DRAIG GEOSCIENCE PTY LTD	INTERPRETATION REPORT: GEOPHYSICAL INVESTIGATION GROUND PENETRATING RADAR (GPR) FREMANTLE PRISON, FREMANTLE, WA	DG1747GLD	Rep. No. 2.0
		Issue date: 06/05/2022	Page 1 of 28

To: Tristan Jónsson Menzies (Golder Associates)

From: Lee Tasker (Draig Geoscience Pty. Ltd.)

Subject: Geophysical Investigation – Ground Penetrating Radar (GPR), Fremantle Prison, Fremantle, WA

1. Introduction & Objectives

Golder Associates (Golder) approached Draig Geoscience (Draig) to provide a quote for a ground penetrating radar (GPR) survey to assist with assessing the underlying ground for an historical sewer line within areas of interest inside the Fremantle Prison property grounds and also outside the Fremantle Prison property grounds (tel. comms. Tristan Menzies, Senior Engineering Geologist, Golder, 23/03/2022). A quotation was provided to Golder on 23/02/2022 (Draig quote ref. DG1747GLD_1.0) and a purchase order to proceed was provided by Tristan Menzies on 12/04/2022.

General site maps of the Fremantle Prison historical main sewer line areas of interest were provided by Golder as part of the quotation submission (see Figure 1 and Figure 2).

Figure 1. A general site map of the Fremantle Prison historical main sewer line within the Fremantle Prison grounds area of interest (red arrow) (image source: Golder).

Figure 2. A general site map of the Fremantle Prison historical main sewer line area of interest outside the Fremantle Prison buildings (white rectangle and red circle) (image source: Golder).

Draig proposed utilising a GPR antenna to cover a depth of coverage of ~5 m within the areas of interest (e.g. 250 MHz antenna). Draig also proposed an approximate 1 m parallel GPR profile spacing, where possible within the areas of interest.

2. Data Acquisition

2.1 Geographical Location and Fieldwork Dates

Data acquisition was conducted along the western flank on the outside of main Fremantle Prison outer walls on Wednesday 20/04/2022 and the GPR survey was completed on the same day.

2.2 Equipment Details and Data Acquisition Parameters

Approximately 1,000 line-m of GPR profile data were acquired across the investigation site over 51 GPR profiles, labelled DAT_0001 to DAT_0051. GPR data were acquired using a Mala GPR 250 MHz antenna with the GPR antenna coupled to a rough terrain cart and calibrated wheel encoder. The 250 MHz antenna provided a depth of coverage to ~5 m.

GPR profile start and end positions were recorded with a GPS survey using a Juniper Systems Geode DGPS unit, acquired through EffiGIS EZTag software and post-processed using EffiGIS EZSurv software.

The GPR survey was split into 6 areas of interest as dictated by the ground conditions encountered at the site. The survey area consisted of grass, concrete and asphalt surfaces. The areas were as follows:

- Area 1 ran under the verandah of a building out onto the grass, and contained 4 profiles (DAT_0001 to DAT_0004);
- Area 2 was located predominantly on grass, but also crossing a concrete footpath, and contained 9 profiles (DAT_0005 to DAT_0013);
- Area 3 was located on the road and contained 13 profiles (DAT_0014 to DAT_0026);
- Area 4 was located on the grass west of the road, with lines split around a tree and light post. The area contained 8 profiles (DAT_0027 to DAT_0034);
- Area 5 was located on a sloped ramp and contained 8 profiles (DAT_0035 to DAT_0042);
- Area 6 was located in a carpark and contained 9 profiles (DAT_0043 to DAT_0051).

GPR profiles were acquired as close as possible parallel to one another at a profile separation of ~0.5 m. A site plan of the approximate GPR profile locations is shown in Appendix A, Figure A1 and photographs of the general site conditions are shown in Figure 3.

(a)  **(b)** 

(c) 

(d) 

(e) 

(f) 

(g) 

(h) 

Figure 3. General site conditions (a) Area 1, facing south; (b) Area 2, facing north; (c) Area 3 facing north; (d) Area 4, facing north; (e) Area 5, facing north; (f) Area 6, facing east; (g) site features in Area 5 including a square rock in wall, and metal pipe extruding from wall; and (h) site features in Area 4 such as concrete service cover, subsidence in grass, light pole and metal drainage grate (image source: Draig Geoscience).

3. Results and Interpretation

3.1. GPR Data Processing Steps

GPR data processing was conducted in the GPR data processing software 'GPR-Slice' (https://www.gpr-survey.com/). GPR depth-slices were created from combining the 2D radargrams in a 3D data volume and these depth-slices were exported as Surfer .grd files from GPR-Slice. Depth-slice data grids are provided as an electronic deliverable to this report in ERMapper (.ers) format (and also displayed in Appendix B, Figures B1-B6). A general processing flow for the GPR data processing is listed below:

- Import raw radar data into GPR-Slice;
- Post-process GPR with GPS data (QC data, check GPS points);
- Time-zero and truncate samples;
- Filter data;
    - Estimated dielectric constant (9) and background electromagnetic velocity (0.1 m/ns) (a depth of coverage ~5 m has been achieved with the 250 MHz GPR antenna using these values), apply background filter, apply amplitude gain, apply bandpass filter (250 MHz data: low-cut = 32 MHz, high-cut = 709 MHz);
- Combine the 2D radargrams into a 3D volume of data and slice through the volume of combined data at a specified depth interval;
    - Number of slices for volume = 41;
    - Thickness of slices = 25 samples, 4.94 nanosec (~0.25 m);
    - Overlap in slices = 50%;
- Grid depth-slices;
    - Grid cell size = 0.1 m;
    - X-search radius = 1.0 m, Y-search radius = 1.0 m, Blanking radius = 1.0 m;
- Display and export gridded depth-slices to Surfer .GRD files for interpretation in DiscoverPA;
- Assess for presence of GPR features in depth-slices and compare with 2D radargrams in 3D space and pick feature location if present;

- Export Shapefile format depth-slice interpretation features (if applicable).
- Export ASCII format radargram section interpretation point features (if applicable).

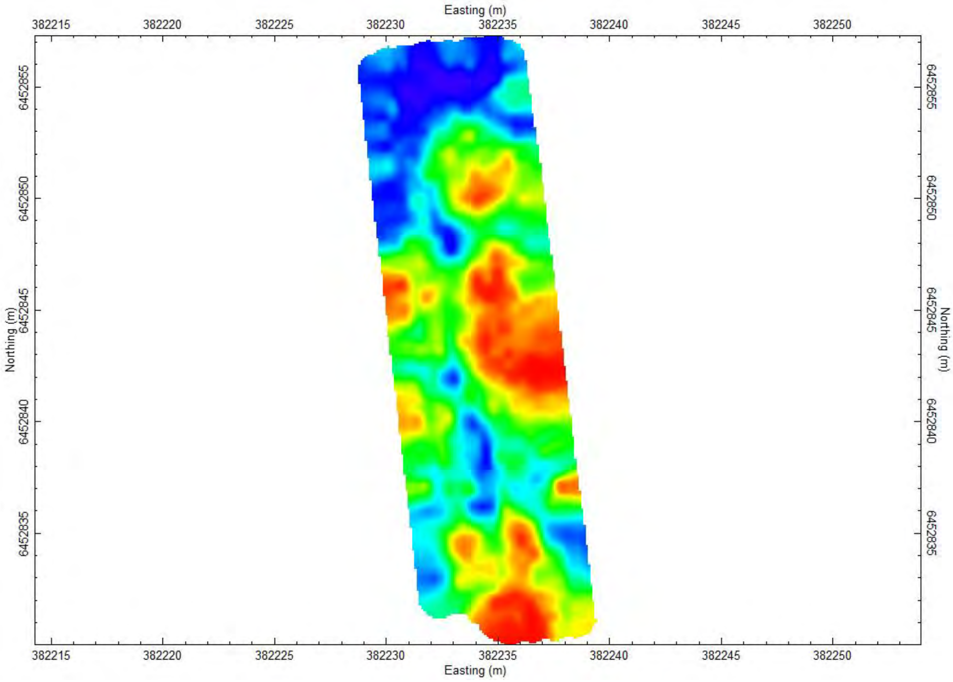
3.2. GPR Data Analysis

Draig interpretated the processed GPR data in two manners; interpreting regions of high amplitude response across the radar depth-slices and also high amplitude features of interest along the radargram section data. Maps presenting depth-slice interpretation linework and radargram section interpretation point features are presented in Appendix C, Figures C1-C6.

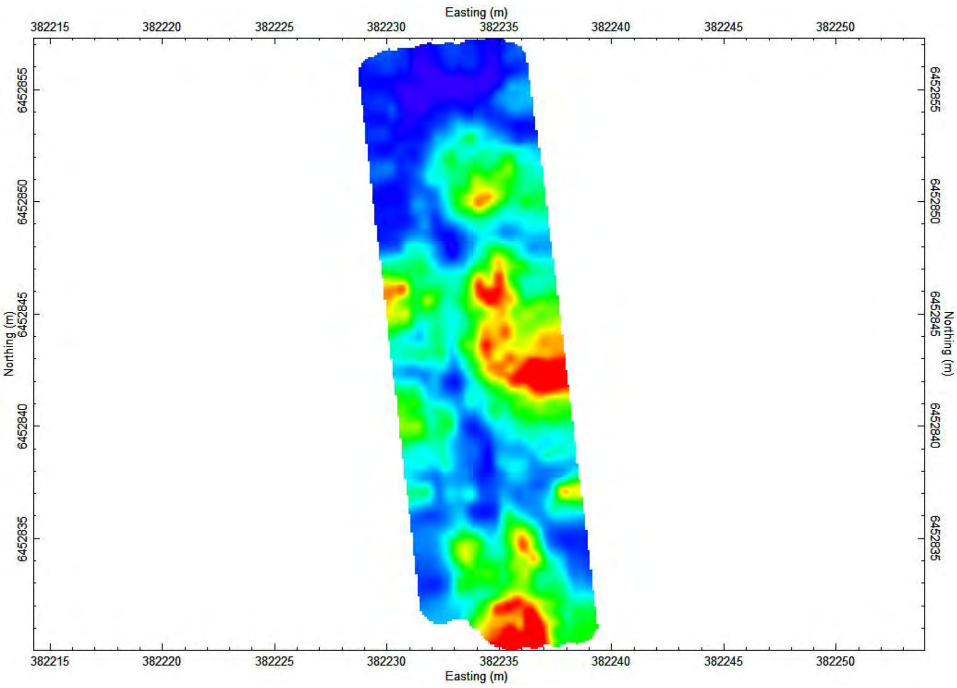
3.2.1. Depth-Slice Interpretation

To aid with interpretation, Draig applied a colour-clip to the average GPR amplitude intensity maps to highlight regions of high amplitude response (red-coloured “hot spots”).

