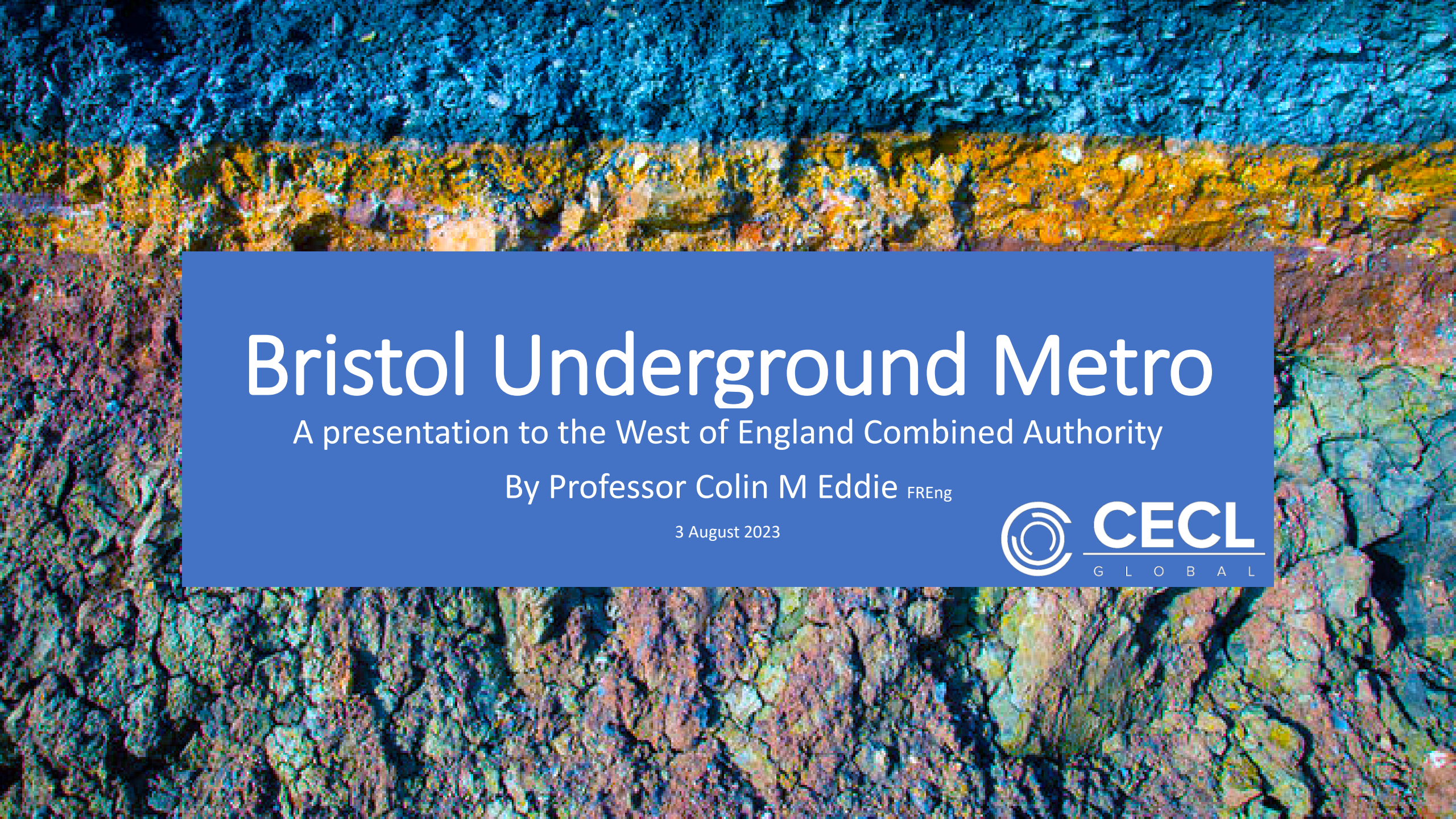


Bristol Underground Metro

A presentation to the West of England Combined Authority

By Professor Colin M Eddie FREng

3 August 2023

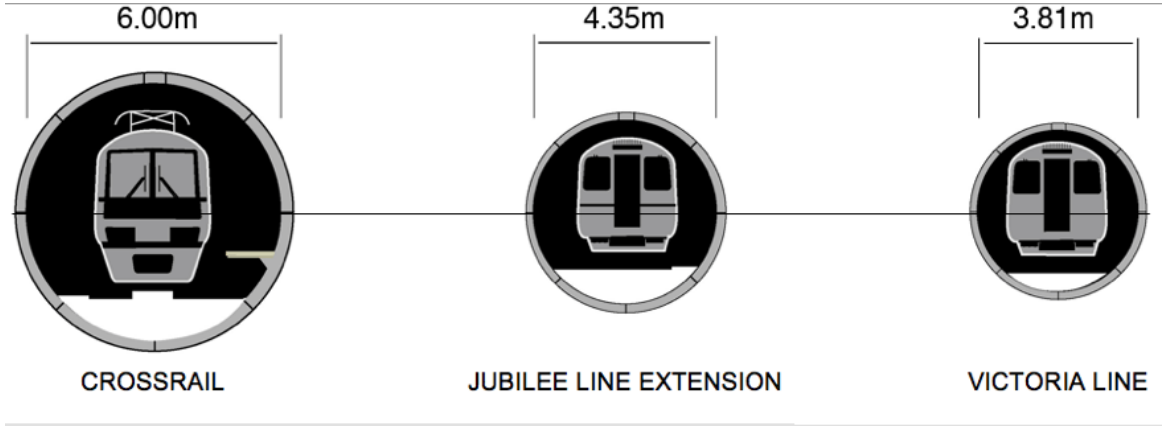
CECL GLOBAL

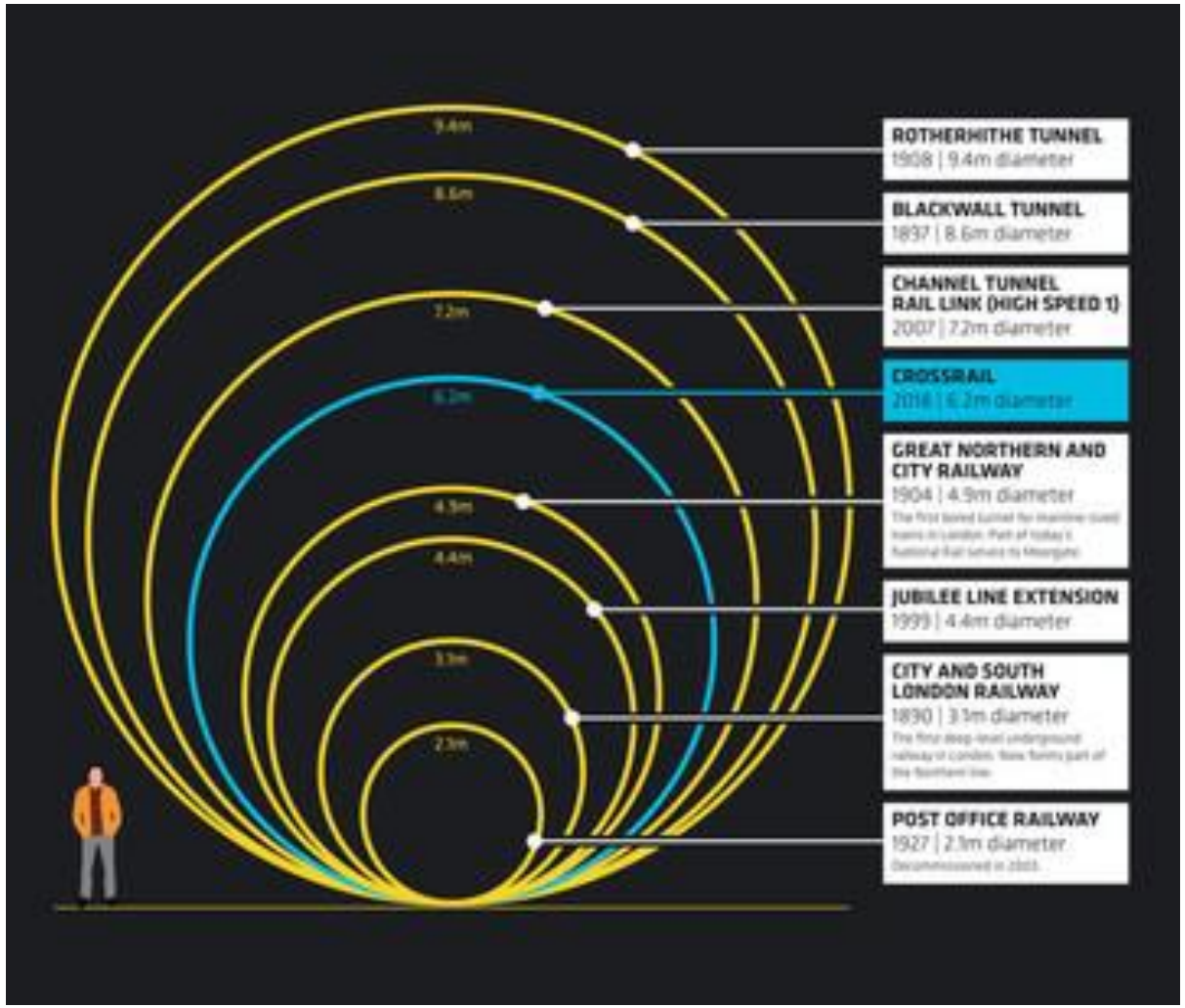
Contents

- Who am I and why am I here?
- UK’s track record of delivering major infrastructure projects
- How can YOU do better
- The feasibility, cost and time of an Underground Metro in Bristol
- Discussion

City	2023 Population
London	8,961,989
Birmingham	984,333
Liverpool	864,122
Sheffield	685,368
Bristol	617,280
Glasgow	591,620
Leicester	508,916
Edinburgh	464,990
Leeds	455,123
Cardiff	447,287
Manchester	395,515

Tunnel Size?

