How Large Scale Civil Engineering Projects Realise the Potential of a City:

Thames Tideway Improving London's Sewer System

Steve Woodrow – Head of Tunnelling (Europe)

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Introduction

1. Setting the Scene: A Brief History of London's Sewer System
2. Improving the Sewer System: The Tideway Scheme
3. The Thames Tunnel
   - Main Tunnel
   - Interception of Combined Sewer Overflows (CSOs)
   - Current Status
4. The Lee Tunnel
   - Current Status
   - Shaft Construction
   - Main Tunnel
5. Close

Setting the Scene:
A brief History of London's Sewer System

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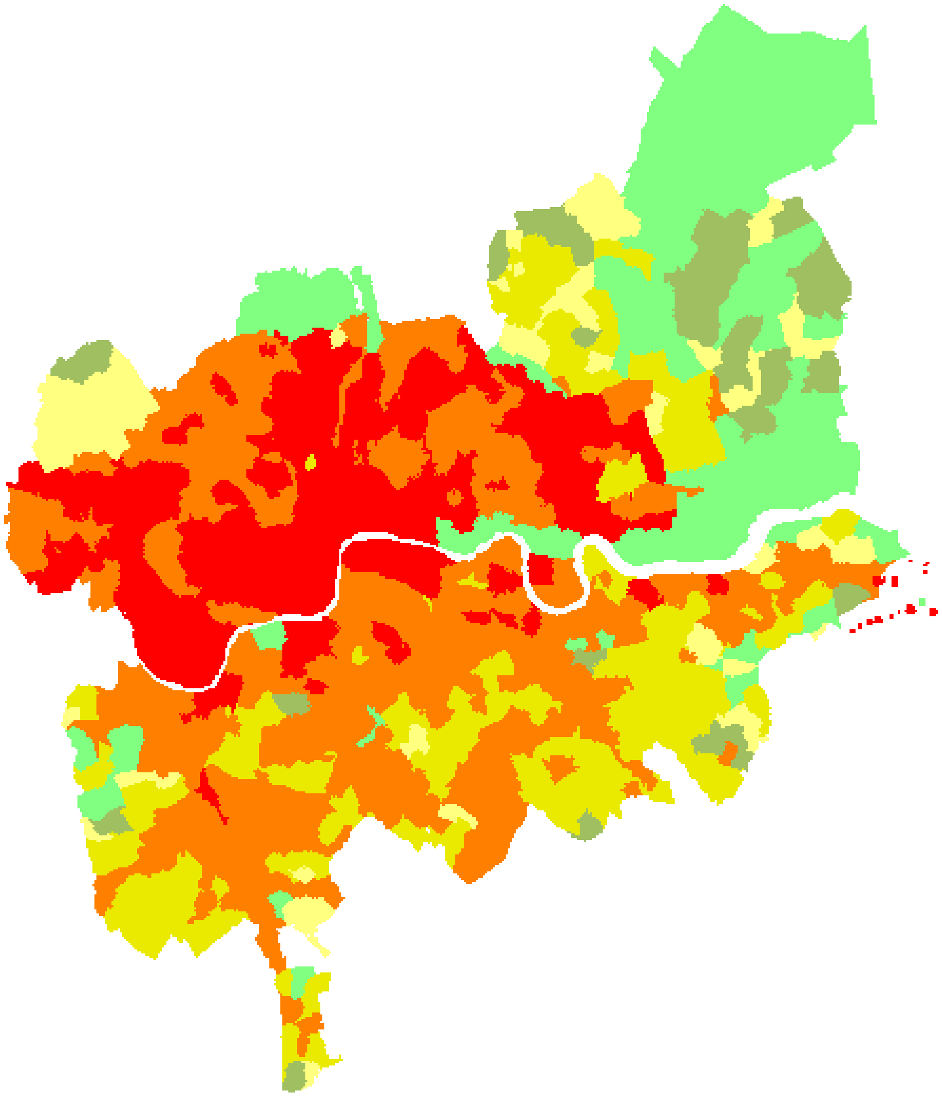
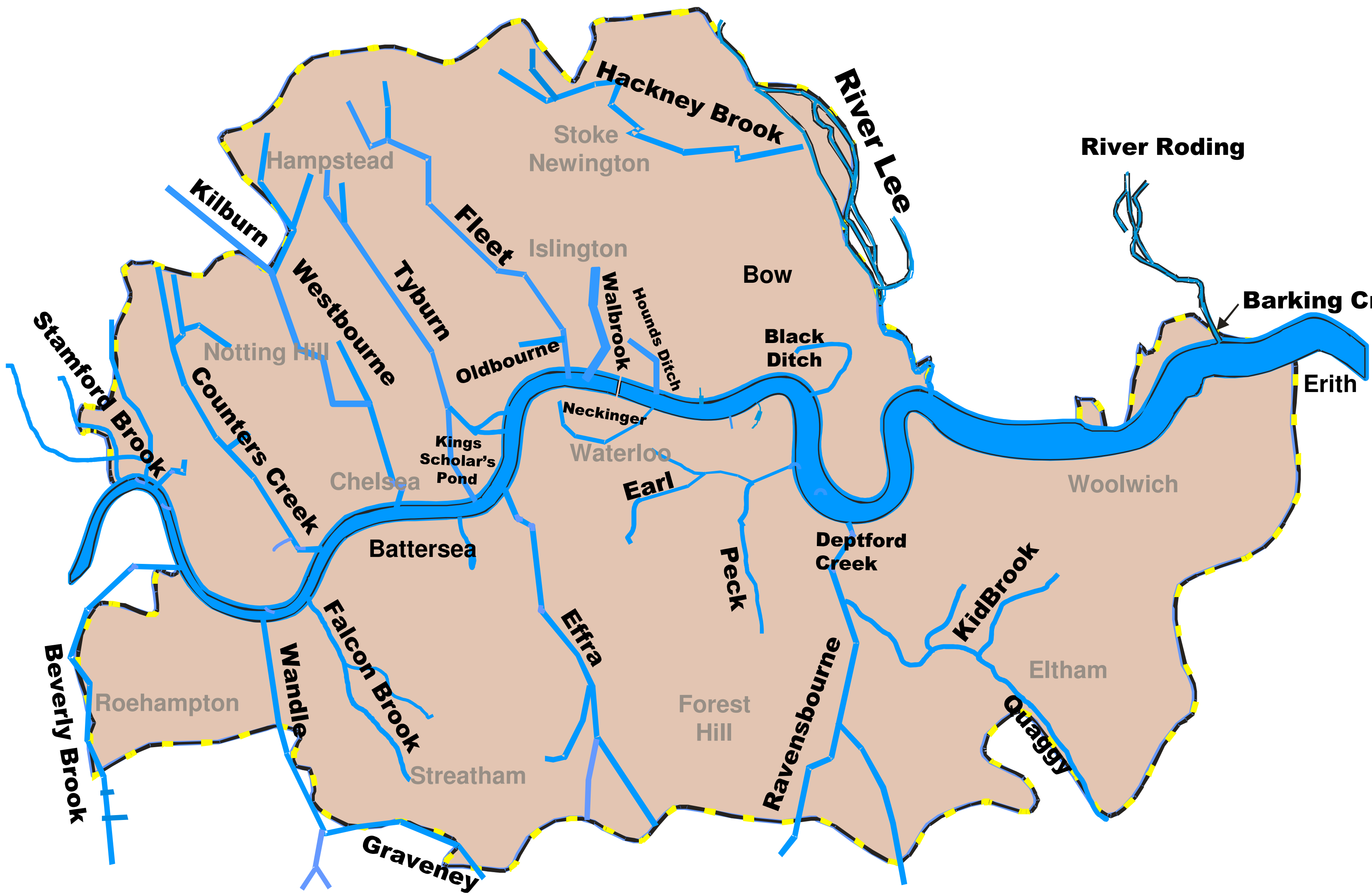
London's Sewerage Network: Present Day



0-5 %	Separate system
5-10 %	
10-20 %	Partially separate system
20-40%	
40-70%	Combined system
70-100%	

The Lost Rivers of London



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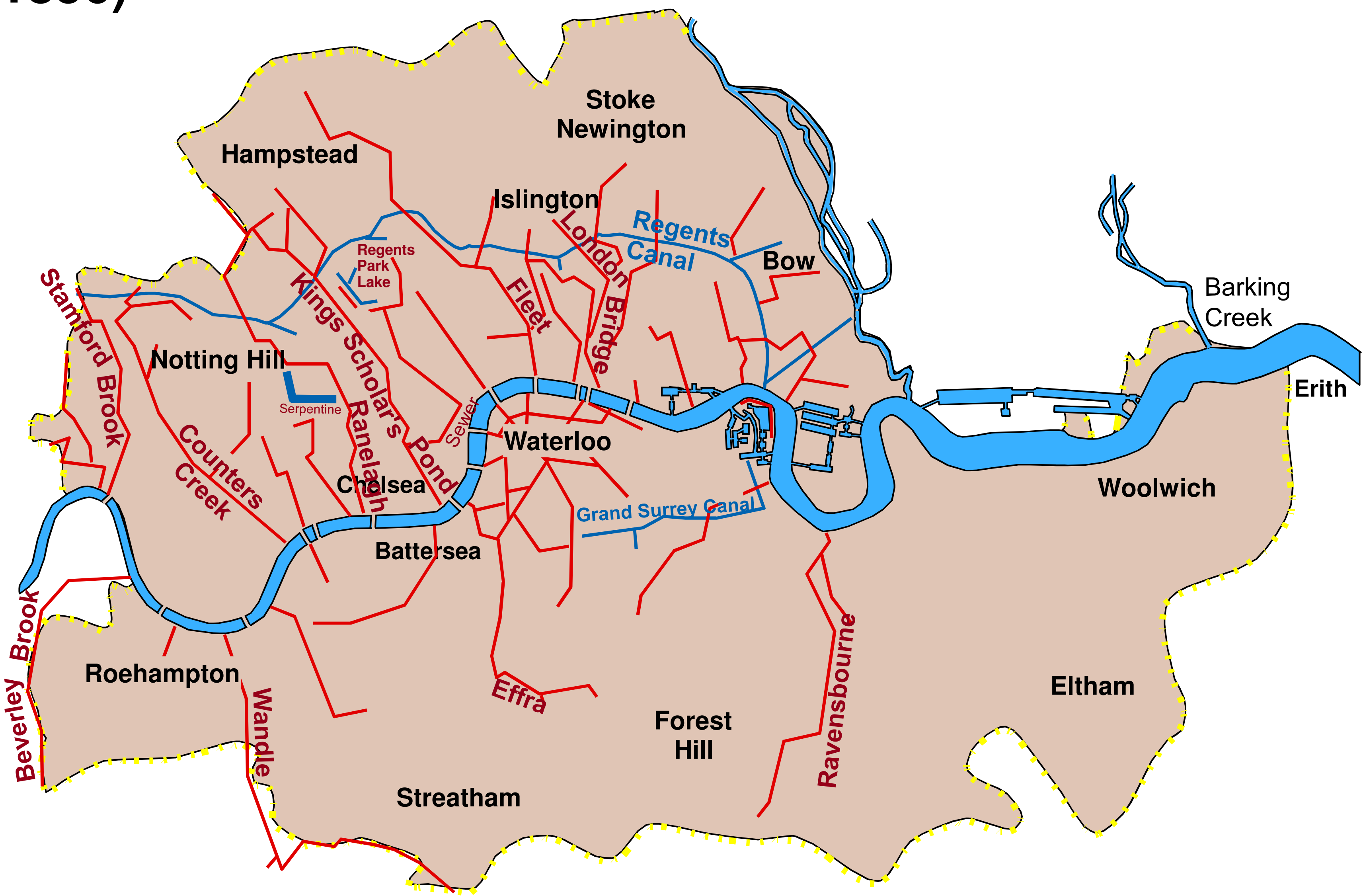
Main Sewers Vested in the Metropolitan Board of Work (1856)

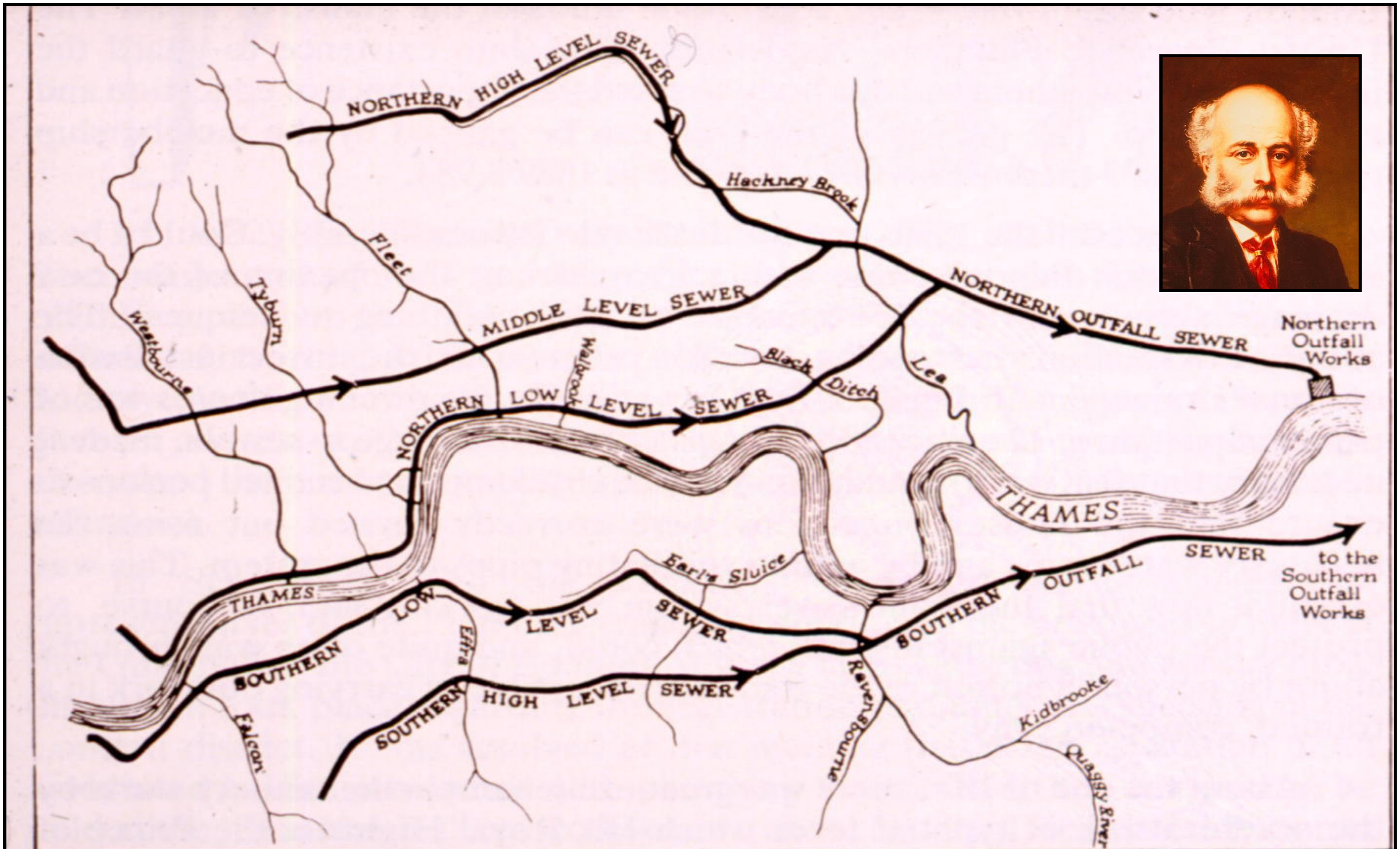


The Great Stink of 1858

FARADAY GIVING HIS CARD TO FATHER THAMES

And we hope the Dirty Fellow will consult the learned Professor.

Bazelgette’s Plan: Interceptor Sewers



Bazalgette’s Plan for Intercepting Sewers

Intercepting Sewers by the Metropolitan Board of Works (1859-1873)

Central London Intercepting Sewers (Present Day)

