Assessment and Decision Frameworks for Seawall Structures

2013

Appendix D

Site Field Data Collection

SYDNEY COASTAL COUNCILS GROUP

Coastal Adaptation Decision Pathways Project **(CAP)**

The Sydney Coastal Councils Group (SCCG) is a voluntary Regional Organisation of Councils representing fifteen coastal and estuarine councils in the Sydney region. The Group promotes cooperation and coordination between Members to achieve the sustainable management of the urban coastal environment.

Project Management

Geoff Withycombe
Executive Officer
Sydney Coastal Councils Group

Douglas Lord
Director
Coastal Environment Pty Ltd

Professor Rodger Tomlinson
Director
Griffith Centre for Coastal Management
Griffith University

Project Co-ordination

Dr Ian Armstrong
Project Officer - Climate Change Adaptation
Sydney Coastal Councils Group
Ph: 02 9288.5802
ian@sydneycoastalcouncils.com.au

Australian Government
Department of Climate Change and Energy Efficiency

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Cover image: Coastal seawall. Provided by Douglas Lord

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Appendix D
Site Field Data Collection

Prepared for

Sydney Coastal Councils Group

Prepared by

Water Research Laboratory
University of New South Wales
110 King Street
Manly Vale NSW 2093

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SYDNEY COASTAL COUNCILS GROUP

Part A	Synthesis Report
Part B	Appendices Appendix A – Literature Review Appendix B – Geotechnical Considerations Appendix C – Economic Considerations Appendix D – Site Field Data Collection Appendix E – Case Study Bilgola Appendix F – Case Study Clontarf Appendix G – Case Study Gold Coast

Appendix D Preface

This Appendix was prepared by the Water Research Laboratory (WRL) of the University of New South Wales for this Report titled Assessment and Decision Frameworks for Seawall Structures. The purpose of the information in this Appendix was to assess the potential for using remote sensing to obtain relevant data on an existing buried rock armoured seawall. This included field assessment using ground penetrating radar, jetting and excavation of a 30-year old seawall buried under a foredune at Bilgola on Sydney's northern beaches. The information would then be used to assess the likely future performance of that wall under a rising sea level scenario (Appendix E of this report).

The purpose of the assessment reported in this Appendix should not be construed as a definitive assessment of the construction adequacy or otherwise of any of the seawalls at Bilgola Beach. The study provides a demonstration of how this remote sensing may be used to obtain crucial information relating to the otherwise inaccessible seawall. In particular, many of the design parameters inferred may not be correct and have not been verified. They could be refined with more detailed investigation.

The authors of the WRL report were A. Mariani and I. Coghlan. The field assessment using the ground penetrating radar was undertaken by Associate Professor Leonhard Bernhold from the School of Civil and Environmental Engineering at the University of New South Wales and is included in this Appendix. The overall assessment has been published by WRL as a single Report WRL2012/13 titled *Seawall Structure Assessment at Bilgola and Clontarf, Sydney, NSW* which includes the information herein as Appendix D, Appendix E and Appendix F. That WRL report was released in September 2012 and can also be viewed in that format.

The information included here has been taken in its entirety from the WRL report and is a true reflection of the original advice provided to the project by the Water Research Laboratory. No additions, edits or changes have been made to their final report, other than minor editorial and layout changes for consistency in appearance. References to sections, figures and tables are to those included within this Appendix or the associated Appendices as quoted.

As appropriate, information from this Appendix has been incorporated or referenced in the main report for this project.

CONTENTS

TABLES

FIGURES

Glossary

gabion	A factor of safety usually expressed as a height above the designated inundation level commonly applied for planning purposes
recession	The landward movement of a shoreline over time (e.g. receding shoreline). Can be caused by erosion resulting in more sediment leaving a coastal compartment than is entering it, or as a result of sea level rise inundating the shoreline over time
recession	The landward movement of a shoreline over time (e.g. receding shoreline). Can be caused by erosion resulting in more sediment leaving a coastal compartment than is entering it, or as a result of sea level rise inundating the shoreline over time
reno mattress	Flat wire mesh baskets filled with rocks, used to prevent erosion by water. See also gabion
scour	Erosion, normally by the action of flowing water or wave action
storm scour	The level of erosion of the seabed that occurs during a specific storm event. Usually measured as the lowering of the seabed against a fixed point or structure e.g. at the toe of a seawall
toe	The seaward base of a seawall
toe level	The level of the seaward base of a seawall

Acronyms

AHD	Australian Height Datum -
ARI	average recurrence interval
GPR	Ground Penetrating Radar
LGA	Local Government Area

1. Introduction

The Water Research Laboratory (WRL) of the University of New South Wales (UNSW) was engaged by Sydney Coastal Councils Group (SCCG) to undertake three case studies assessing existing seawalls in Sydney. At the request of SCCG, each case study was documented as a stand-alone appendix within the main report.

The present scope of works included the following case studies:

- Remote Sensing Assessment of a Buried Seawall Structure (Bilgola Beach Case Study) (this report, Appendix D to main report)
- Assessment of Open Coast Seawalls (Bilgola Beach Case Study) (Appendix E to main report)
- Assessment of Estuarine Beach Seawalls (Clontarf Case Study) (Appendix F to main report).

Note that the results presented in this report should not be used to assess the suitability or otherwise of any particular structure, nor to determine the suitability of any structure in protecting development at Bilgola Beach. Rather, the case study has been prepared as a practical, useful and usable framework to assist local government in managing and assessing generic seawall structures where no detailed design information is available.

The objective of this investigation was the trial of a non-intrusive technology (ground penetrating radar (GPR)) to determine several key geometric parameters of an existing buried seawall. This report aimed to verify the reliability and suitability of GPR for this purpose, by comparing the GPR outputs to drilling logs.

The objective of the investigations presented in Appendices E and F was to analyse the suitability of existing seawalls to withstand the occurrence of 1-, 10-, 50- and 100-year-ARI events for present-day conditions and for the 2050 and 2100 planning horizons, including sea level rise projections. The general methodology applied for the assessment of these coastal structures consisted of the following tasks (also presented diagrammatically in Figure 1.1):

- data compilation: an initial data and literature review including review of previous site investigations
- seawall characterisation: establishing relevant engineering design parameters such as crest and toe levels, construction method etc.
- environmental conditions: establishing design parameters in terms of wave and water level conditions and relevant coastal processes such as erosion, recession and inundation
- seawall assessment: a stability assessment with regards specifically to coastal processes
- remedial options: a list of upgrade, replacement and maintenance options, and
- future management: recommendations provided for further monitoring and data collection.

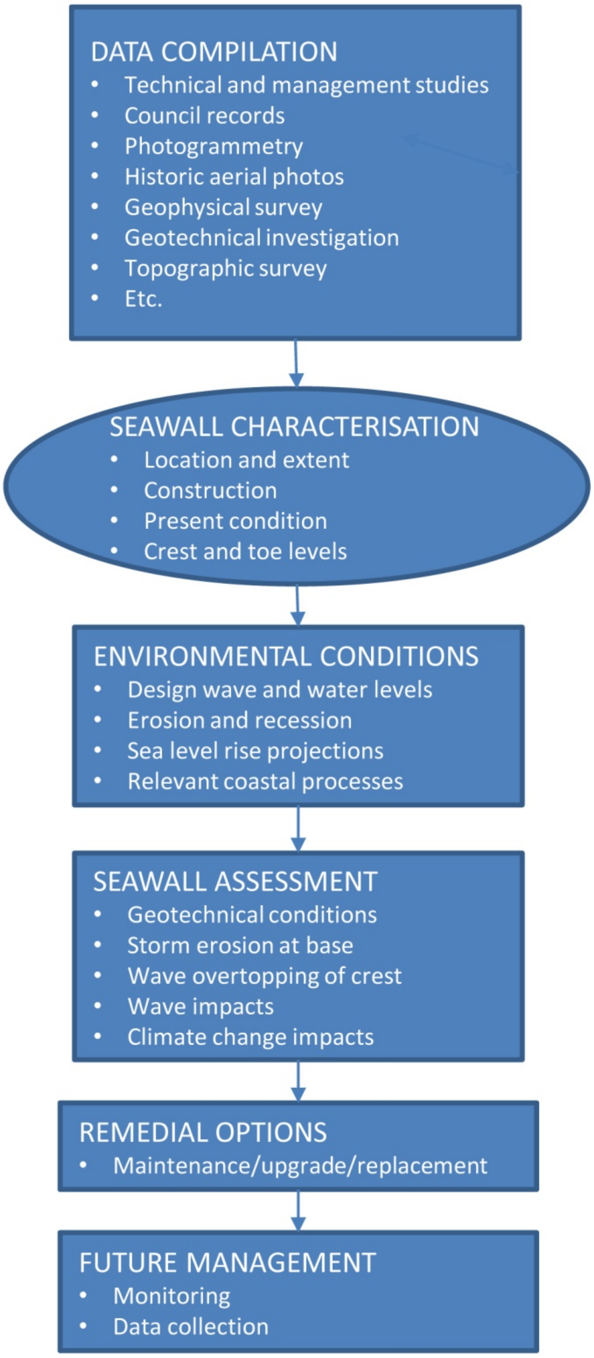


Figure 1.1 Methodology Applied for Seawall Suitability Assessment in Appendices E and F

2. Remote Sensing Assessment of a Buried Seawall Structure (Bilgola Beach Case Study)

2.1 Overview

The Water Research Laboratory was engaged by Sydney Coastal Councils Group to undertake a remote sensing assessment of a buried seawall structure. In consultation with SCCG, Bilgola Beach was selected as an appropriate location to undertake the case study on remote sensing of an existing seawall. **Note that the results presented in this report should not be used to assess the suitability or otherwise of any particular structure, nor to determine the suitability of any structure in protecting development at Bilgola Beach**. Rather, the case study has been prepared as a practical, useful and usable framework to assist local government in managing and assessing existing seawall structures where no detailed design information is available.

Bilgola Beach is part of the Pittwater Council Local Government Area (LGA) and its coastline includes the 500 m long sandy foreshore bordered by rocky headlands at both ends of the beach (Bilgola Head in the north and Newport Head in the south). A cul-de-sac road, eight private properties, a café, a car park, Bilgola Surf Life Saving Club (SLSC), a promenade and a swimming pool are located along the foreshore. Figure 2.1 presents the study area location.

There are several discrete seawall structures along Bilgola Beach as follows:

- Bilgola Beach Seawall 1: the sloping section of rock seawall located seaward of seven private properties (1, 3, 5, 7, 9, 11 and 13 Allen Avenue). At the time of writing, this section of wall was almost entirely buried by the dune.
- Bilgola Beach Seawall 2A: the vertical stone and concrete section of seawall located seaward of one private property (21 Bilgola Avenue).
- Bilgola Beach Seawall 2B: the sloping gabion seawall located 15 to 20 m landward of Seawall 2A. At the time of writing, this section of wall was entirely buried by fill.
- Bilgola Beach Seawall 3: the vertical section of seawall located seaward of Billies Café, a car park and Bilgola SLSC. This section of wall is constructed of dressed or cut sandstone blocks.

Since Seawall 1 is almost entirely buried by a revegetated dune, it was selected as the structure on which to carry out the remote sensing assessment. The location of this structure is shown with respect to the other seawalls within the Bilgola Beach foreshore in Figure A.2. Geotechnical and geophysical investigations including the experimental application of Ground Penetrating Radar (GPR) and the drilling of a series of test boreholes was undertaken to assess various aspects of Seawall 1. The objective of the survey was to determine the following parameters:

- seawall crest level
- seawall toe level
- seawall slope
- approximate seawall rock dimensions, and
- delineation of beach storm lag layers to assist with estimates of storm scour levels.

Additionally, the purpose of the investigation was the trial of a non-intrusive technology (GPR) in order to minimise the disturbance to the dune. There is little documentation of GPR use for coastal applications, and this project aimed to verify its reliability and suitability for this purpose, by comparing the GPR outputs to drilling logs.