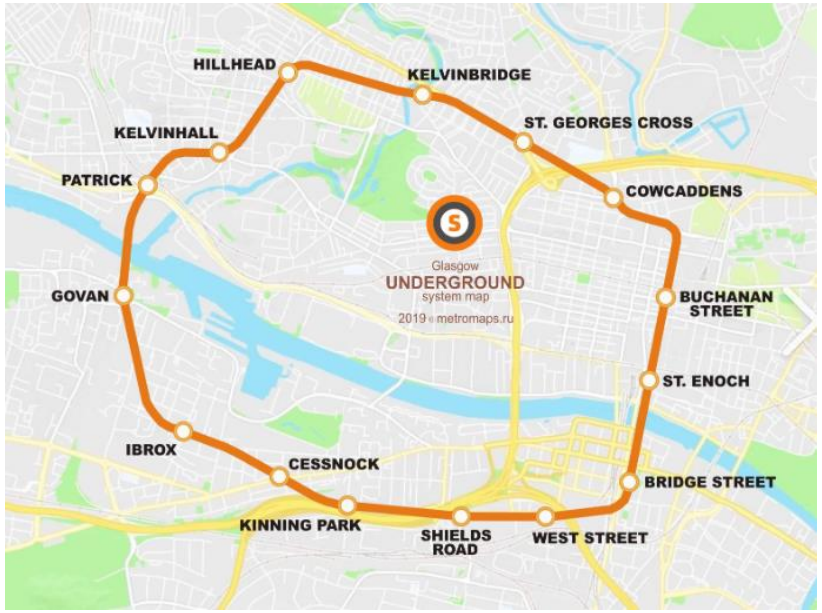

6.00m
4.35m
3.81m
CROSSRAIL
JUBILEE LINE EXTENSION
VICTORIA LINE


ROTHERHITHE TUNNEL
1908 | 9.4m diameter
BLACKWALL TUNNEL
1897 | 8.6m diameter
CHANNEL TUNNEL RAIL LINK (HIGH SPEED 1)
2007 | 7.2m diameter
CROSSRAIL
2018 | 6.2m diameter
GREAT NORTHERN AND CITY RAILWAY
1904 | 4.9m diameter
JUBILEE LINE EXTENSION
1999 | 4.4m diameter
CITY AND SOUTH LONDON RAILWAY
1890 | 3.1m diameter
POST OFFICE RAILWAY
1927 | 2.7m diameter

Glasgow Underground (3.5m Excavated Dia.)

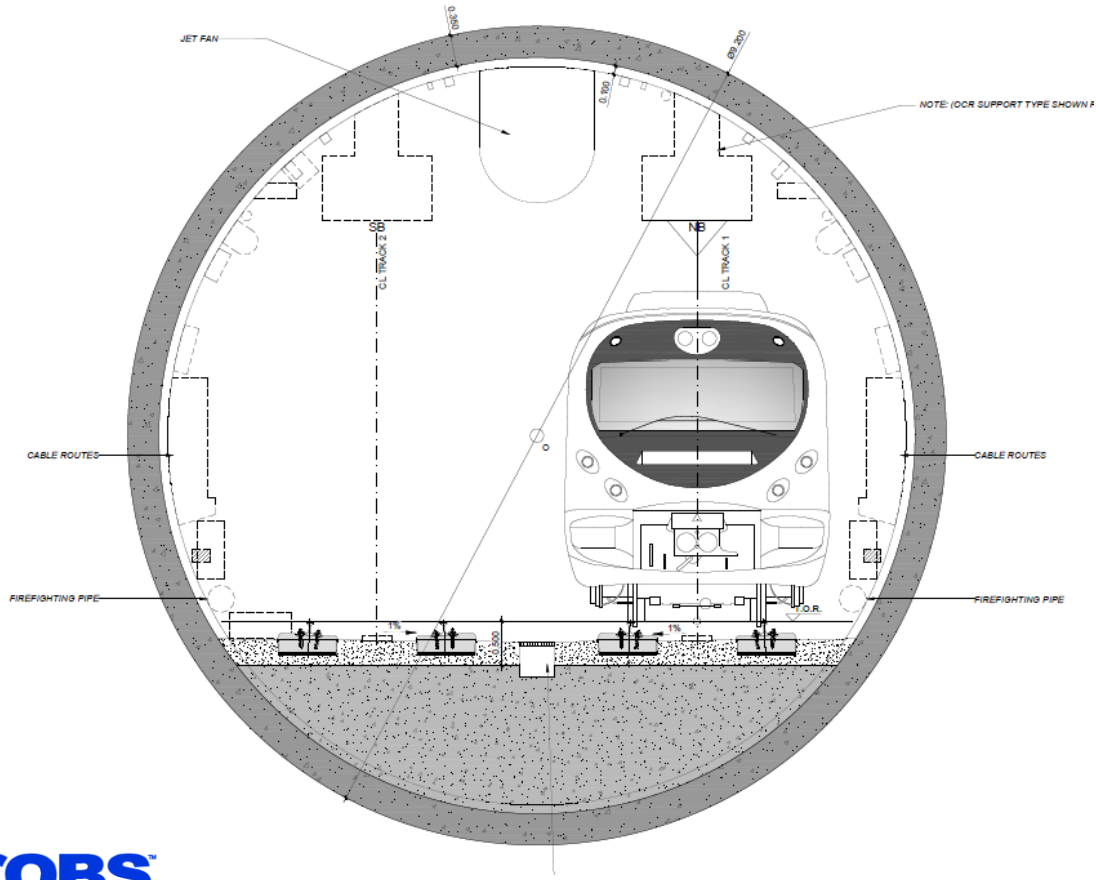
The subway system was constructed as a circular loop almost 6+1⁄2 miles (10.5 kilometres) long and extends both north and south of the River Clyde. The tracks have the unusual narrow gauge of 4 ft (1,219 mm), and a nominal tunnel diameter of 11 ft (3.4 m), even smaller than that of the deep-level lines of the London Underground (11 ft 8+1⁄4 in or 3.56 m at their smallest); the rolling stock is considerably smaller.

The system is described as two lines, the Outer Circle and Inner Circle, which simply refers to the double track, having trains running clockwise and anticlockwise respectively around the same route in separate tunnels. Stations use a variety of platform layouts including single island platforms, opposing side platforms and in some stations such as Hillhead one side and one island platform.



Dublin Metrolink

Dublin Metrolink (9.5m Excavated Diameter) Twin Track



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West of England Combined Authority - Underground Metro

Prepared for

Bristol City Council as the Lead Authority

October 2017

ch2m:

steer davies gleave

4.6.3 Below Ground Stations

4.6.3.1 Station Depth

The running tunnels are assumed to have a 5.2m internal diameter (ID) with 0.4m thick tunnel lining meaning their outside diameter (OD) is approximately 6m. Following good tunnelling practice, it has been assumed that for the majority of tunnelling the clearance above the tunnels will be close to twice the tunnel diameter so a clearance of 10m has taken. Including a 0.5m gap below the tunnel to drive or transfer the Tunnel Boring Machine through the station means that the top of the foundation slab at stations needs to be approximately 16.5m below ground level (BGL). With a foundation slab assumed to be up to 1.5m deep the depth of the station box is 18m BGL and the platform is approximately 13m BGL:

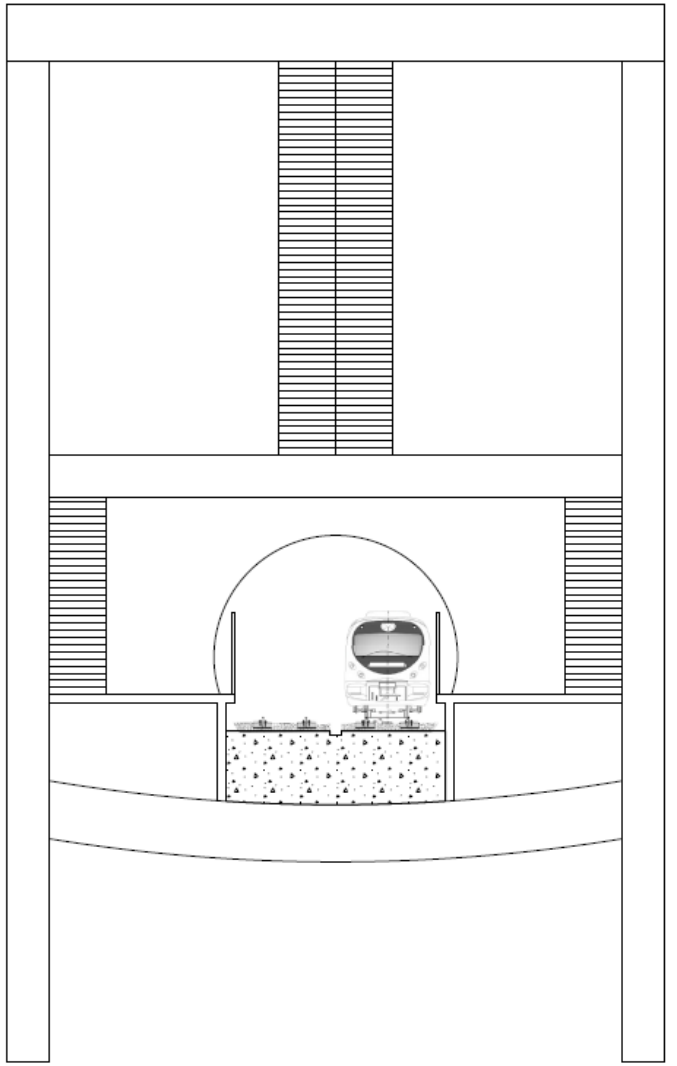
Figure 4.5 – Typical Station and Cross Section

The diaphragm walls (D-walls) are assumed to be 1m thick and constructed to a depth of approximately 25-30m deep depending on the ground conditions.

We have assumed 1.5m thick to a depth of 35m

Standard Station Design

- 100m x 20m



Bristol public transport network vision

Key

- Rail routes
- Segregated bus routes
- Over or underground rapid routes
- Existing stops
- Proposed new stops
- Existing Park & Ride sites
- Proposed new Park & Ride sites

BD13645

Tunnel Options used for Pricing Purposes

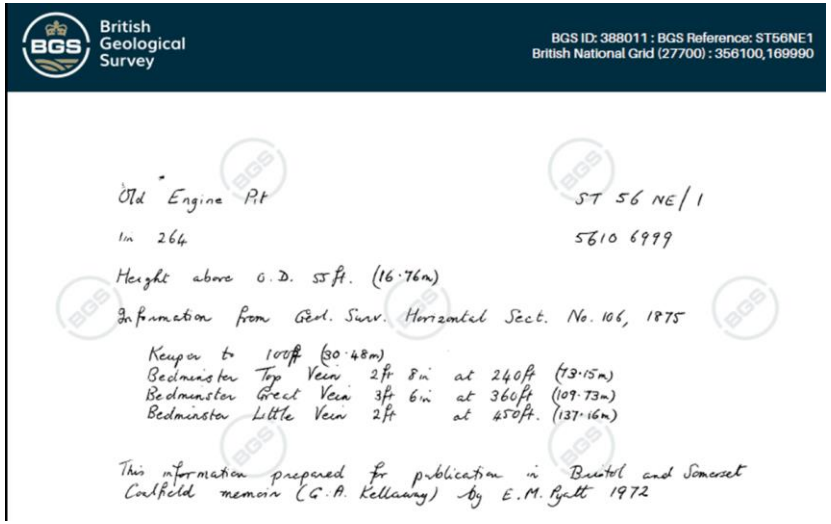
Project	Internal Dimater (m)	External Diameter (m)	Excavated Diameter (m)	Lining Thickness (mm)
Single Tunnel - Twin Track	8.50	9.20	9.50	365
Twin Tunnel - Single Track	5.20	5.80	6.05	300

Route	Tunnel Length (m)
1 - Airport	9064
2 - North	14153
3 - North East	10630
4 - South East	7603

Ground Conditions at Tunnel Horizon and associated Geo-hazards

- Ground Conditions
  - Weak sedimentary rocks (Mudstone / Sandstone / Limestone).
  - Moderate to low water pressures
  - Coal measures (and therefore mine workings) unlikely to be encountered

- Geo-Hazards
  - Stickiness and breakdown of the weak rock
  - Abrasion in the Sandstone