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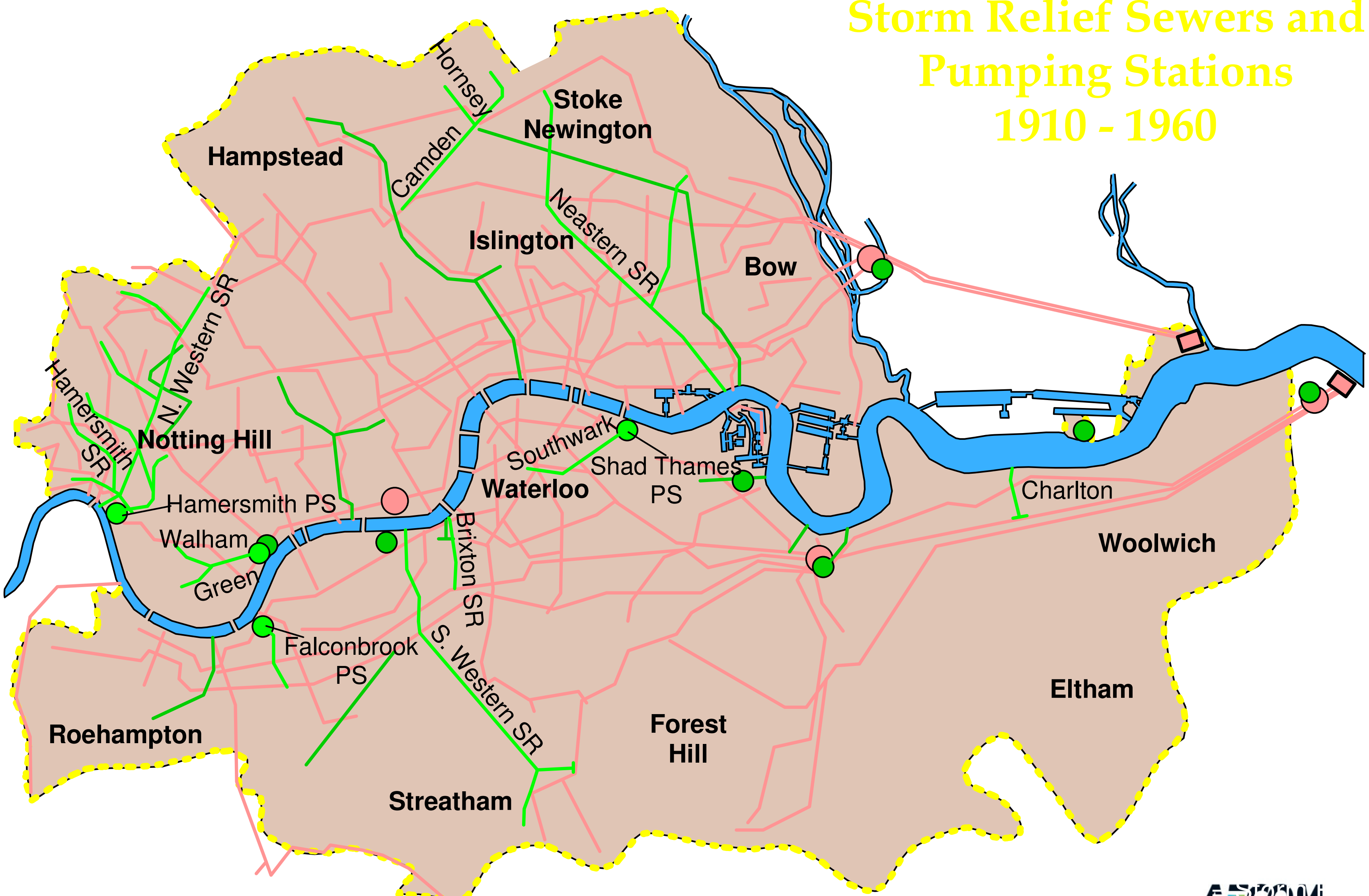
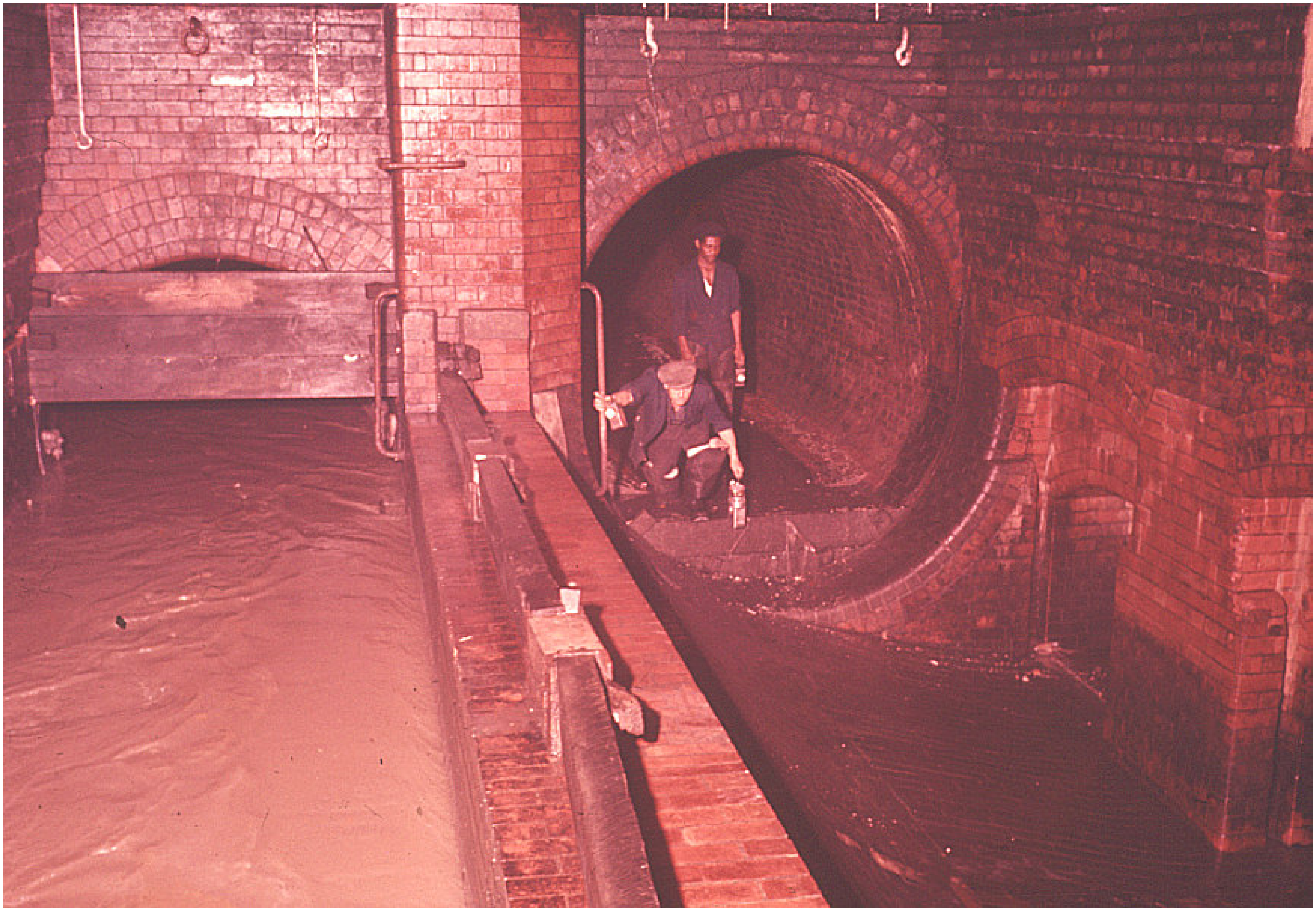
Storm Relief Sewers & Pumping Stations (1910 to 1960



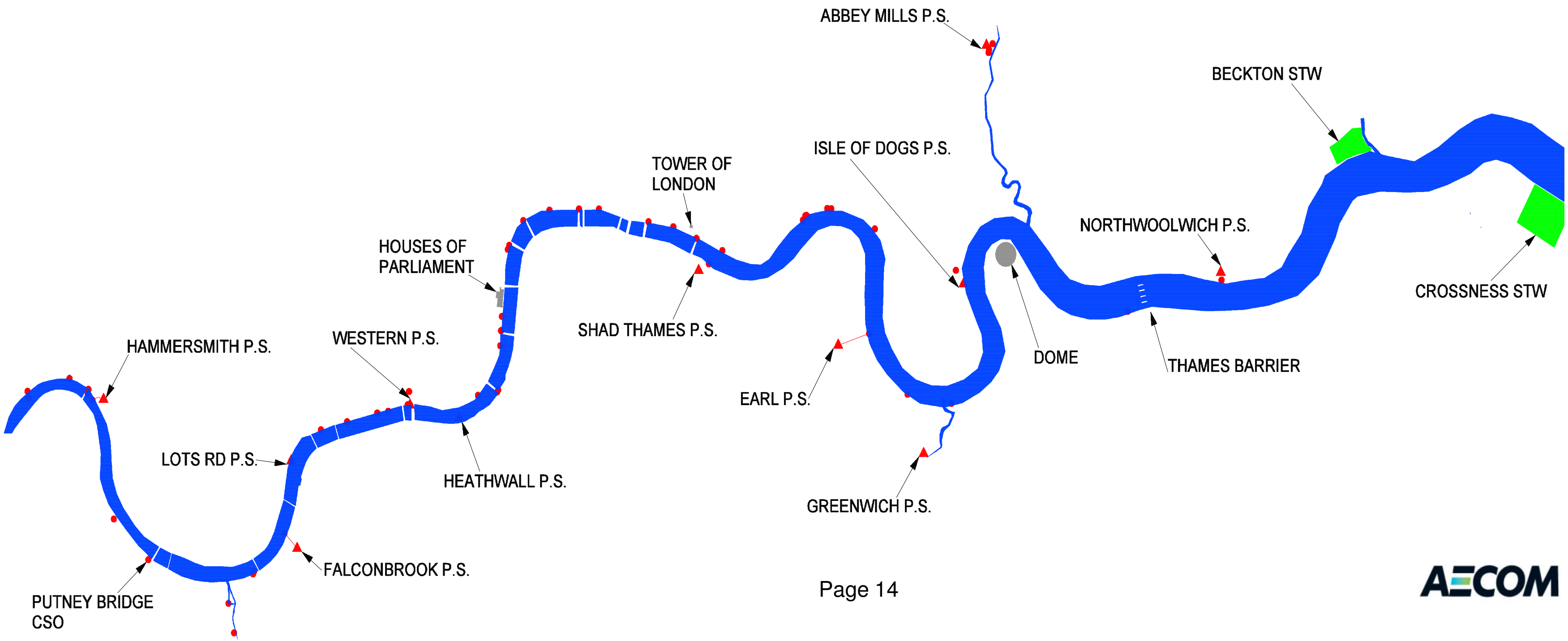
Combined Sewer Overflows

Combined Sewer Overflows



London's Sewers & Combined Sewer Overflows

- CSO points along the Thames to prevent flooding.
- 57 CSOs Discharge to the Thames
- Typical Annual Discharge 39million tonnes with a typical frequency 60 times per year



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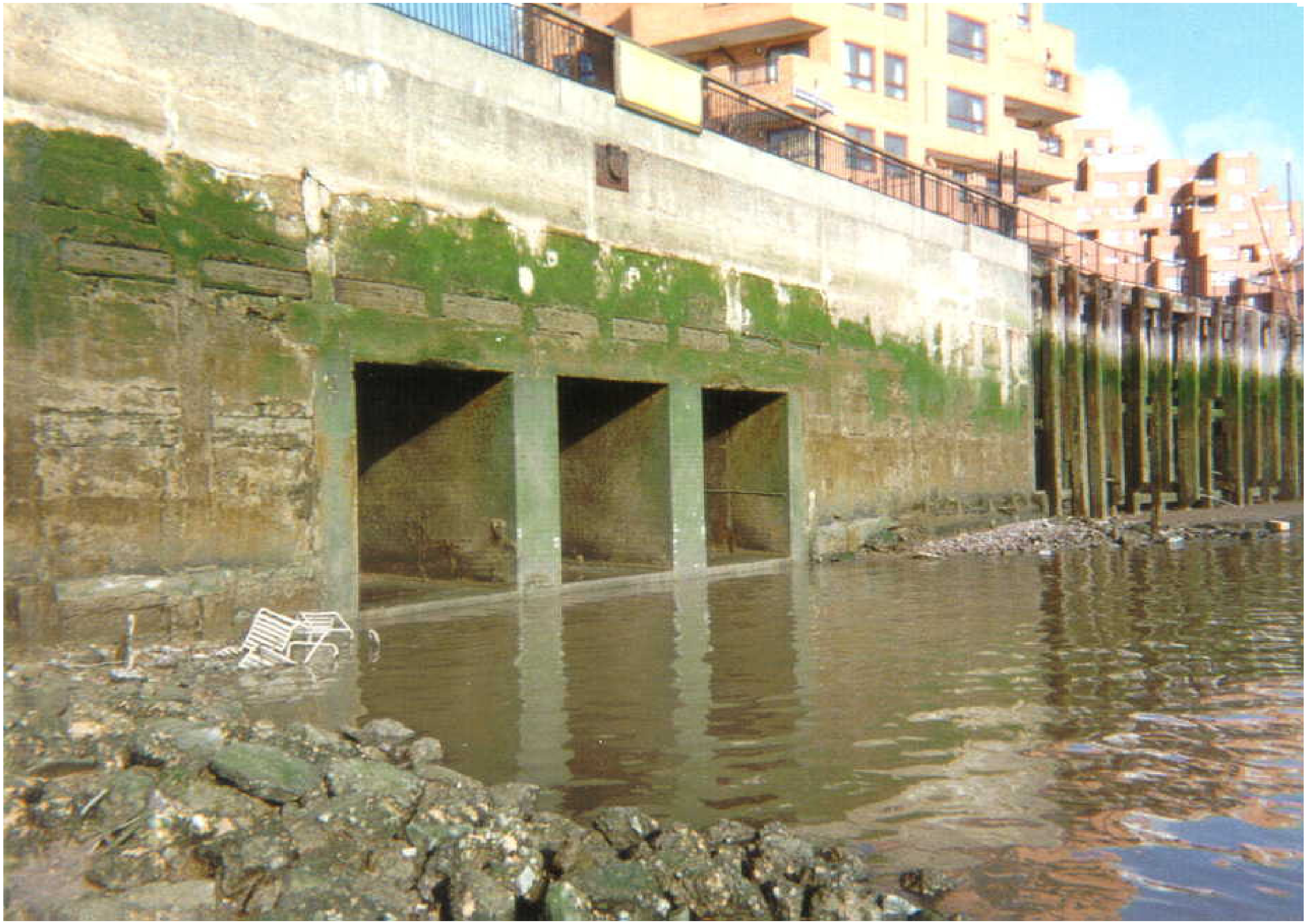
Combined Sewer Overflows



Combined Sewer Overflows

CSO Pollution

- 39 million tonnes of sewage discharged to tidal River Thames in a typical year. Enough to fill the Royal Albert Hall 450 times.
- As little as 2mm of rain can now trigger a discharge.
- Environmental - tides mean the sewage stays in the river for weeks, affecting dissolved oxygen levels and habitats
- Human – frequency of Combined Sewer Overflow (CSO) discharges is a potential hazard to all river users
- Legal – the UK fails to comply with the EU Urban Waste Water Treatment Directive

CSO Pollution – Sewage Solids

CSO Pollution – Ecological Impacts

CSO Pollution – Recreational River Use & Tourism

CSO Pollution – Health Risks

- 3000-5000 recreational users per week
- Typically 60 days per year when sewage system overflows to the river
- 120 days of ‘elevated health risk’

Improving the Sewer System: The Tideway Scheme

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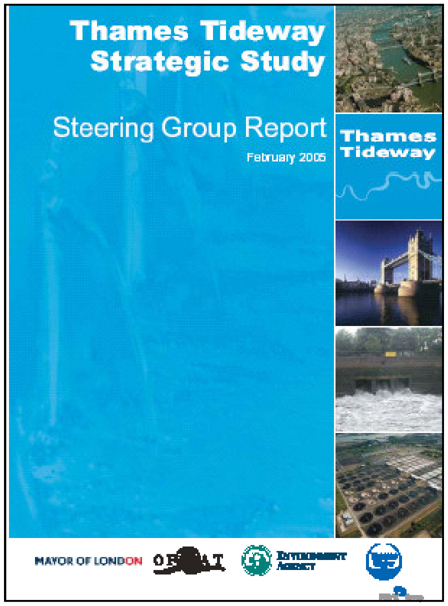
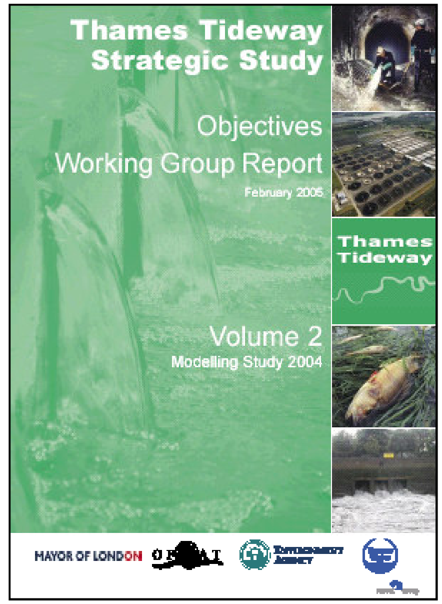
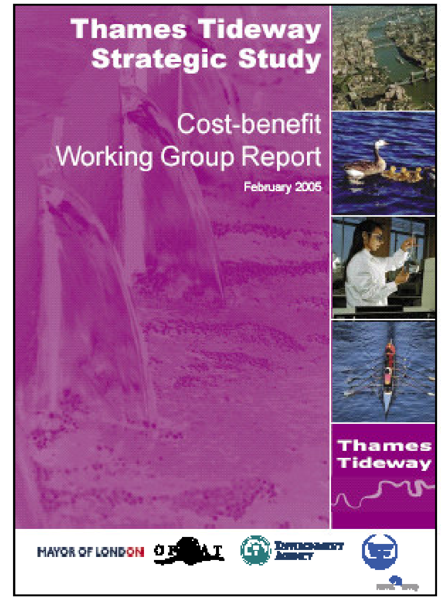
Thames Tideway Working Group

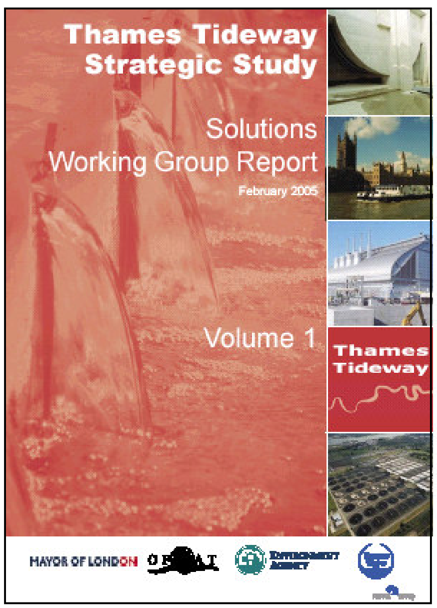
- Objective: To reduce the impact of intermittent sewage discharges and further improve water quality in the Thames Tideway, to benefit the ecosystem, and facilitate use and enjoyment of the river

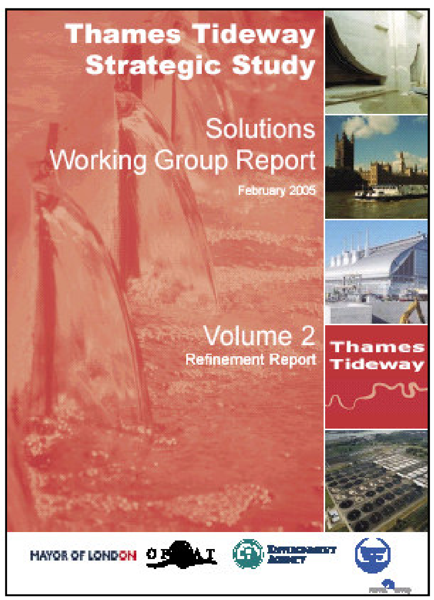
Thames Tideway Strategic Study Reports

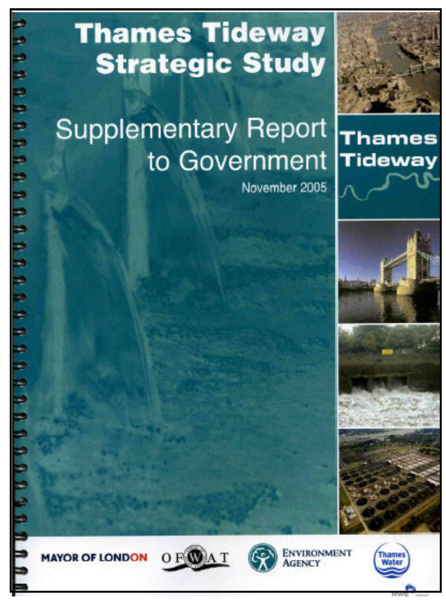








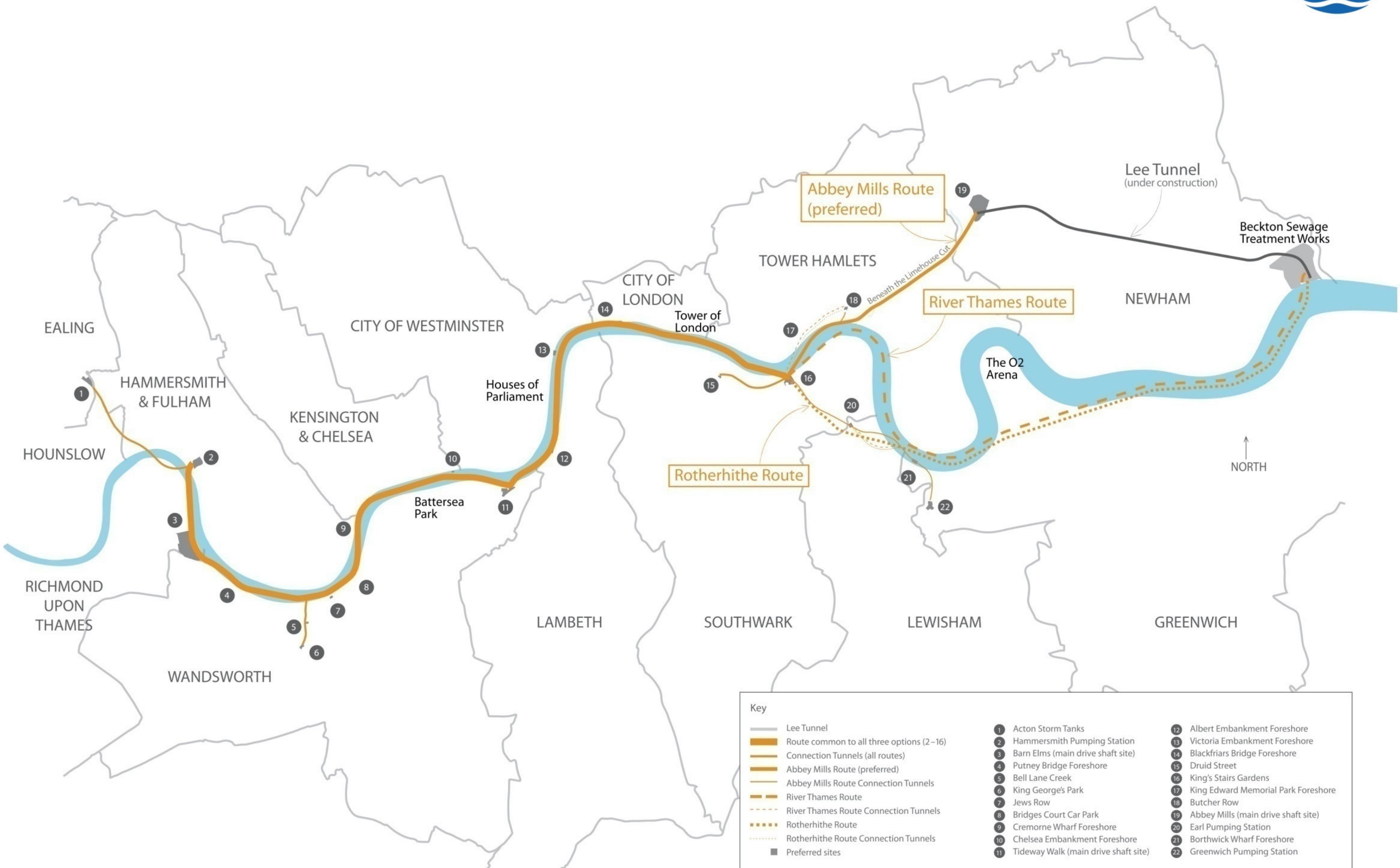




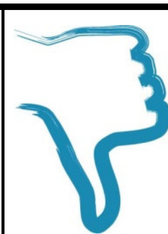
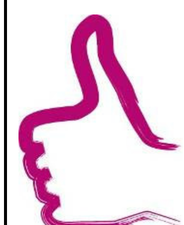
Responding to Concerns