A linear (increasing) transform (rainbow colour-scale) was applied to each individual average GPR amplitude intensity map with a bandpass cut-off/clip of 1-97/98%. (The linear transform stretches the colour-scale from the lowest value data value to lowest mapped colour, to highest value mapped to highest mapped colour.) Figure 4 shows an example of an unclipped and clipped average GPR amplitude intensity map. Once colour-clipped, high amplitude response targets were interpreted and traced. Figure 5 shows an example of the interpretation linework to outline a zone of high amplitude (hot spot).



(a)



(b)

Figure 4. (a) An average GPR amplitude intensity map for site Area 03 (Depth-Slice 25) showing no colour clip (full colour-scale) and (b) showing a 1-97% clipped colour-scale. The clipped colour-scale was the colour-scale used for data interpretation.

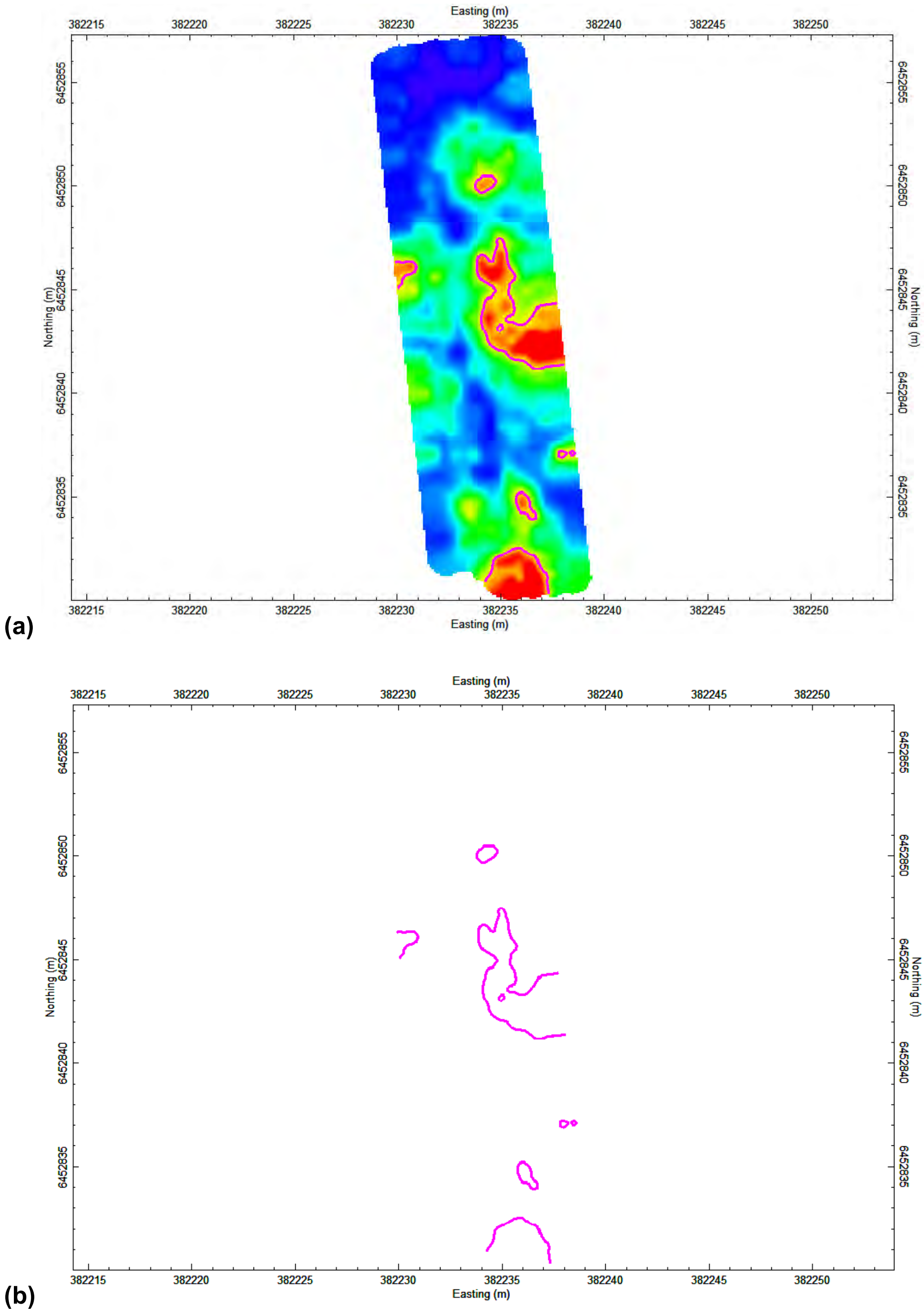


Figure 5. Example of interpretation of average GPR amplitude intensity map for high amplitude zones (hot spot). (a) An average GPR amplitude intensity map at site 03 (Depth-Slice 25) with 1-97% clipped colour-scale applied and interpretation drawn (magenta line), (b) interpretation linework only (magenta line).

These high amplitude zones were grouped into designated depth intervals and coloured as shown in Figure 6.

Figure 6. High amplitude zone (depth-slice interpretation) designated depth intervals and colour coding.

3.2.2. Radargram Section Interpretation

Draig initially interpreted the radargram sections for high amplitude responses that appeared anomalous to the reflections surrounding the feature. Examples of high amplitude response features are shown in Figure 7 and Figure 8 (black dots/magenta arrows – top of high amplitude response features). These features may be associated with underground tunnels, buried infrastructure, lithological changes with the geological material and regions of possible fracturing/voiding. The interpreted radargram point features were then grouped into 0.0-0.99 m, 1.0-1.99 m, 2.0-2.99 m, 3.0-3.99 m and 4+m depth brackets (see Appendix C, Figure C1-C6).

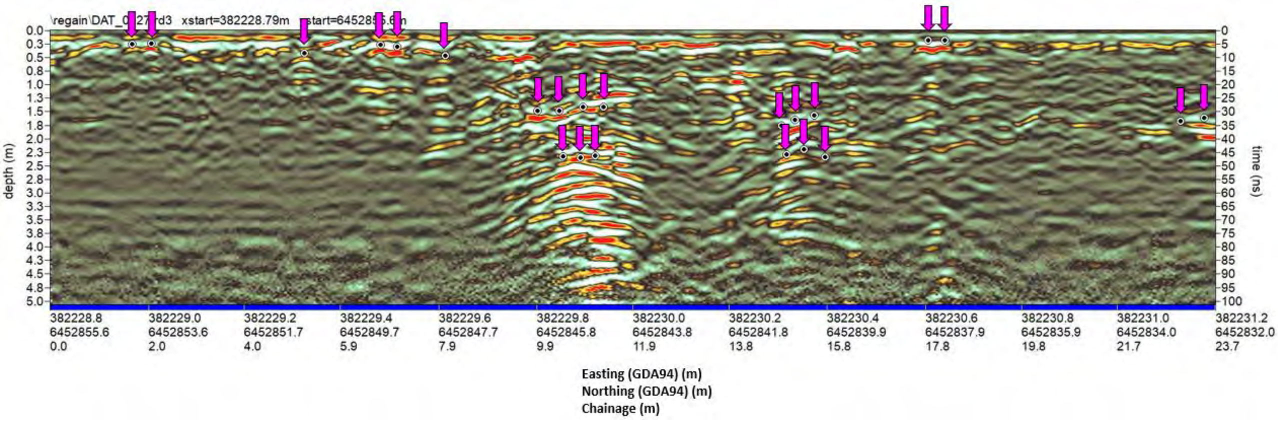


Figure 7. Radargram DAT_0027 interpreted high amplitude response features (black dots/magenta arrows – top of high amplitude response feature).

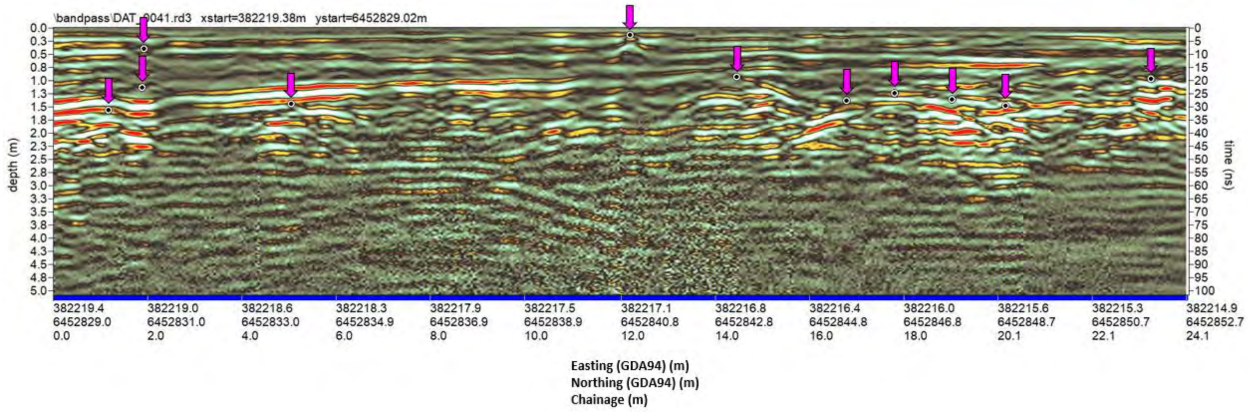


Figure 8. Radargram DAT_0041 interpreted high amplitude response features (black dots/magenta arrows – top of high amplitude response feature).

3.2.3. Estimated Tunnel Alignment of Interest

The top of the historical sewer line is interpreted to occur at a depth of ~2.05 m, as observed in the GPR response. E.g. The feature observed in Figure 9 (DAT_0010 radargram) at ~382240.8 mE, 6452841.5 mN and ~2.1 m depth is interpreted as likely to be caused by the top of the historical sewer line/tunnel.