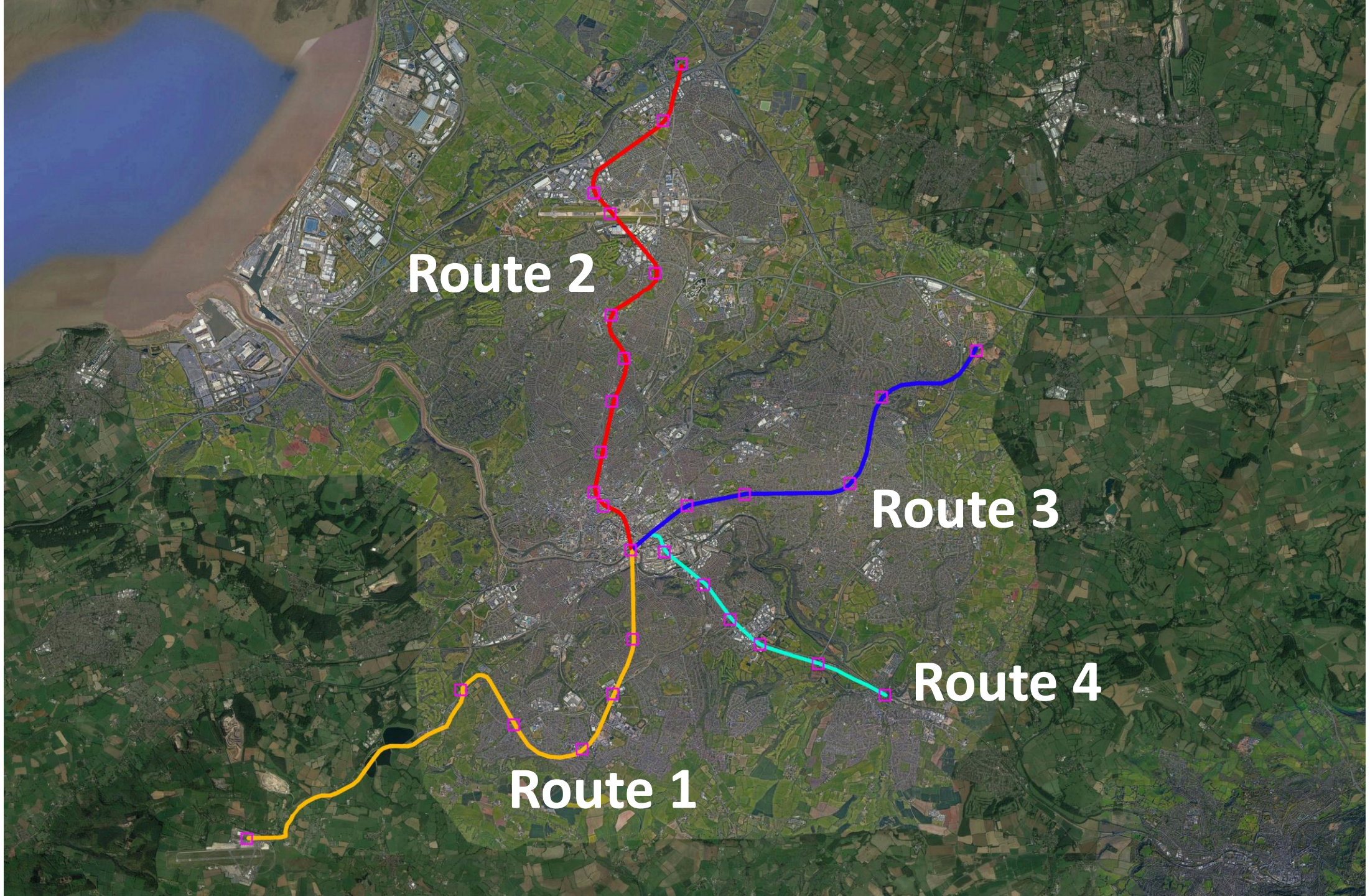


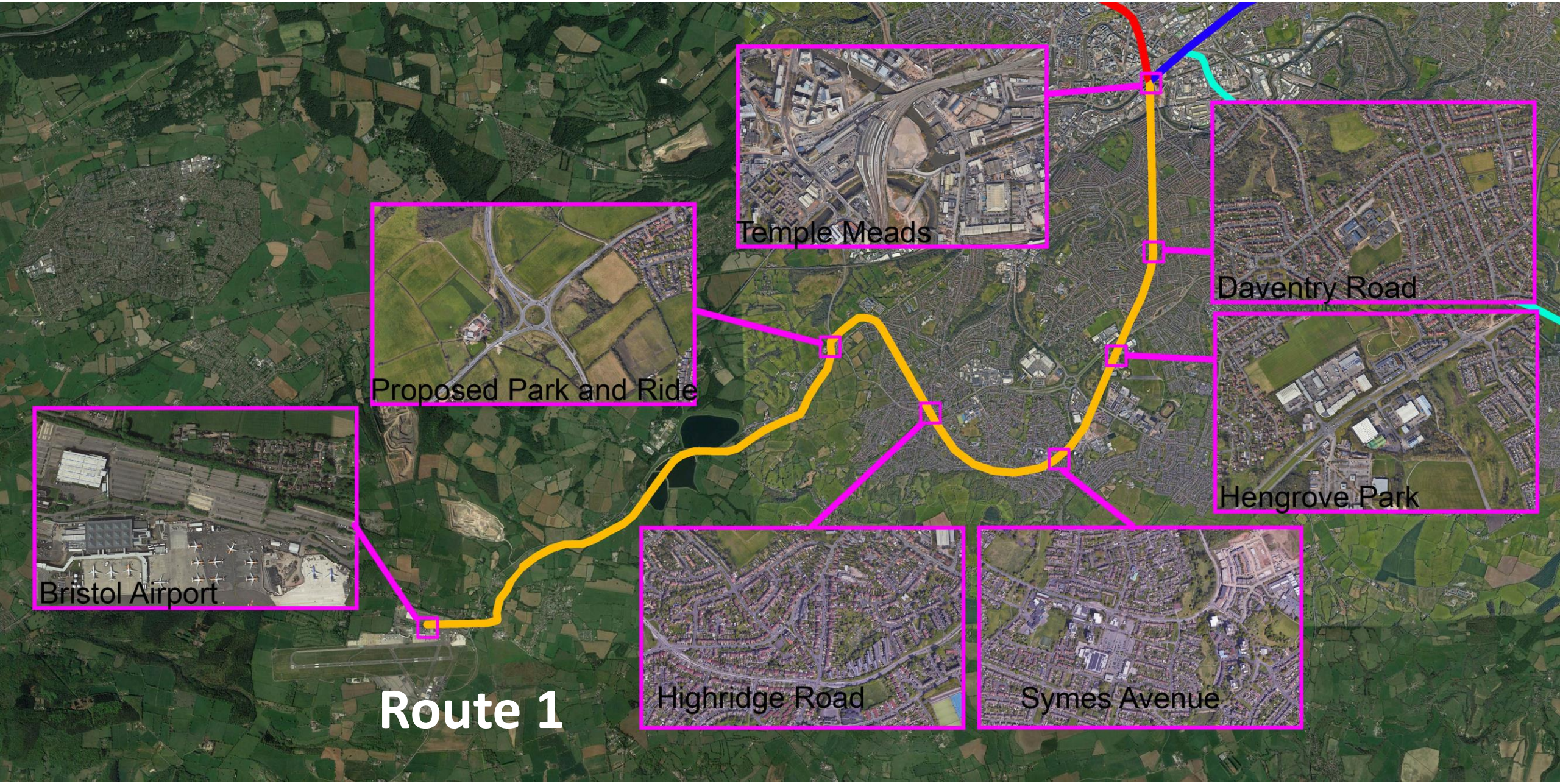
Key Assumptions

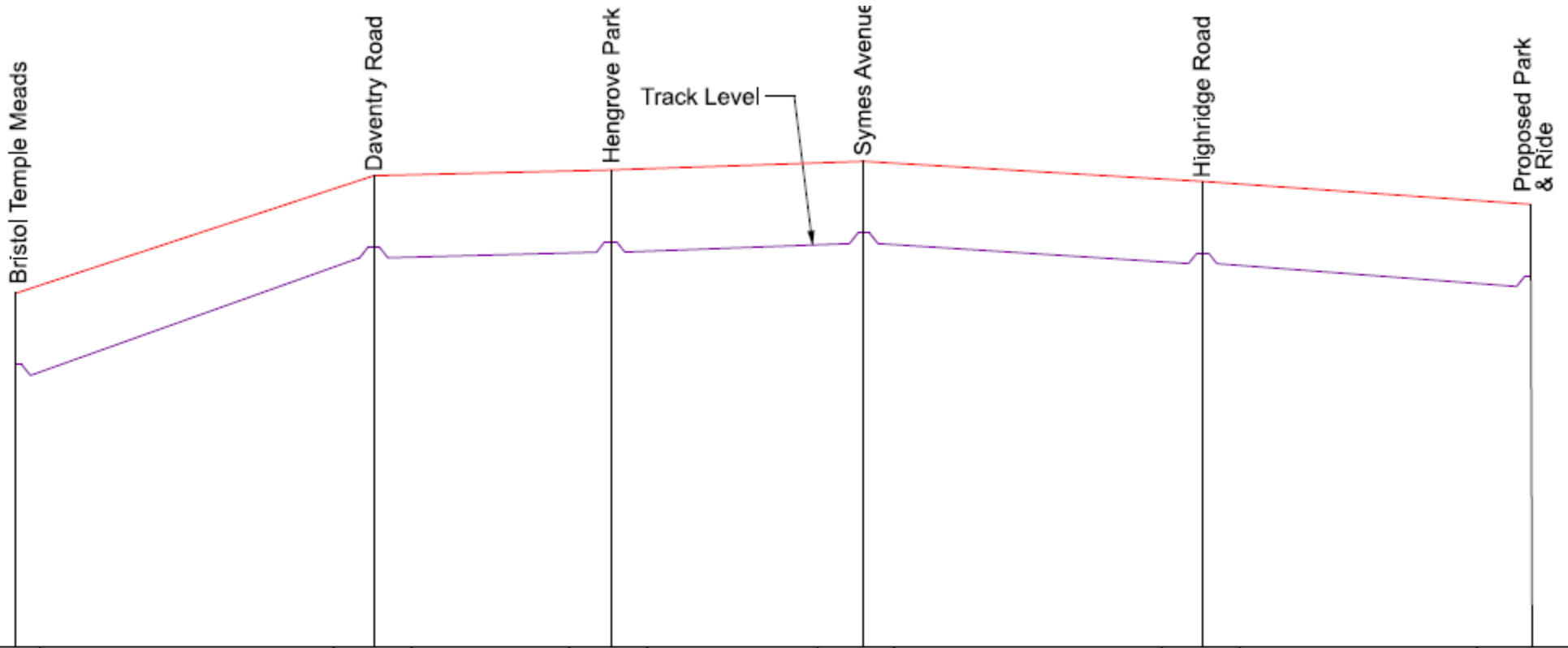
- Design completed before Contractor Procured
- Planning approvals in place before Contractor Procured
- Tunnels for each route will be constructed from the farthest underground station to Bristol Temple Meads
- A single JV is selected to build everything on each route (to eliminate interfaces)
- Standardised tunnel and station designs are utilised throughout
- All tunnels will be constructed using Slurry TBMs, with continuous mining capability and a single pass, twin gasket, boltless tunnel lining
- Stations (100m by 20m) will be constructed within diaphragm walls
- A suitable spoil disposal facility will be identified which is relatively close to each drive site and which will not attract land fill or aggregate taxes
- Station boxes will be excavated in advance of TBM arrival (TBM push through)
- A Geotechnical Baseline Report will be used

Costs NOT included

- Client costs
- Land / compulsory purchase costs
- Cost of the planning process
- Surveys - ecology, archaeology etc.
- Service diversions at stations
- Electrical power supplies to tunnel drive sites
- Inflation (costs are Q3-23)
- Rolling stock
- Optimism bias