- Various studies, including:
  - Noise
  - Vibration
  - Air quality (including dust emissions)
  - Odour
  - Lighting impact
  - Traffic impact (including road users and pedestrians)
- Preliminary Environmental Information Report and Code of Construction Practice published at consultation stage.
- Coordination with the council, owners and tenants on the site to achieve a mutually acceptable solution on relocating businesses.

Third Party Interfaces – Local Authorities



Options Considered by Strategic Studies

Action before sewer: Source Control and Sustainable Urban Drainage Systems (SUDS)	
Within sewer network: Localised storage and separation	
In-river: More ‘Bubbler’ and ‘Skimmer’ vessels	
Intercept overflows: Central storage and transfer	

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Findings of Strategic Studies

Thames Water

- Two Principle Problems Identified:
  - Overloaded sewage treatment works; discharging directly into the river after heavy rainfall
  - Overloaded sewer network; discharging into the river via CSOs.

- Three Solutions Identified:

Thames Tunnel
Creating a cleaner, healthier River Thames

Lee Tunnel
Creating a cleaner, healthier River Thames

Sewage Works Upgrades
Creating a cleaner, healthier River Thames

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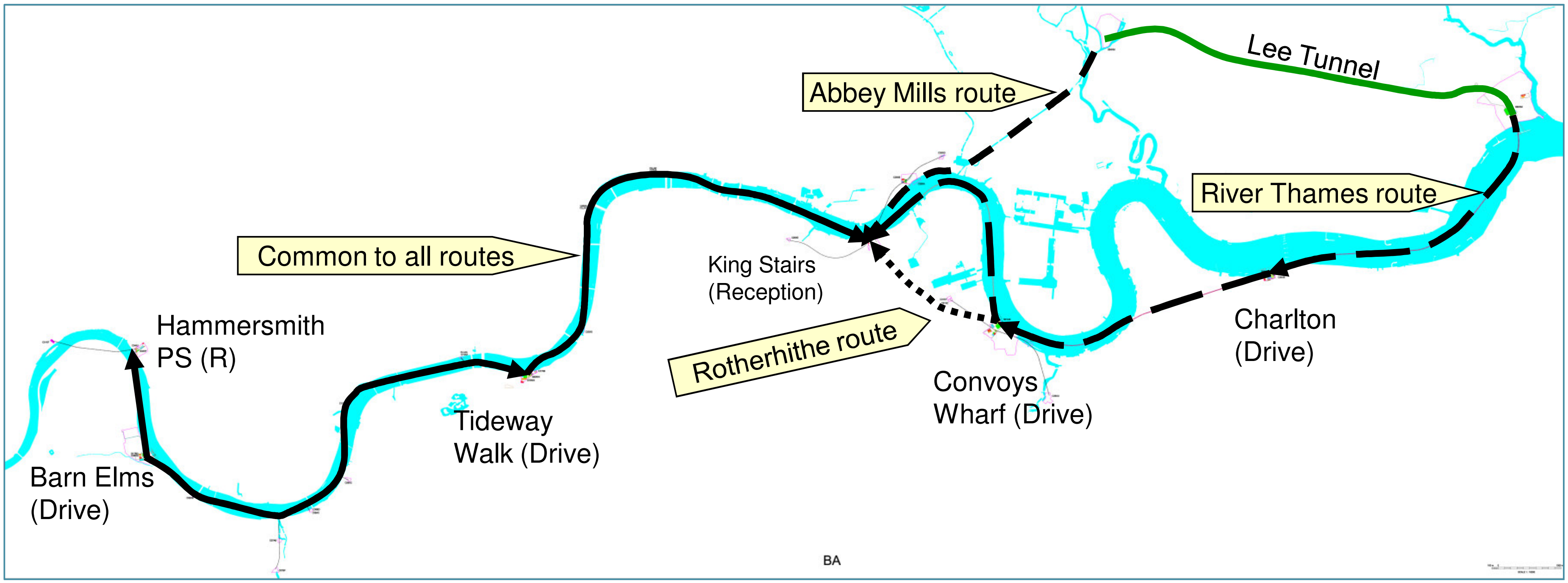
Alignment Options



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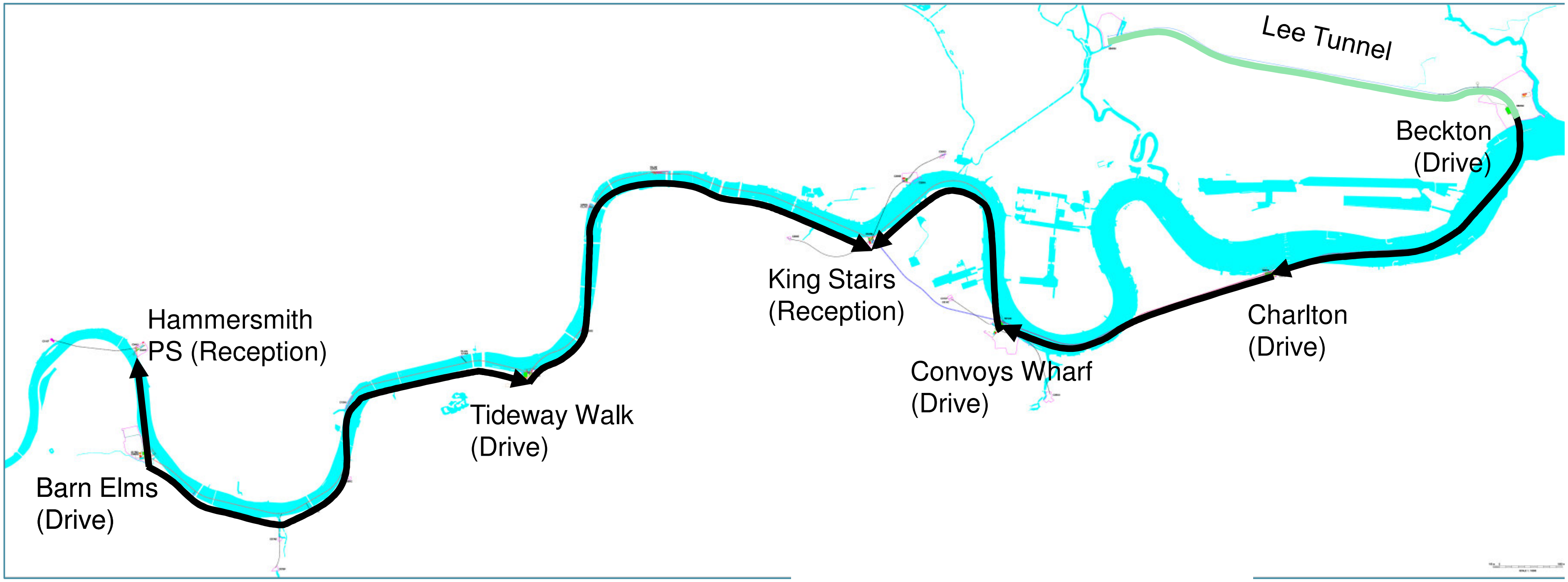
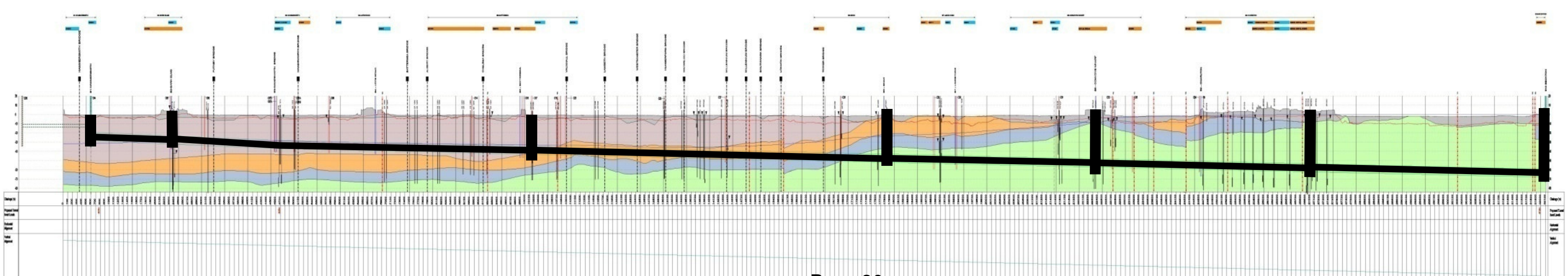
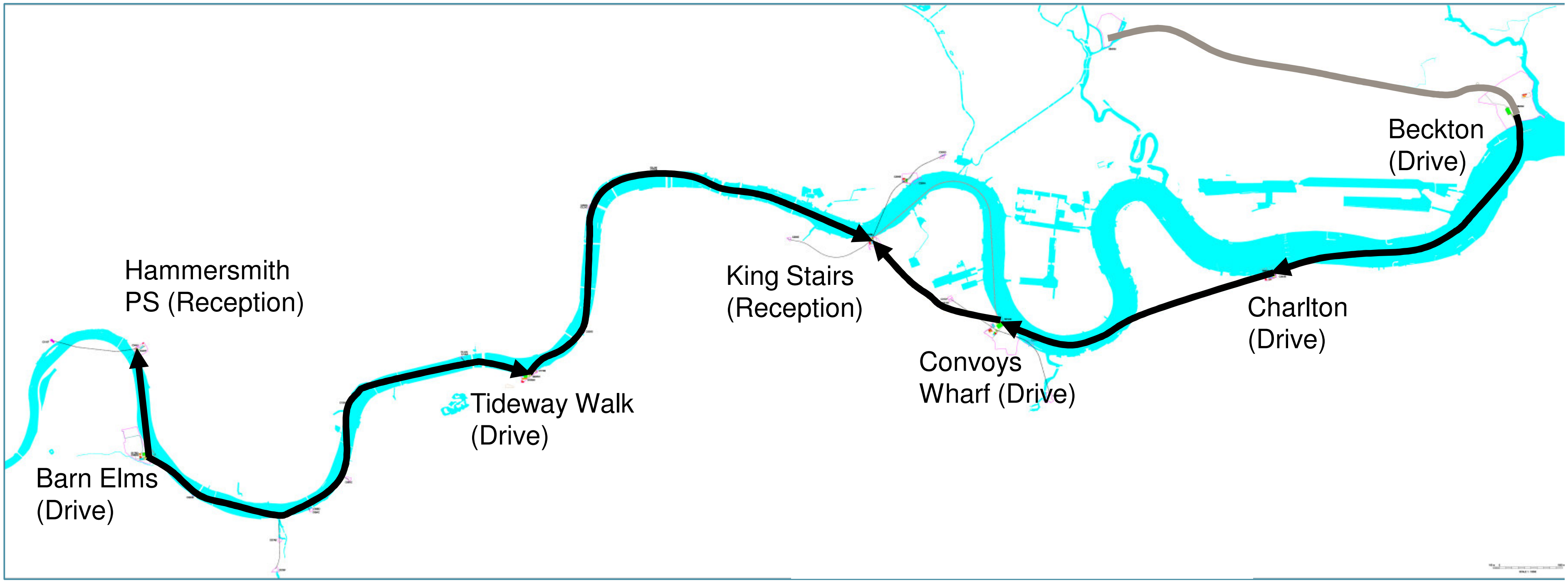
River Thames Route

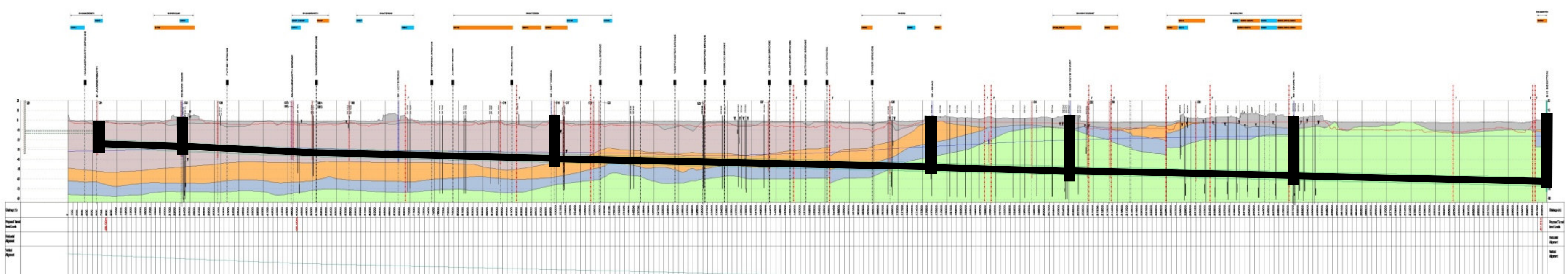




BASELINE BOREHOLES AND PIEZOMETERS
Scale = 1:1 Horiz 1:10 Vert

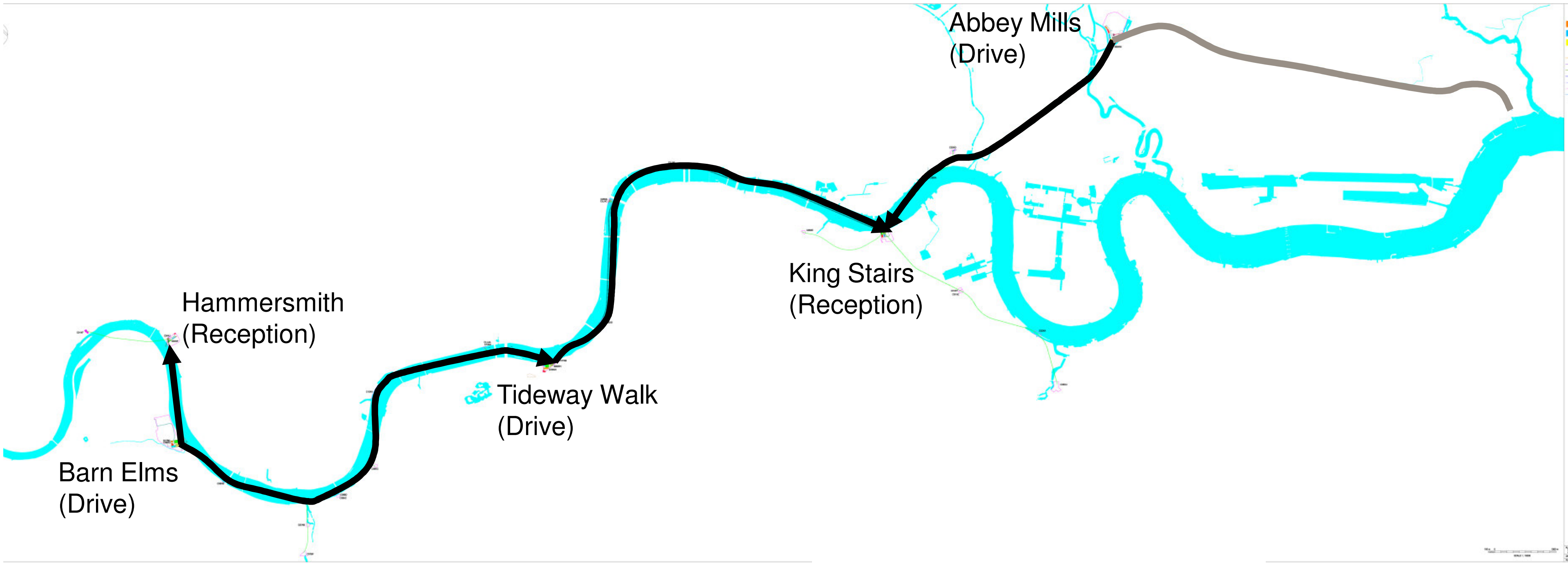
Rotherhithe Route

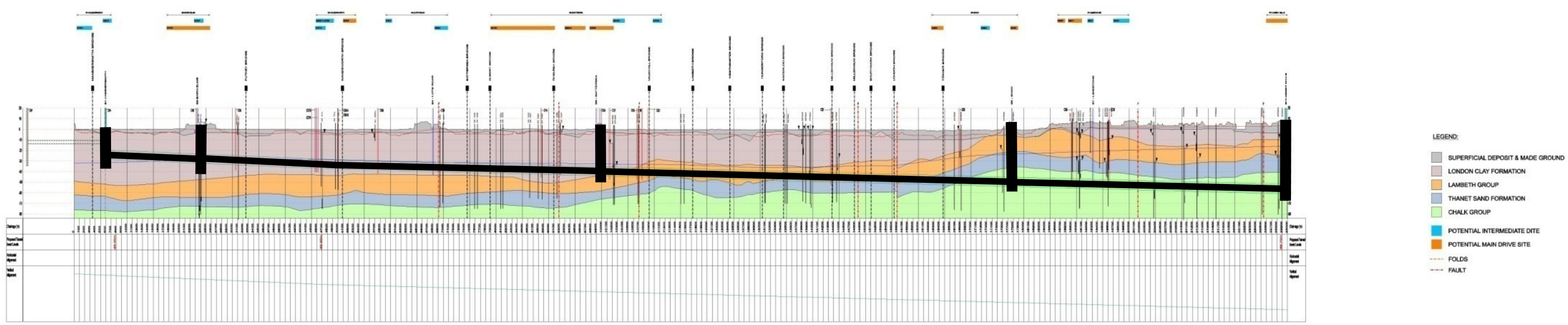




OPTION 1 BOREHOLES AND PIEZOMETERS
Scale = 1:1 Horiz 1:10 Vert

Abbey Mills Route (Preferred Option)





OPTION 2 VIA S7 BOREHOLES AND PIEZOMETERS
Scale = 1:1 Horiz 1:10 Vert

Comparison of Route Options

	Thames	Rotherhithe	Abbey Mills
Capturing CSO discharges – Tunnel volume (million m3) – Spill volume (mill m3/typical yr) – Number of Spill Events (typical yr)	 1.83 1.1 2	 1.78 1.2 2	 1.5 2.0 4
Drive length – Main Tunnels – Connection Tunnels	 32km 8.5km	 30km 8.5km	 22km 9.0km
Third party interfaces – Tunnelling below built up areas	 3km	 5km	 4.5km
Drive sites – Number of main drive sites	 5	 5	 3
Construction Programme	2020	2020	2020
Cost	Similar	Similar	15 to 20% cheaper

Early Works – Lee Tunnel

- Abbey Mills is worst offender in terms of discharge into Thames (via the River Lee), which accounts for 16million tonnes of the 39million tonnes of sewage discharged into the Thames each year.
- Lee Tunnel carried out as separate Contract in advance of the Thames Tunnel Works as provides Biggest 'Bang for your Buck'
- Also benefits to programme, 'spend profile', and lessons learned for future Thames Tunnel Contracts.