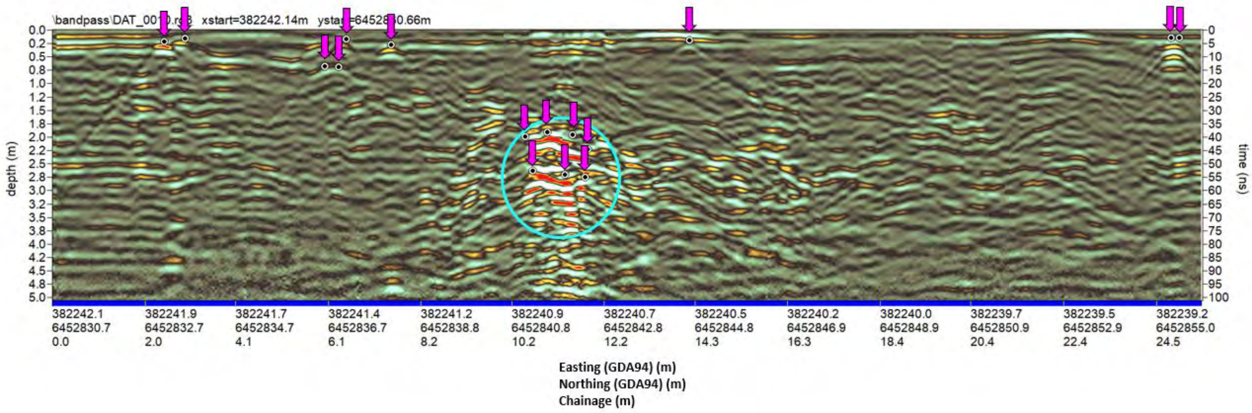


Figure 9. Radargram DAT_0010 interpreted high amplitude response features (black dots/magenta arrows – top of high amplitude response feature). Interpreted historical sewer location circled in cyan.

Following this feature through the GPR data and images, the location of the historical sewer line is interpreted to extend ~E-W from the SW corner of the building's verandah (~ 382243.0 mE, 6452841.7 mN, 2.4 m depth, DAT_0006) to approximately 2 m into the road west of the building's western gated fenceline (~ 382235.0 mE, 6452842.4 mN, 2.2 m depth, DAT_0018). At this point, a high amplitude GPR response is observed extending approximately northwards, parallel to the road direction, to ~382234 mE, 6452847 mN, a distance of ~6 m. This area when viewed in the 2D radargram images displays what appears to be a subsurface ground disturbance (see Figure 10 for an example). Where this subsurface change is observed in the 2D radargrams also coincides with a sudden decrease in GPR amplitude response for the historical sewer line feature, making it difficult to interpret the sewer line's location westwards beyond that point.

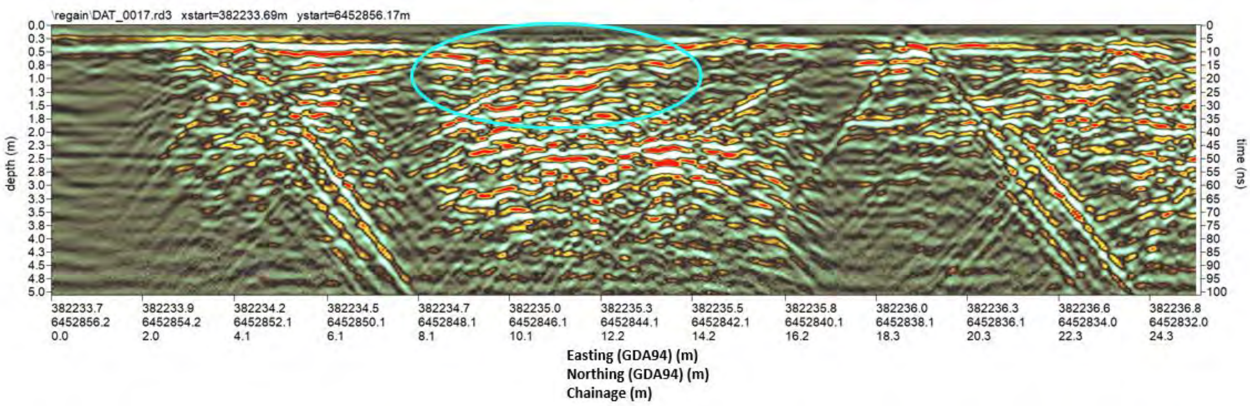


Figure 10. Radargram DAT_0017 with zone of ground disturbance highlighted (circled in cyan).

4. Conclusions

Draig were able to successfully identify the location of the historical sewer line within the area of investigation utilising the GPR method.

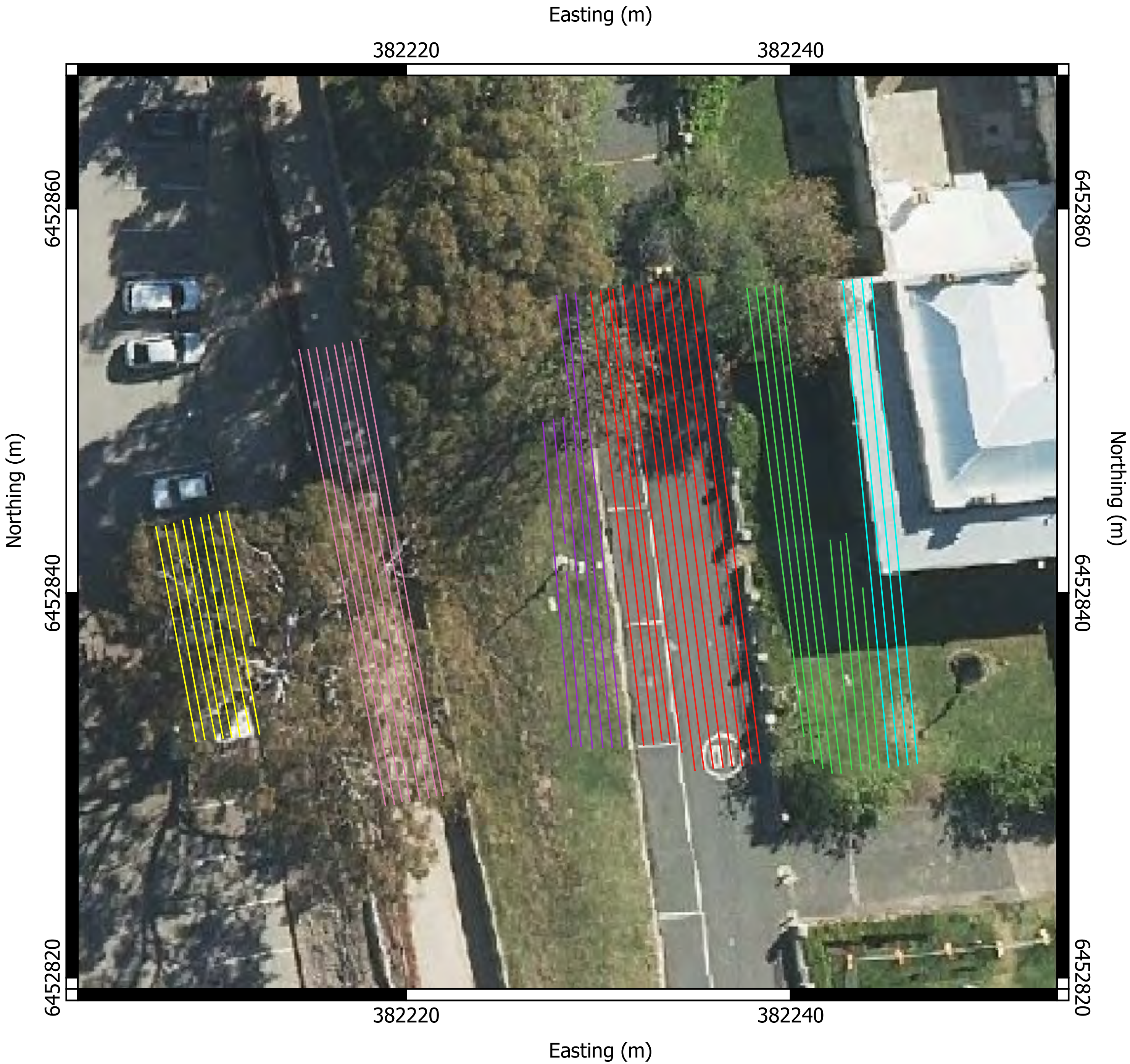
The sewer line is located at ~2.1-2.4 m depth (top of the sewer). It is interpretable for a length of ~9 m, between the SW corner of the building extending westwards to ~2 m into the adjacent road.

The GPR results also revealed an area of subsurface ground disturbance underneath the road, coinciding with the location of where the historical sewer line ceases to be interpretable, extending ~6 m north in the direction of the road.

It is not clear whether the historical sewer tunnel terminated at the western-most interpreted location, where a subsurface disturbance is located beneath the road, or whether it exists west of that location but has collapsed or been infilled with host/local material. In either of the latter two cases, this may have decreased the material contrast and resulted in an indiscernible GPR response.

Three other shallow linear features were also identified in the 0-1 m depth range – two south of the historical sewer line extending ~E-W from the eastern edge of the surveyed area (Area 1) to the western edge of Area 4 (grassed area west of the road), and a third extending ~E-W beneath the ramped walkway (Area 5). These are likely associated with utilities.