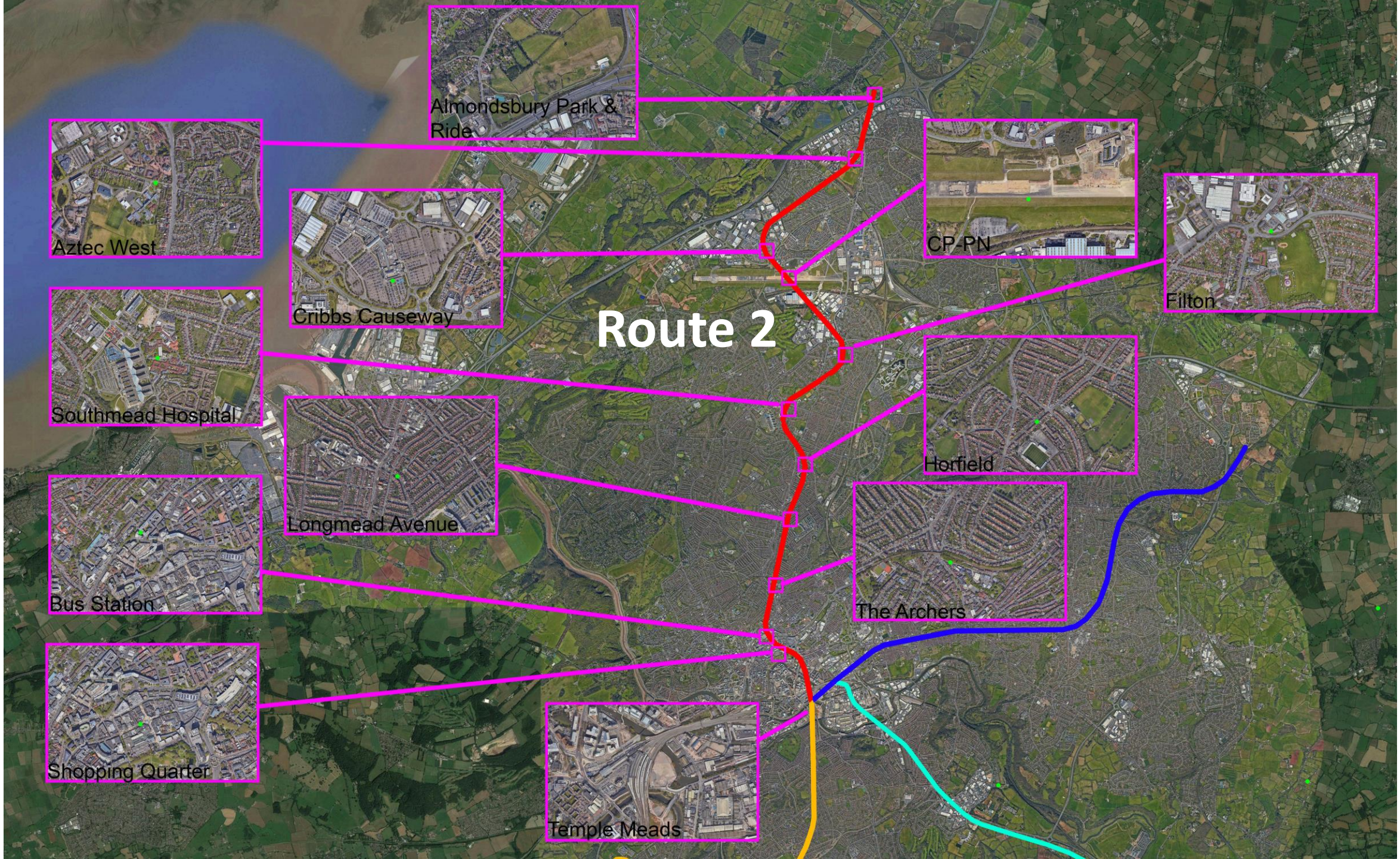

Route 2
Route 3
Route 4
Route 1

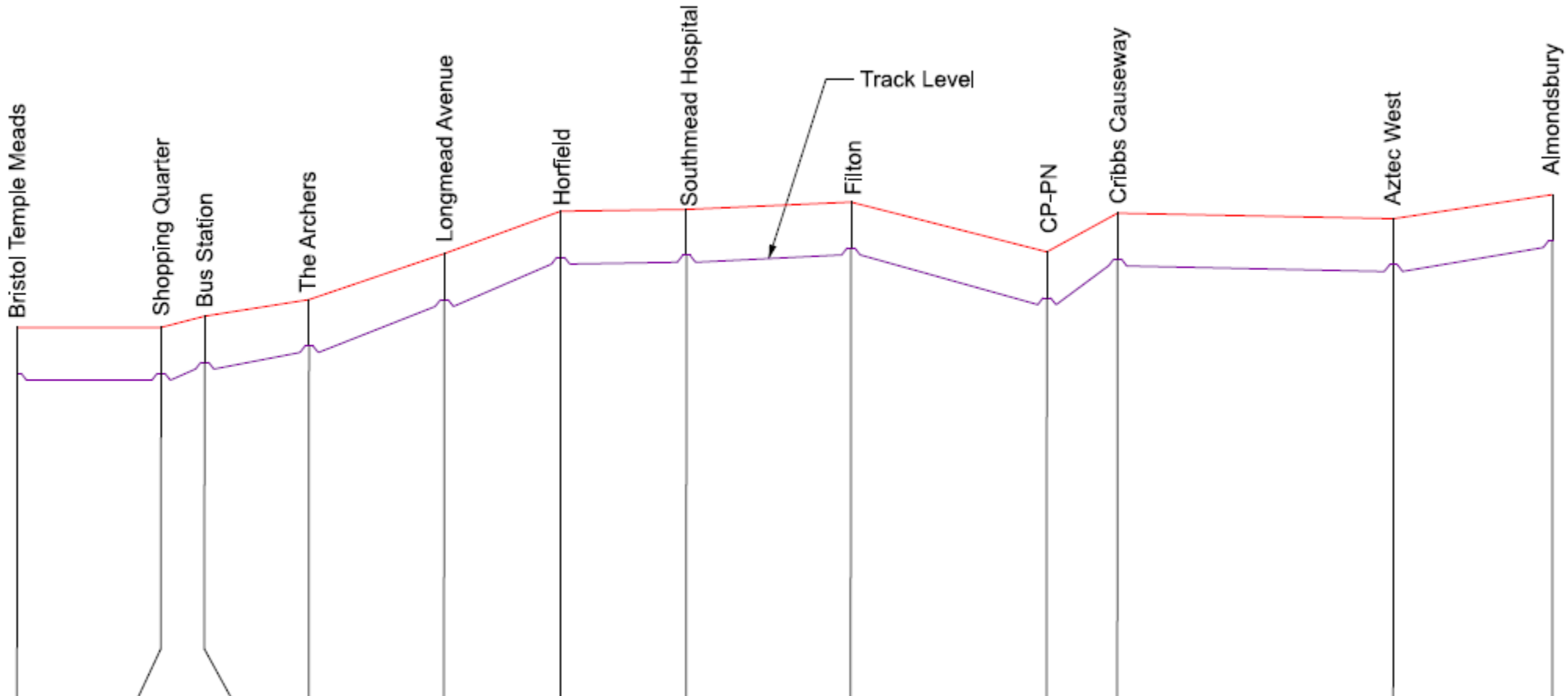

Temple Meads
Daventry Road
Proposed Park and Ride
Hengrove Park
Bristol Airport
Highridge Road
Symes Avenue
Route 1



Chainage	0		2140		3558		5072		7101		9064
Ground Level (m APD)	116		158		160		163		156		148
Track Level (m APD)	91		133		135		138		131		123
Depth to Track (m)	25		25		25		25		25		25
Length (m)		2140		1418		1514		2029		1963	
Gradient		51		709		505		-290		-245	