Abbey Mills, River Lee and the Olympics

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The Olympics Zone
Thames Water
N
Northern Coach Park
Stratford City Development
Stratford International Station
River Lee Navigation
River Lee
Old Ford Locks
Main Stadium
Mid & High Level Interceptor Sewers
Wick Lane CSO
Western Coach Park
Southern Coach Park
Lower Lee Valley Regeneration
A
F
NOS to Beckton
Abbey Mills CSO
Low Level Interceptor Sewers
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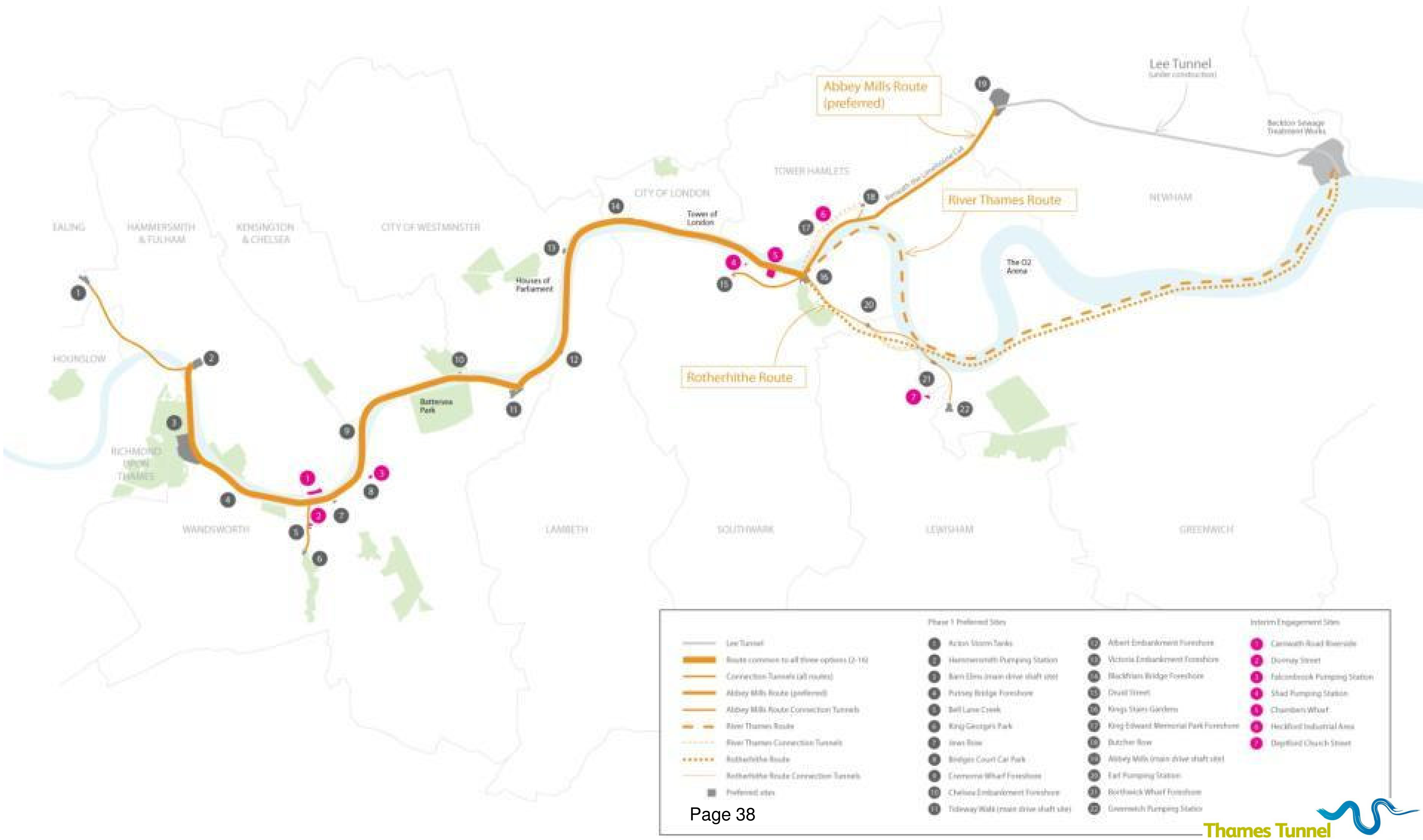
The Thames Tunnel

The Thames Tunnel: Preferred Route
(Stage 1 Consultation and Interim Engagement)



Thames Tunnel
Creating a cleaner, healthier River Thames

Thames Tunnel: Programme

Summer 2010
Public consultation 1st round

Late 2010
Analysis of responses and scheme amendments

Mid-2011
Public consultation 2nd round

2012
Planning submission

2013
Start of main construction

2020 Completion

Thames Water

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Thames Tunnel: Funding

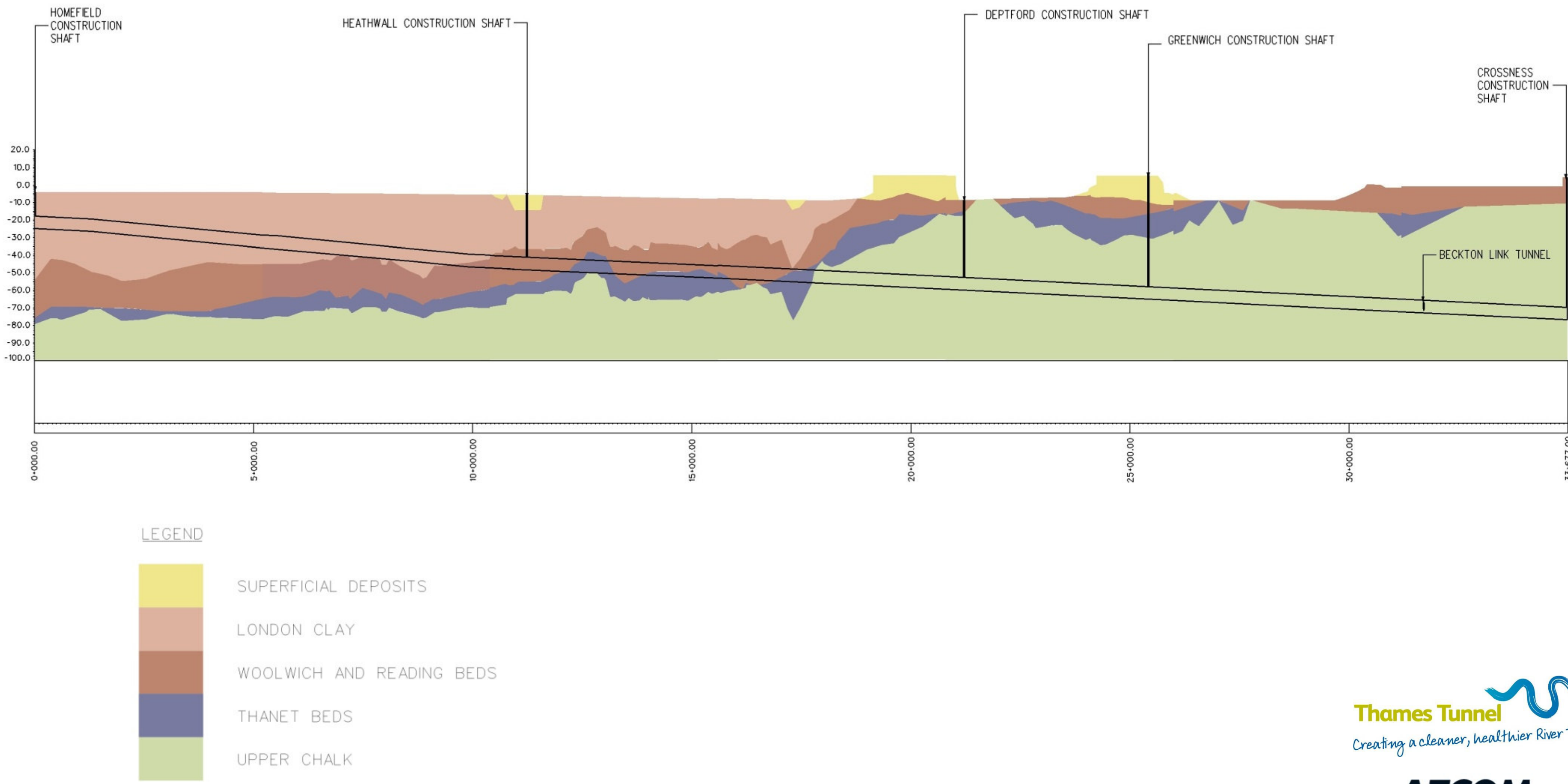
- The costs for the construction of the Thames Tunnel will be paid for by Thames Water wastewater customers.
- Estimated total costs of building the Abbey Mills Route £3.6 billion, up to 20% cheaper than the other routes.
- We expect that the construction and operation of the Thames Tunnel will require our average bill to have risen by slightly more than £1 a week by 2018.

Main Tunnel Works: Statistics

- Tideway Tunnel
  - 7.2m Internal Diameter
  - 35km length at up to 85m depth
- Main Shafts
  - 25m – 40m Internal Diameter at up to 85m depth
  - 5no. Shafts
- Abbey Mills Link
  - 5m Internal Diameter
  - 4.5km length at up to 65m depth

Thames Water

Main Tunnel Works
Ground Conditions: Geotechnical Long Section



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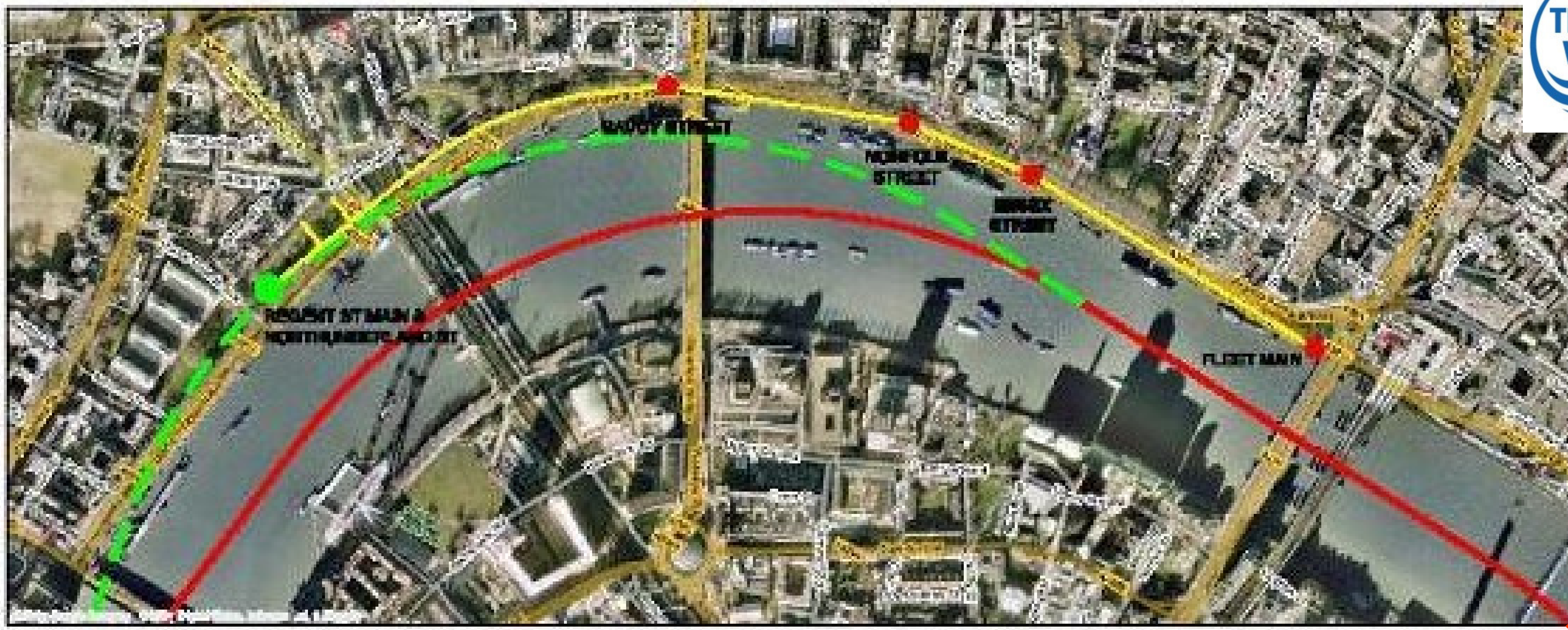
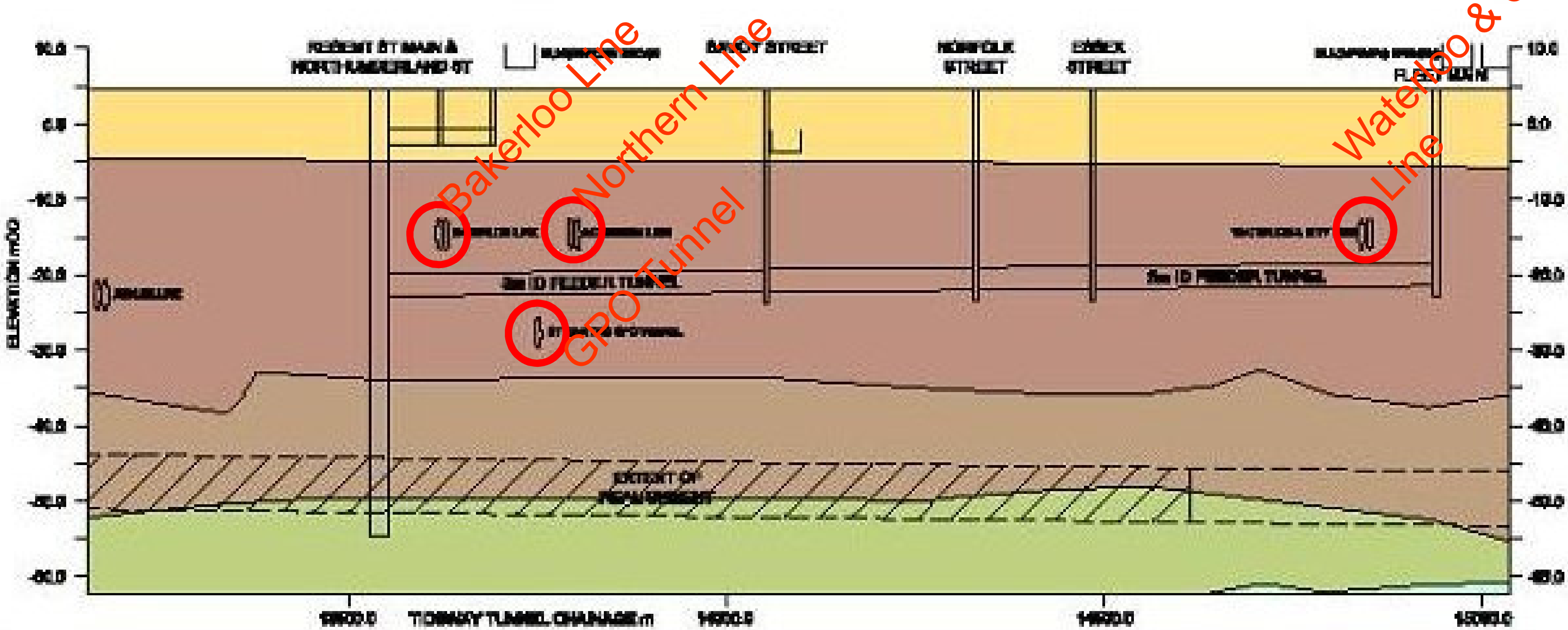
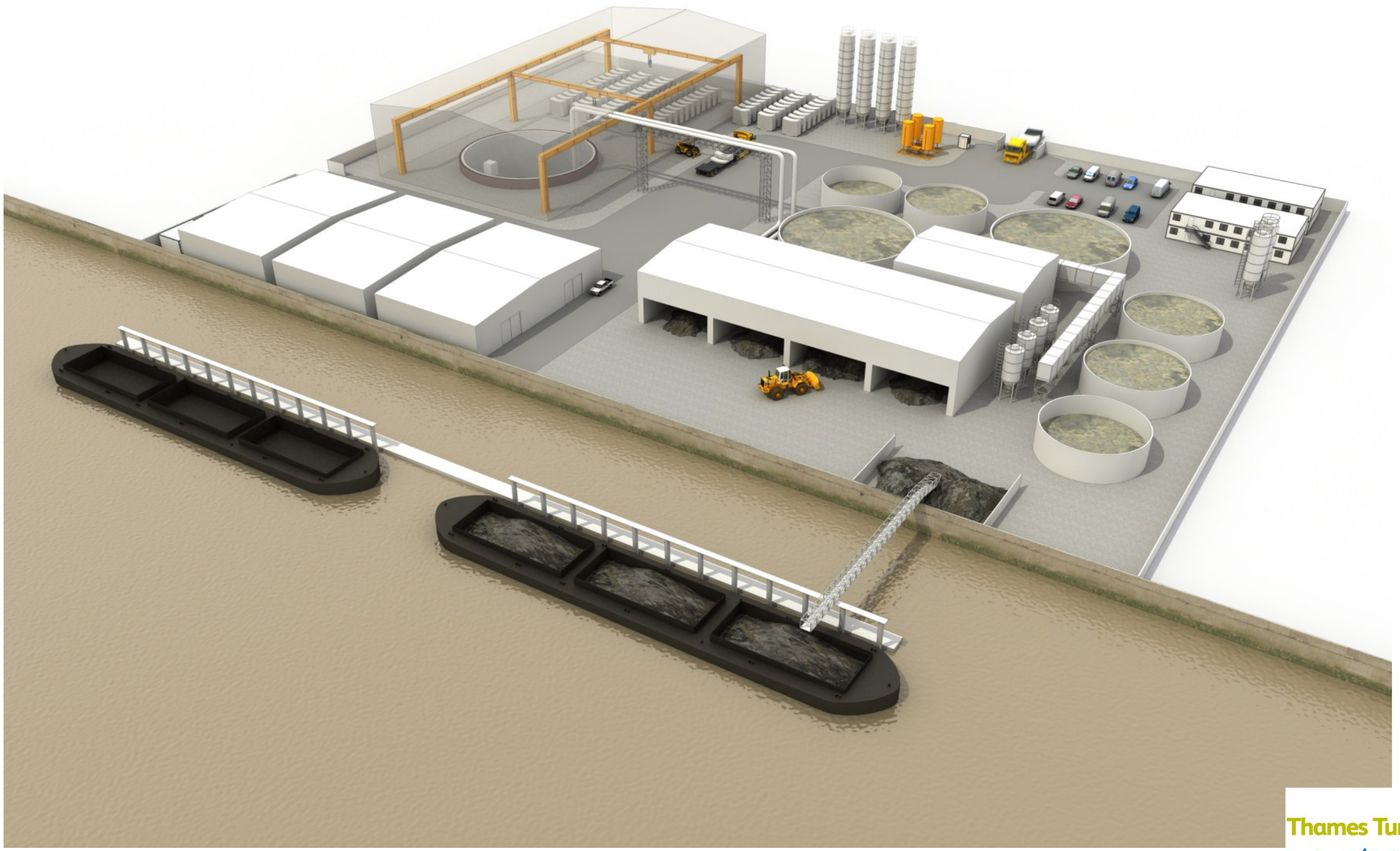
Thames Water