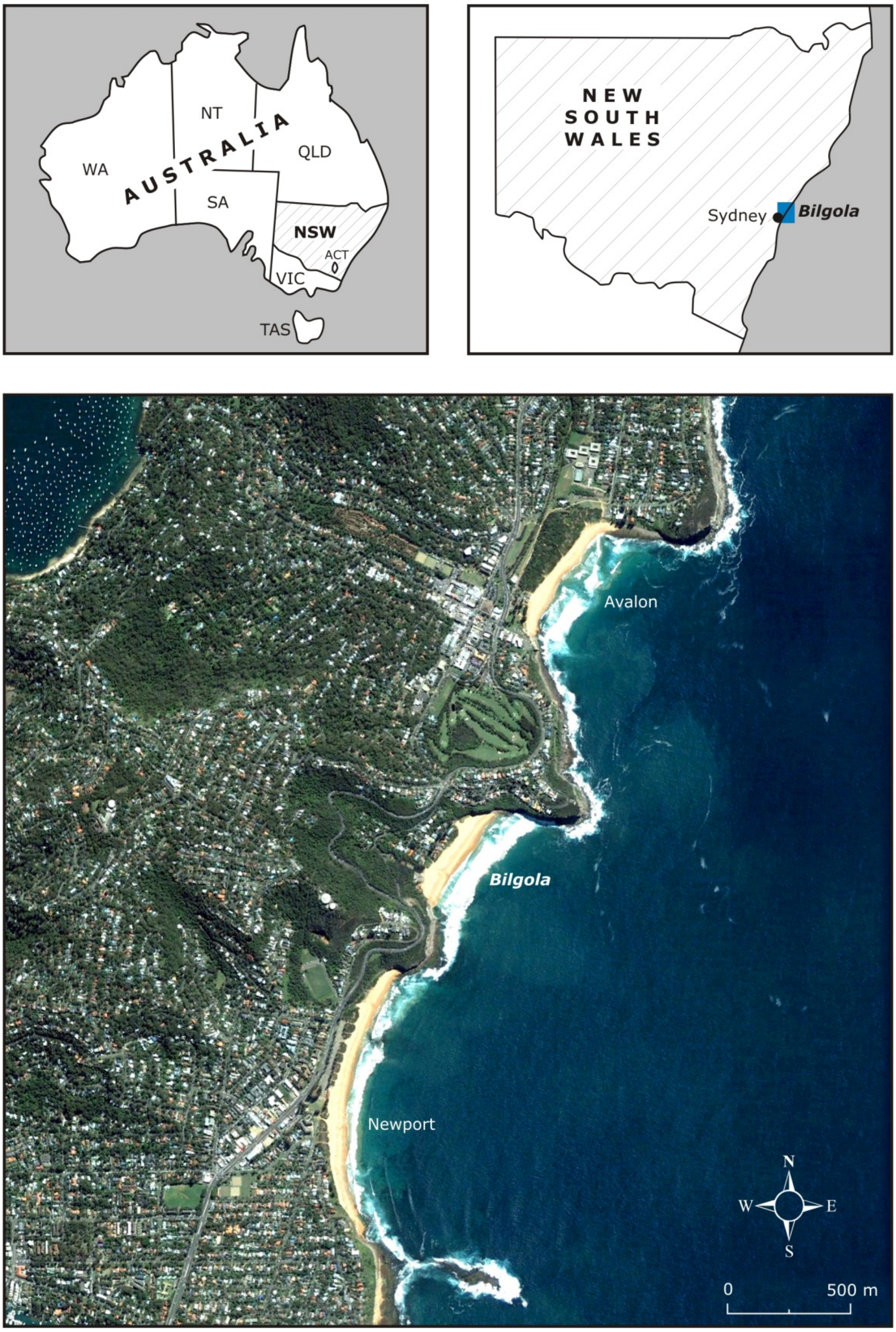


Figure 2.1 Location of Bilgola Beach, Sydney, NSW

Figure 2.2 Seawall Locations at Bilgola Beach

In parallel to this report, WRL also prepared two other reports for SCCG concerning the suitability of the seawalls at Bilgola Beach (Mariani and Coghlan, 2012a) and Clontarf (Mariani and Coghlan, 2012b) to withstand the occurrence of the adopted design storm events. In addition to the remote sensing assessment undertaken for Bilgola Beach Seawall 1, trial test pits were excavated at the structure fronting Bilgola SLSC (Bilgola Beach Seawall 3) to determine its toe level. This information was then referenced in the Bilgola Beach seawall condition assessment in Mariani and Coghlan (2012a). Trial tests pits were not required at Bilgola Beach Seawalls 2A and 2B and Clontarf Seawalls 1 and 2 as the toe levels are documented in previous geotechnical investigations and available design drawings. The excavation of trial test pits at Clontarf Seawall 3 (fronting Monash Crescent) could not be facilitated as part of this project. As no other information for this structure is available, the toe level at Clontarf Seawall 3 remains unknown (Mariani and Coghlan, 2012b).

2.2 Ground Penetrating Radar Investigation (Bilgola Beach Seawall 1)

GPR technology uses electromagnetic (EM) waves transmitted from an antenna which reflects off layers and objects in the ground. The reflections are received with the antenna and create a picture of the subsurface characteristics based on the response time of the electromagnetic waves. As the transmitting and receiving antenna is moved along the surface, records are collected and displayed side by side, resulting in a continuous cross-section, also known as a radar profile. Expert interpretation of the output 'diffraction signature' allows the identification of different material types at depth. GPR has previously been used to assist in the detection of the buried toe of old seawalls at Collaroy-Narrabeen Beach (Lord, 1999).

The GPR investigation was directed by Dr Leonhard Bernold of the University of New South Wales using a MALA Geoscience RAMAC GPR with a 500 MHz shielded antenna mounted on a mobile cart. The GPR investigation at Bilgola is part of a broader master's research thesis. Key aspects of the research that are relevant for the assessment of the coastal structures in Bilgola are summarised in this report. Dr Bernold's report on the GPR survey findings is presented in Addendum I.

The survey was undertaken by Dr Leonhard Bernold, Mr Amir Tavakolitabaezavareh and Mr Alessio Mariani on 28 April 2012. Ten sections (Sections 1-8 and Sections 12-13) across the dune fronting Allen Avenue properties were surveyed using GPR screening. The section locations (Figure 2.3) were selected in relation to the accessibility of the terrain, as the presence of thick vegetation in some locations did not allow the passage of the GPR equipment. Section lengths varied from approximately 15 to 30 m in a generally south-east to north-west direction across the assumed seawall location. Each section was topographically surveyed using WRL's RTK-GPS survey equipment. Measurements of sand density and water content were also made during the investigation. Photos of the survey are shown in Figure 2.4.

Additional Sections 9-11 (not shown on Figure 2.4) were surveyed in front of Bilgola Beach Seawall 3 (fronting Bilgola SLSC) to attempt to identify the delineation of beach storm lag layers to assist with estimates of storm scour levels. However, these surveys were inconclusive and beach storm lag layers were not able to be established at this location using GPR.

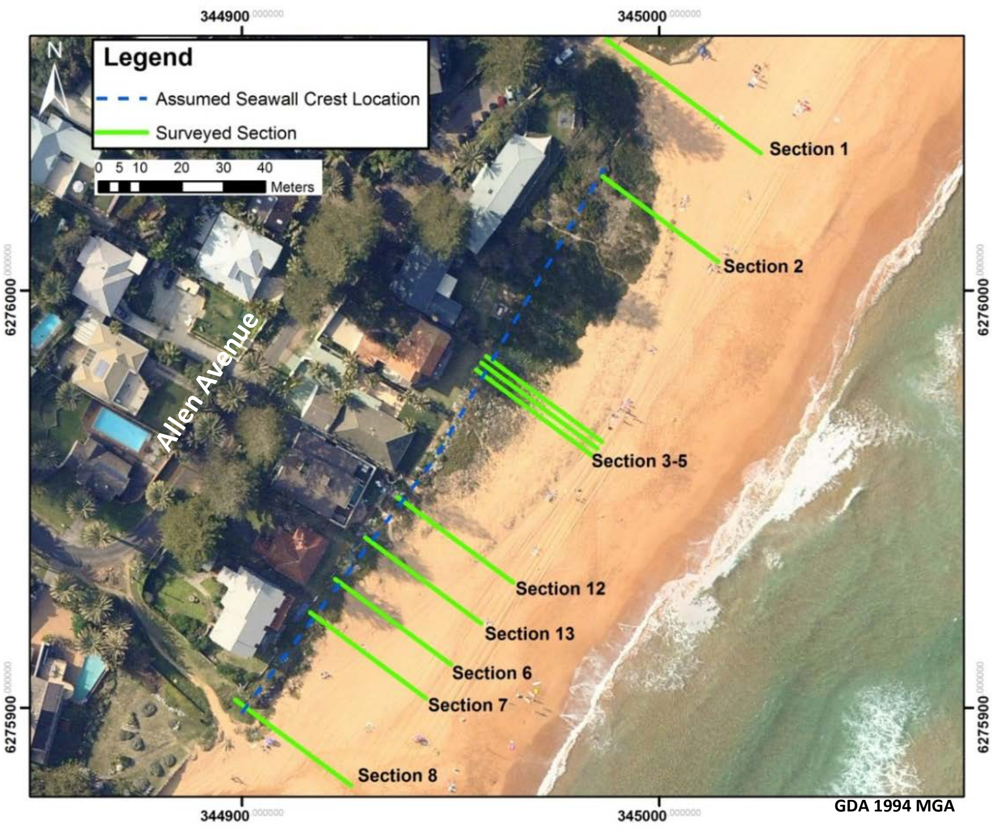


Figure 2.3 Location of Survey Sections Along the Dune Fronting Allen Avenue Properties

Figure 2.4 Photos of GPR Survey and RTK-GPS Survey

2.3 TEST BOREHOLE DRILLING (BILGOLA BEACH SEAWALL 1)

Drilling of boreholes was undertaken by MacDonald Contracting Australia Pty Ltd on 10 May 2012 under the direction and supervision of WRL staff Mr Alessio Mariani and Mr Hamish Studholme. Test boreholes were used to support and validate the GPR survey findings. The unconsolidated dune sands allowed jet air drilling of a 50 mm PVC casing into the sand down to refusal (i.e. until a hard substrate was reached).

A total of 60 test boreholes were drilled at 3 metre intervals along selected sections previously surveyed using GPR (Sections 3, 6, 7, 12 and 13). Locations of these sections are shown in Figure 2.3 and test borehole logs are presented in Addendum II. Borehole locations were topographically surveyed using WRL's RTK-GPS equipment. For each borehole, relative depths of refusal were recorded and absolute levels (m AHD) could then be inferred using the topographic data from the RTK-GPS survey. Photos of the drilling are shown in Figure 2.5.

Figure 2.5 Borehole Drilling on the Dune Fronting Number 5 Allen Avenue

2.4 Comparison of GPR and Drilling Survey Findings (Bilgola Beach Seawall 1)

Drilling was undertaken along Sections 3, 6, 7, 12 and 13 to support and verify the GPR findings. Locations of hard objects as established by the drilling survey are presented in Figure 2.6. For each section, Figures 2.7 (Sections 3, 6 and 7) and 2.8 (Sections 12 and 13) show plots of:

- Dune level as surveyed by RTK-GPS
- hard substrate levels (i.e. assumed rock location) as derived from drilling refusal depths, and
- hard substrate as derived from GPR analysis.

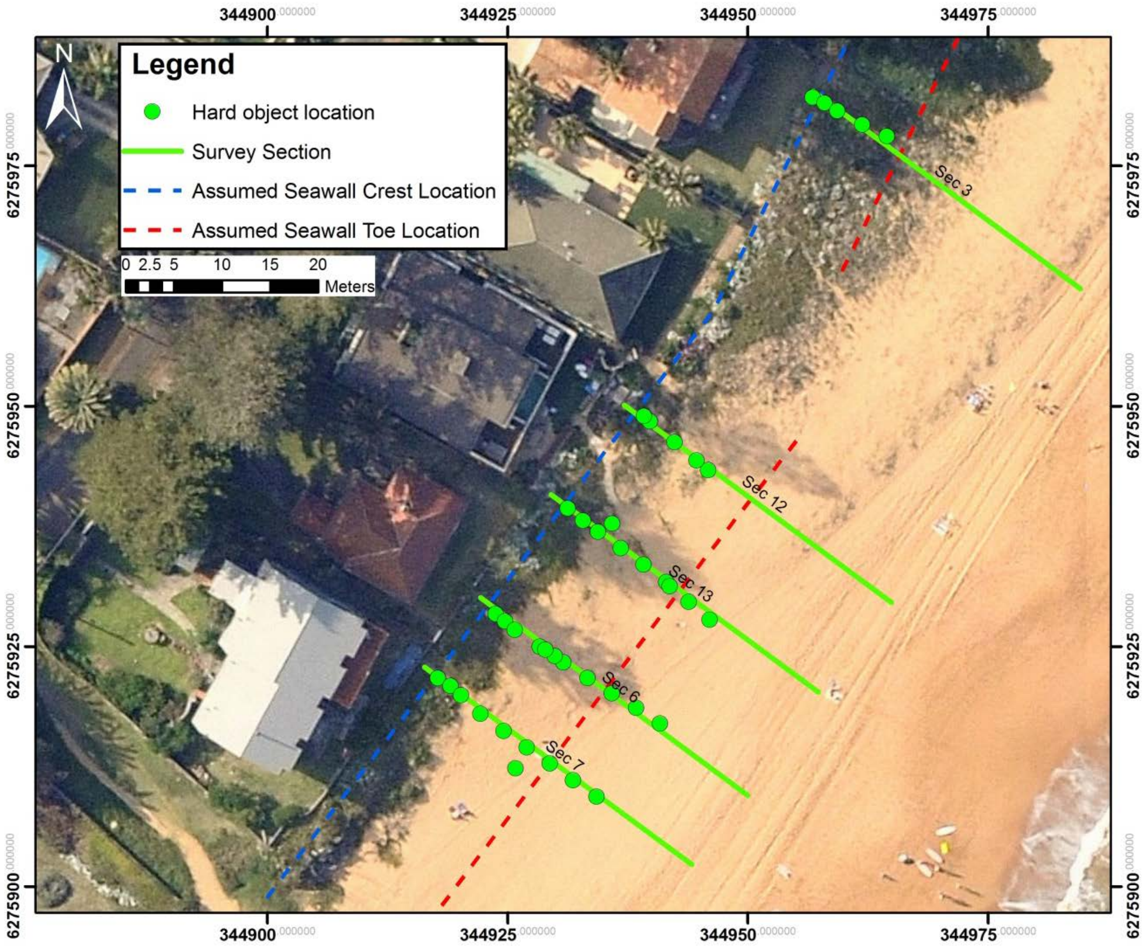


Figure 2.6 Hard Object Location and Predicted Crest and Toe Level Location

The rock locations as predicted by GPR analysis were compared to the hard substrate levels as recorded from drilling refusal depths. In most cases, the borehole data confirmed the results of the GPR. In isolated locations both the boreholes and GPR indicated the presence of hard objects that were discontinuous with the surrounding area. The interpretation of GPR sub-surface mapping relied heavily on the experience of the 'interpreter' with isolated hard objects generally more clearly identifiable than clusters of rocks. Objects exceeding 3 metres of depth were not identified by the GPR screening; the use of other antennas (>500 MHz) may enable objects at greater depths to be detected. On the basis of this comparison, for coastal applications, WRL recommends the use of the GPR technology be supplemented by a dataset of test boreholes at selected locations.