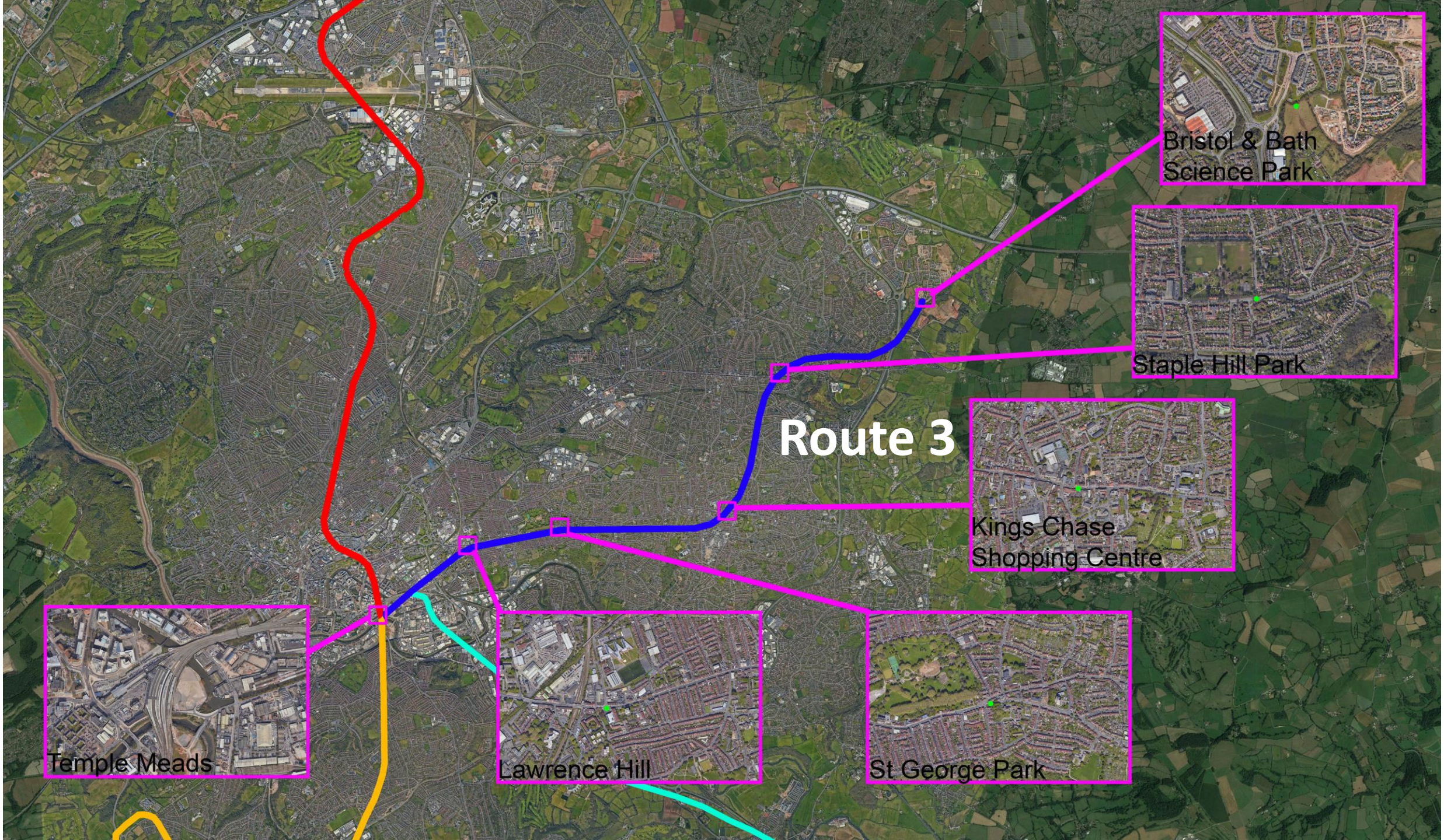
Route 1

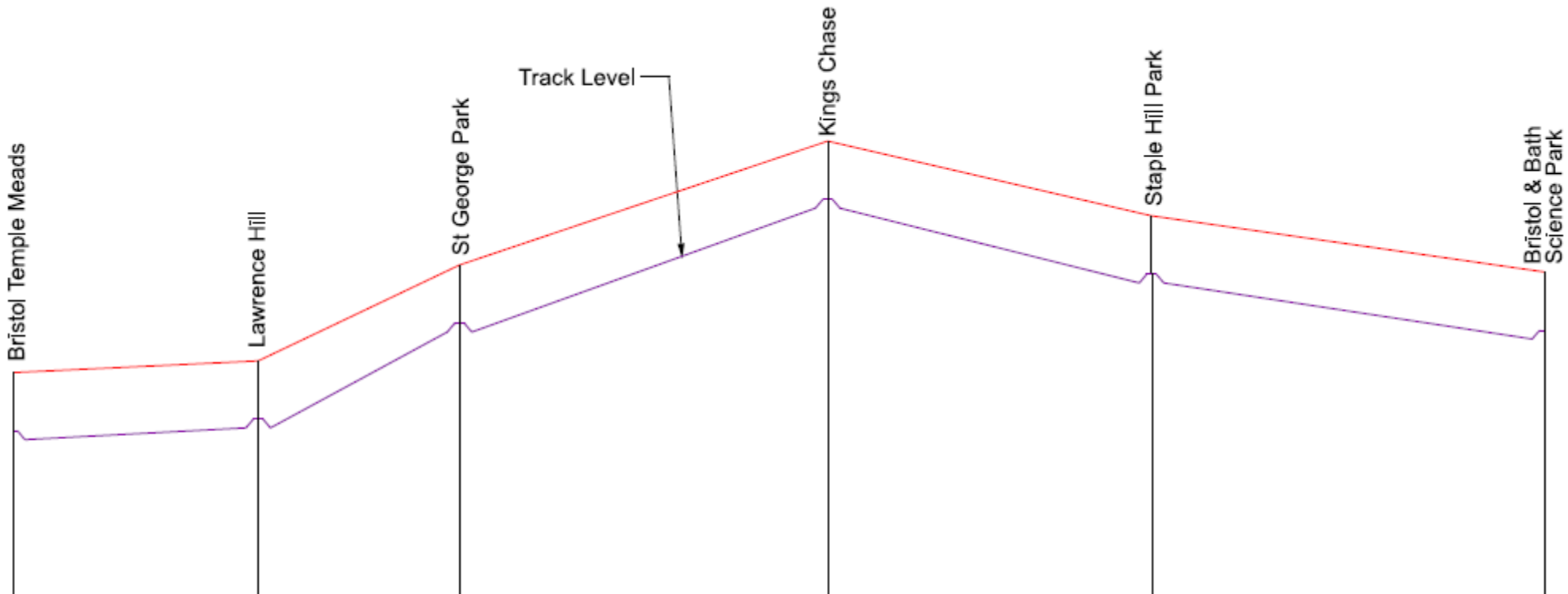

Route 2
Almondsbury Park & Ride
Aztec West
Cribbs Causeway
CP-PN
Filton
Southmead Hospital
Longmead Avenue
Horfield
Bus Station
The Archers
Shopping Quarter
Temple Meads



Chainage	0		1325		1727		2689		3936		5009		6169		7686		9492		10144		12688		14153
Ground Level (m APD)	116		117		123		132		157		180		181		185		158		179		176		189
Track Level (m APD)	91		92		98		107		132		155		156		160		133		154		151		164
Depth to Track (m)	25		25		25		25		25		25		25		25		25		25		25		25
Length (m)		1325		402		962		1247		1073		1160		1517		1806		652		2544		1465	
Gradient		1325		67		107		50		47		1160		379		-67		31		-848		113	

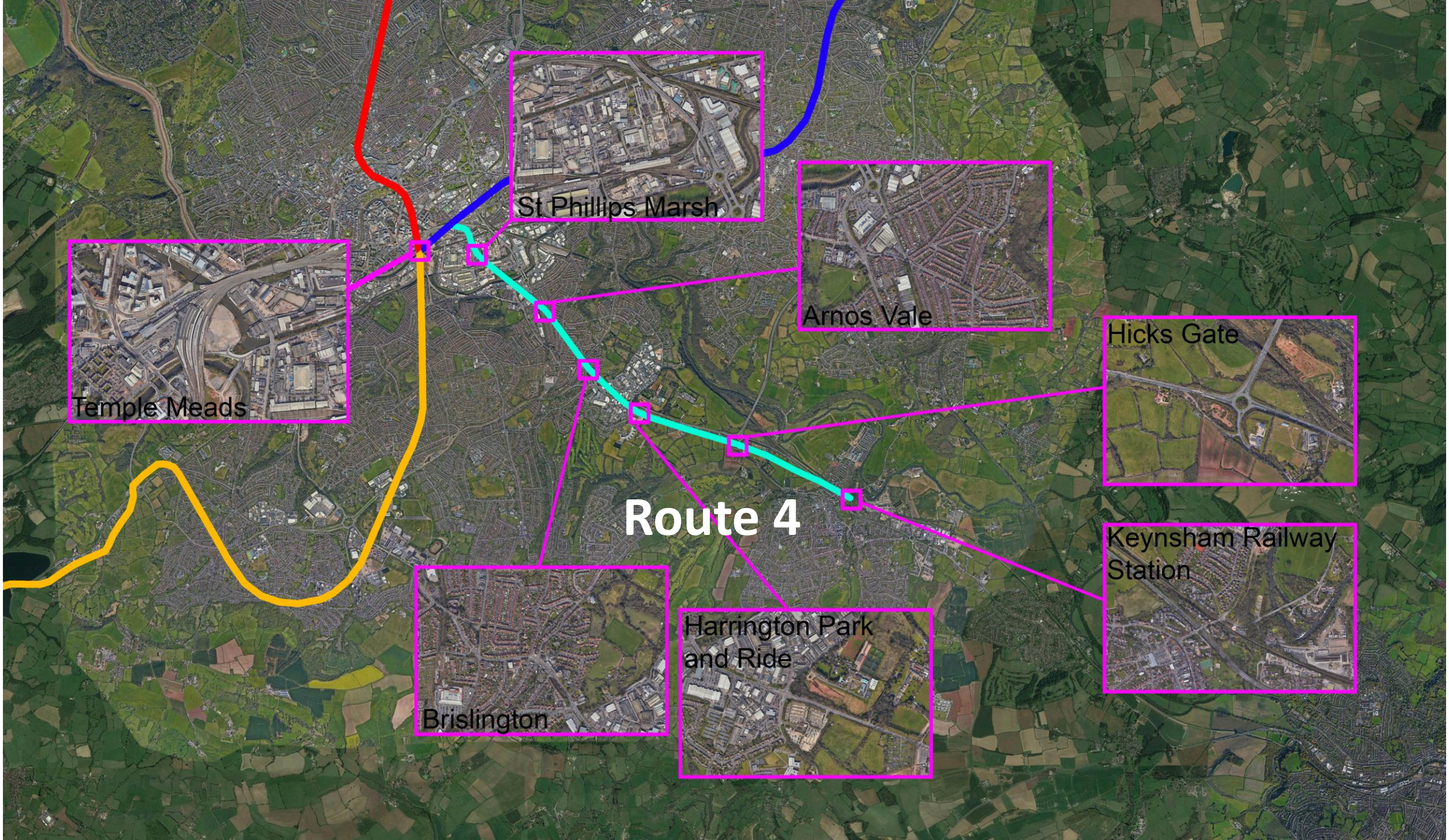
Route 2

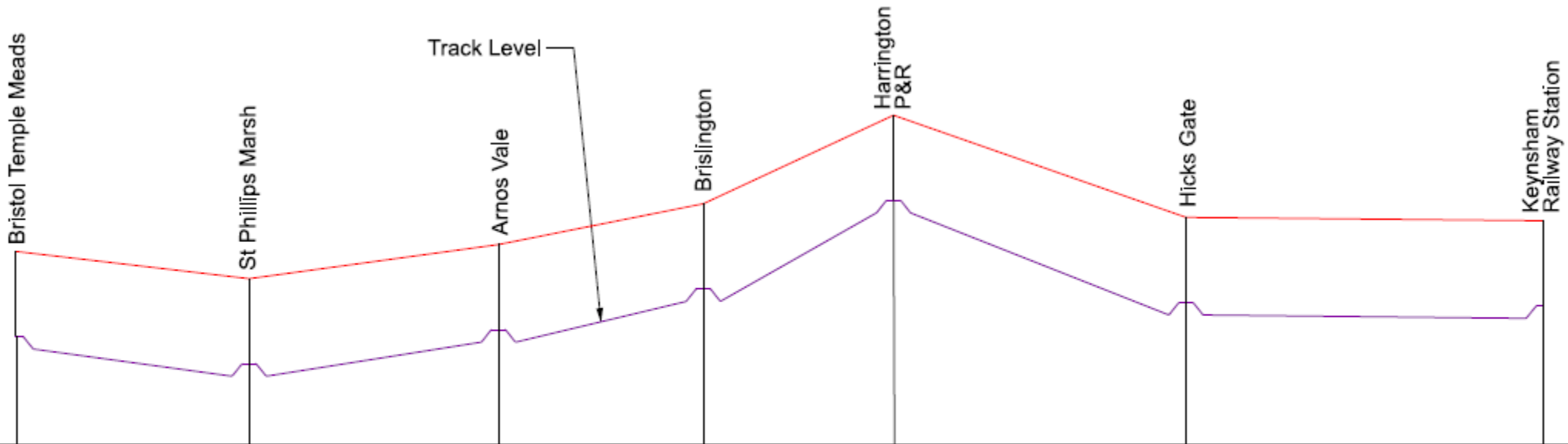

Route 3
Bristol & Bath Science Park
Staple Hill Park
Kings Chase Shopping Centre
Temple Meads
Lawrence Hill
St George Park