Main Tunnel Works
Use of River for Construction Traffic



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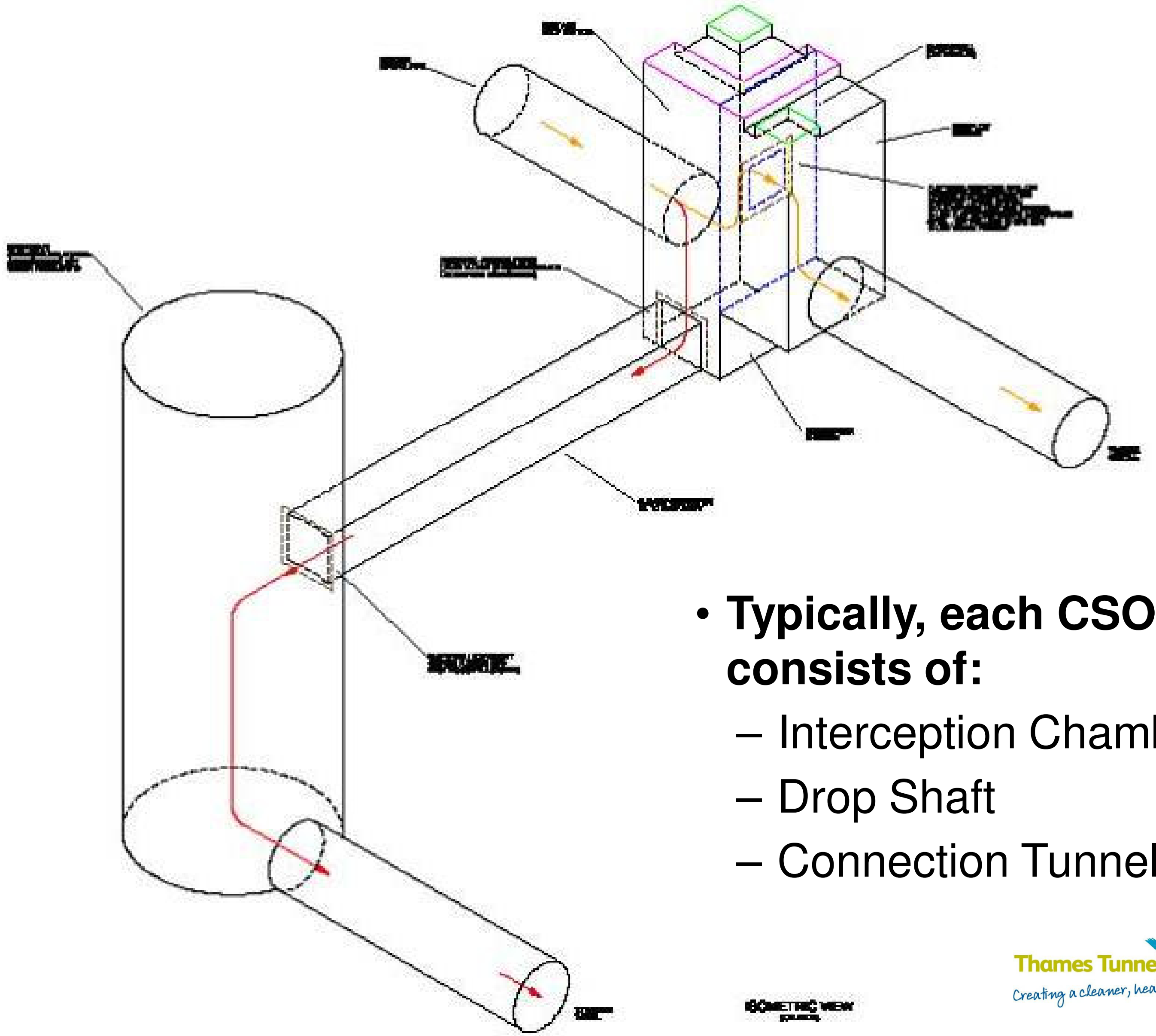
CSO Works: Statistics

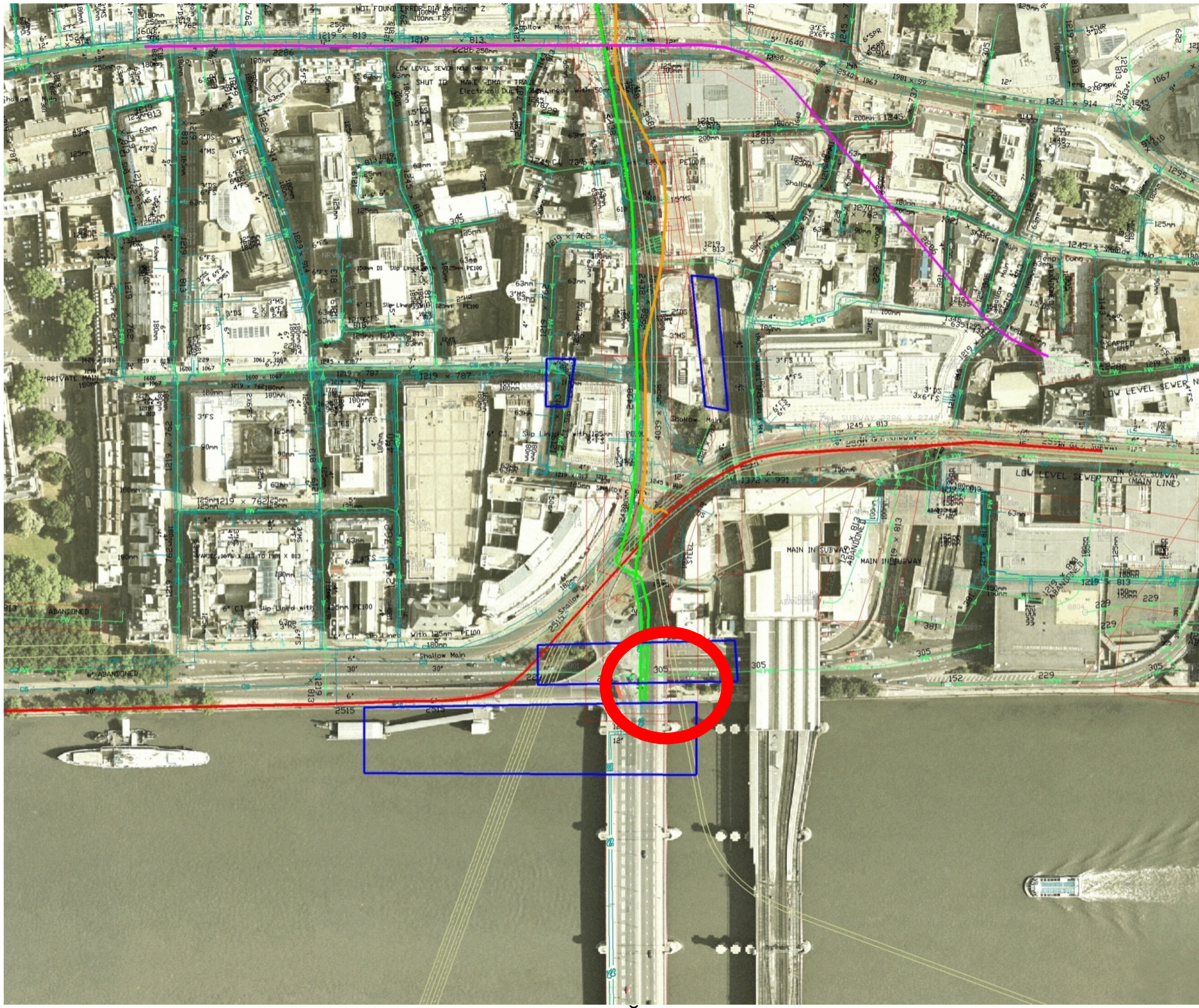
- CSO's
  - 36no. CSO Connections (Reduced to 20no. with value Engineering)
  - Consisting of Connection Chamber, Drop Shaft & Tunnel
- Connection Chambers
  - Sizes vary
  - Plan Areas Ranging from 2m x 3m to 13m x 13m
- CSO Drop Shafts
  - Internal Diameters vary: 6.0m, 7.5m & 9.0m
- CSO Connection Tunnels
  - Internal Diameters vary: 1.5m, 2.0m & 3.0m
  - Total combined length of over 7km

CSO Works:
Principles for Interception Chambers



- **Typically, each CSO Connection consists of:**
  - Interception Chamber
  - Drop Shaft
  - Connection Tunnel to Main Tunnel

Examples of Constrained CSO Sites: Fleet Sewer



Examples of Constrained CSO Sites: Fleet Sewer

Examples of Constrained CSO Sites: Fleet Sewer

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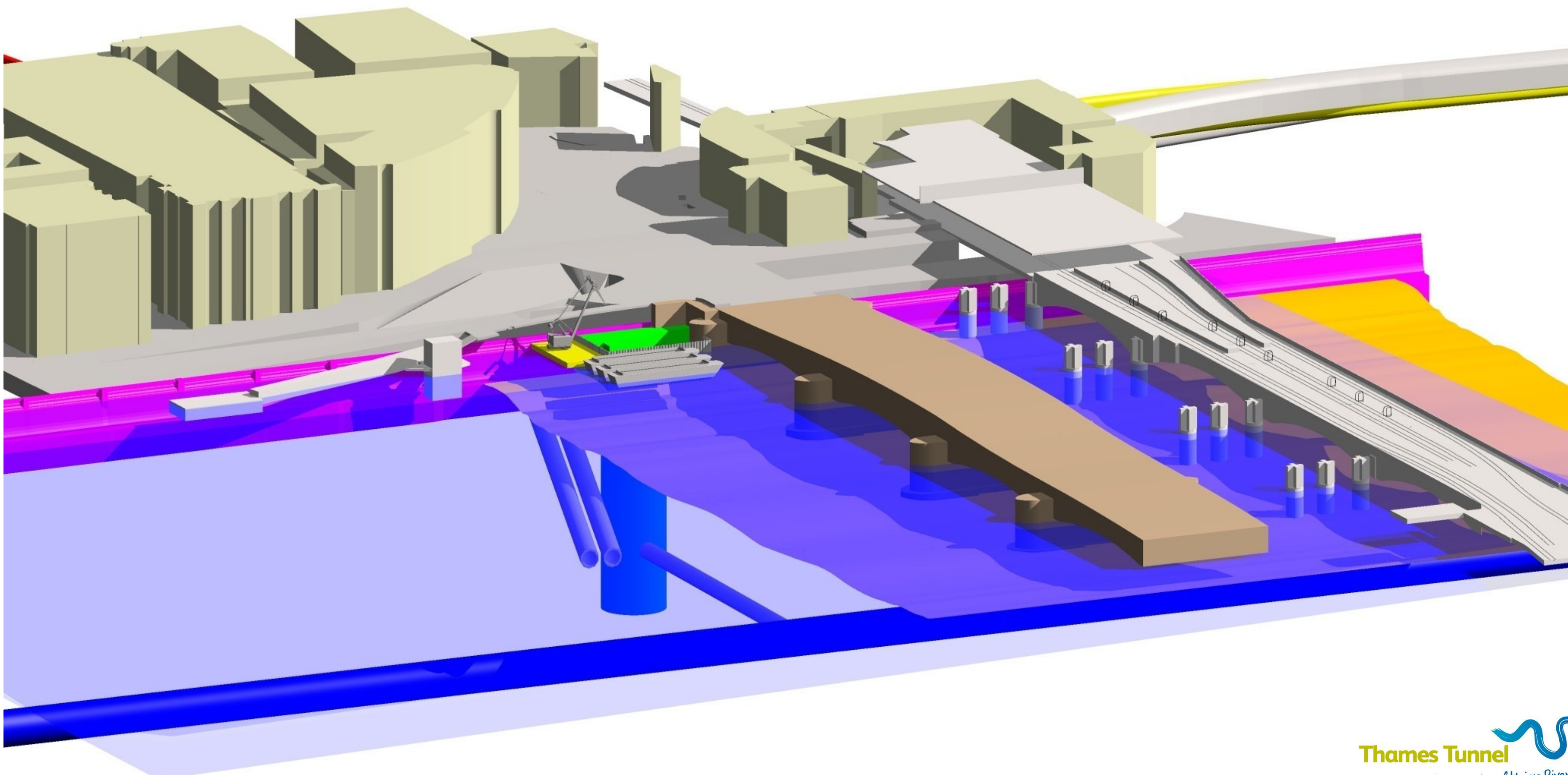
Examples of Constrained CSO Sites: Fleet Sewer

- Third party issues: Blackfriars Road Bridge, Network Rail, District & Circle Line, Waterloo & City Line Tunnels & Bankside Cable Tunnel.



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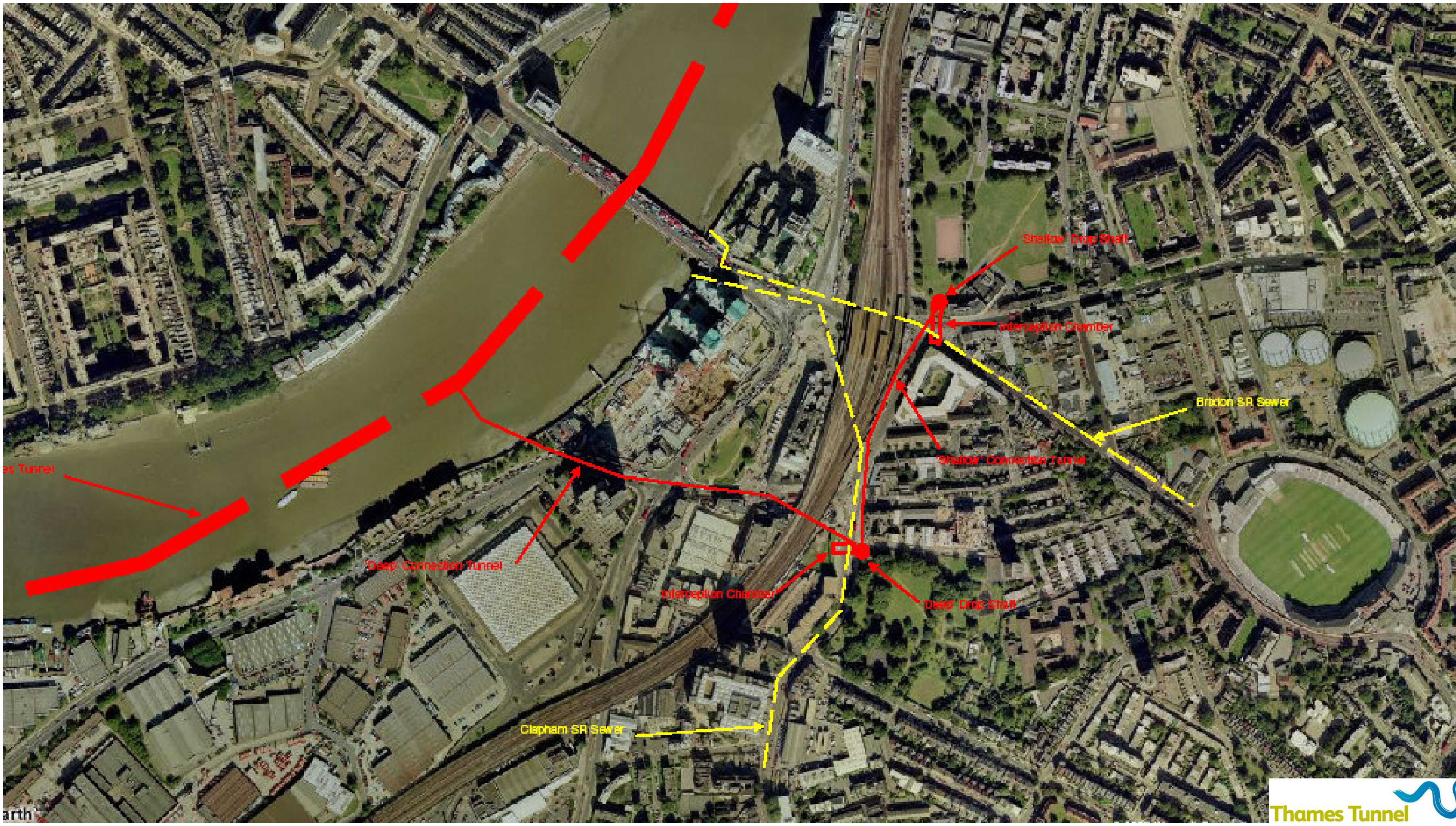
Examples of Constrained CSO Sites: Brixton & Clapham Storm Relief Sewers

Examples of Constrained CSO Sites: Brixton & Clapham Storm Relief Sewers



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Examples of Constrained CSO Sites: Shad Pumping Station Outfall