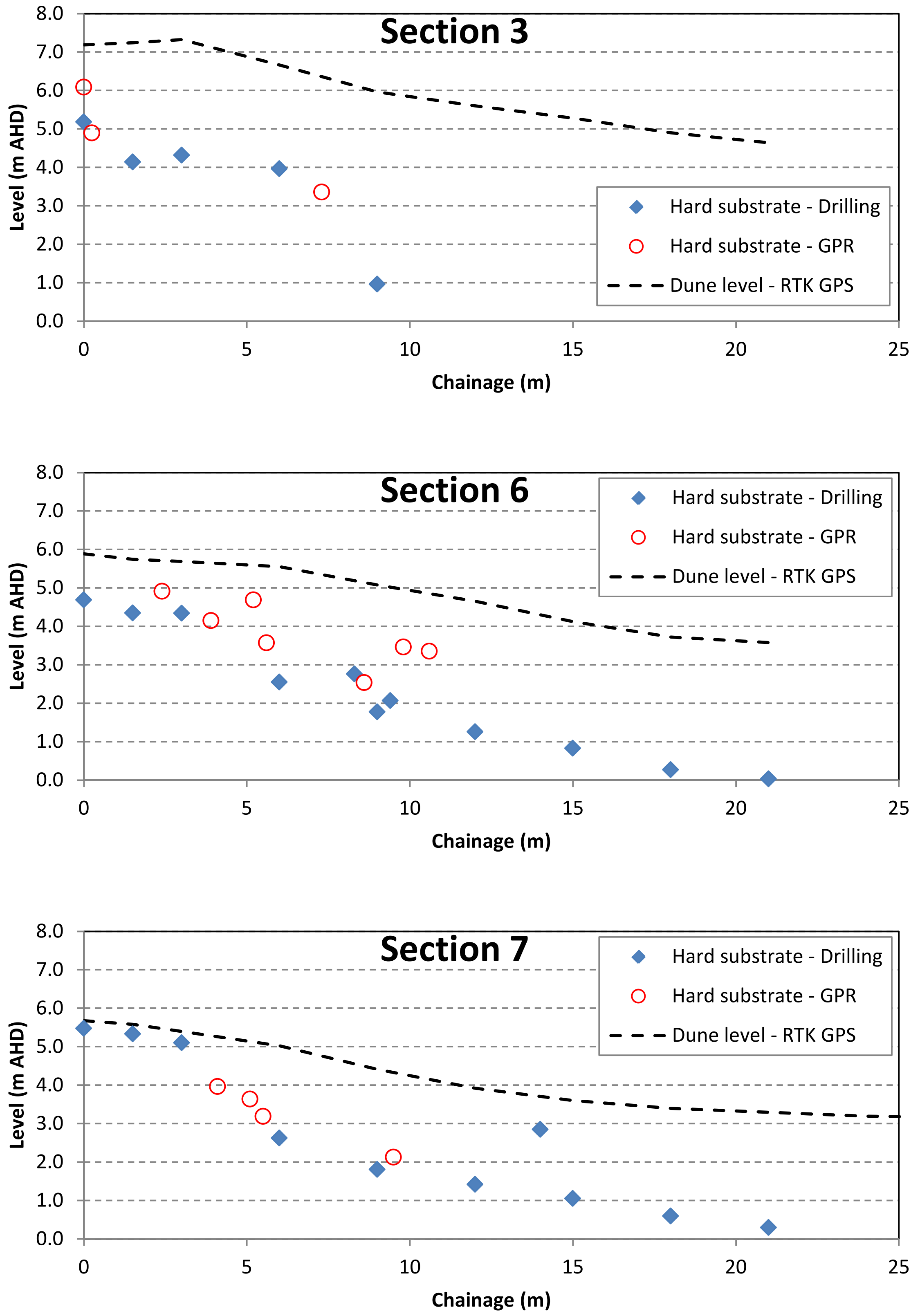


Figure 2.7 Levels of Hard Substrate from Drilling and GPR Surveys – Section 3, 6 and 7

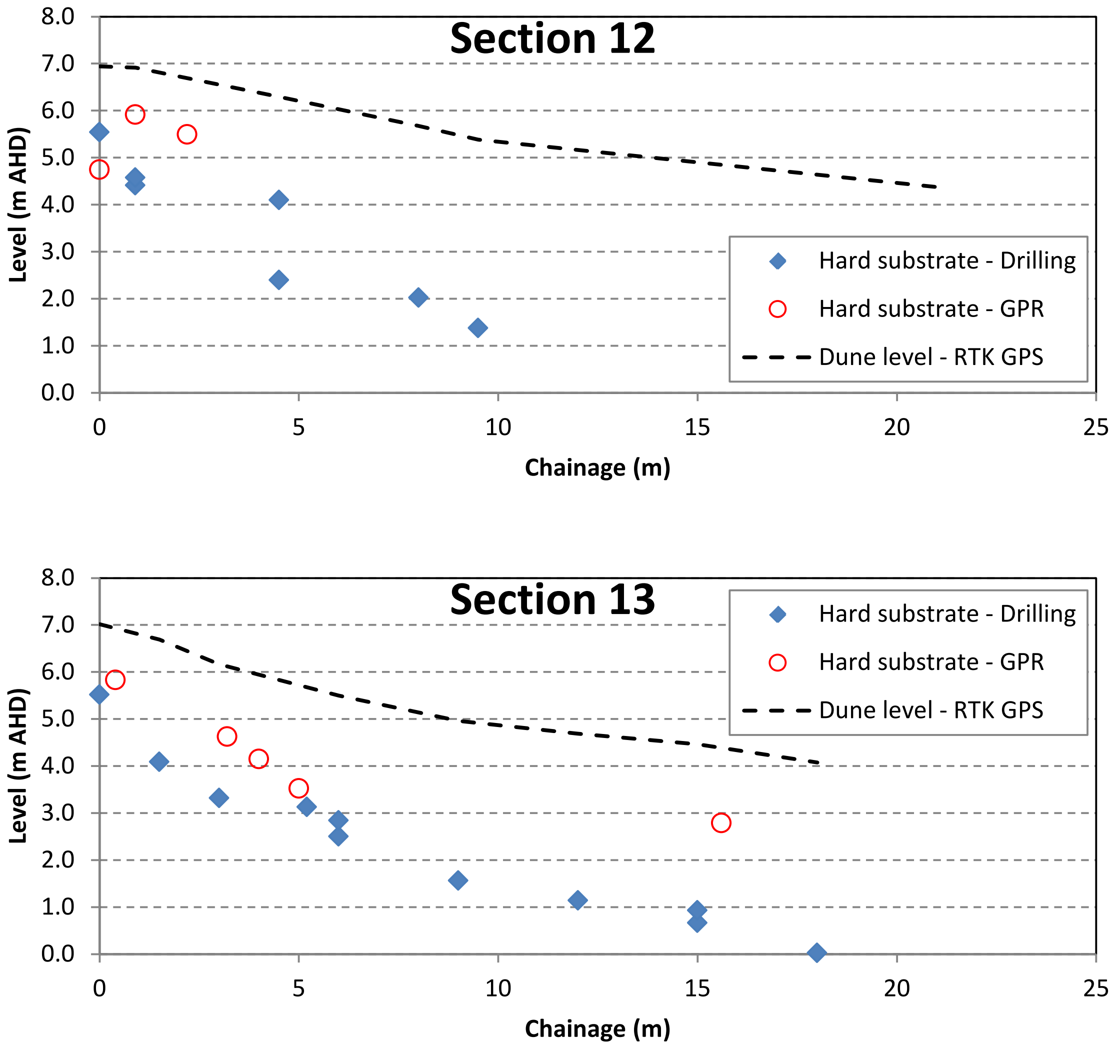


Figure 2.8 Levels of Hard Substrate from Drilling and GPR Surveys – Sections 12 and 13

2.5 Test Pit Excavation (Bilgola Beach Seawall 3)

On 10 May 2012, three test pits (TP1, TP2 and TP3) were also excavated in front of the structure located seaward of Bilgola SLSC (Bilgola Beach Seawall 3) to determine the nature and level of the footing as well as to confirm the presence of toe protection. The excavator provided by Pittwater Council was operated by Mr Andrew Bell of Pittwater Council, while Mr Doug Lord and Mr Alessio Mariani were supervising the operation. Following excavation, the toe elevation of Seawall 3 was topographically surveyed using WRL's RTK-GPS equipment.

The location of the test pits is shown in Figure 2.9. Based on the test pit investigation, the seawall appears to be founded on sand with toe levels of approximately 2.0 m AHD. Excavation exposed a toe protection constructed using flat rock blocks (high length-to-thickness ratio) densely placed in a double layer at a level of approximately 3.0 m AHD. Photos of the excavation test pits are shown in Figures 2.10, 2.11 and 2.12.

The crest elevation of Seawall 3 was also topographically surveyed using WRL's RTK-GPS equipment.

Figure 2.9 Location of Test Pits in Front of Bilgola SLSC Seawall

Figure 2.10 Excavation of Test Pit TP1

Figure 2.11 Excavation of Seawall Toe Protection Blocks

Figure 2.12 Seawall Toe Exposed at Test Pit TP1

2.6 Seawall Characteristics (Bilgola Beach Seawalls 1 and 3)

The characteristics of Bilgola Beach Seawalls 1 and 3 as derived by the range of geophysical surveys undertaken are presented in Table 2.1. Note that while the GPR survey was able to identify the relative size of isolated rocks (i.e. large, medium or small), approximate rock masses could not be confirmed by GPR analysis and are reported as per the review of available literature in Mariani and Coghlan (2012a).

Table 2.1 Summary of Bilgola Beach Seawall Characteristics from Field Survey

Seawall	Location	Construction	(1)Crest Level (m AHD)	(2)Toe Level (m AHD)
1	Buried under dune fronting Allen Avenue properties	Sloping (1V:2H or flatter) rock seawall, 0.05-4 t rock	4.5-6.5	0.0-1.5
3	Fronting Bilgola SLSC	Vertical sandstone blocks set in mortar	4.5-5.0	2.0

Notes:

(1) For Seawall 1, as per GPR and drilling; for Seawall 3, as per RTK-GPS survey

(2) For Seawall 1, as per GPR and drilling; for Seawall 3, as per excavation

2.7 Future Mapping

The buried seawall structure fronting the private properties at Allen Avenue, Bilgola Beach (Seawall 1) has been assessed as a case study using a remote sensing technique (GPR). From this assessment, generic information to describe the seawall structures can be derived. Ground penetrating radar can be used to detect a variety of buried media at depth along the foreshore of sandy beach including:

- rock (boulders, gravel and bedrock)
- major soil layers
- major sand layers
- salt water table levels
- concrete
- other hard objects, and
- voids.

The major advantage of using GPR rather than intrusive monitoring techniques alone (such as borehole drilling and test pit excavations) is that measurements with excellent spatial resolution are able to be achieved within a relatively short amount of time. The equipment is also relatively lightweight and can be readily deployed with minimal disturbance to sand dunes.

However, several disadvantages of using GPR include:

- interpretation of 'diffraction signatures' relies heavily on the experience of the operator
- clusters of rocks are less identifiable than isolated hard objects
- detection of objects exceeding 3 to 4 m depth may require alternative antennas

- surveying cannot be undertaken during or shortly after rainfall
- saltwater-saturated sand effectively blanks the GPR signal below 3 m AHD ground level
- approximate mass of buried rocks may not be able to be measured, and
- presence of thick vegetation will not allow the passage of GPR equipment.

On the basis of this case study examining the suitability of GPR as a remote assessment technique for buried seawalls, WRL recommends that it is a very useful tool for the rapid provision of data with excellent spatial resolution. However, GPR surveys should be undertaken in conjunction with a series of test boreholes to confirm the inferred conditions from the sub-surface mapping. These boreholes can be at a reduced density over the study area compared to what would be adopted if drilling alone was used. Note that while the crest level, toe level and slope of a buried seawall may be readily measured by GPR, the approximate mass of buried rocks may not. To maximise the quality and extent of measurements, it is recommended that GPR surveys on a sandy beach foreshore not be undertaken during or shortly after rainfall or during the upper half of the tidal cycle (to minimise salt water table levels).

Research of the effectiveness of GPR to detect buried seawalls is ongoing as part of a broader master's research thesis supervised by Dr Leonhard Bernold. Future publications (based on this thesis) regarding additional measurements undertaken on Bilgola Beach Seawall 1 as well as a buried seawall, a partially buried slotted walkway and buried stormwater pipes at Freshwater Beach (Warringah Council) should be reviewed as they become available. WRL understands that Dr Bernold is continuing to work on the following at Bilgola Beach:

- integration of the RTK-GPS survey equipment on board the mobile GPR cart
- integration of the GPR survey results with geographical information systems (GIS)
- use of filters to possibly detect the approximate mass of the buried boulders, and
- creation of a three-dimensional 'image' of the buried seawall.

2.8 Conclusions

The assessment of a buried seawall located along Bilgola Beach (Seawall 1) was undertaken to review the suitability of a remote sensing technique; ground penetrating radar. The GPR surveys were accompanied by RTK-GPS measurements of the dune level and a series of test boreholes to confirm the presence of hard substrate levels (i.e. assumed rock locations). The crest level, toe level and slope of the buried seawall were readily measured by GPR and validated by the test borehole results. While the GPR survey was able to identify the relative size of isolated rocks (i.e. large, medium or small), approximate rock masses could not be confirmed by GPR analysis. GPR surveys attempting to delineate beach storm lag layers were also inconclusive. In addition to the remote sensing assessment undertaken for Bilgola Beach Seawall 1, trial test pits were excavated at the structure fronting Bilgola SLSC (Seawall 3) to determine its toe level. The advantages, disadvantages and limitations of using GPR rather than intrusive monitoring techniques alone were also discussed. Recommendations were provided for the generic use of GPR for the mapping of existing buried seawalls.