Chainage	0		1704		3101		5656		7904		10630
Ground Level (m APD)	116		122		163		216		184		160
Track Level (m APD)	91		97		138		191		159		135
Depth to Track (m)	25		25		25		25		25		25
Length (m)		1704		1397		2555		2248		2726	
Gradient		284		34		48		-70		-114	

Route 3


St Phillips Marsh
Arnos Vale
Temple Meads
Hicks Gate
Route 4
Keynsham Railway Station
Brislington
Harrington Park and Ride



Chainage	0		1160		2401		3421		4368		5824		7603
Ground Level (m APD)	116		109		119		131		157		127		126
Track Level (m APD)	91		84		94		106		132		102		101
Depth to Track (m)	25		25		25		25		25		25		25
Length (m)		1160		1241		1020		947		1456		1779	
Gradient		-166		124		85		36		-49		-1779	

Route 4

Tunnel Cost Calculator (short version)

Benchmark Calculator for TBM Tunnels

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Project: For Bristol Metro. Example: Dublin Metrolink - Single Tunnel - Twin Track route 2
Date: 01/08/2023
Made By: Eyre Hover
Checked By:

INPUTS		
Tunnel Length (Portal to Portal)	14153	m
Number of Drives	1	
Number of TBMs	1	
TBM launched from	Portal	
Number of Cross-Passages	0	
Total Tunnel Length	14153	m
Capital Length	14153	m
Tunnel Internal Diameter	8.5	m
Long Average Effective Drive Rate	8.61	m/shift
Number of Working Shifts per Week	14	
Muck Away (Rate for in the Solid)	12.5	£/m³
Consumables	12.5	£/m³
Average Cost of Labour	442.5	£/shift
Design %	10	%
Risk %	10	%
Prelims %	25	%

Variable Outputs		
Ring Thickness	365	mm
Segmental Lining Internal Diameter	8.500	m
Ring External Diameter	9.230	m
Excavated Diameter	9.445	m
Excavated Spoil per m	70.069	m³
Excavated Spoil per shift	603.6	m³
Net Cost of TBM(s)	£ 20,143,099	£
Net Cost of Backup Plant	£ 10,071,549	£
Labour per shift	29	No
Site Set-Up and Temp Works	£ 8,625,000	£

Time Related Costs £/Shift		
	£/shift	
Labour cost per shift	£	12,833
Cost of electricity and Fuel per shift	£	7,181

Tunnel Prime Cost Analysis £/m			
	£/m	%
Ring Cost per m	£ 6,353	39%
Other materials per m	£ 2,118	13%
Tunnel Services per m	£ 947	6%
Labour Cost per m	£ 1,490	9%
Cost of Electricity and Fuel per m	£ 834	5%
Consumables per m	£ 876	5%
TBM and Plant & Equipment per m	£ 2,135	13%
Site set-up and Temp Works per m	£ 609	4%
Muck away	£ 876	5%
Total Prime Cost per m	**£ 16,237**	**100%**

Cross-Passage Cost Calculation		
Include Cross Passages ?	No	
Internal Diameter of Cross-Passage	0	m
Length of Cross-Passage	0	m
Ground Treatment Type:		
None		
Cost of ground treatment	£0	
Portal Connection Costs	£0	
Tunnel Construction Costs	£0	
Total Cost per Cross-Passage	£0	
Total Cost of Cross-Passages	**£0**	

Secondary Lining and Waterproofing		
Lining and Waterproofing thickness	0	mm
Secondary lining cost per m	£ -	£/m
Waterproofing cost per m	£ -	£/m
Total Prime Cost per m	£ -	£/m
Cost of Secondary Lining and Waterproofing	**£**	-

Cost Calculation - Tunnel Construction		
Prime cost per m	£	16,237
Total Cost of Tunnel Construction	**£**	**229,804,006**

Drive Rate Calculator	
TBM Operating Mode	Factor
Closed	0.60
Ground Conditions	Factor
Homogeneous Clay/Sand/Rock	0.20
Experience of Tunnel Crew	Factor
High	0.20
Site Logistics	Factor
Good available space / logistics	0.20
Other Complicating Factors	Factor
None	0.20
Length (m)	Factor
14153	0.13
Total	Factor
-	0.93
Drive Rate (m/shift)	13.50
TBM Installation (Weeks)	7
TBM Turnaround (Weeks)	0
TBM Learning Curve (Weeks)	7
TBM Removal (Weeks)	4
Additional Transit Time	24
Total Tunnelling Time (Weeks)	117.35
Long Average Effective Drive Rate (m/week)	120.61

Civil Fit-Out	
Include Civil Fit-Out ?	No
Tunnel Inner Diameter (m)	8.500
Total Cost of Civil Fit-Out	**£0**

MEP	
Include MEP ?	No
Tunnel Category	AA
MEP Tunnel Category Factor	1.0
Total Cost of MEP	**£0**

Cost of Portals and Control Building		
Include Portal	Yes	
Include control building	No	
Portal Type	B	
Portals - Muck Away (Rate for in the Solid, £/m3)	12.5	
Excavation Cost (£/m3)	12.5	
Cost of Bulk Excavation	£	2,378,727
Cost of Road Construction	£	1,823,004
Cost of Granular Fill	£	182,300
Cost of Canopy Area	£	35,245
Cost of Shotcrete and Bolts	£	4,233,645
Type B - no additonal costs	£	-
Cost of Control Building	£	-
Cost of Spoil Reuse and Disposal	£	2,378,727
Total for each Portal and Control Building	**£**	**11,031,649**

GRAND SUMMARY		
Total Cost of Tunnel Construction	£	229,804,006
Total Cost of Cross-Passages	£	-
Cost of Secondary Lining and Waterproofing	£	-
Total Cost of Civil Fit-Out	£	-
Total Cost of MEP	£	-
Total for Portals	£	22,063,297
Temporary Works and Small Tools	£	6,894,120
Total Prime Cost	**£**	**258,761,423**
Design	£	25,876,142
Risk	£	25,876,142
Sub-Total	£	310,513,708
Prelims	£	77,628,427
Grand Total	**£**	**388,142,135**

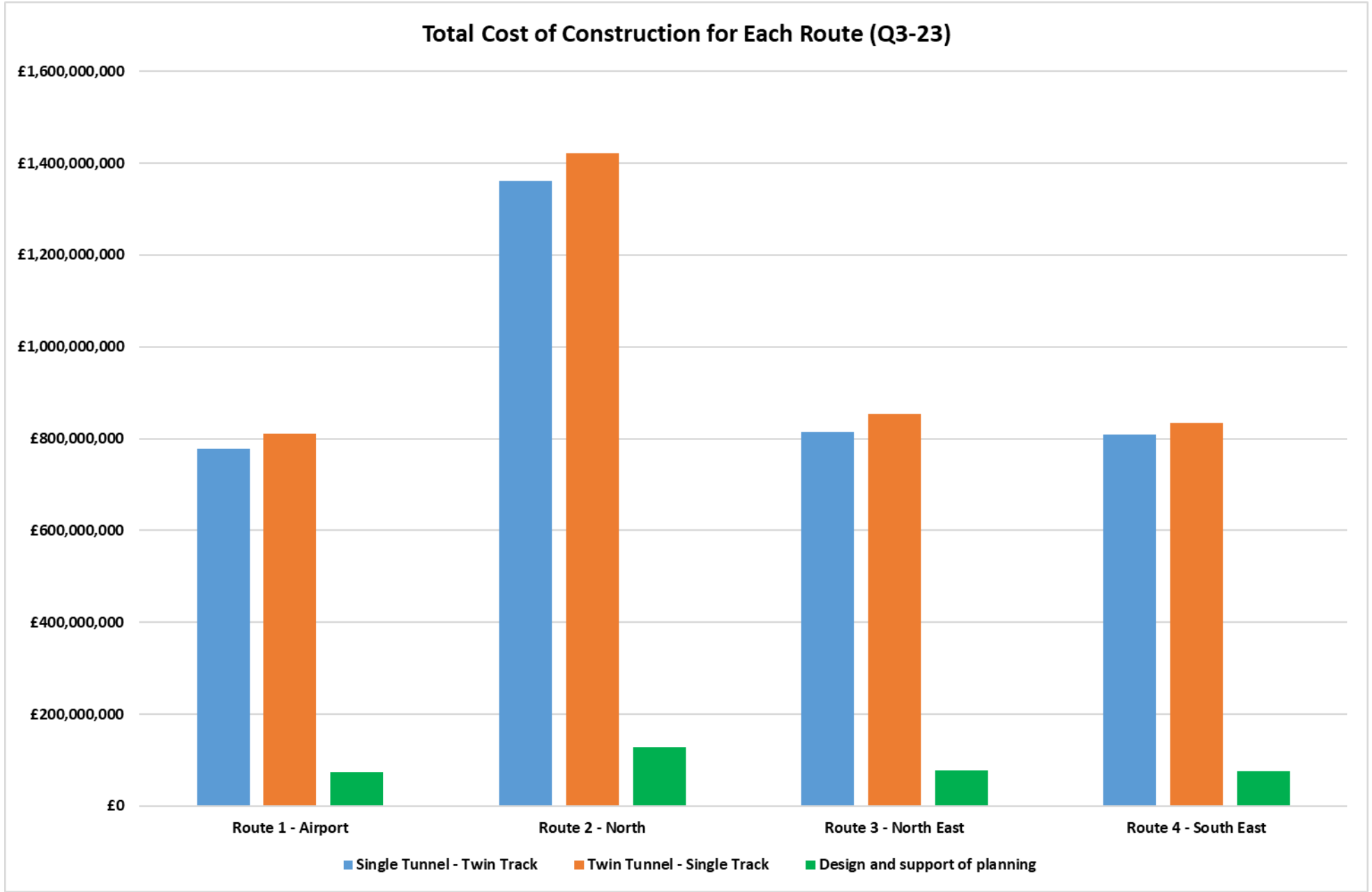
Notes
1. Calculation suitable for segmental tunnels driven using a TBM
2. Applicable to tunnel ID ranging from 3m to 16m
3. Includes all labour, plant and materials
4. Includes risk, design and contractors prelims
5. Number of TBMs should not exceed the number of drives
6. Assumes 12 hour overall shift pattern (10 hours effective working)
7. Costs inflated from Q1 2019 to Q1 2023