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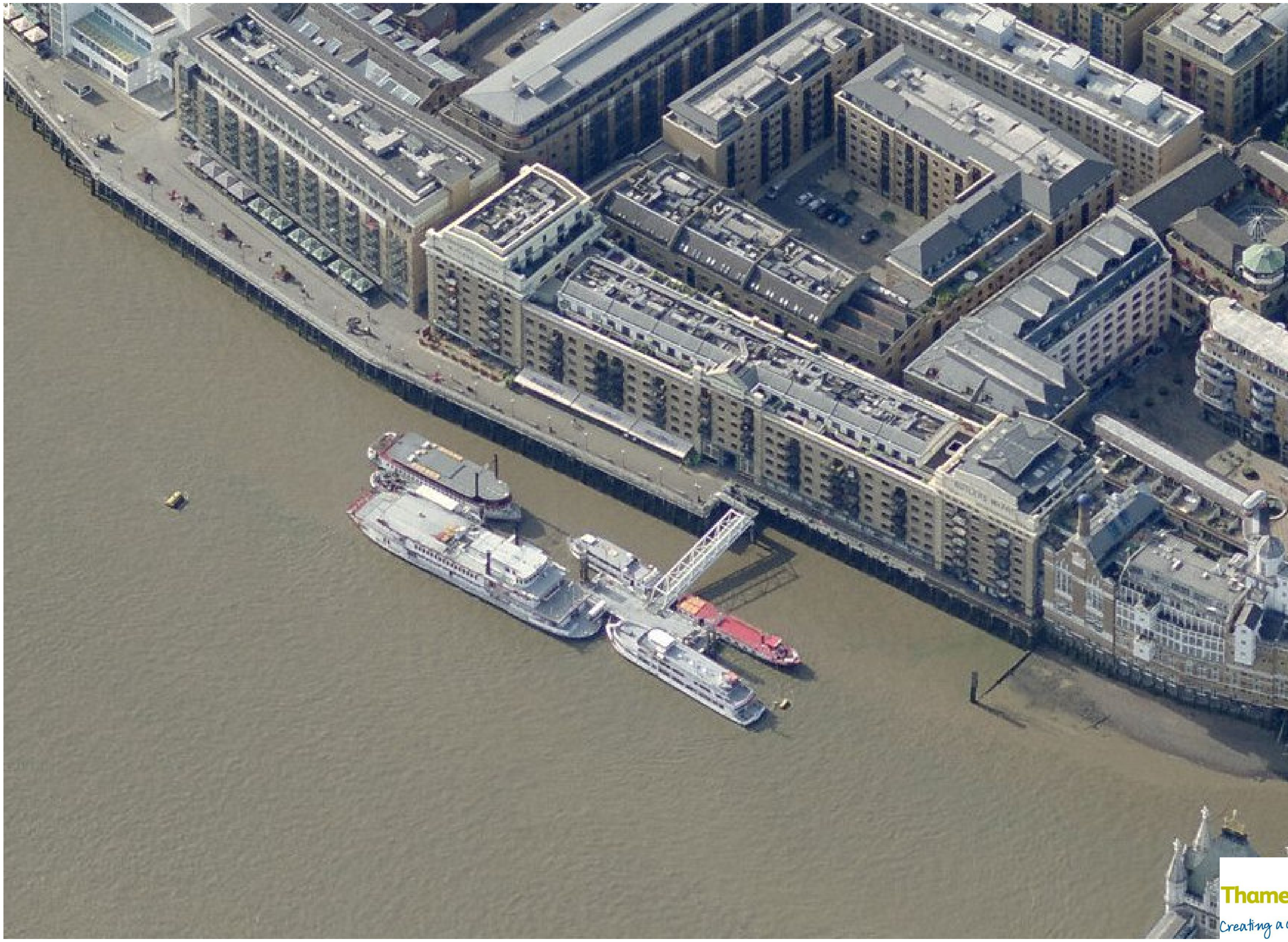
Examples of Constrained CSO Sites: Shad Pumping Station Outfall



Examples of Constrained CSO Sites: Shad Pumping Station Outfall

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Examples of Constrained CSO Sites: Shad Pumping Station Outfall

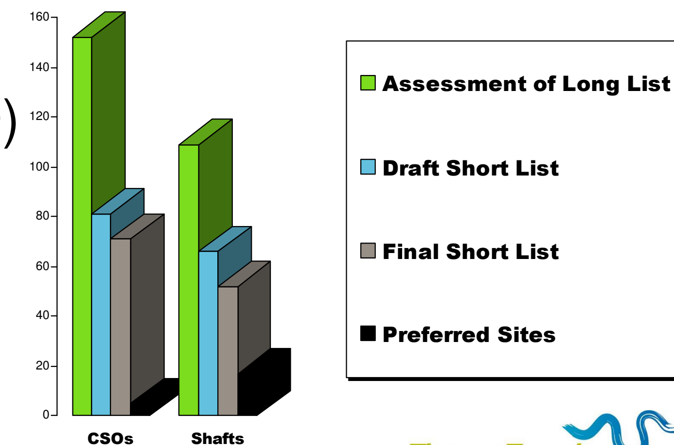
Determining Preferred Sites for Consultation and Planning

This stage comprises a site identification and filtering process, carried out in three main parts:

- 1A - Creation of a long list of potential sites:
  769 potential main tunnel shaft sites & 373 potential CSO sites.

- 1B – Creation of a short list of potential sites:
  Main tunnel shaft sites reduced to 52 & CSO sites reduced to 71.

- 1C – The creation of list of preferred sites:
  5 main shaft site (3 are combine shaft/CSO) & 17 CSO sites.



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The Lee Tunnel

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Lee Tunnel: Summary

- Was largest UK infrastructure project awarded in 2010
- Form the first 20% of the Thames Tideway Tunnel system
- Deepest and largest bored tunnel in London
- Four largest shafts constructed in London

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Lee Tunnel: Purpose

- The Abbey Mills CSO creates 40% of the total discharges in the Thames (via the River Lee)
- Lee Tunnel will eliminate the Abbey Mills discharges

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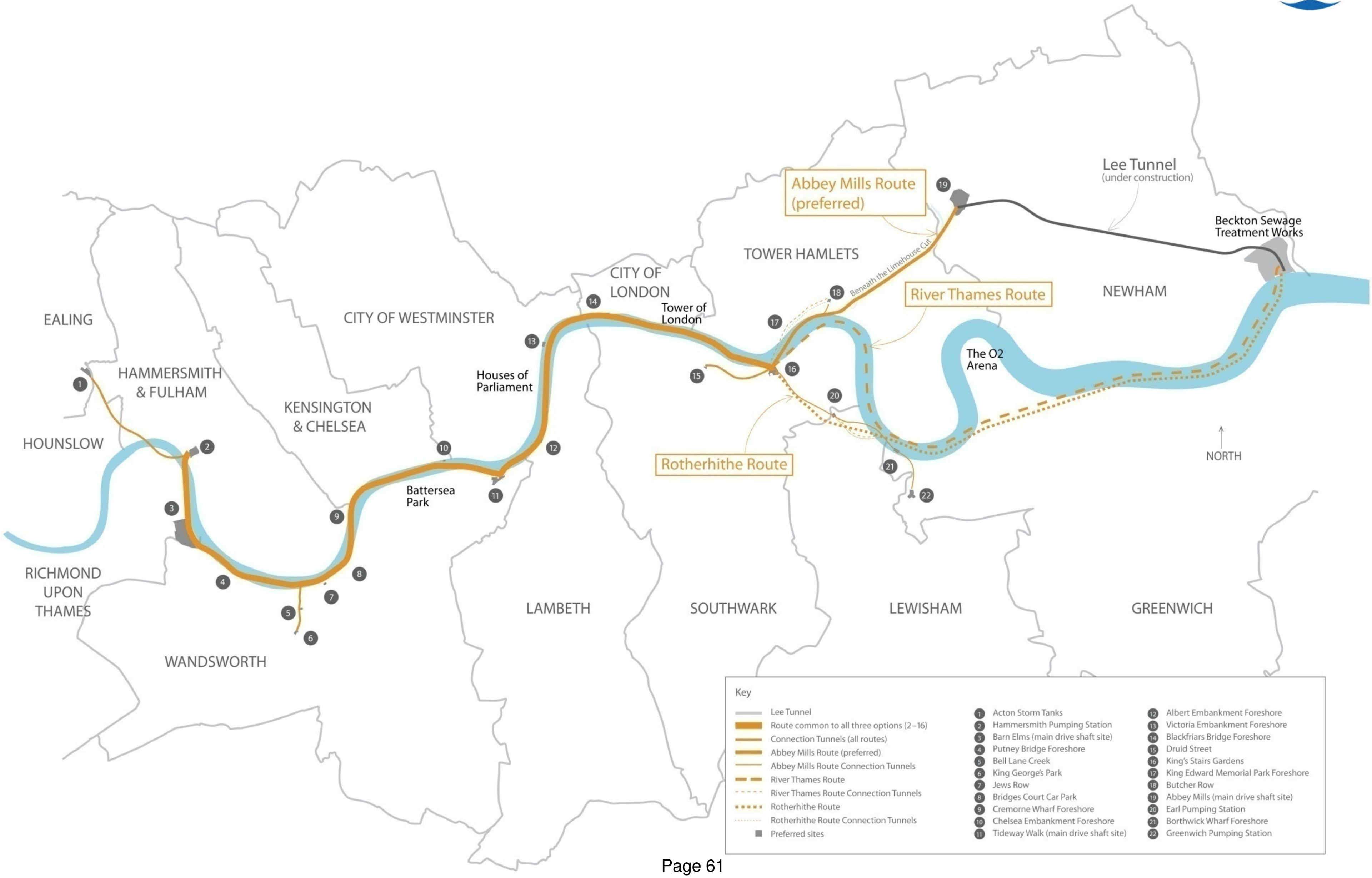
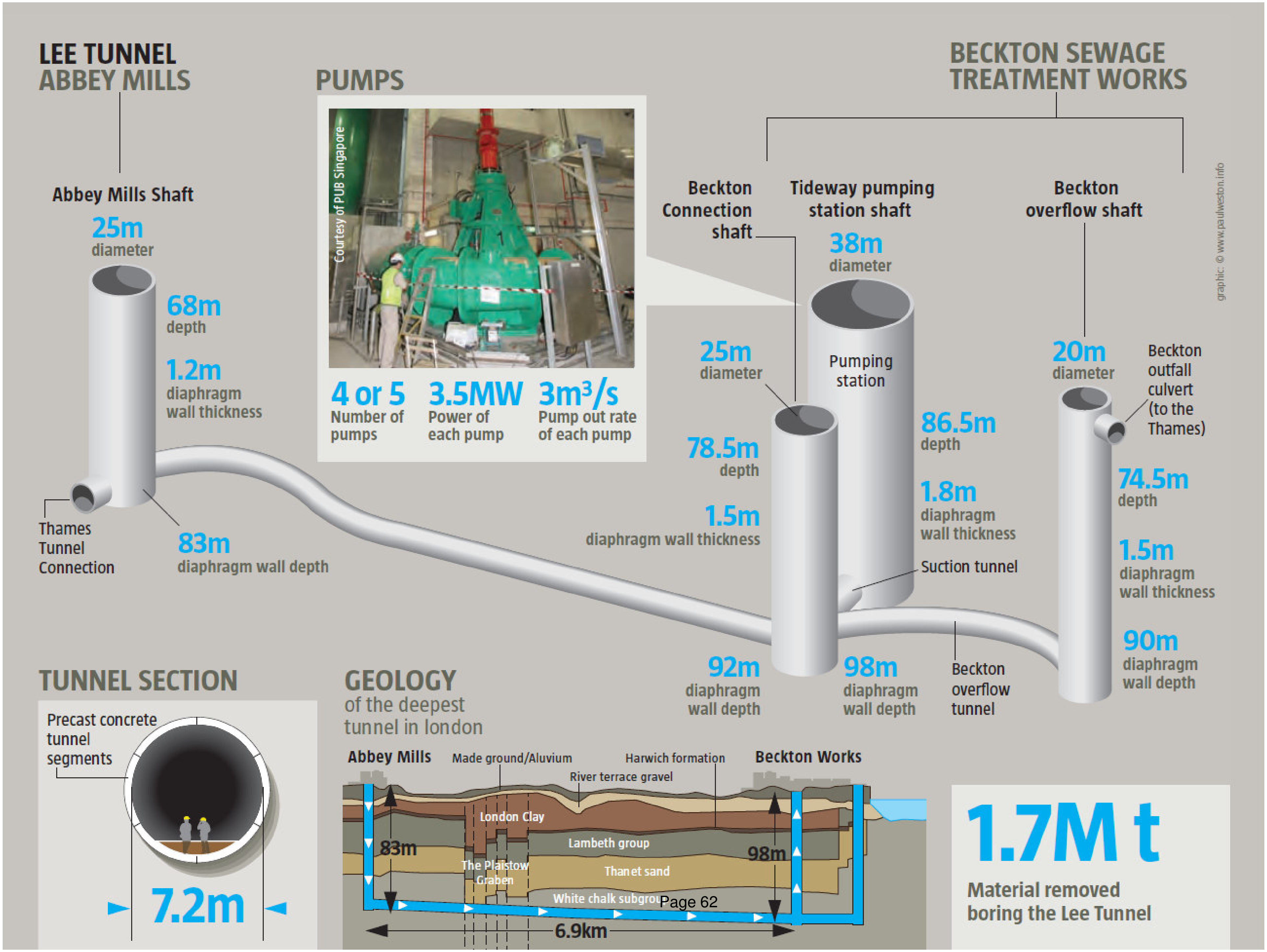
Creating a cleaner, healthier River Thames

Lee Tunnel: Alignment




LEE TUNNEL
ABBEY MILLS
Abbey Mills Shaft
25m
diameter
68m
depth
1.2m
diaphragm
wall thickness
Thames
Tunnel
Connection
83m
diaphragm wall depth
PUMPS
Courtesy of PUB Singapore
4 or 5
Number of
pumps
3.5MW
Power of
each pump
3m³/s
Pump out rate
of each pump
BECKTON SEWAGE
TREATMENT WORKS
Beckton
Connection
shaft
Tideway pumping
station shaft
38m
diameter
Pumping
station
Beckton
overflow shaft
graphic: © www.paulweston.info
25m
diameter
78.5m
depth
1.5m
diaphragm wall thickness
86.5m
depth
1.8m
diaphragm
wall thickness
Suction tunnel
20m
diameter
Beckton
outfall
culvert
(to the
Thames)
74.5m
depth
1.5m
diaphragm
wall thickness
92m
diaphragm
wall depth
98m
diaphragm
wall depth
Beckton
overflow
tunnel
90m
diaphragm
wall depth
TUNNEL SECTION
Precast concrete
tunnel
segments
7.2m
GEOLOGY
of the deepest
tunnel in london
Abbey Mills
Made ground/Aluvium
Harwich formation
Beckton Works
River terrace gravel
London Clay
Lambeth group
83m
98m
The Plaistow
Graben
Thanet sand
White chalk subgrou
6.9km
1.7M t
Material removed
boring the Lee Tunnel

Lee Tunnel: Contract

- Overall Budget of £635m
- Design and Construct Contract based on Employer Reference Design
- New Engineering Contract NEC 3rd Edition Option C – Activity Schedule
- Awarded to MVB – Consortium of Morgan Sindall, Vinci Construction Grands Projets, Bachy Soletanche Limited
- Project Management Team (PMT) led by CH2M Hill
- AECOM carried out concept and preliminary studies and reference design, and is now providing technical support on site to Thames Water.

Lee Tunnel: Programme

May 2008:	Submission of Lee Tunnel Planning Application
Aug 2008:	Issue of Tender Documents
Jan 2010:	Award of Design and Construction Contract
Sep 2010:	Commence Overflow Shaft Construction (20m ID)
Jan 2011:	Commence Pumping Station Shaft Construction (38m ID)
Mar 2011:	Commence Connection Shaft Construction (25m ID)
Aug 2011:	Commence Abbey Mills Shaft F Construction (25m ID)
Nov 2011:	Complete Overflow Shaft Construction
Dec 2011:	Lower TBM Down Overflow Shaft
Feb 2012:	Commence TBM Drive
Apr 2015:	Lee Tunnel Operational

Lee Tunnel
Creating a cleaner, healthier River Thames

Lee Tunnel:
The Team

- Thames Water
- CH2M Hill
- AECOM
- Morgan Vinci Bachy JV
- UnPS
- Bachy Soletanche
- Mott MacDonald

Lee Tunnel: TBM being Lowered into Drive Shaft

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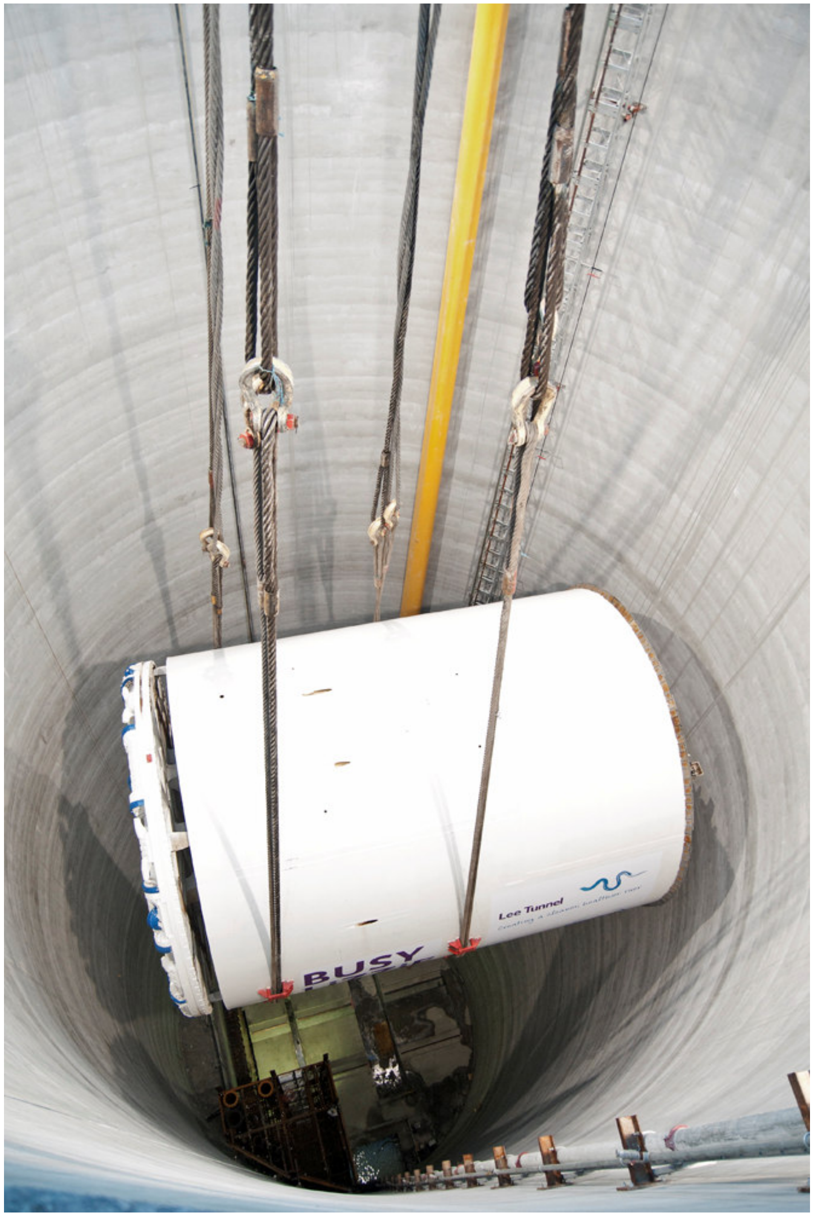
Lee Tunnel: TBM being Lowered into Drive Shaft



