” 2020.

[4] AtkinsRéalis, *5161805_EWE_DR_MOR_1150_I_Rev01 Mortarstown WWTP Upgrade Proposed Inlet Pumping Station,* Dublin, 2024.

[5] Priority Geotechnical, “CIP Lot 5 - Mortarstown, Site Investigation - Factual Report,” Dublin, 2022.

[6] Pipe Jacking Association, “Pipejacking design guidance for CDM duty holders,” 2024.

[7] Pipe Jacking Association, “An introduction to pipe jacking and microtunnelling,” 2017.

[8] Herrenknecht, “AVN1200TB - AVN1800TB Pipe Jacking,” Schwanau, 2022.

[9] Atkins, “Mortarstown Waste Water Treatment Plant & Kilkenny Road Pumping Station: Utility Services Report,” Galway, 2019.