Single Tunnel – Twin Track

Route	Route 1 - Airport	Route 2 - North	Route 3 - North East	Route 4 - South East
Length (m)	9064	14153	10630	7603
Tunnel Construction	£177,947,826	£247,729,775	£198,355,604	£152,696,022
Stations	£332,313,960	£664,627,920	£332,313,960	£387,699,620
Systemwide, track and comms	£53,384,348	£74,318,932	£59,506,681	£45,808,807
Risk (10%)	£56,364,613	£98,667,663	£59,017,625	£58,620,445
Contractor's Staff (10%)	£56,364,613	£98,667,663	£59,017,625	£58,620,445
Prelims, overhead and Profit (15%)	£101,456,304	£177,601,793	£106,231,724	£105,516,801
Total	**£777,831,664**	**£1,361,613,745**	**£814,443,219**	**£808,962,139**

Twin Tunnel – Single Track

Route	Route 1 - Airport	Route 2 - North	Route 3 - North East	Route 4 - South East
Length (m)	9064	14153	10630	7603
Tunnel Construction	£195,796,694	£280,825,986	£220,362,948	£166,395,197
Stations	£332,313,960	£664,627,920	£332,313,960	£387,699,620
Systemwide, track and comms	£58,739,008	£84,247,796	£66,108,884	£49,918,559
Risk (10%)	£58,684,966	£102,970,170	£61,878,579	£60,401,338
Contractor's Staff (10%)	£58,684,966	£102,970,170	£61,878,579	£60,401,338
Prelims, overhead and Profit (15%)	£105,632,939	£185,346,306	£111,381,443	£108,722,408
Total	**£809,852,535**	**£1,420,988,349**	**£853,924,394**	**£833,538,459**

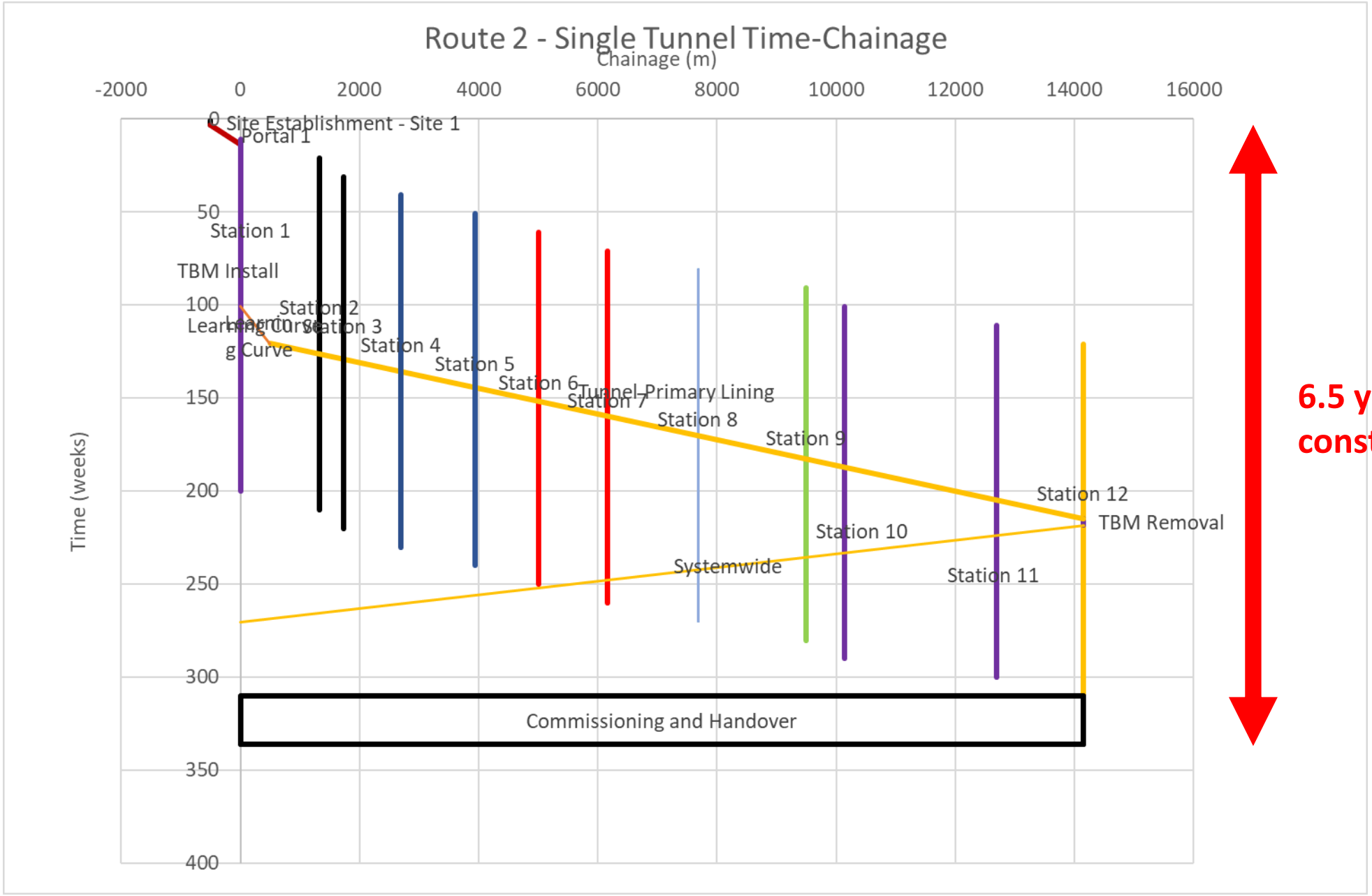

Total Cost of Construction for Each Route (Q3-23)
£1,600,000,000
£1,400,000,000
£1,200,000,000
£1,000,000,000
£800,000,000
£600,000,000
£400,000,000
£200,000,000
£0
Route 1 - Airport
Route 2 - North
Route 3 - North East
Route 4 - South East
Single Tunnel - Twin Track
Twin Tunnel - Single Track
Design and support of planning

Combined Cost

(assuming four routes are constructed underground)

Single Tunnel - Twin Track	
Combined Construction (assuming four JVs)	£3,596,693,787
Combined Design	£155,000,000
Total	**£3,751,693,787**

Twin Tunnel - Single Track	
Combined Construction (assuming four JVs)	£3,752,146,756
Combined Design	£160,000,000
Total	**£3,912,146,756**


Route 2 - Single Tunnel Time-Chainage
Chainage (m)
-2000
0
2000
4000
6000
8000
10000
12000
14000
16000
Time (weeks)
0
50
100
150
200
250
300
350
400
Site Establishment - Site 1
Portal 1
Station 1
TBM Install
Learning Curve
Station 2
Station 3
Station 4
Station 5
Station 6
Station 7
Tunnel Primary Lining
Station 8
Station 9
Station 10
Station 11
Station 12
TBM Removal
Systemwide
Commissioning and Handover
6.5 years of construction

Contents

- Who am I and why am I here?
- UK’s track record of delivering major infrastructure projects
- How can YOU do better
- The feasibility, cost and time of an Underground Metro in Bristol
- Discussion

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