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Lee Tunnel: TBM being Lowered into Drive Shaft

Lee Tunnel: TBM Slurry Treatment Plant

Lee Tunnel

Creating a cleaner, healthier River Thames

Lee Tunnel:
Excavated Material Removed by Barge (for reuse)

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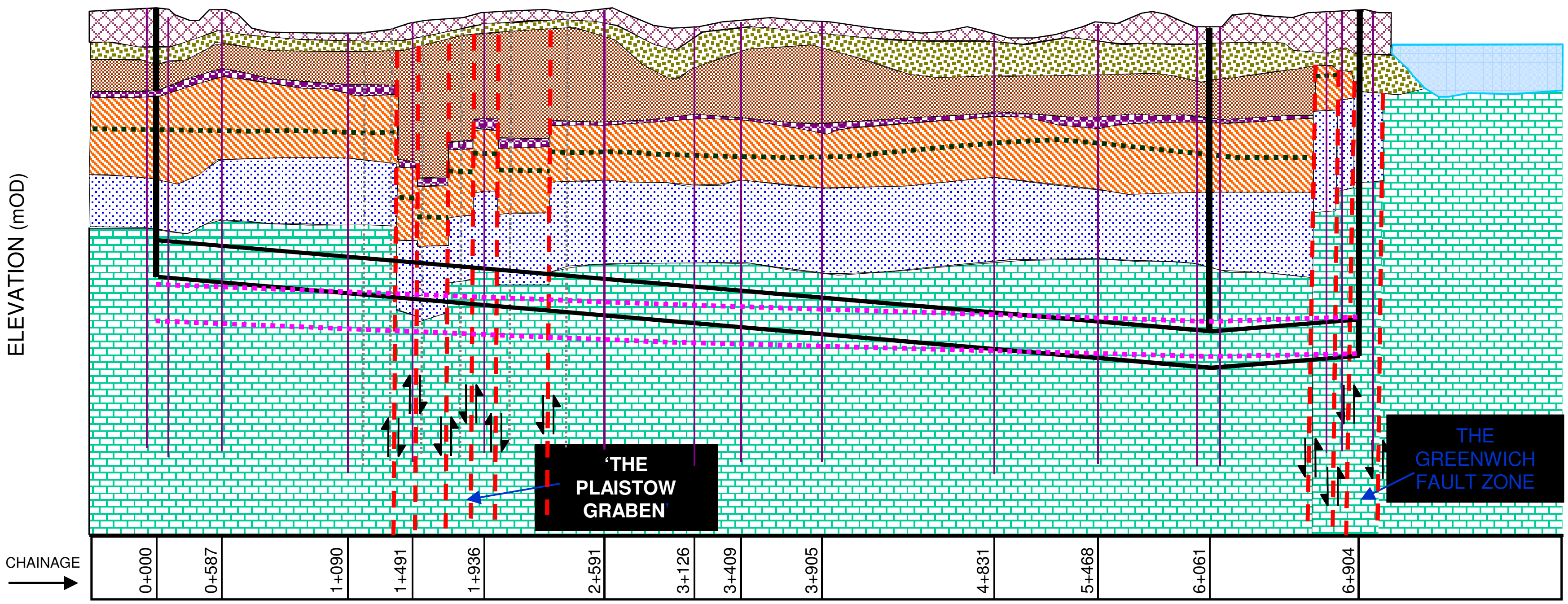
Lee Tunnel:
Geotechnical Profile



KEY TO GEOLOGY

- MADE GROUND / ALLUVIUM
- RIVER TERRACE GRAVEL
- LONDON CLAY FORMATION
- HARWICH FORMATION
- LAMBETH GROUP
- THANET SAND FORMATION
- WHITE CHALK SUBGROUP
- GEOLOGICAL FAULT
- POSITION OF MID LAMBETH GROUP HIATUS
- BOREHOLE AND DESIGNATION

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Lee Tunnel:
Precast Concrete Segmental Tunnel Linings

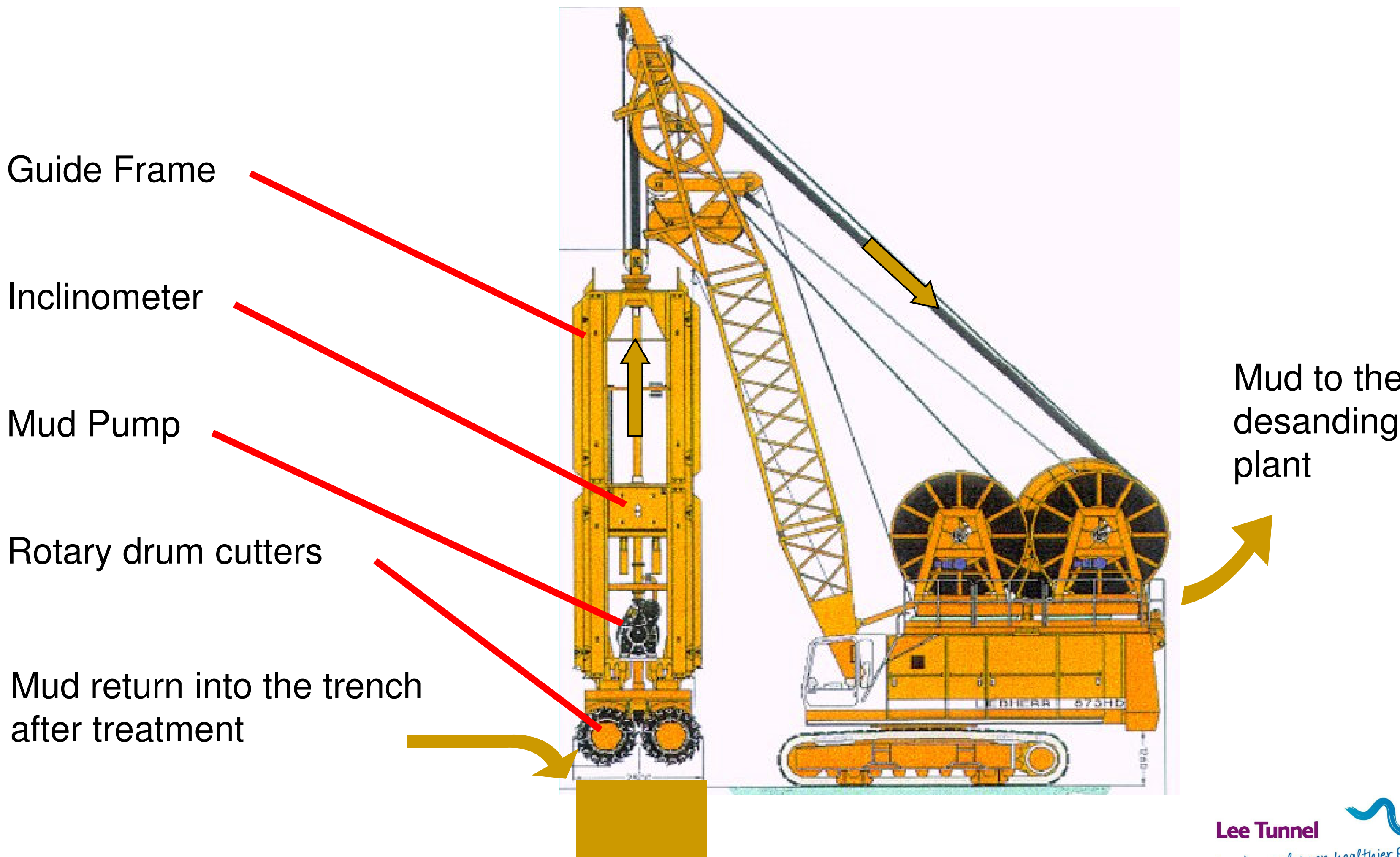
- Precast concrete segments 7 + key, 7.8m dia
- Universal ring 21mm taper
- 350mm thick
- Steel fibre reinforced
- Cast in EPDM gaskets optimising production
- Moulds and segments laser checked

Lee Tunnel: Shaft Primary Linings

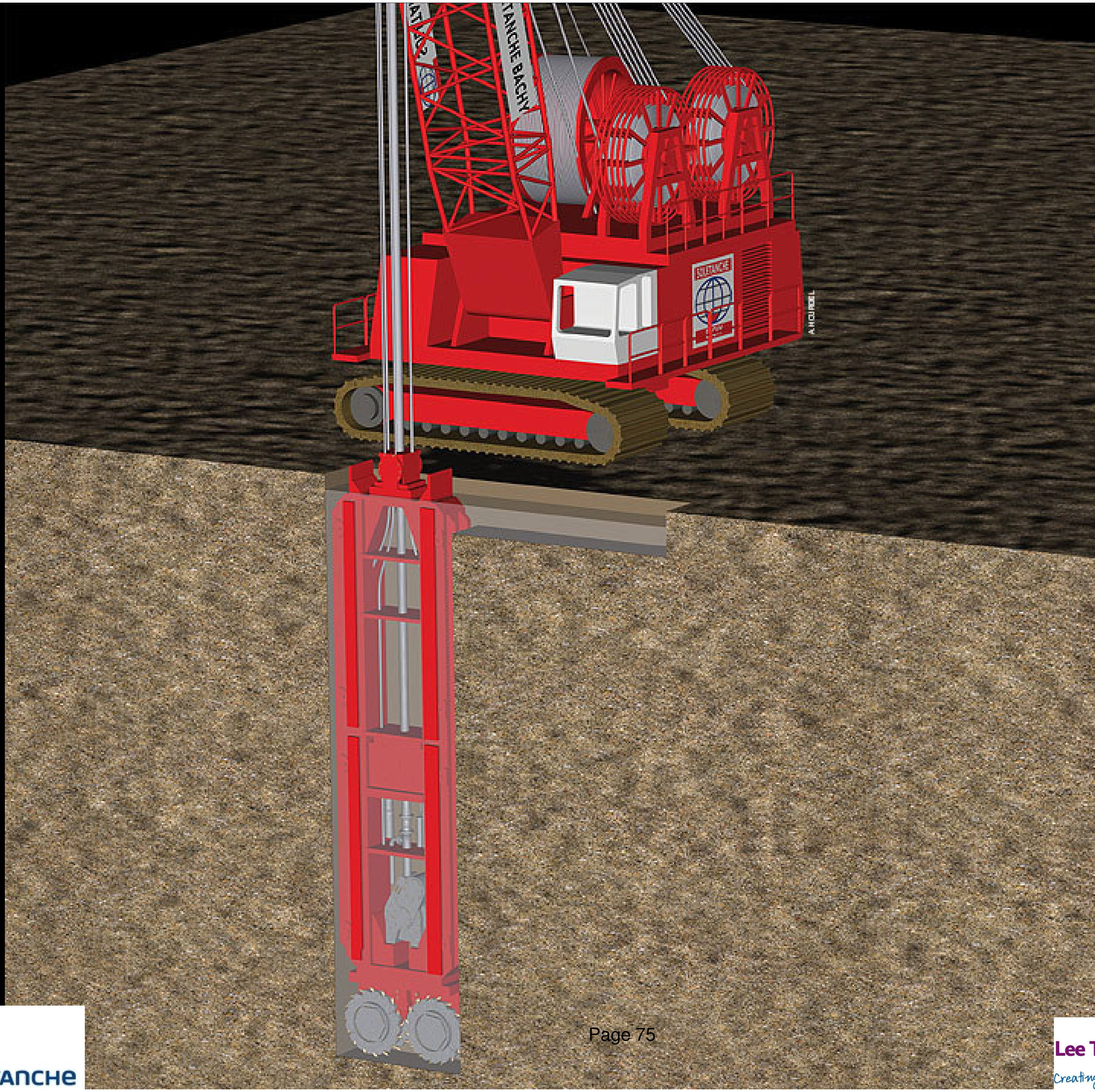
- Four deepest shafts in London
- Excavation over 85m
- Shaft Primary Lining Constructed Using Diaphragm Wall techniques
- 98m max depth
- 1.8m max thickness
- 1400m^3 max single pour

The Hydrofraise - Basic Operation

Thames Water



Thames Water



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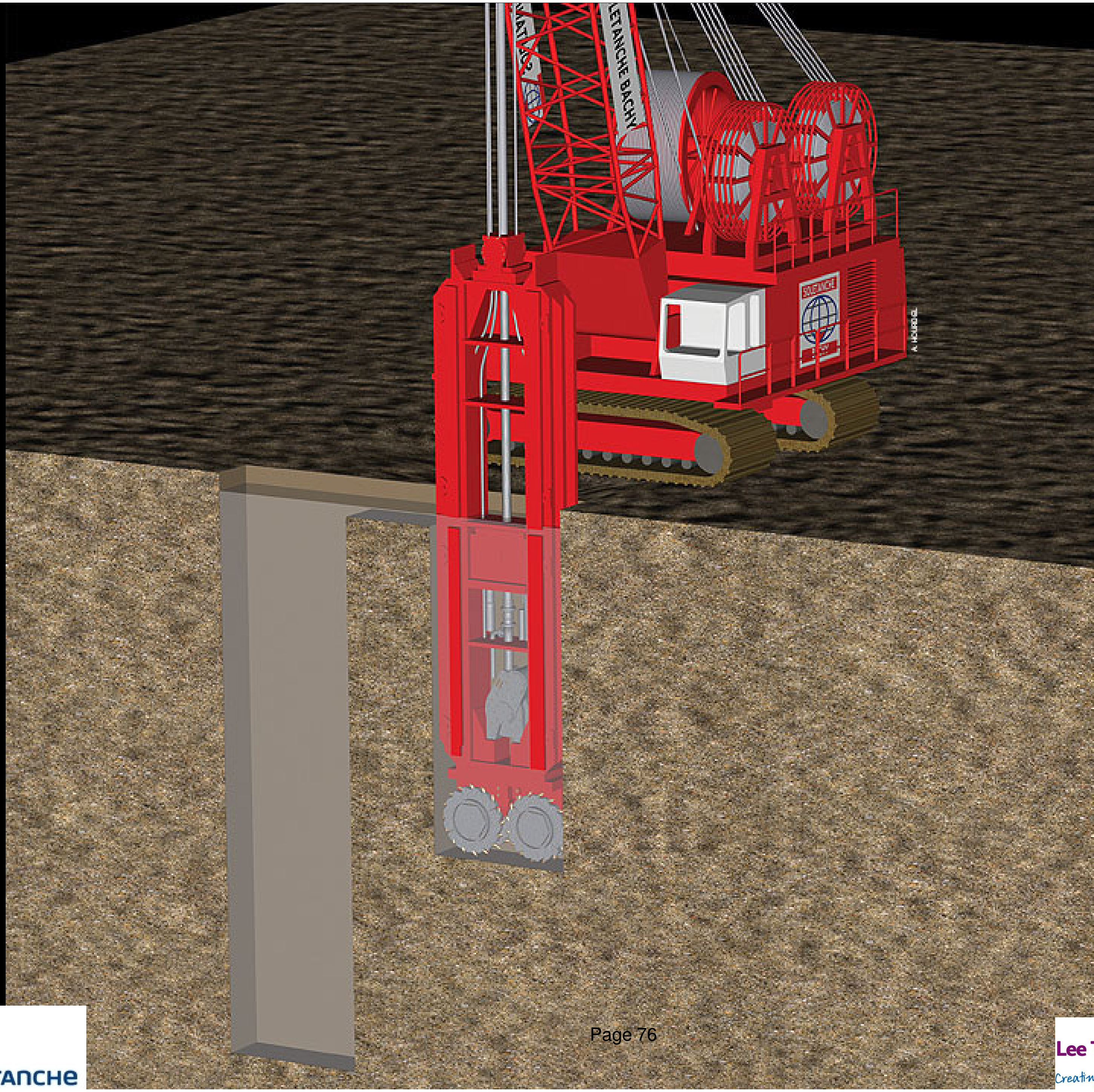
Lee Tunnel
Creating a cleaner, healthier River Thames