APPENDIX A – SITE PLAN



Legend

GPR survey line

- Area 1 - Verandah
- Area 2 - Grass
- Area 3 - Road
- Area 4 - Grass
- Area 5 - Ramp
- Area 6 - Carpark

0 5 10 m

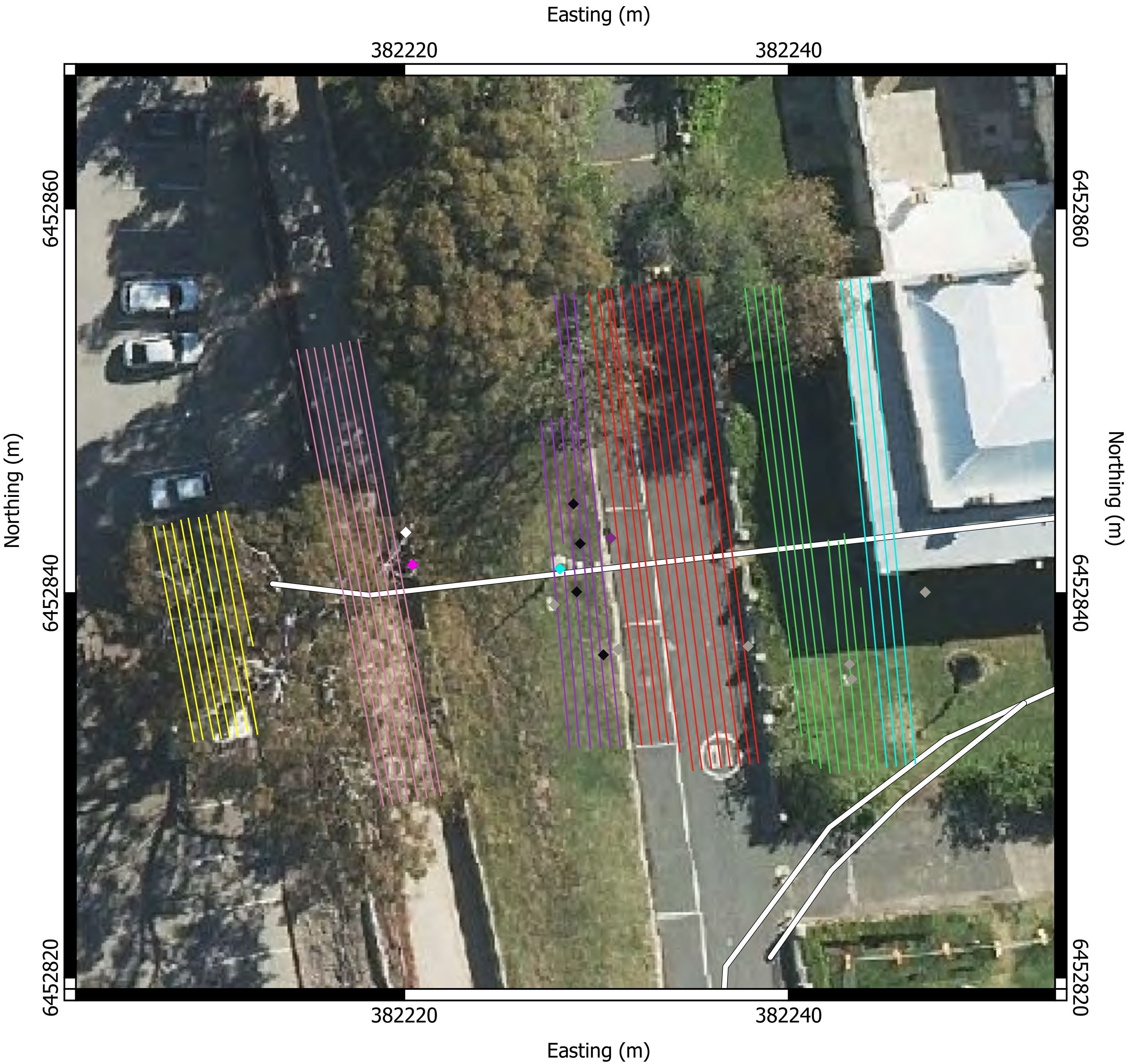
Image source: Landgate Satellite

DRAIG GEOSCIENCE PTY LTD

Fremantle Prison, Fremantle, WA

GPR Survey - Site Plan

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: A1	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

GPR survey line

- Area 1 - Verandah
- Area 2 - Grass
- Area 3 - Road
- Area 4 - Grass
- Area 5 - Ramp
- Area 6 - Carpark

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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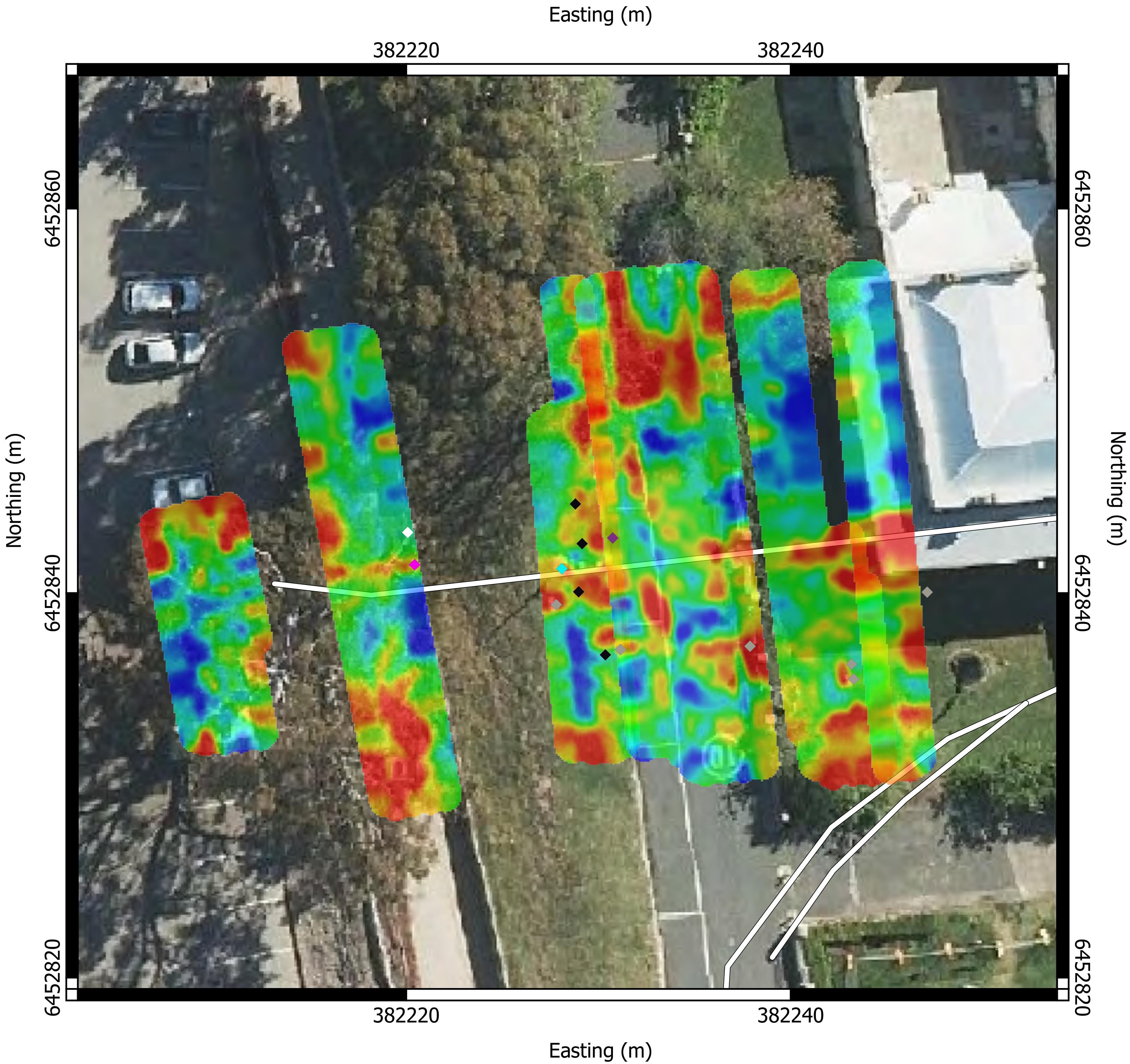
Fremantle Prison, Fremantle, WA

GPR Survey - Site Plan with Site Features

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: A2	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300