3. References

Lord, D (1999), *Collaroy/Narrabeen Sea Wall Survey and Assessment*, Manly Hydraulics Laboratory, Technical Report MHL 974.

Mariani, A and Coghlan, I R (2012a), 'Assessment of Open Coast Seawalls (Bilgola Beach Case Study)', Appendix B, *Seawall Structure Assessment at Bilgola and Clontarf Sydney NSW*, WRL Technical Report 2012/13.

Mariani, A and Coghlan, I R (2012b), 'Assessment of Estuarine Beach Seawalls (Clontarf Case Study)', Appendix C, *Seawall Structure Assessment at Bilgola and Clontarf Sydney NSW*, WRL Technical Report 2012/13.

ADDENDUM I: BILGOLA BEACH GROUND PENETRATING RADAR INVESTIGATION

REPORT

GPR INVESTIGATION OF BILGOLA ROCK SEAWALL

By

Dr. Leonhard Bernold

Associate Professor, Civil and Environmental Engineering

UNSW

May 2012

A) OVERVIEW OF THE FIELD WORK

The field work was executed on April 28, 2012. Ten passes were made with the GPR cart and the data stored on a laptop. Following image presents the situation and the work performed.

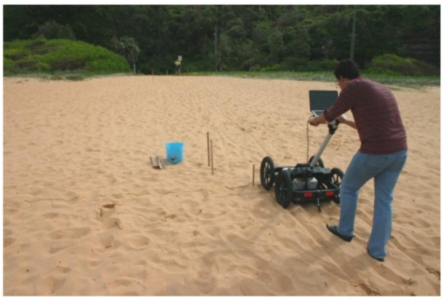


Figure 1: GPR Preparing for Profile 1 at Towards Beach Entrance

Figure 2: Vegetation Inhibits Profile 2

Figure 3: Parallel GPR Profiles 3, 4, 5

Figure 4: Profile 13 Close to Property Line

Figure 5: GPR Profile 8 and Start GPS Surveying

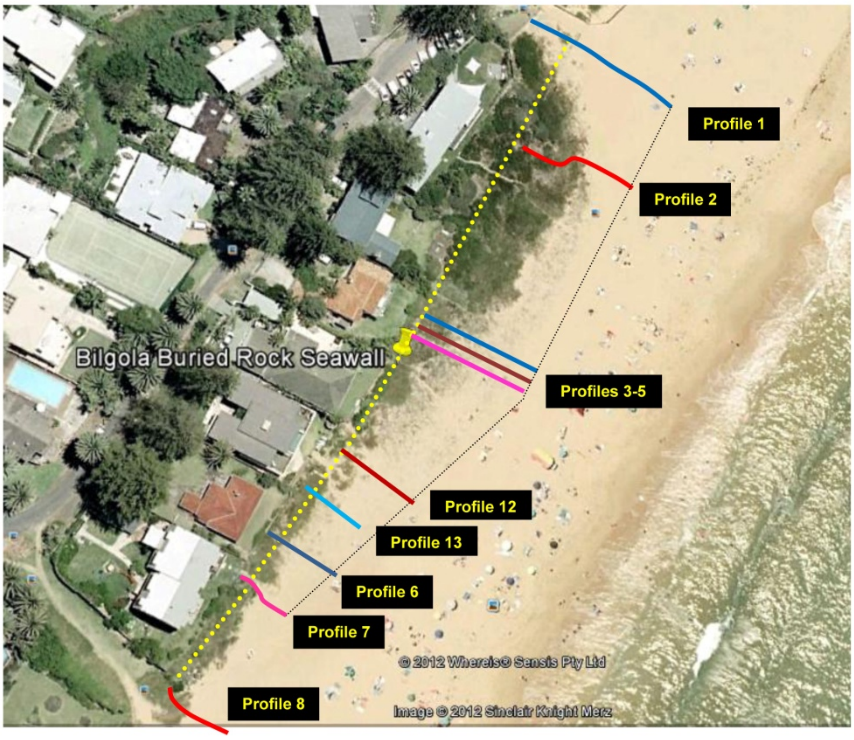
Figure 6: Cone Penetrometer Test at Profile 12 Pt. D

B) SPATIAL DESCRIPTION OF SELECTED GPR PASSES

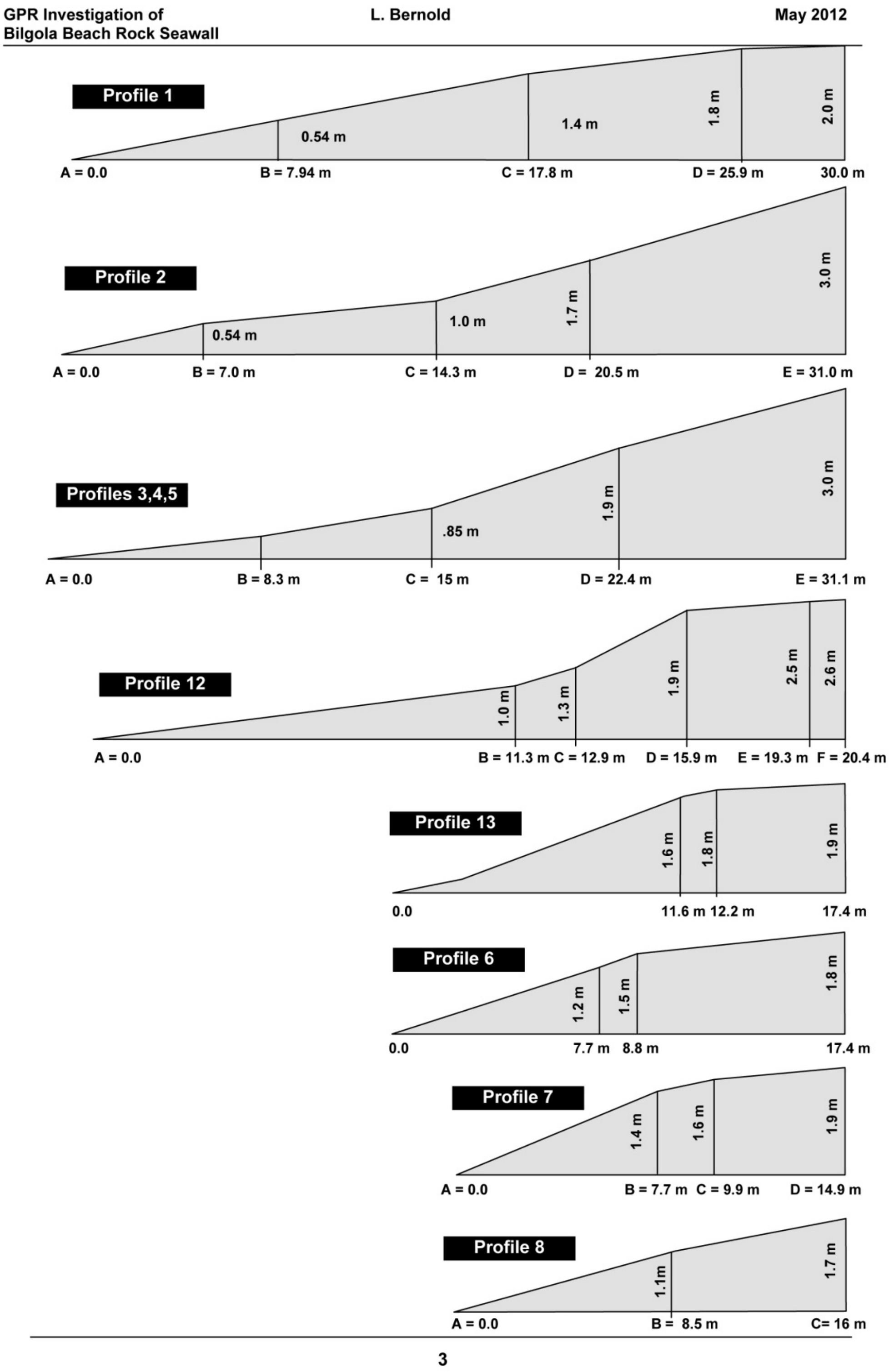
The investigation was based on 10 GPR runs perpendicular to the buried seawall. The selection of the location had to consider the brushes and thick vegetation making access with the GPR impossible. Each pass was numbered and surveyed at points A-F using GPS (by Alessio Mariani from WRL)

Figure 7: Google Earth Display of Survey Points for Profiles (Section) 1- 13

Figure 8: Layouts of Profiles 1 -13



2


GPR Investigation of
Bilgola Beach Rock Seawall
L. Bernold
May 2012
Profile 1
0.54 m
1.4 m
1.8 m
2.0 m
A = 0.0
B = 7.94 m
C = 17.8 m
D = 25.9 m
30.0 m
Profile 2
0.54 m
1.0 m
1.7 m
3.0 m
A = 0.0
B = 7.0 m
C = 14.3 m
D = 20.5 m
E = 31.0 m
Profiles 3,4,5
.85 m
1.9 m
3.0 m
A = 0.0
B = 8.3 m
C = 15 m
D = 22.4 m
E = 31.1 m
Profile 12
1.0 m
1.3 m
1.9 m
2.5 m
2.6 m
A = 0.0
B = 11.3 m
C = 12.9 m
D = 15.9 m
E = 19.3 m
F = 20.4 m
Profile 13
1.6 m
1.8 m
1.9 m
0.0
11.6 m
12.2 m
17.4 m
Profile 6
1.2 m
1.5 m
1.8 m
0.0
7.7 m
8.8 m
17.4 m
Profile 7
1.4 m
1.6 m
1.9 m
A = 0.0
B = 7.7 m
C = 9.9 m
D = 14.9 m
Profile 8
1.1m
1.7 m
A = 0.0
B = 8.5 m
C= 16 m
3

C) ANALYSIS OF GPR DATA FOR EACH PROFILE

This section presents the GPR data, its analysis and the predicted location of buried rocks and other hard objects.

Profile 1:

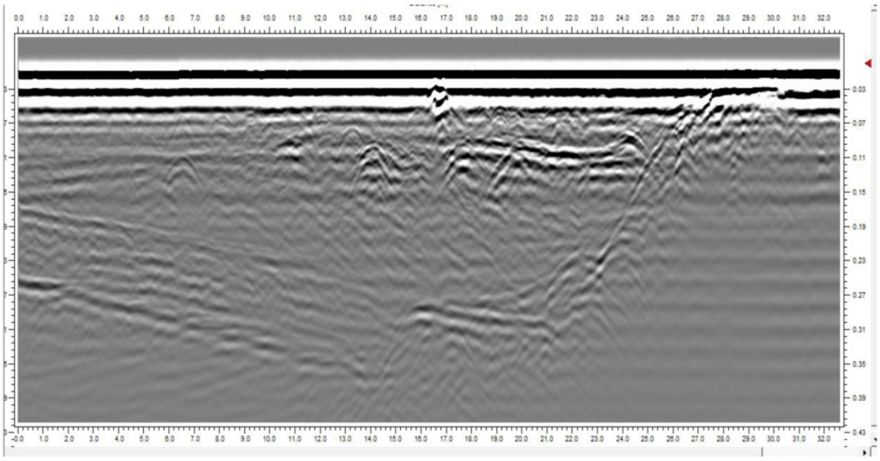


Figure C.1.1 GPR Raw Data

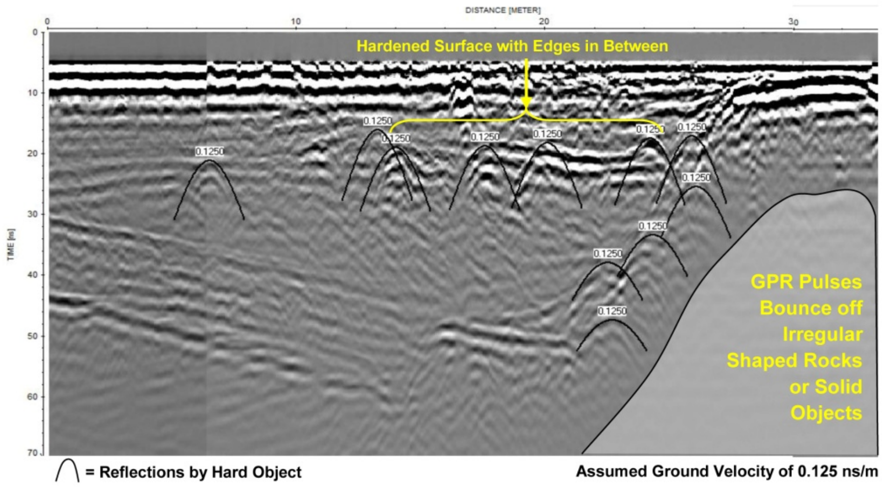


Figure C.1.2 Analysis of GPR Data

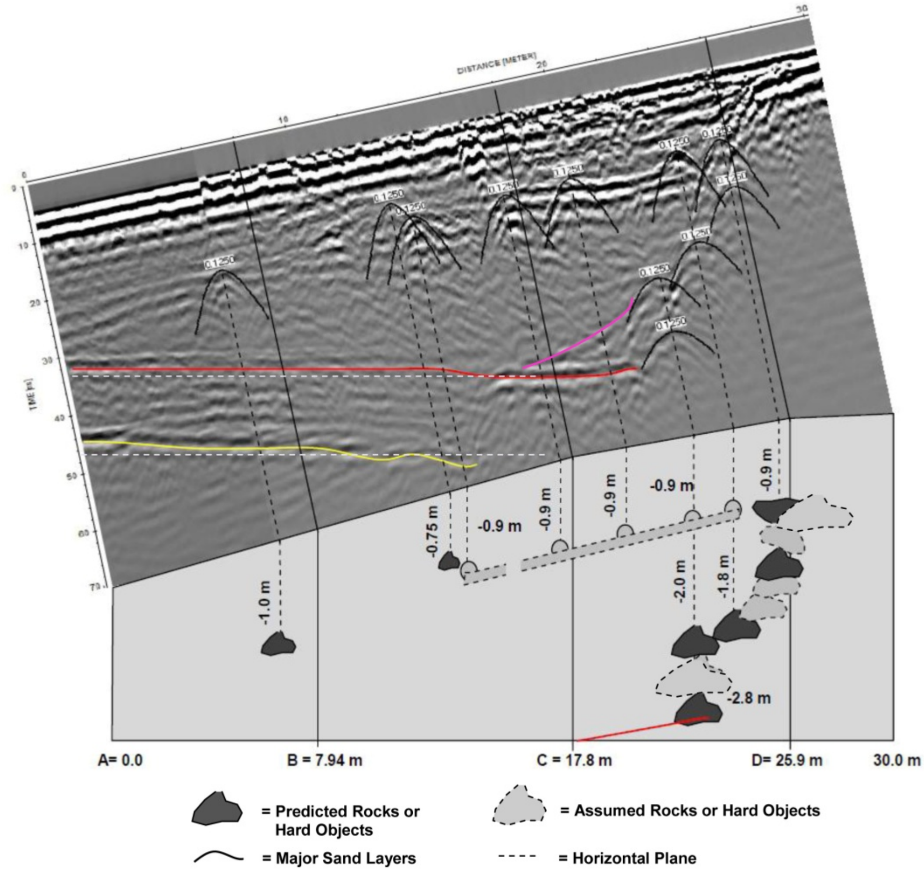


Figure C.1.3 Possible Location of Buried Rocks and other Hard Objects

Profile 2:

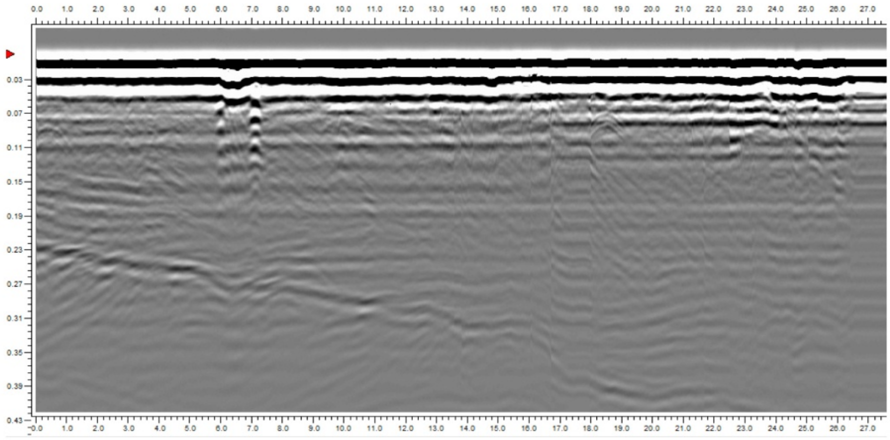


Figure C.2.1 GPR Raw Data

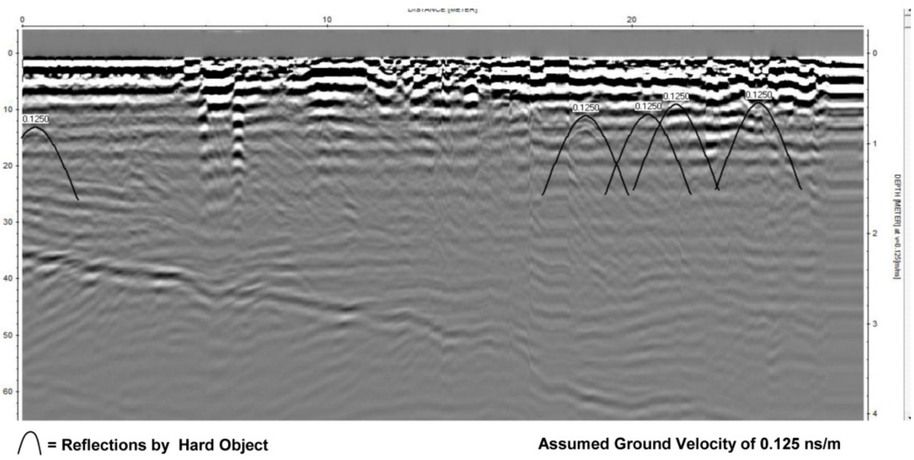


Figure C.2.2 Analysis of GPR Data

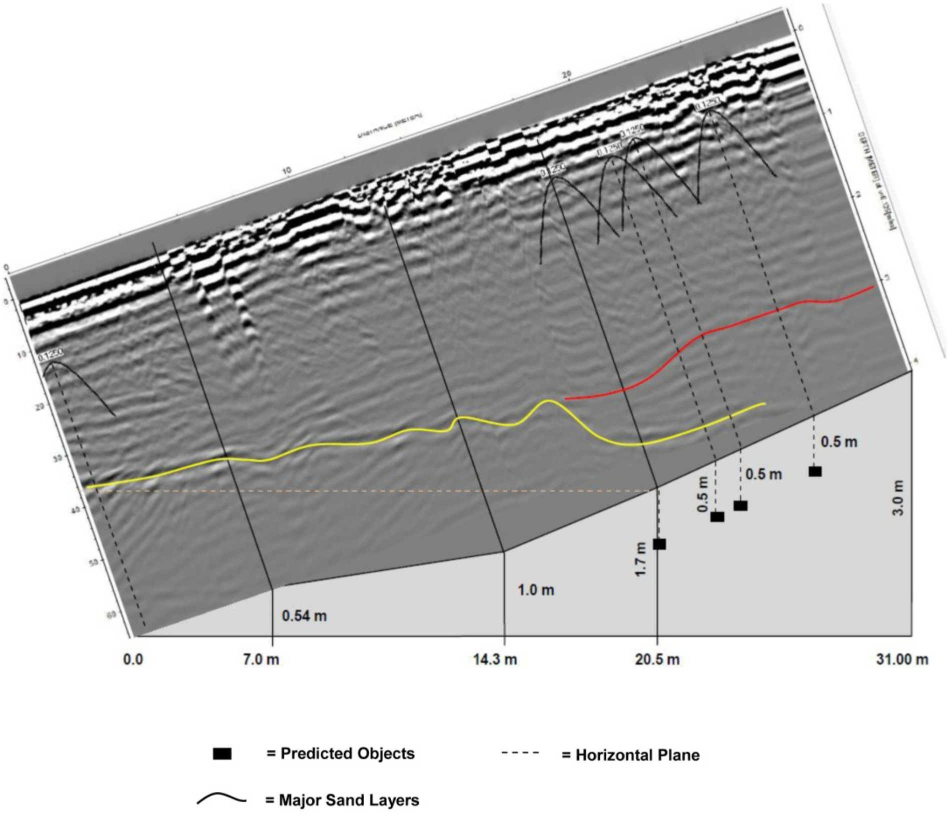


Figure C.2.3 Possible Location of Buried Rocks and other Hard Objects

Profile 3:

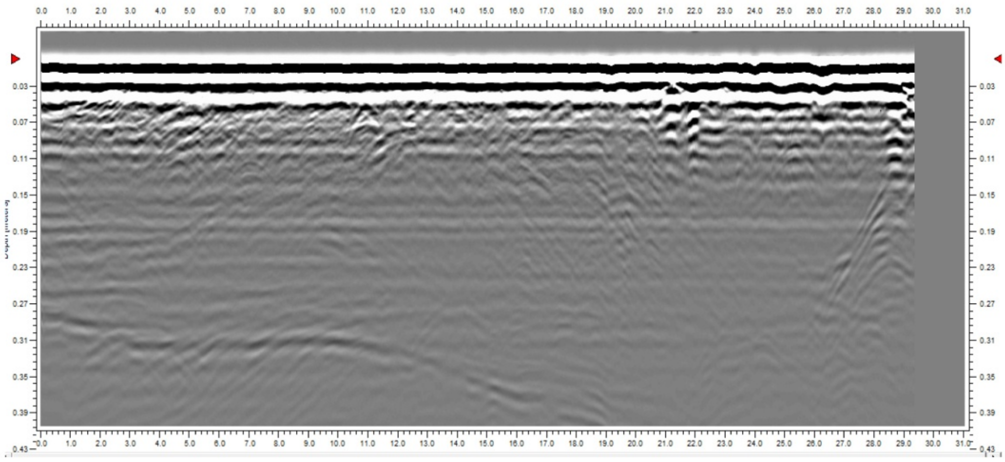
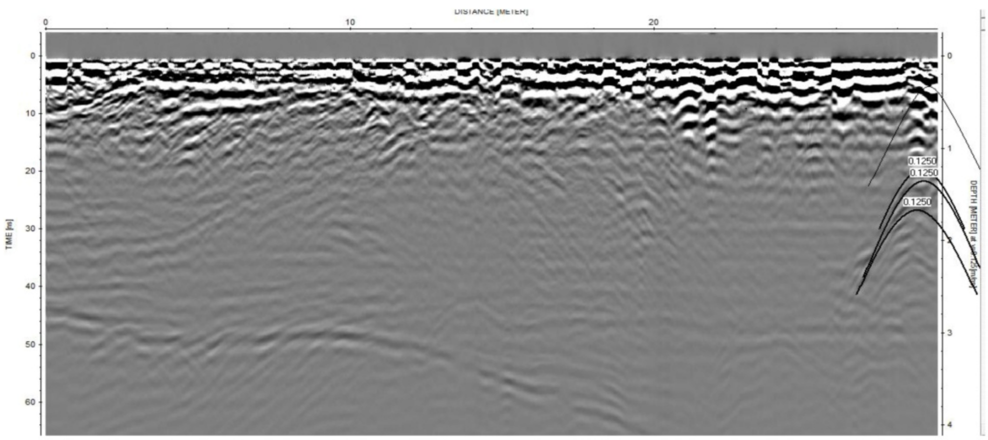


Figure C.3.1 GPR Raw Data



⋂ = Reflections by Hard Object   Assumed Ground Velocity of 0.125 ns/m

Figure C.3.2 Analysis of GPR Data

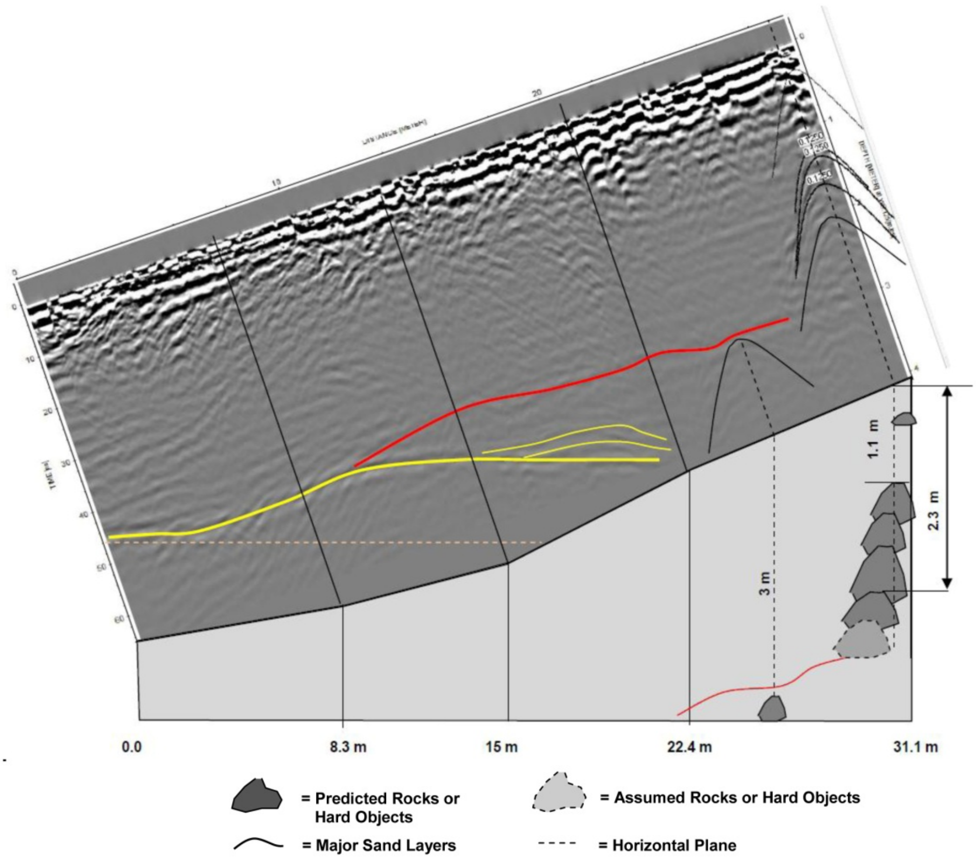


Figure C.3.3 Possible Location of Buried Rocks and other Hard Objects

Profile 4:

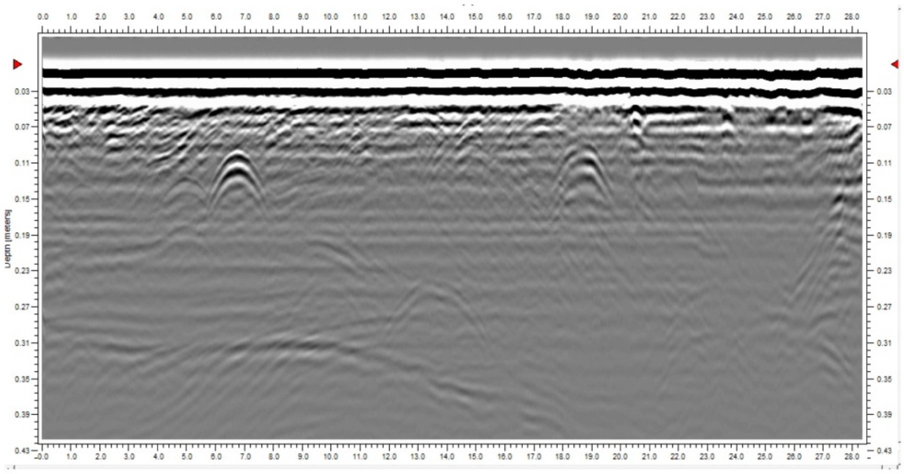


Figure C.4.1 GPR Raw Data

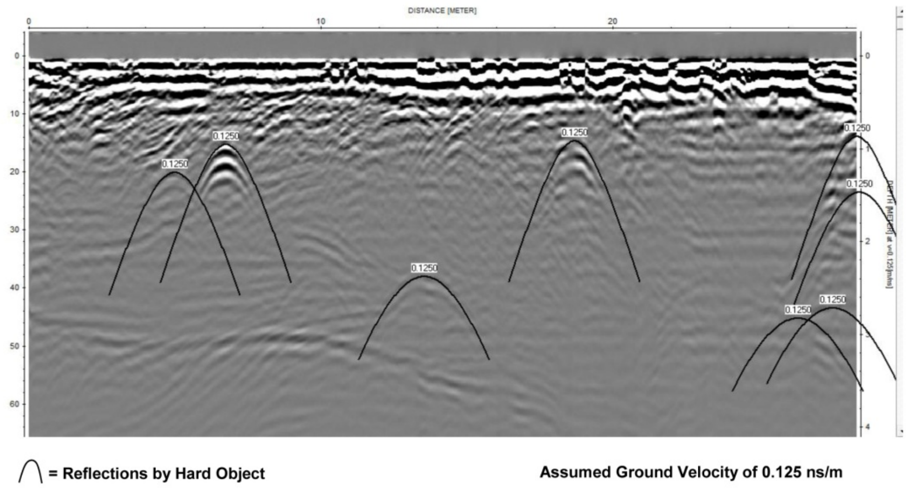


Figure C.4.2 Analysis of GPR Data

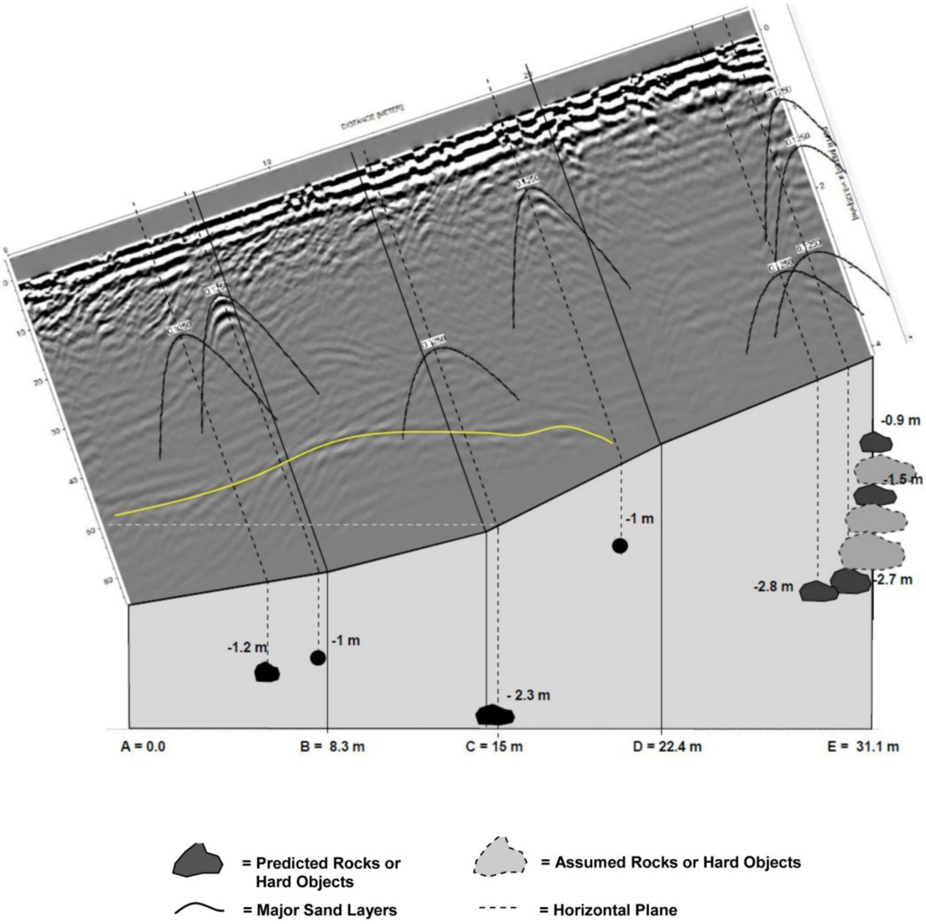


Figure C.4.3 Possible Location of Buried Rocks and other Hard Objects

Profile 5:

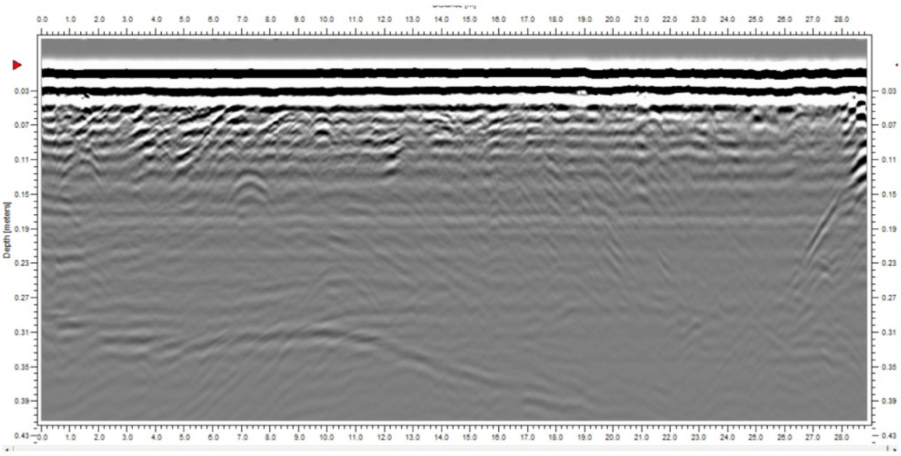


Figure C.5.1 GPR Raw Data

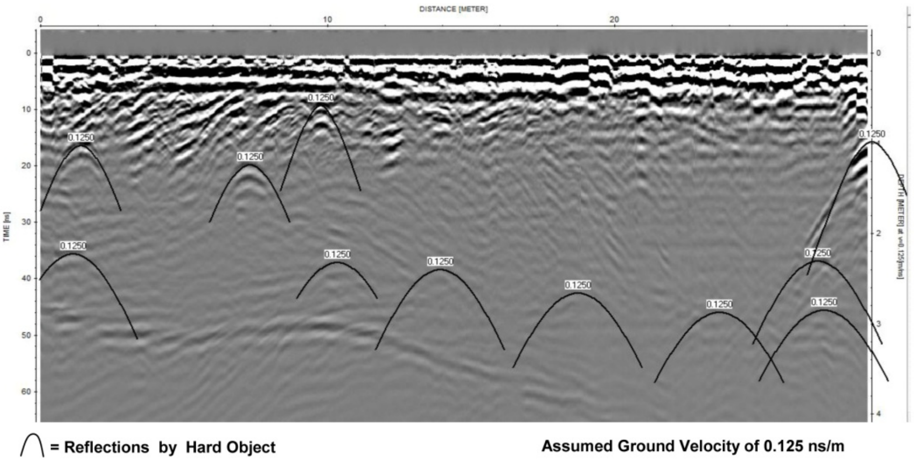


Figure C.5.2 Analysis of GPR Data

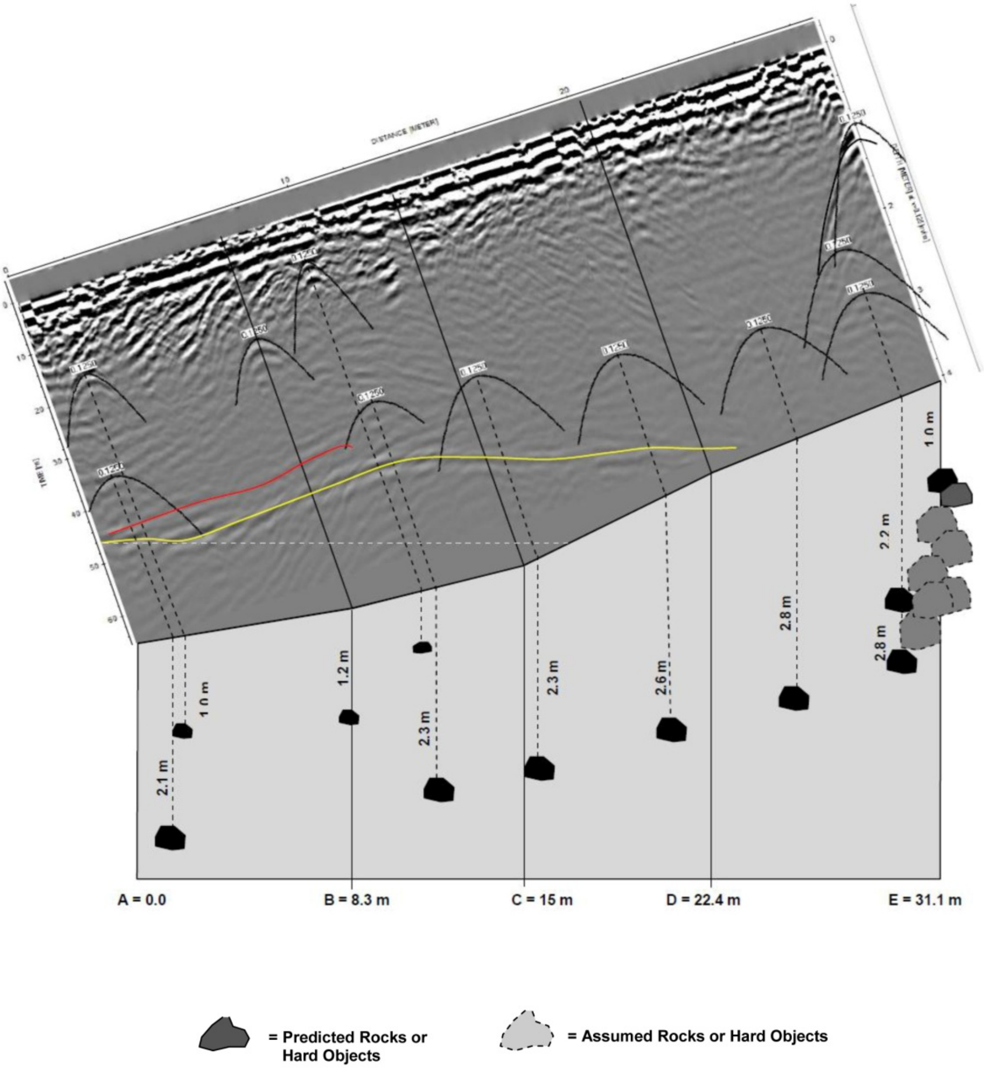


Figure C 5.3 Possible Location of Buried Rocks and other Hard Objects

Profile 6:

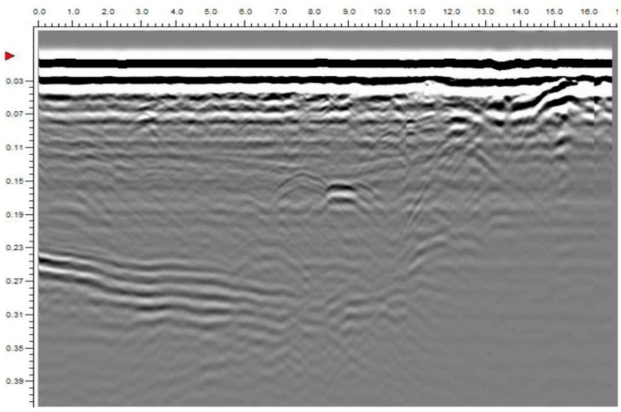
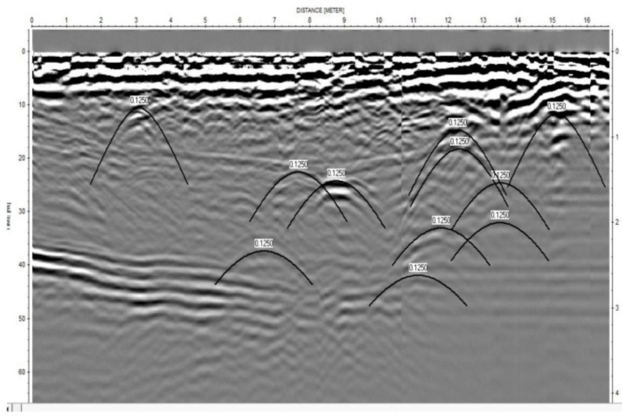