Thames Water



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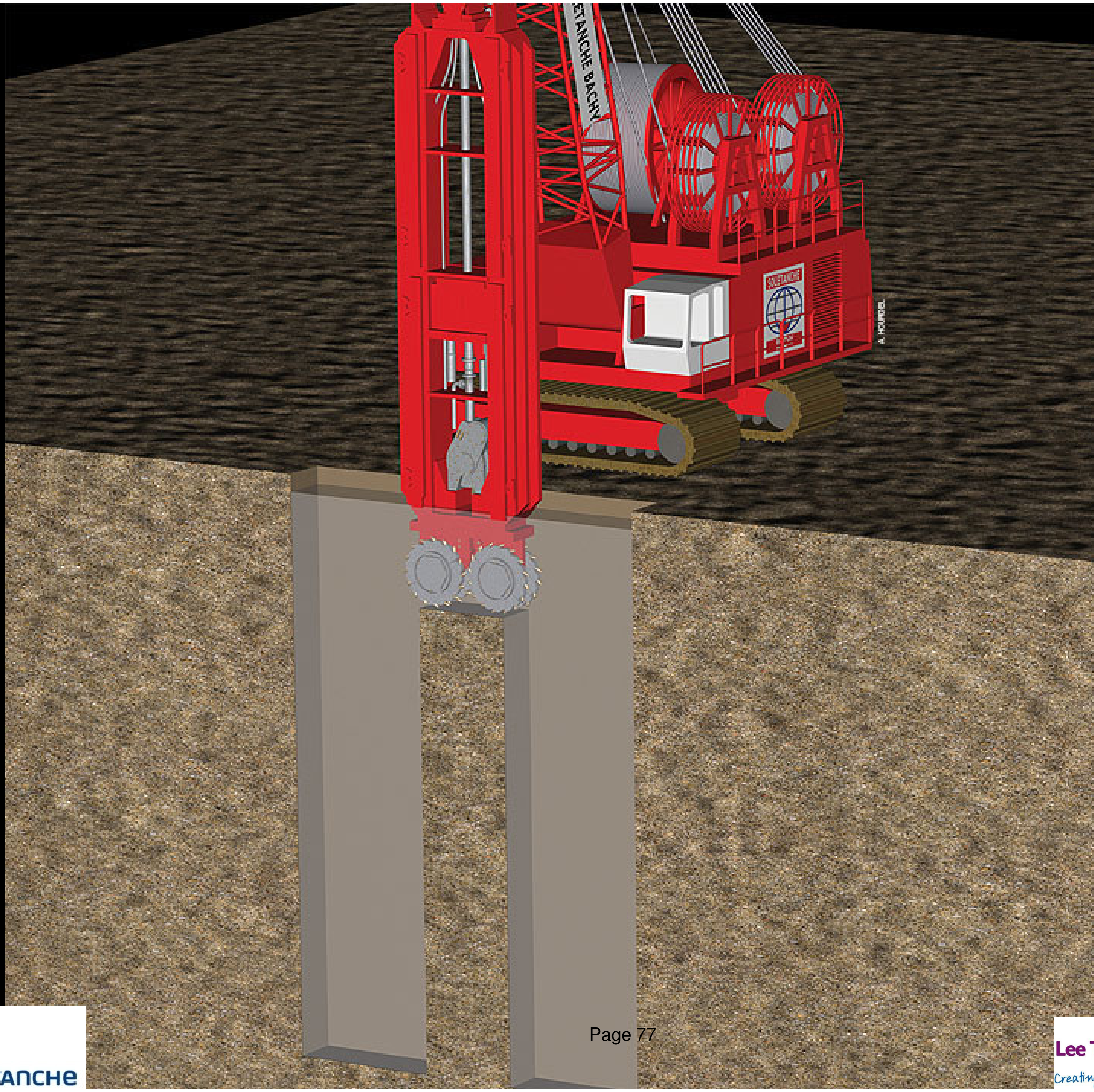
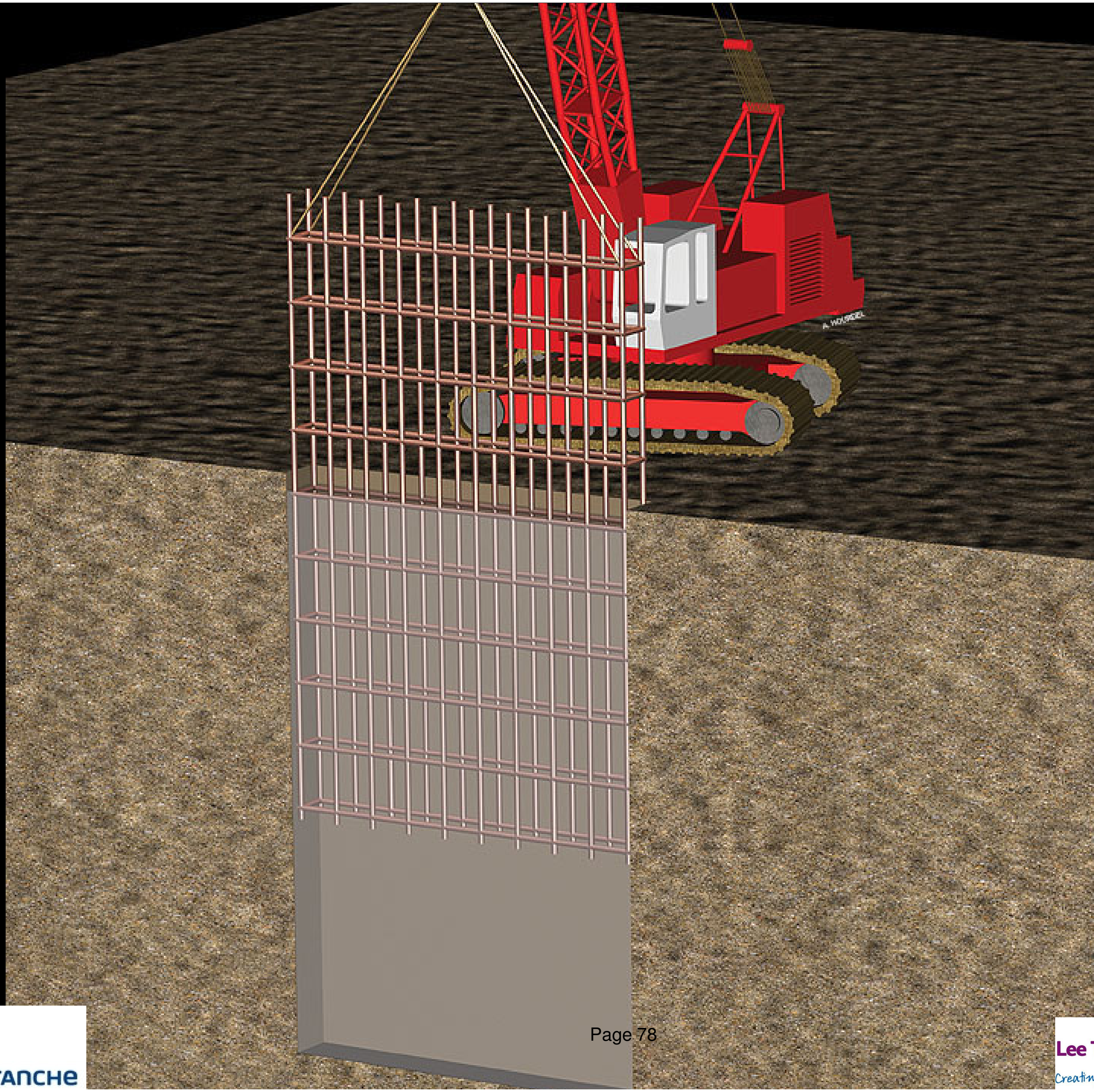


Thames Water



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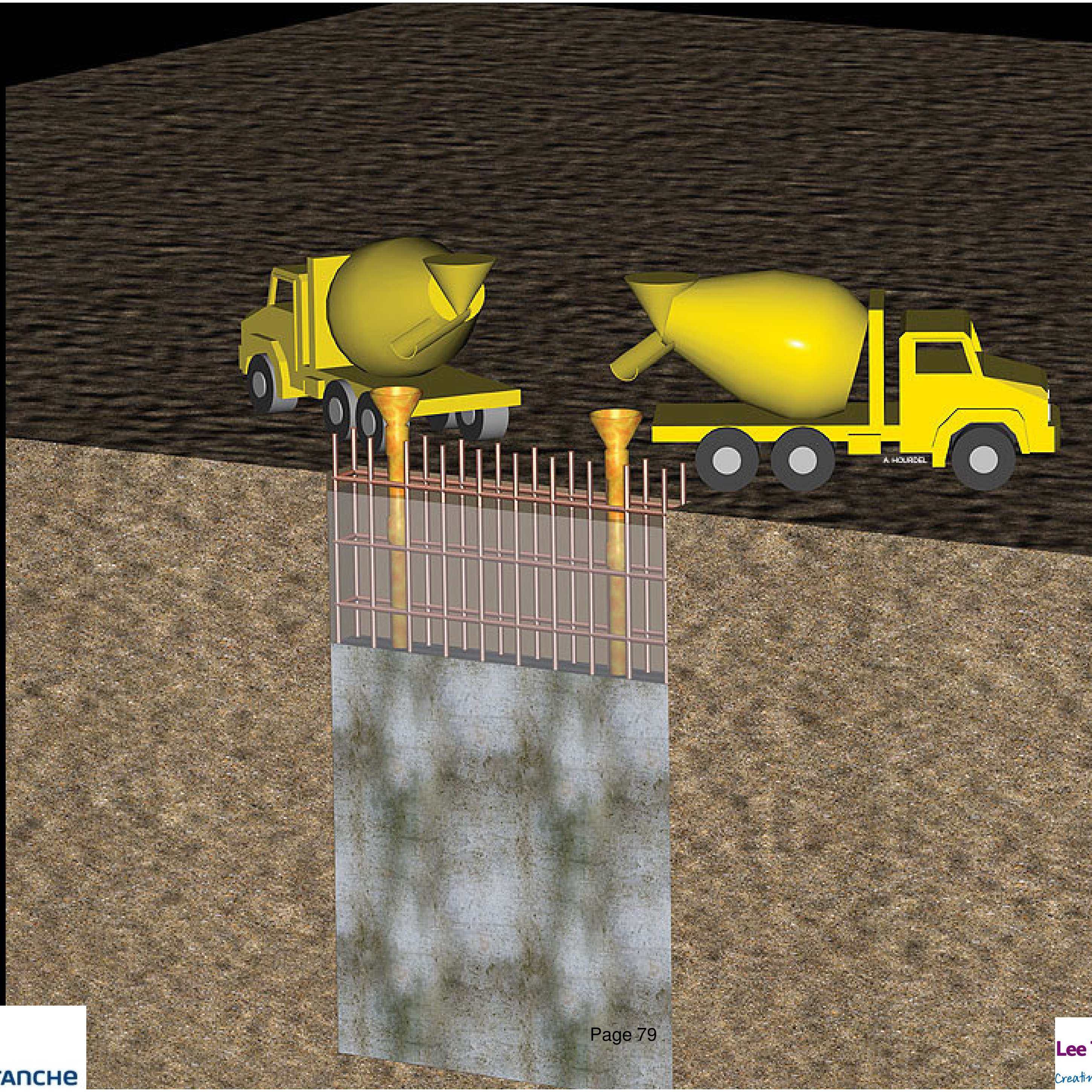

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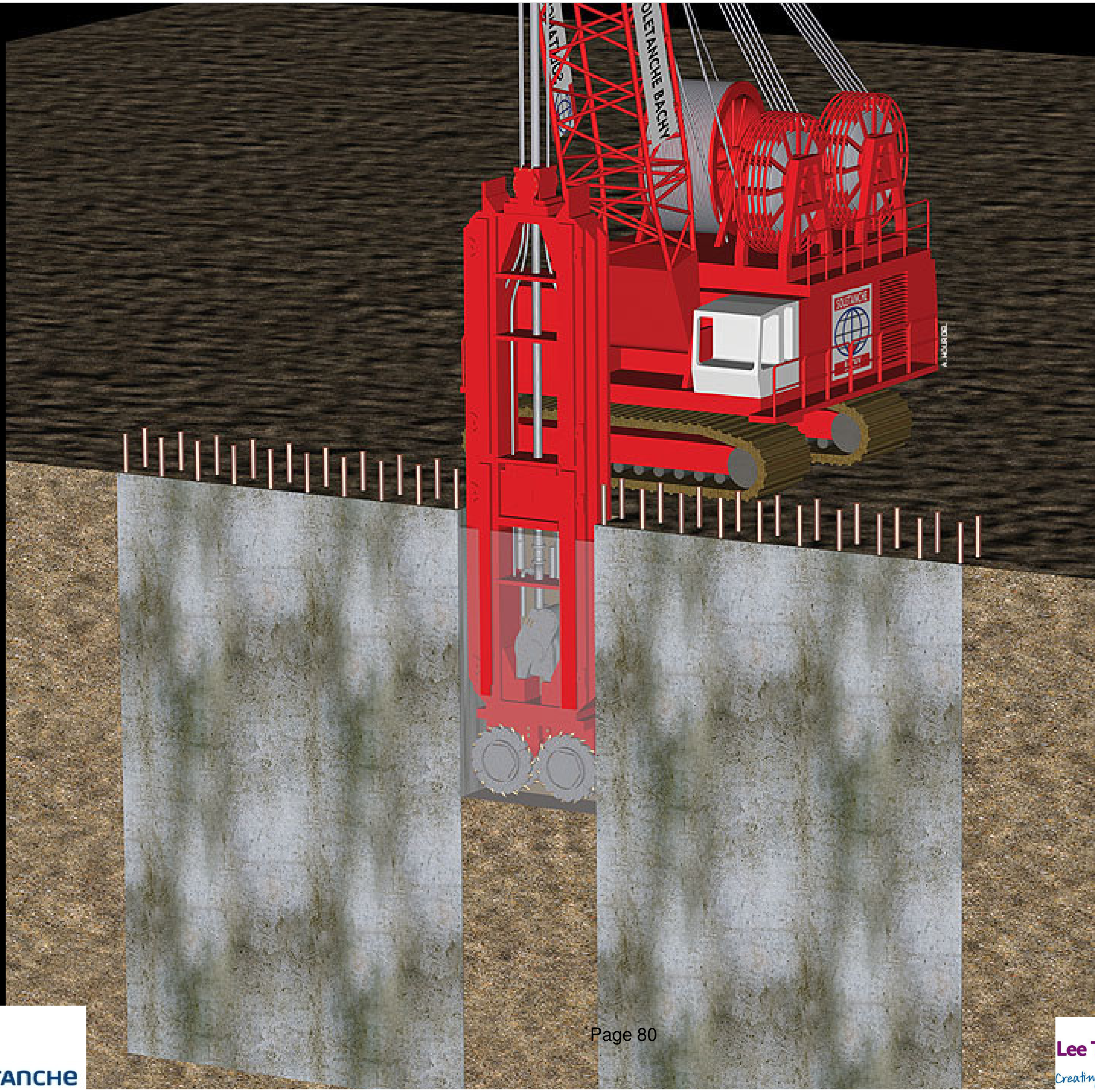

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Lee Tunnel
Creating a cleaner, healthier River Thames

Lee Tunnel:
Shaft Secondary Linings

Lee Tunnel:
Shaft Secondary Linings

- Initial approach was to pour reinforced concrete lining against the D-Wall
- Lining shrinks and cools, is compressed by groundwater pressures and creeps further
- Lining becomes independent, and must resist internal pressures in hoop tension

Lee Tunnel: Shaft Secondary Linings

- Concrete Chimney cast on slip membrane
- Annulus filled with high flow concrete
- Avoids shrinkage cracking, tension development & future elastic shortening
- Allows linings to be mostly designed as plain concrete
- Allows lining to be slipformed
- Steel fibres to increase durability (20kg/m^3)
- Saved 700 tonnes of reinforcement per shaft
- Innovative approach taken by JV team, including designers, contractors and client

Lee Tunnel:
Shaft Secondary Linings – Trials and Testing

- Slip Joint Tested to ascertain optimal coefficient of friction
- Low heat mix to minimise shrinkage and cracking: on site trials
- Different dosages and types of steel fibres trialled
- Ring cracking tests held in Belgium
- Slipform testing on site, with further full-scale tests at BRE

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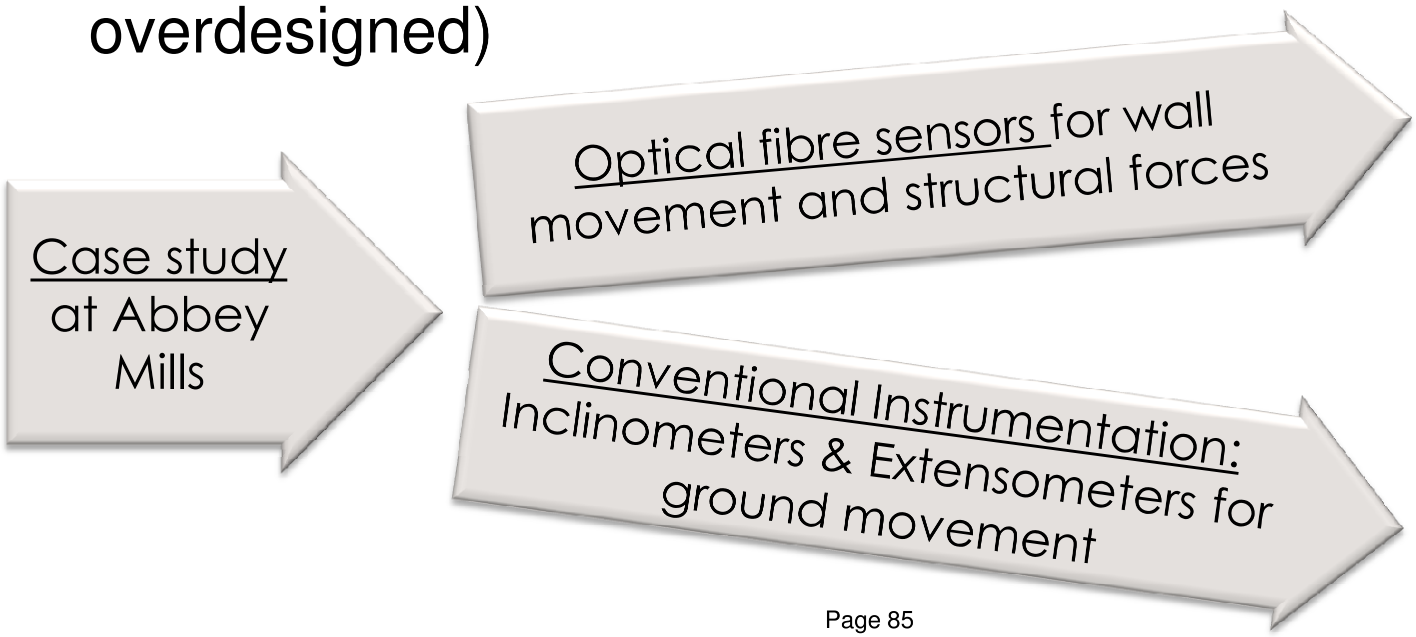
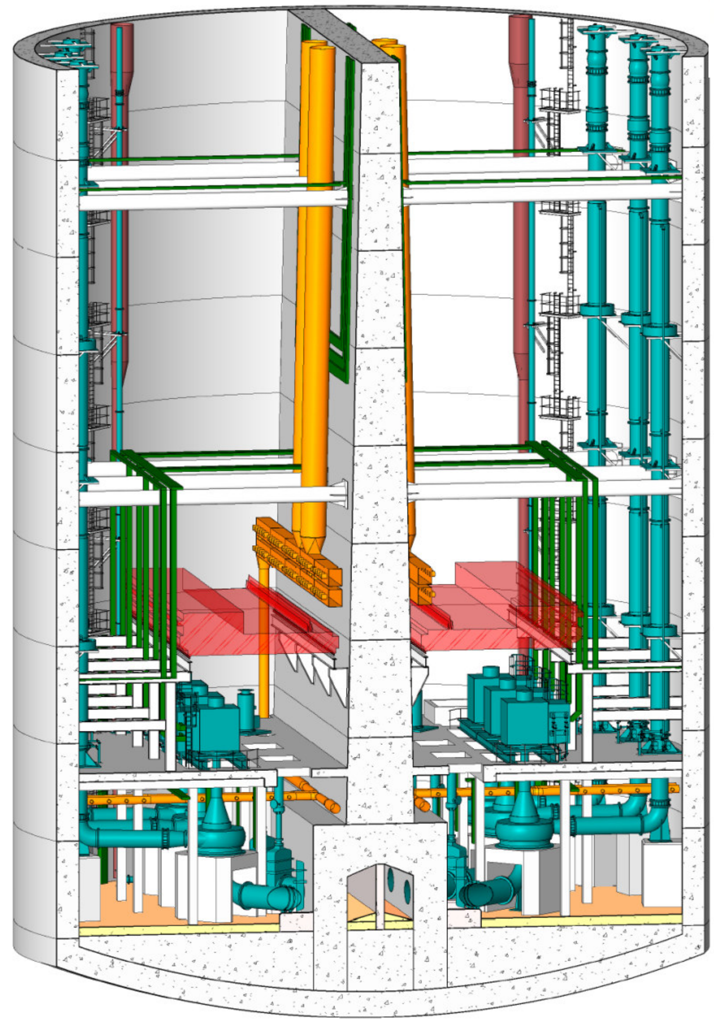
Lee Tunnel:
Monitoring Shaft Performance (University of Cambridge)

- Limited knowledge on ground movement around circular excavations
- Only one case study which is frequently referred to (New & Bowers 1994)
- Structural behaviour not fully understood (potentially overdesigned)



Lee Tunnel:
M&E Requirements

Main Pump Impellor
KSB



Pumping Shaft
Internal layou

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Lee Tunnel: Summary of Key Details

- Largest Contract since TW privatisation
- Capital value £635M
- Deepest Tunnel and shafts
- Largest Pumping Station
- Biggest TBM lift 800T
- Pump motors over 50T
- Prevents 16M tonnes of sewage entering River Lee

Close

Summary:

- London's aging sewer infrastructure unable to cope with population growth and demand.
- Need for Upgrade
- Alternative Options Considered through Strategic Studies.
- Preferred Option for Storage and Transfer Tunnel
  - Lee Tunnel (Currently in Construction)
  - Thames Tunnel (Currently at Design for Planning Stage)
- Construction Constraints – Working around existing Infrastructure and Minimising Impact on Third Parties
- Need for Innovation and Research

QUESTIONS?