APPENDIX B – GPR DATA DEPTH-SLICES



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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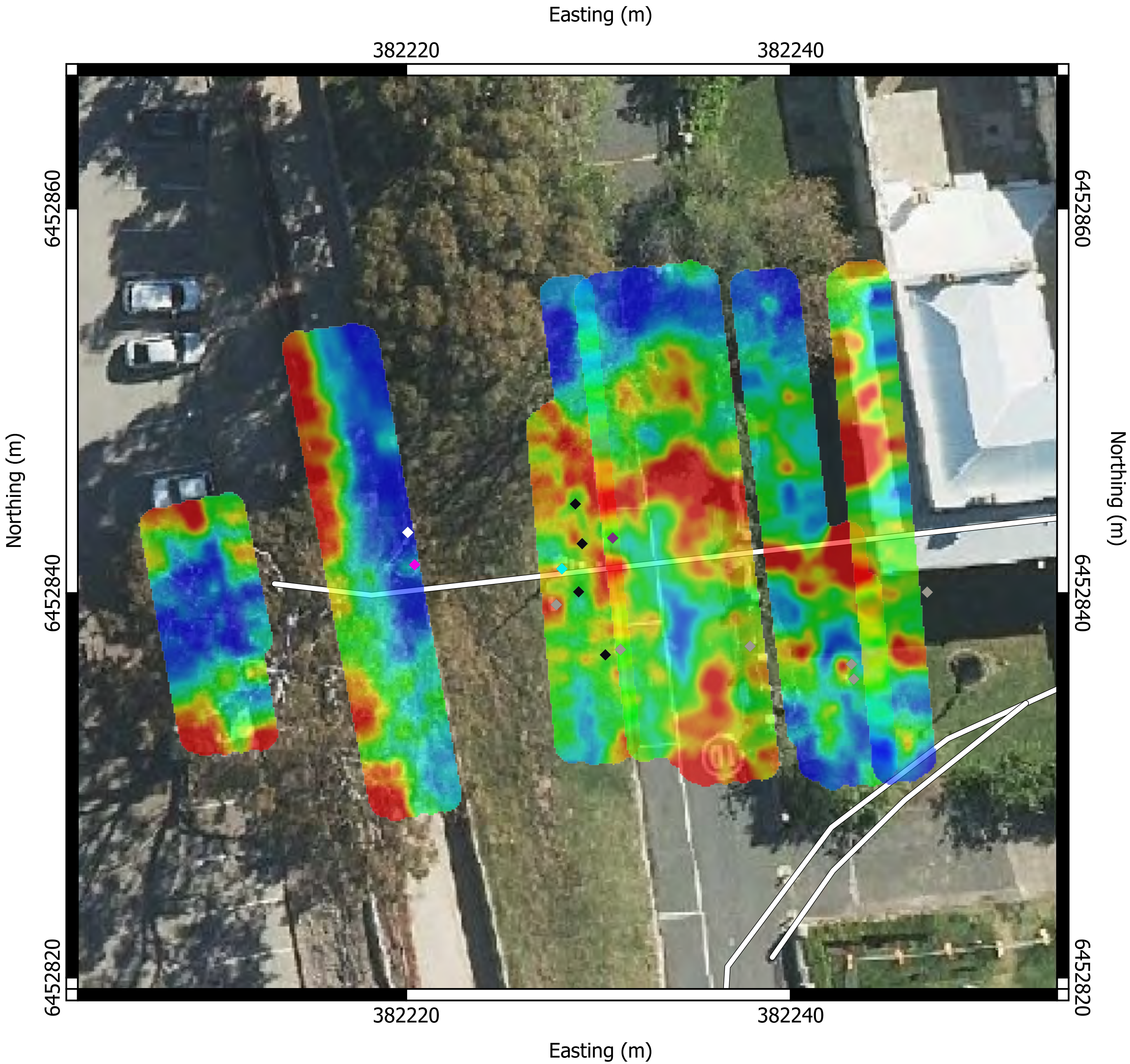
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 0.25 - 0.49 m (Slice 03)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B1	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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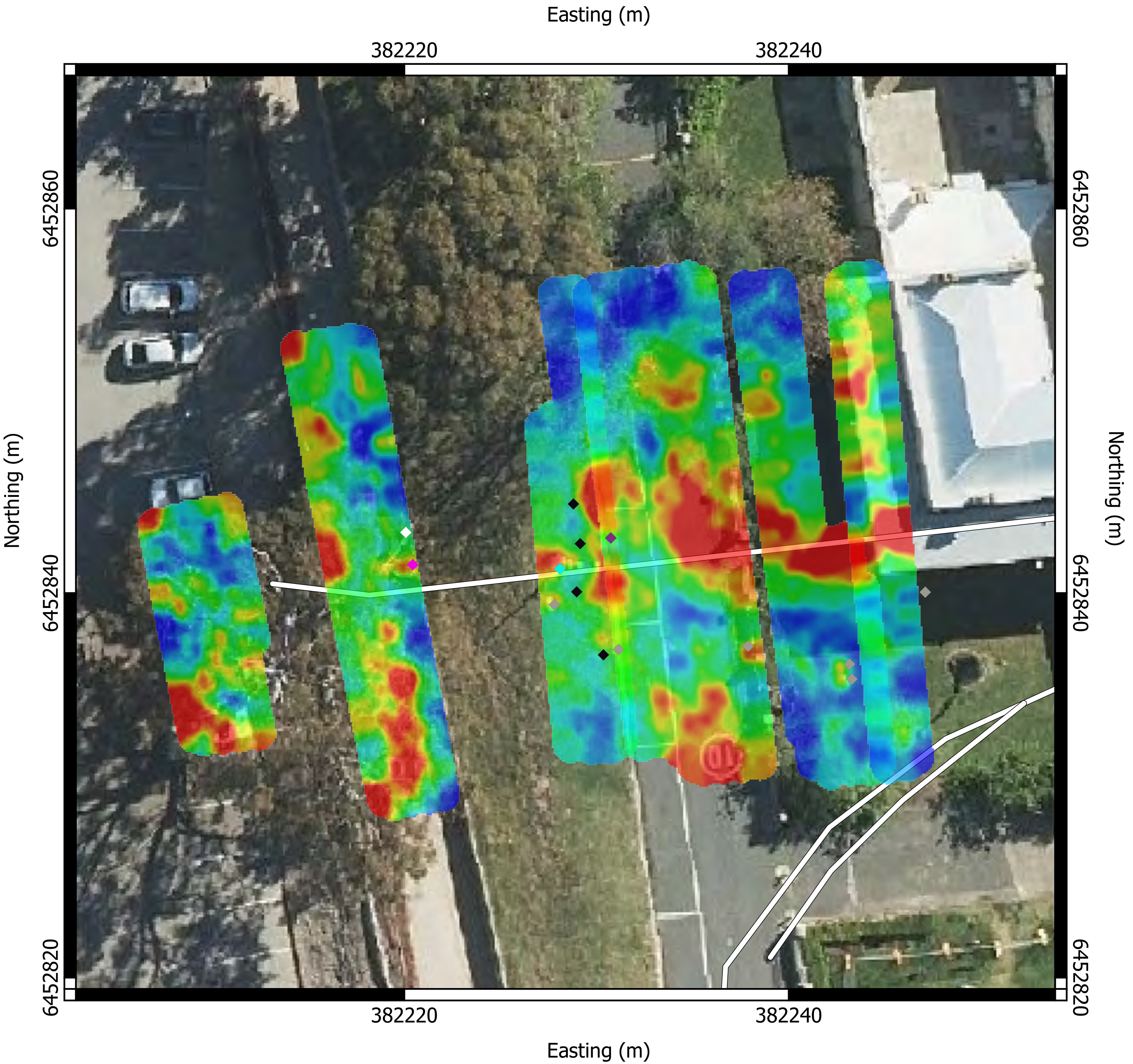
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 1.49 - 1.74 m (Slice 13)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B2	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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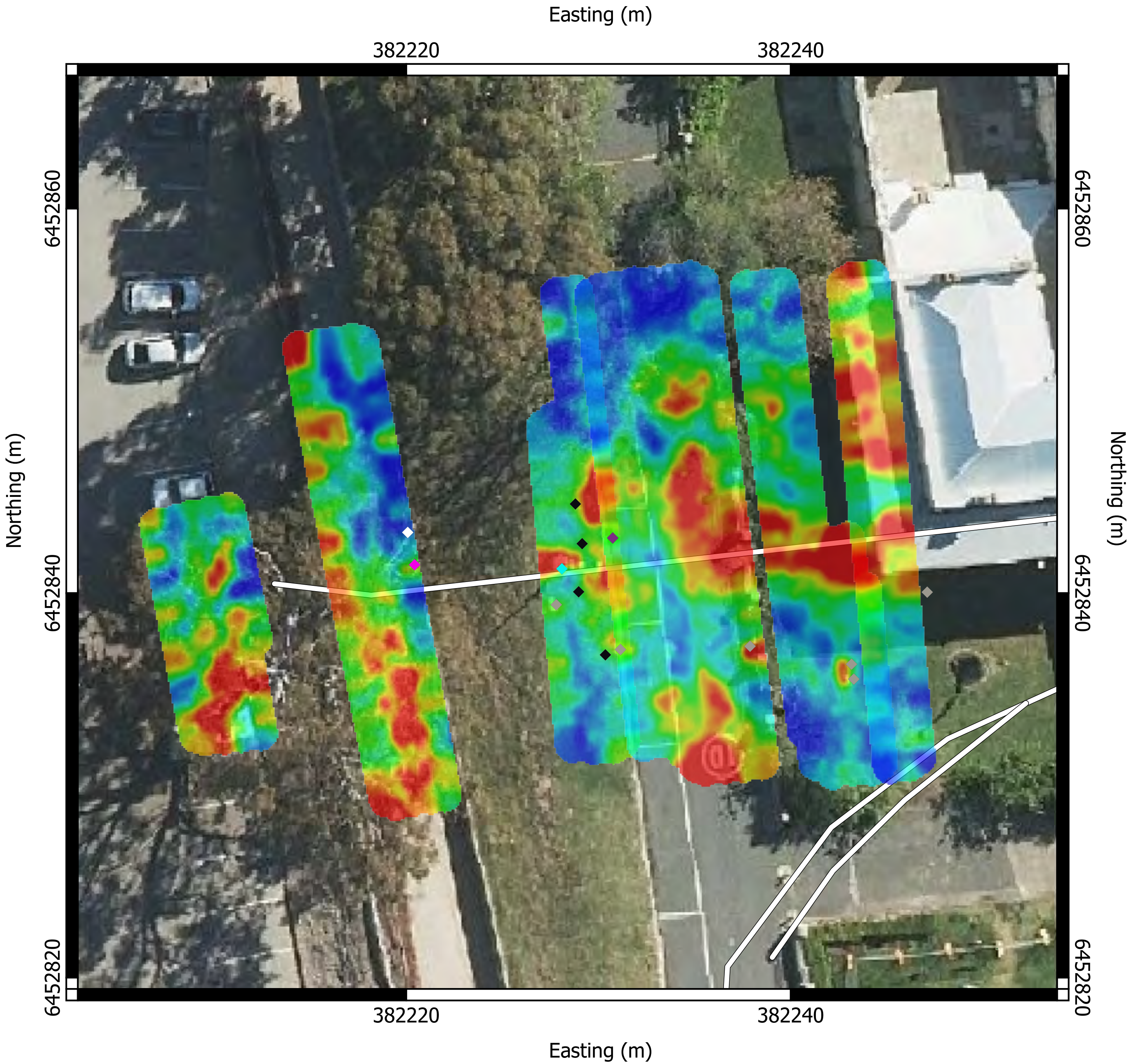