Figure C.6.1 GPR Raw Data



= Reflections by Hard Object   **Assumed Ground Velocity of 0.125 ns/m**

Figure C.6.2 Analysis of GPR Data

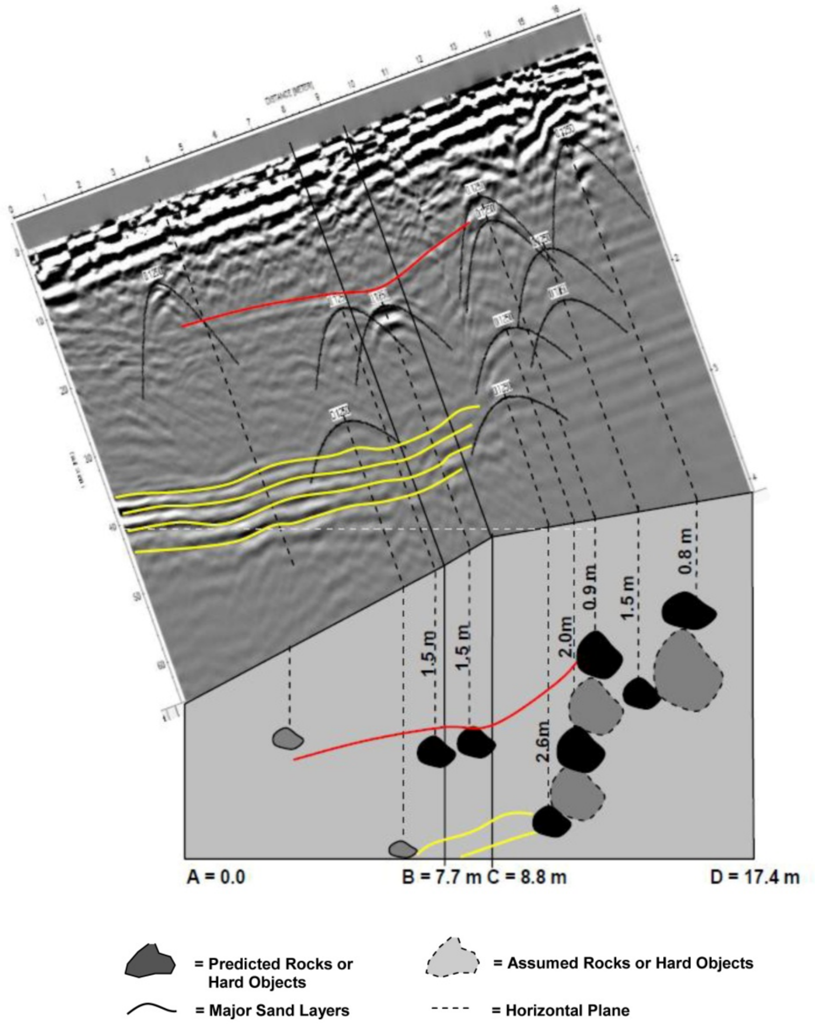


Figure C6.3 Possible Location of Buried Rocks and other Hard Objects

Profile 7:

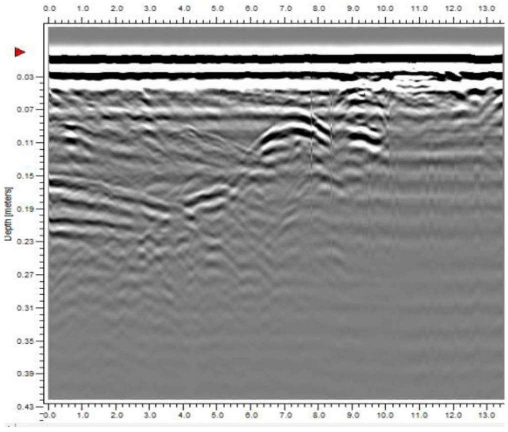
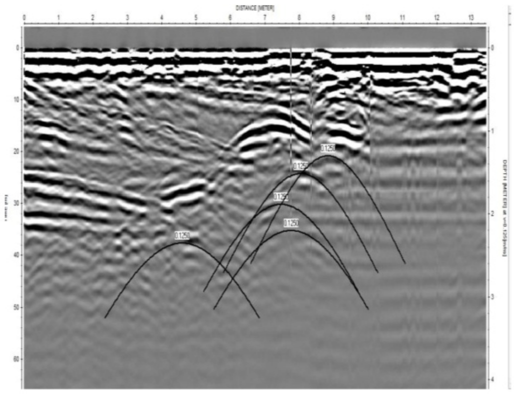


Figure C.7.1 GPR Raw Data



= Reflections by Hard Object   Assumed Ground Velocity of 0.125 ns/m

Figure C7.2 Analysis of GPR Data

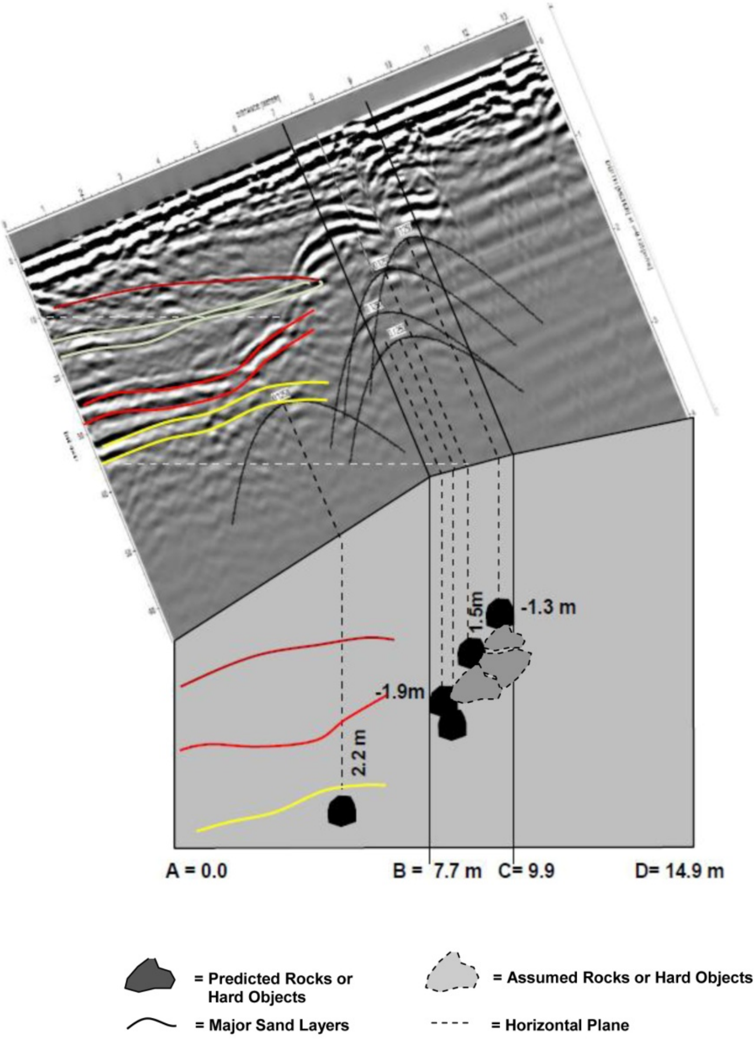


Figure C7.3 Possible Location of Buried Rocks and other Hard Objects

Profile 8:

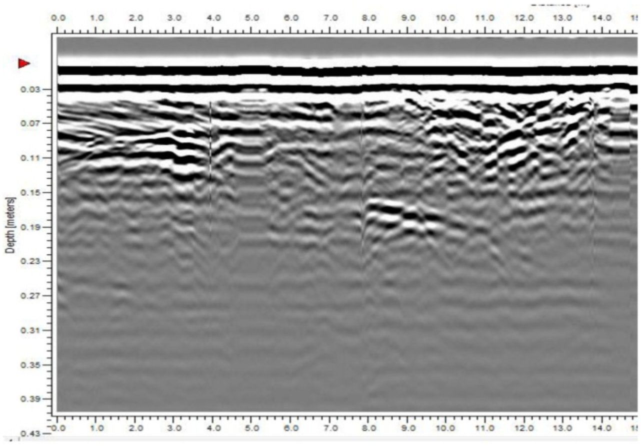
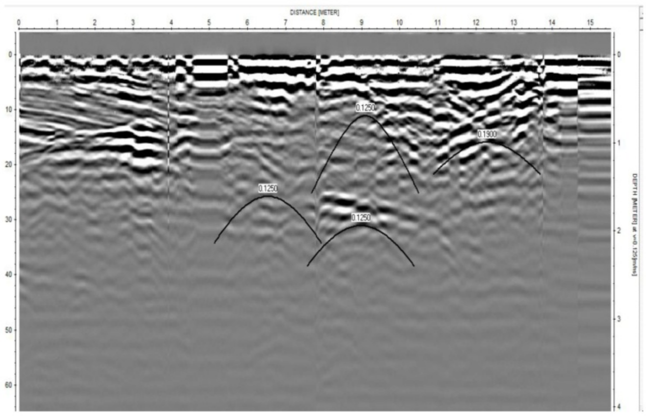


Figure C.8.1 GPR Raw Data



= Reflections by Hard Object **Assumed Ground Velocity of 0.125 ns/m**

Figure C.8.2 Analysis of GPR Data

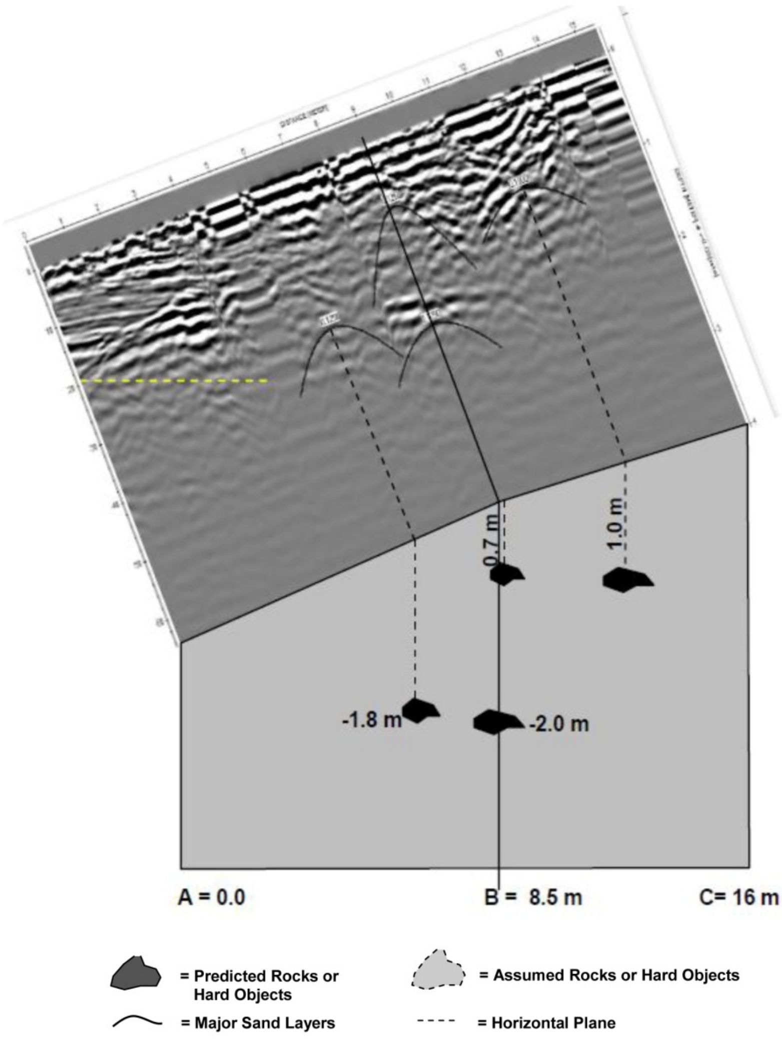


Figure C8.3 Possible Location of Buried Rocks and other Hard Objects

Profile 12:

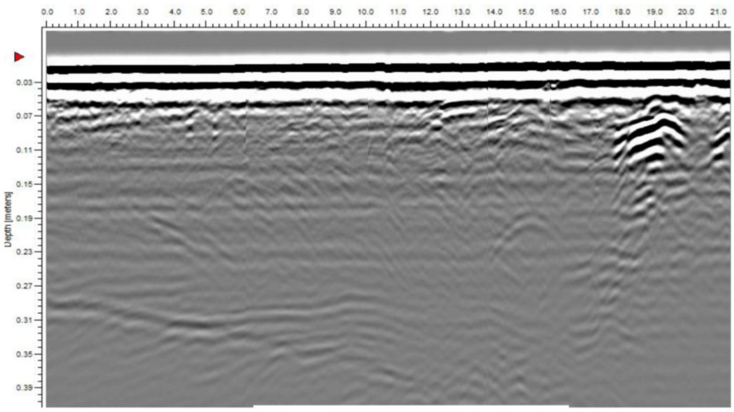


Figure C.12.1 GPR Raw Data

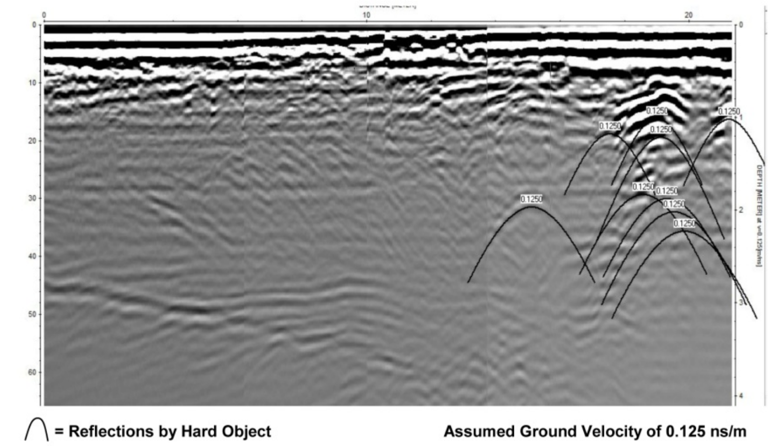


Figure C.12.2 Analysis of GPR Data

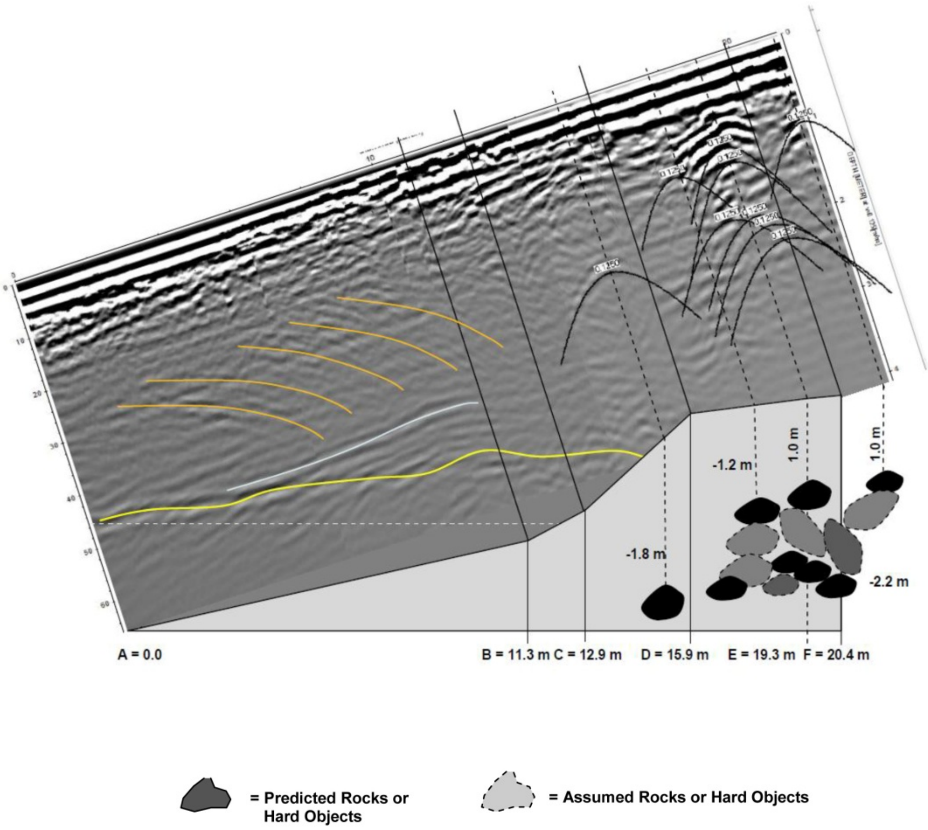


Figure C.12.3 Possible Location of Buried Rocks and other Hard Objects

Profile 13:

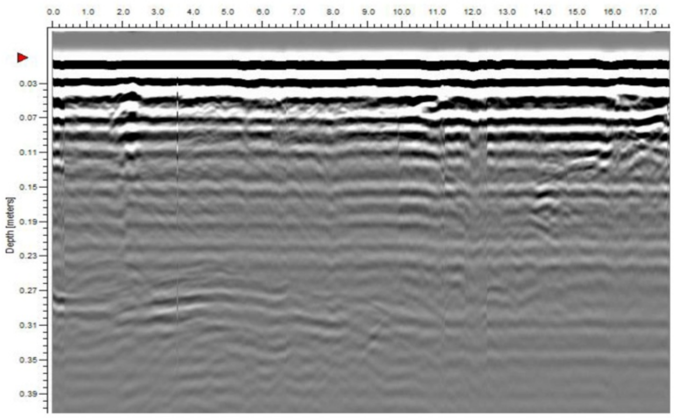
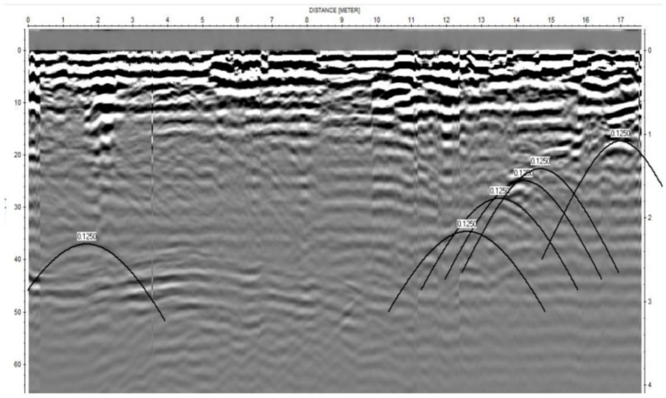


Figure C.13.1 GPR Raw Data



= Reflections by Hard Object Assumed Ground Velocity of 0.125 ns/m

Figure C.13.2 Analysis of GPR Data

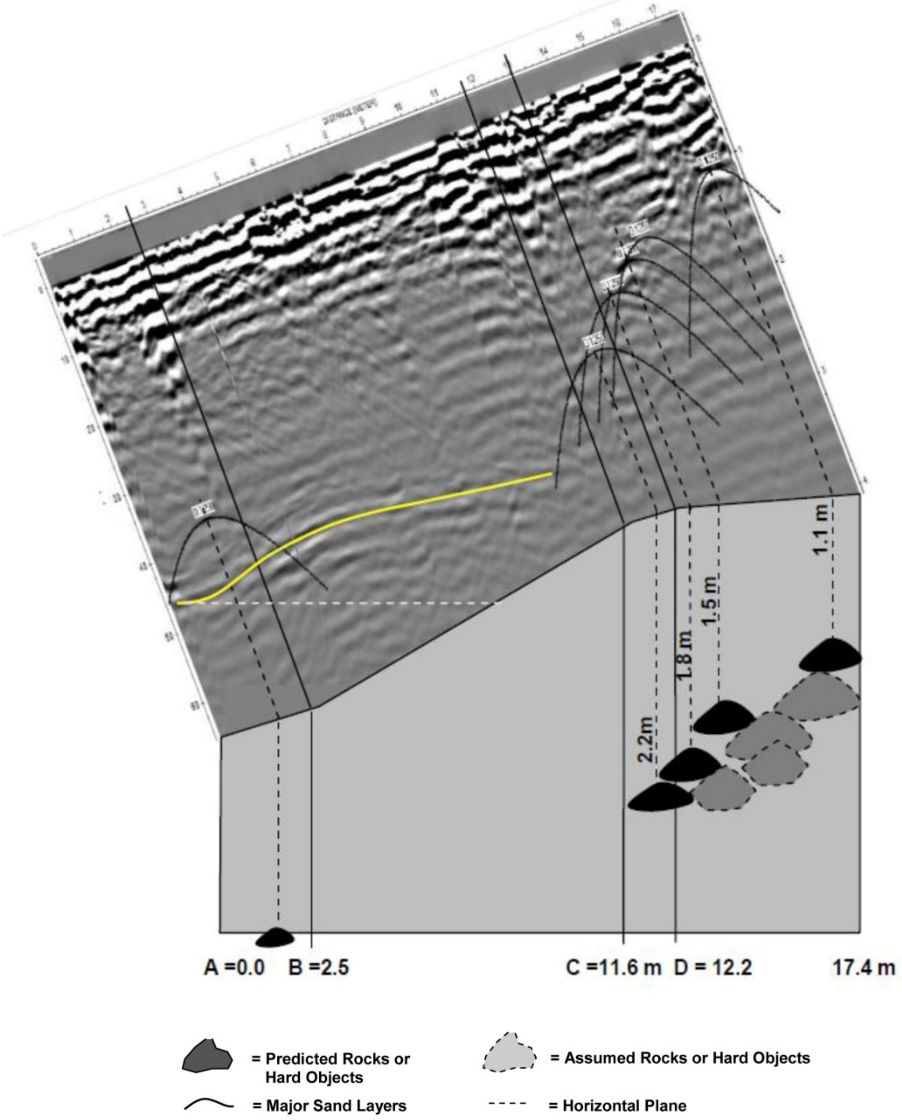


Figure C.13.3 Possible Location of Buried Rocks and other Hard Objects

Addendum II: Bilgola Beach Drilling Survey Borehole Logs

Name	[1]Easting (m)	[1]Northing (m)	Ground Level (m AHD)	[2]Latitude (deg.)	[2]Longitude (deg.)	Depth of Refusal (m)
BIL_SEC6_1	344923.761	6275928.36	5.89	-33.6452	151.32775	1.20
BIL_SEC6_2	344924.75	6275927.59	5.74	-33.64521	151.32776	1.40
BIL_SEC6_3	344925.741	6275926.693	5.69	-33.64522	151.32777	1.35
BIL_SEC6_4	344928.367	6275924.964	5.55	-33.64523	151.3278	3.00
BIL_SEC6_5	344930.8	6275923.326	5.07	-33.64525	151.32783	3.30
BIL_SEC6_6	344933.333	6275921.681	4.66	-33.64526	151.32785	3.40
BIL_SEC6_7	344935.842	6275920.101	4.12	-33.64528	151.32788	3.30
BIL_SEC6_8	344938.369	6275918.584	3.72	-33.64529	151.32791	3.45
BIL_SEC6_9	344940.862	6275916.938	3.58	-33.64531	151.32793	3.55
BIL_SEC6_A	344936.16	6275919.747	4.05	-33.64528	151.32788	undetermined
BIL_SEC6_B	344929.921	6275923.964	5.27	-33.64524	151.32782	3.20
BIL_SEC6_C	344928.94	6275924.636	5.51	-33.64523	151.32781	2.75
BIL_SEC6_D	344922.391	6275929.625	5.87	-33.64519	151.32774	undetermined
BIL_SEC7_1	344917.747	6275921.7	5.67	-33.64526	151.32768	0.20
BIL_SEC7_2	344919.061	6275920.854	5.58	-33.64527	151.3277	0.25
BIL_SEC7_3	344920.162	6275919.896	5.40	-33.64528	151.32771	0.30
BIL_SEC7_4	344922.189	6275917.963	5.03	-33.64529	151.32773	2.40
BIL_SEC7_5	344924.567	6275916.181	4.41	-33.64531	151.32776	2.60
BIL_SEC7_6	344926.998	6275914.468	3.92	-33.64533	151.32778	2.50
BIL_SEC7_7	344929.392	6275912.794	3.60	-33.64534	151.32781	2.55
BIL_SEC7_8	344931.804	6275911.025	3.39	-33.64536	151.32783	2.80
BIL_SEC7_9	344934.244	6275909.316	3.29	-33.64537	151.32786	3.00
BIL_SEC7_10	344936.867	6275907.335	3.19	-33.64539	151.32789	3.70
BIL_SEC7_11	344938.505	6275906.265	3.16	-33.6454	151.32791	3.40
BIL_SEC7_12	344940.781	6275904.503	3.10	-33.64542	151.32793	3.40
BIL_SEC7_13	344944.078	6275902.327	2.92	-33.64544	151.32797	3.30
BIL_SEC7_A	344925.819	6275912.295	3.80	-33.64535	151.32777	0.95
BIL_SEC7_B	344920.987	6275917.98	5.19	-33.64529	151.32772	undetermined
BIL_SEC7_C	344920.157	6275919.808	5.44	-33.64528	151.32771	undetermined
BIL_SEC7_D	344916.243	6275922.822	5.65	-33.64525	151.32767	undetermined
BIL_SEC12_A1	344954.485	6275936.205	4.37	-33.64513	151.32808	4.05

Name	[1]Easting (m)	[1]Northing (m)	Ground Level (m AHD)	[2]Latitude (deg.)	[2]Longitude (deg.)	Depth of Refusal (m)
BIL_SEC12_A2	344954.485	6275936.205	4.37	-33.64513	151.32808	4.50
BIL_SEC12_B	344945.864	6275943.322	5.38	-33.64507	151.32799	4.00
BIL_SEC12_C	344944.65	6275944.319	5.67	-33.64506	151.32798	3.65
BIL_SEC12_D1	344942.376	6275946.217	6.30	-33.64504	151.32795	3.90
BIL_SEC12_D2	344942.376	6275946.217	6.30	-33.64504	151.32795	2.20
BIL_SEC12_E	344939.813	6275948.423	6.92	-33.64502	151.32793	2.34
BIL_SEC12_E	344939.813	6275948.423	6.92	-33.64502	151.32793	2.50
BIL_SEC12_F	344939.203	6275948.946	6.95	-33.64502	151.32792	1.40
BIL_SEC13_1	344946.018	6275927.752	4.08	-33.64521	151.32799	4.05
BIL_SEC13_2	344943.854	6275929.615	4.46	-33.64519	151.32797	3.80
BIL_SEC13_3	344941.5	6275931.661	4.69	-33.64517	151.32794	3.55
BIL_SEC13_4	344939.132	6275933.5	4.96	-33.64516	151.32792	3.40
BIL_SEC13_5	344936.762	6275935.194	5.50	-33.64514	151.32789	3.00
BIL_SEC13_6	344934.393	6275936.894	6.17	-33.64512	151.32787	2.85
BIL_SEC13_7	344932.858	6275938.058	6.69	-33.64511	151.32785	2.60
BIL_SEC13_8	344931.28	6275939.376	7.02	-33.6451	151.32783	1.50
BIL_SEC13_A	344943.844	6275929.787	4.40	-33.64519	151.32797	undetermined
BIL_SEC13_B	344941.866	6275931.225	4.63	-33.64518	151.32795	3.70
BIL_SEC13_C	344935.869	6275937.774	6.04	-33.64512	151.32788	3.20
BIL_SEC13_D	344935.391	6275938.128	6.18	-33.64511	151.32788	undetermined

Notes:

(1) MGA 1994 GDA Zone 56

(2) WGS84

SYDNEY COASTAL COUNCILS GROUP

Sydney Coastal Councils Group Inc.

councils caring for the coastal environment

Level 14, Town Hall House

456 Kent Street

GPO Box 1591

SYDNEY NSW 2001

t: +61 2 9246 7326

f: +61 2 9265 9660

e: info@sydneycoastalcouncils.com.au

w: www.sydneycoastalcouncils.com.au.com.au