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 2.60 - 2.85 m (Slice 22)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B3	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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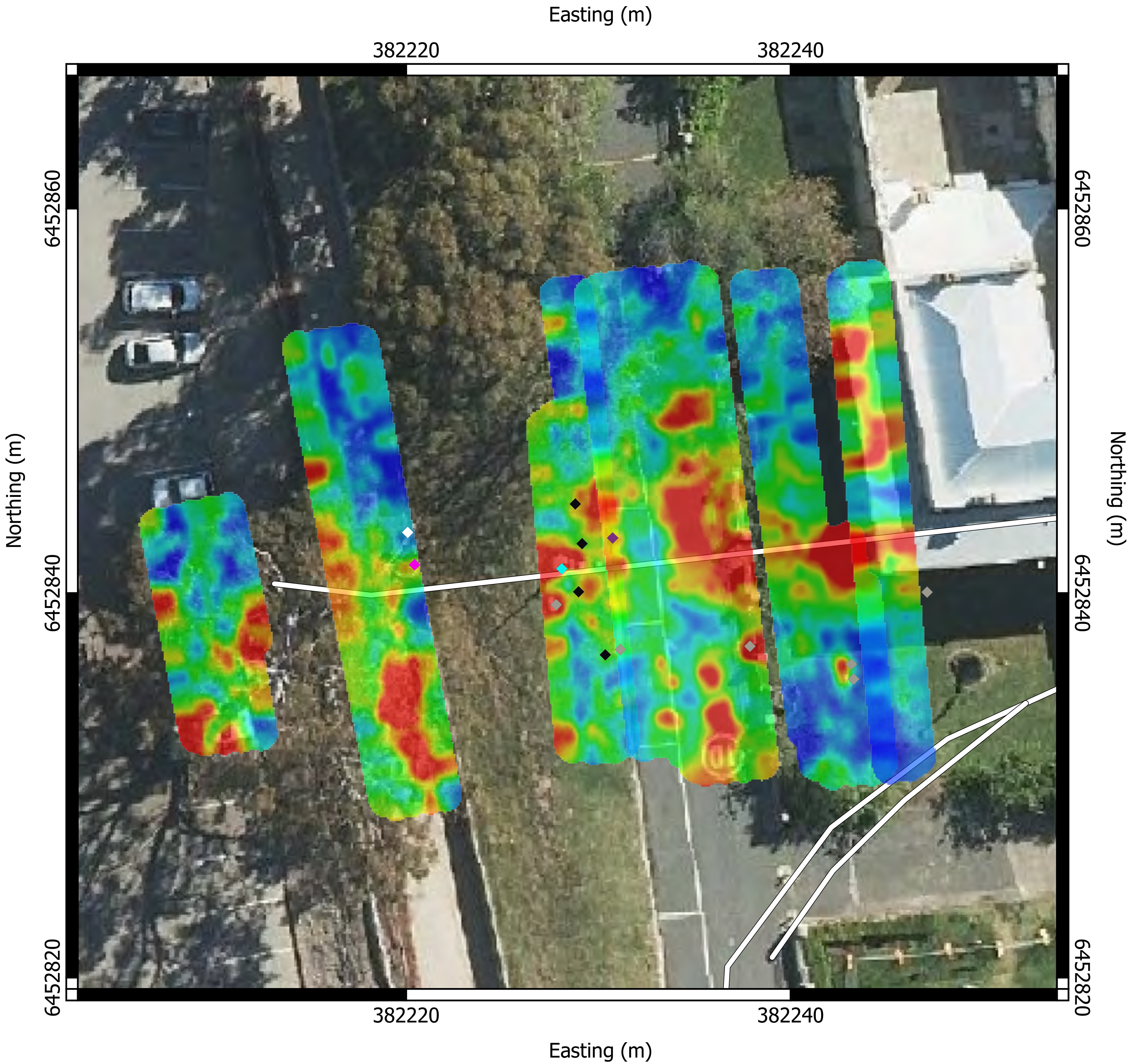
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 3.10 - 3.35 m (Slice 26)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B4	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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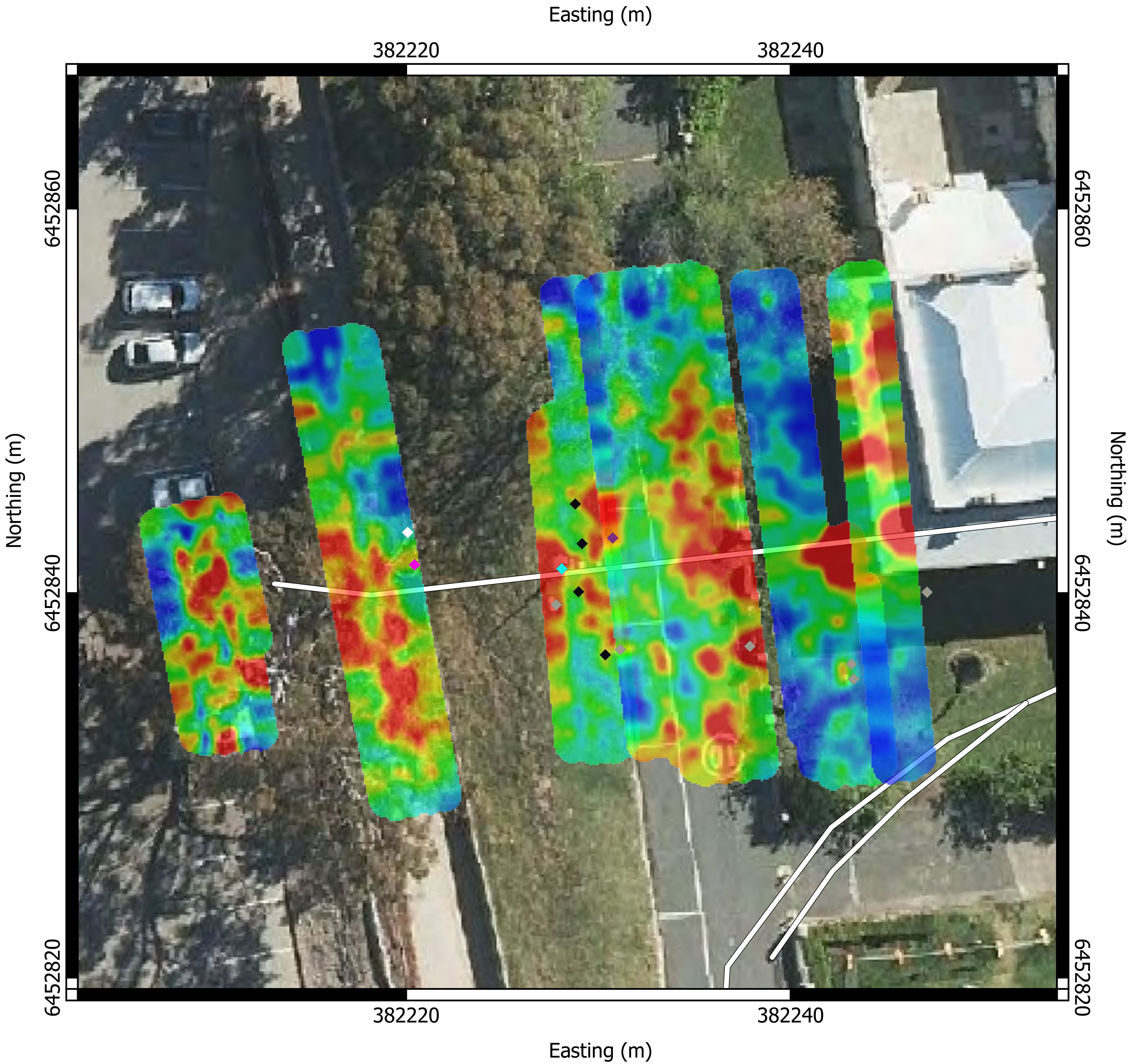
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 4.09 - 4.34 m (Slice 34)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B5	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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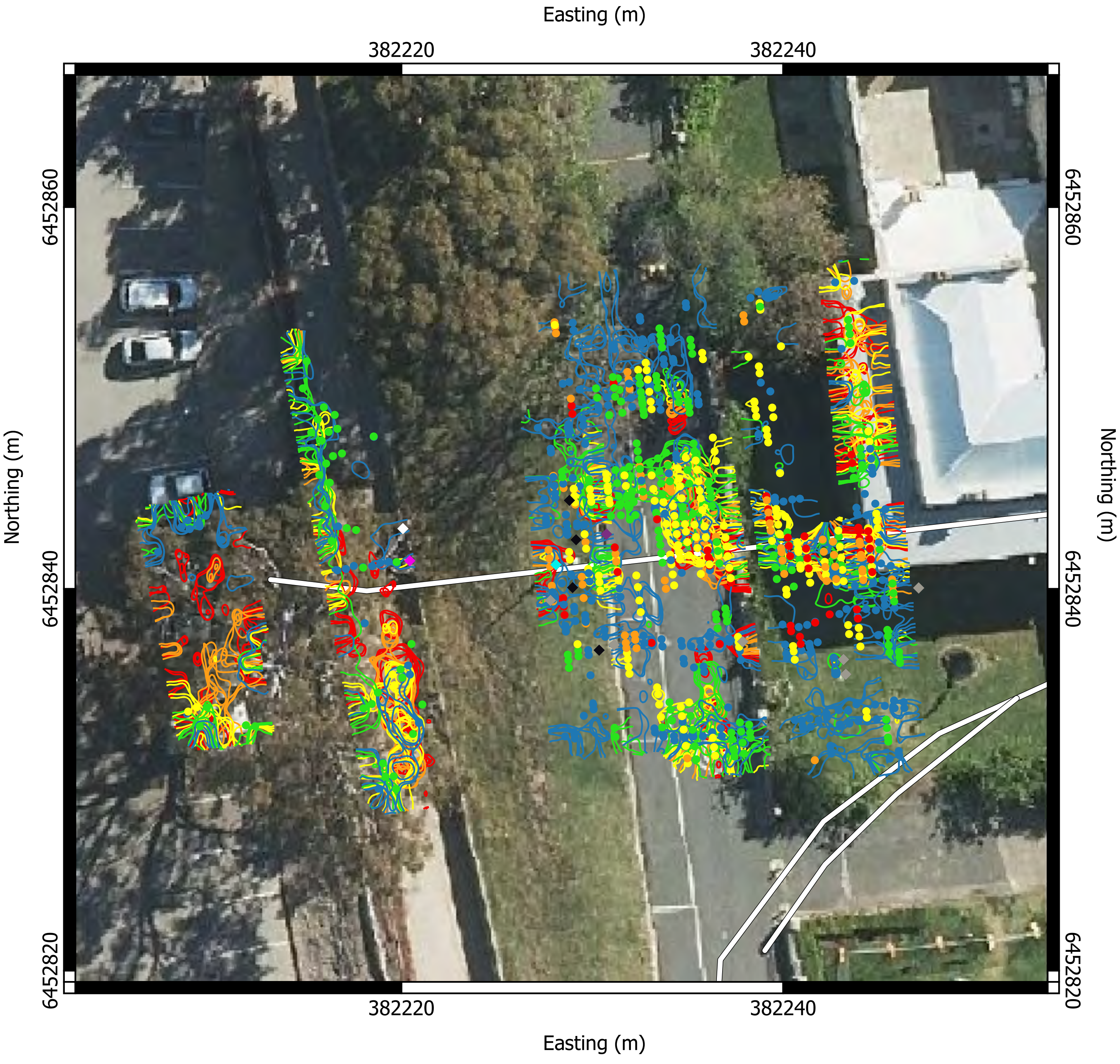
Fremantle Prison, Fremantle, WA

Average GPR amplitude intensity for depth range 4.96 - 5.09 m (Slice 41)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: B6	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300

APPENDIX C – GPR FEATURE INTERPRETATION PLOTS



Legend

Outline of Interpreted Zones of High Amplitude

- Depth 0.00 - 0.99 m (slices 01 - 07)
- Depth 1.00 - 1.99 m (slices 10 - 15)
- Depth 2.00 - 2.99 m (slices 18 - 23)
- Depth 3.00 - 3.99 m (slices 26 - 31)
- Depth 4.00 - 5.09 m (slices 34 - 41)

Location of Interpreted Points of High Amplitude

- Depth 0.00 - 0.99 m
- Depth 1.00 - 1.99 m
- Depth 2.00 - 2.99 m
- Depth 3.00 - 3.99 m
- Depth 4.00 m and greater

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

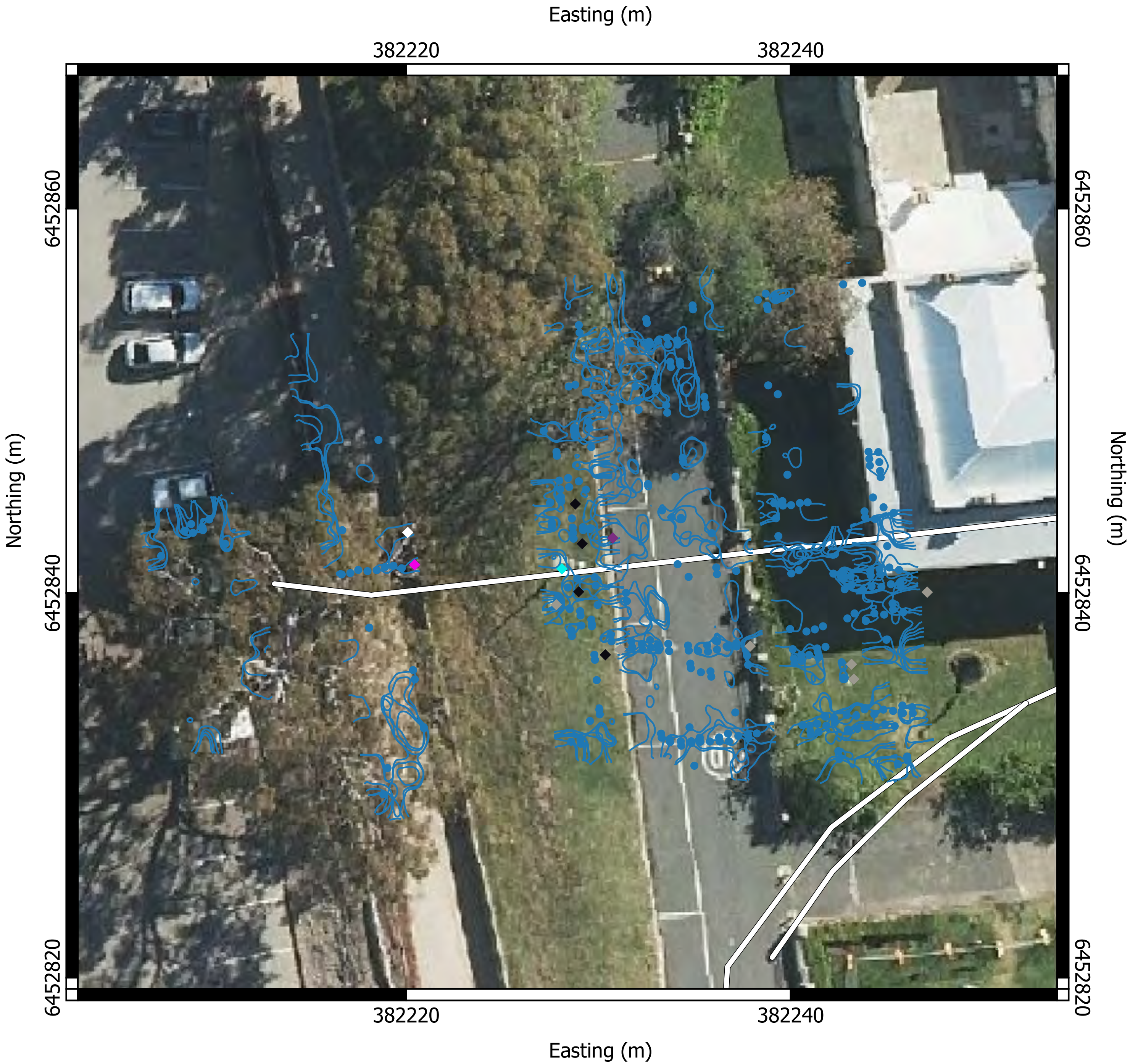
Image source: Landgate Satellite

DRAIG GEOSCIENCE PTY LTD

Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C1	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Outline of Interpreted Zones of High Amplitude

- Depth 0.00 - 0.99 m (slices 01 - 07)

Location of Interpreted Points of High Amplitude

- Depth 0.00 - 0.99 m

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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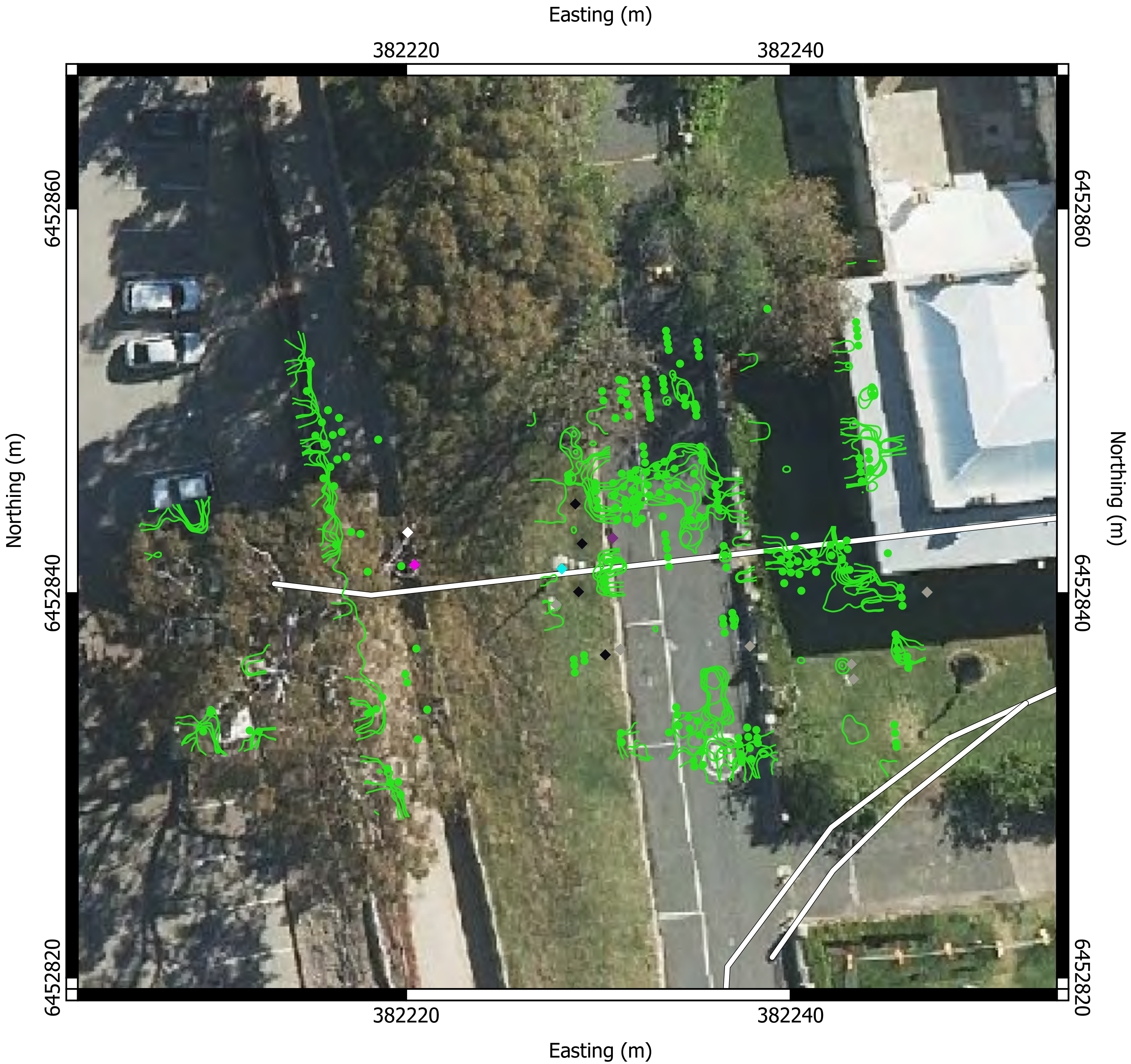
Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude (Depths 0.00 - 0.99 m)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C2	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Outline of Interpreted Zones of High Amplitude
- Depth 1.00 - 1.99 m (slices 10 - 15)

Location of Interpreted Points of High Amplitude
- Depth 1.00 - 1.99 m

Locations of site features
- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

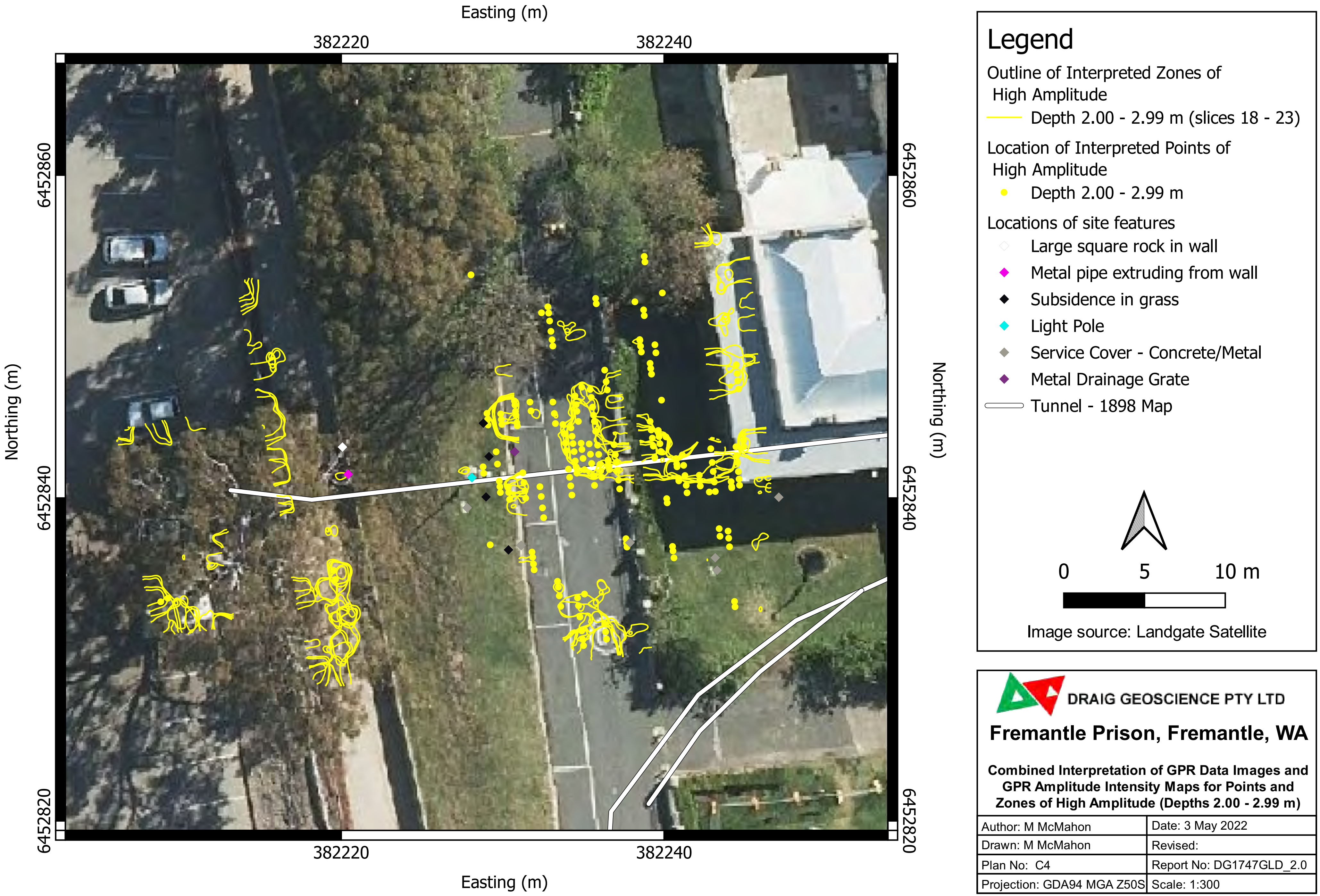
Image source: Landgate Satellite

DRAIG GEOSCIENCE PTY LTD

Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude (Depths 1.00 - 1.99 m)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C3	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300

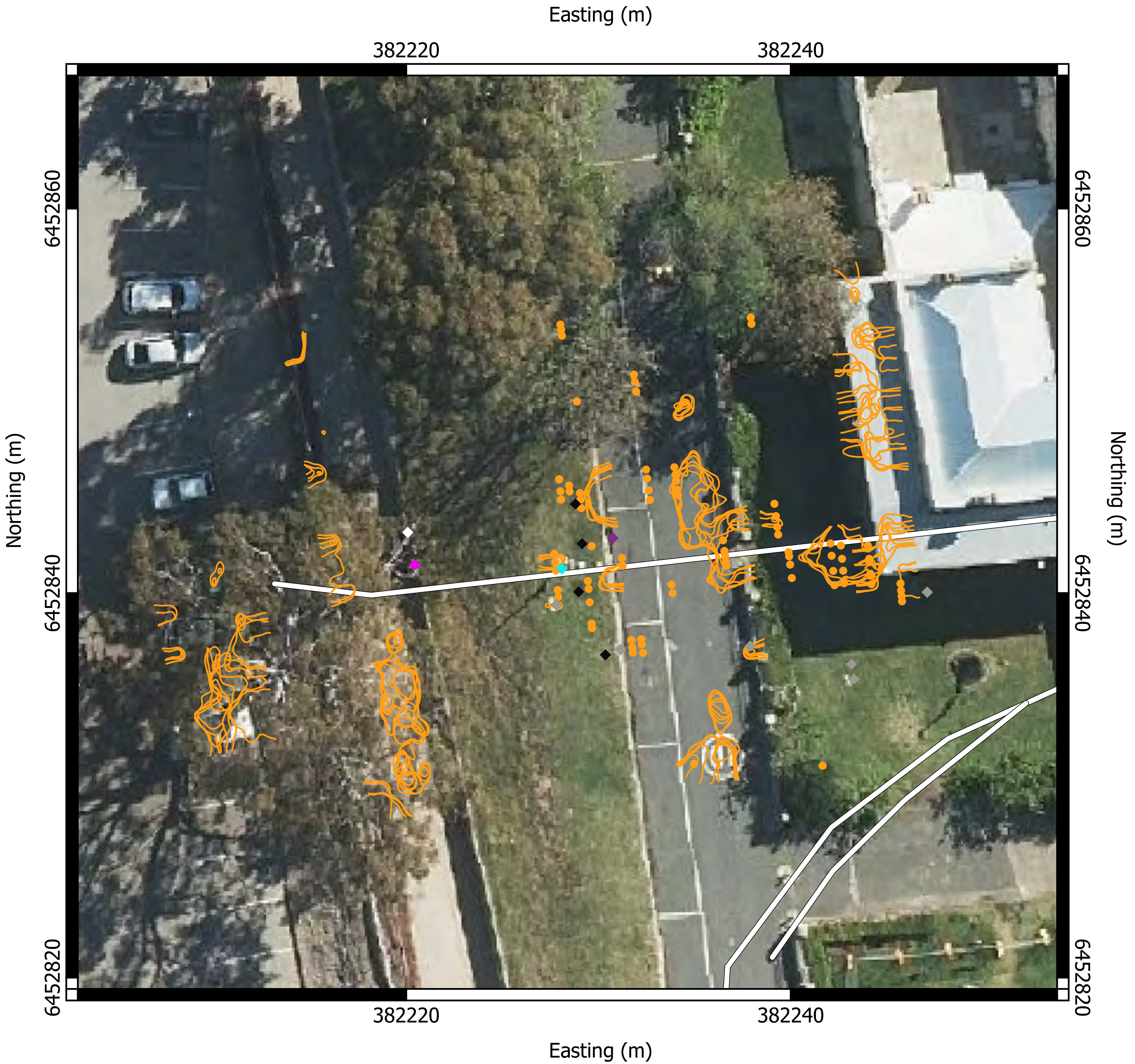


DRAIG GEOSCIENCE PTY LTD

Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude (Depths 2.00 - 2.99 m)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C4	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Outline of Interpreted Zones of High Amplitude
- Depth 3.00 - 3.99 m (slices 26 - 31)

Location of Interpreted Points of High Amplitude
- Depth 3.00 - 3.99 m

Locations of site features
- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

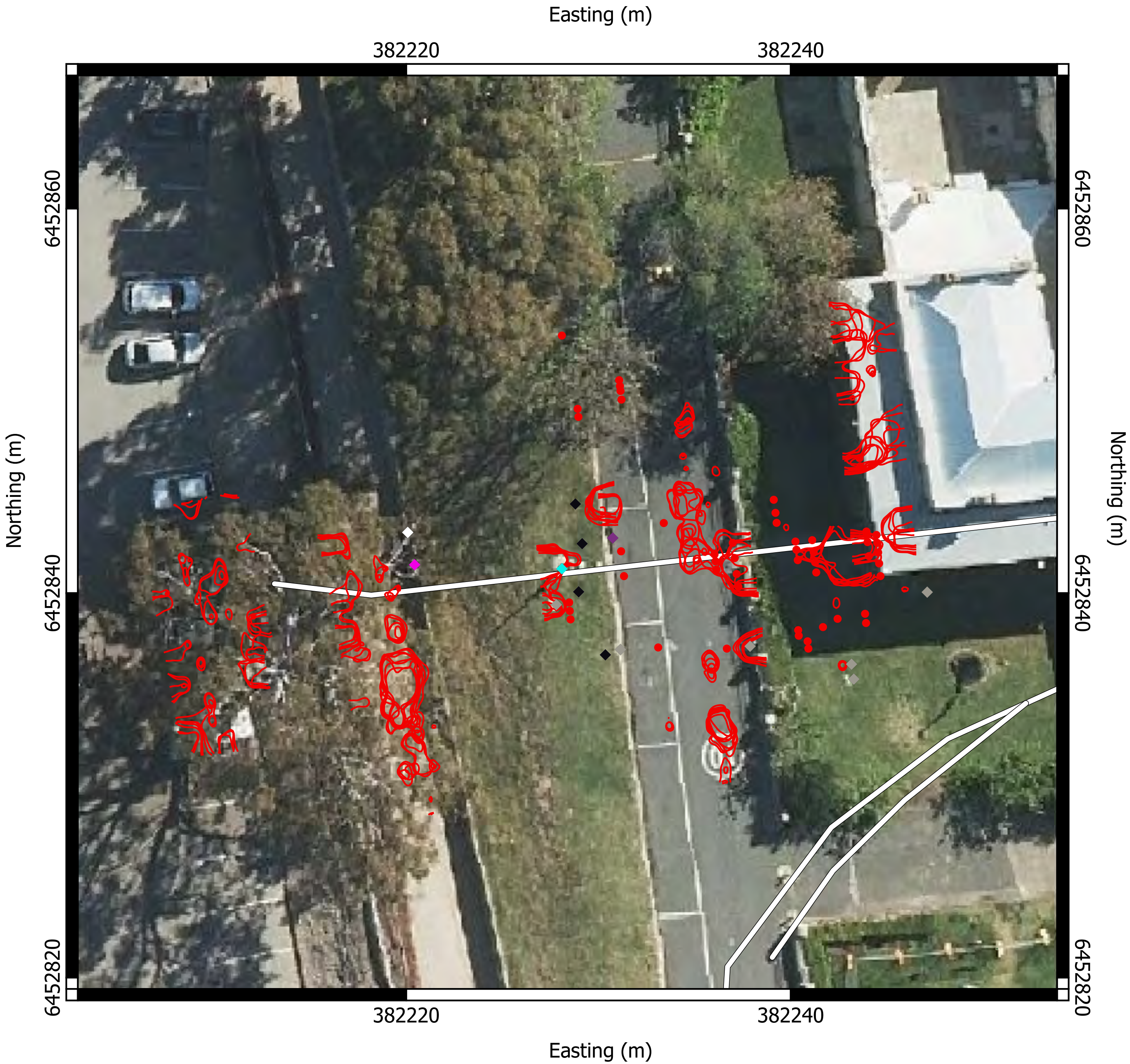
Image source: Landgate Satellite

DRAIG GEOSCIENCE PTY LTD

Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude (Depths 3.00 - 3.99 m)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C5	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300



Legend

Outline of Interpreted Zones of High Amplitude

- Depth 4.00 - 5.09 m (slices 34 - 41)

Location of Interpreted Points of High Amplitude

- Depth 4.00 m and greater

Locations of site features

- Large square rock in wall
- Metal pipe extruding from wall
- Subsidence in grass
- Light Pole
- Service Cover - Concrete/Metal
- Metal Drainage Grate
- Tunnel - 1898 Map

0 5 10 m

Image source: Landgate Satellite

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Fremantle Prison, Fremantle, WA

Combined Interpretation of GPR Data Images and GPR Amplitude Intensity Maps for Points and Zones of High Amplitude (Depths 4.00 m and over)

Author: M McMahon	Date: 3 May 2022
Drawn: M McMahon	Revised:
Plan No: C6	Report No: DG1747GLD_2.0
Projection: GDA94 MGA Z50S	Scale: 1:300