






Land Transport Authority

Environmental Impact Assessment on Central Catchment Nature Reserve for the Proposed Cross Island Line

FINAL CONSTRUCTION & OPERATION ENVIRONMENTAL IMPACT ASSESSMENT REPORT – *VOLUME II*

2 September 2019

The world's leading sustainability consultancy

ERM

Environmental Impact Assessment on Central Catchment Nature Reserve for the Proposed Cross Island Line

Final Construction & Operation EIA – *Volume II*

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Client
Land Transport Authority Singapore

Project No
0256660

Project Summary

The Land Transport Authority commissioned ERM to undertake environmental impact assessment studies relating to the construction and operation of the Cross Island Line (CRL) at or in close proximity to the Central Catchment Nature Reserve (CCNR), in Singapore. The phased studies are:

- *Phase 1a*: Environmental Baseline
- *Phase 1b*: EIA of the Soil Investigation (SI) Works
- *Phase 2*: EIA of the construction and operation of the CRL for the two route options.

This document presents ***Volume II*** of the Construction & Operation (C&O) EIA (*Phase 2*) for the Project.

Date
2 September 2019

Approved by

Alastair Scott
Senior Partner, on behalf of ERM (S) Pte Ltd

Revision	Description	By	Checked	Approved	Date
008	Final C&O Environmental Impact Assessment Report - Vol II	JS / EY / OSY / MO	WG / BB / TF / IC / RRD	AS	02.09.19
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003	Pre-Final C&O Environmental Impact Assessment Report - Vol II	JS / EY / OSY / MO	WG / BB / TF / IC / RRD	AS	4.7.18
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1 INTRODUCTION

In accordance with the Terms of Reference for the Project EIA, one round of baseline data gathering was undertaken to establish the baseline conditions of the Project study area. The baseline data gathering exercise was undertaken in 2014 to 2015 during the SI phase of the Project, and included the following field surveys:

- Ecology;
- Mapping of streams and canals, which included an observation of physical characteristics such as flow speed and turbidity;
- Surface water quality sampling of physical, chemical and biological parameters;
- Noise measurement;
- Vibration measurement;
- Measurement of airborne concentrations of particular matter, PM_{10} and $PM_{2.5}$; and
- Count of visitors to the trails within CCNR and Windsor Nature Park.

Primary data collected from the field surveys were supplemented with secondary data obtained from published literature and online databases. Detailed findings from this baseline data gathering are presented in *Volume II* (Footnote 1) of the SI EIA Report for the Project [(1)]. The locations of the non-ecological and ecological surveys are presented in *Figure 1.1* and *Figure 1.2* respectively.

This Volume of the EIA Report is an addendum to the SI EIA Report and presents the updated geological and hydrogeological baseline findings from the SI works completed in 2017. The baseline data presented in this Volume of the EIA Report and *Volume II* of the SI EIA Report will be used to inform this EIA report at the feasibility stage of the Project's C&O phase. Further detailed baseline studies specific to the worksites will be conducted to inform a separate study at the Advanced Engineering Stage (AES) of the Project.

The baseline update for the Project has been developed from the review of existing information gathered from online sources and field surveys (or primary data) undertaken by LTA contractors. Further details on the information sources and findings of the baseline characterization are reported within the respective chapters.

The remainder of this volume (II) is structured as follows:

- *Chapter 2* presents the Project location and setting as of 2018;
- *Chapter 3* presents the ecological and biodiversity baseline as established from environmental studies undertaken in 2014 and 2015, as well as from supplementary data obtained since then;

(Footnote 1) https://www.lta.gov.sg/content/dam/ltaweb/corp/PublicTransport/files/Final%20SI%20EIA%20Volume%20II.pdf

- *Chapter 4* presents an update of the geology of the Project study area; and
- *Chapter 5* presents an update of the water environment, i.e. surface water and groundwater features within the Project study area.

Figure 1.1: Locations of Non-Ecological Surveys

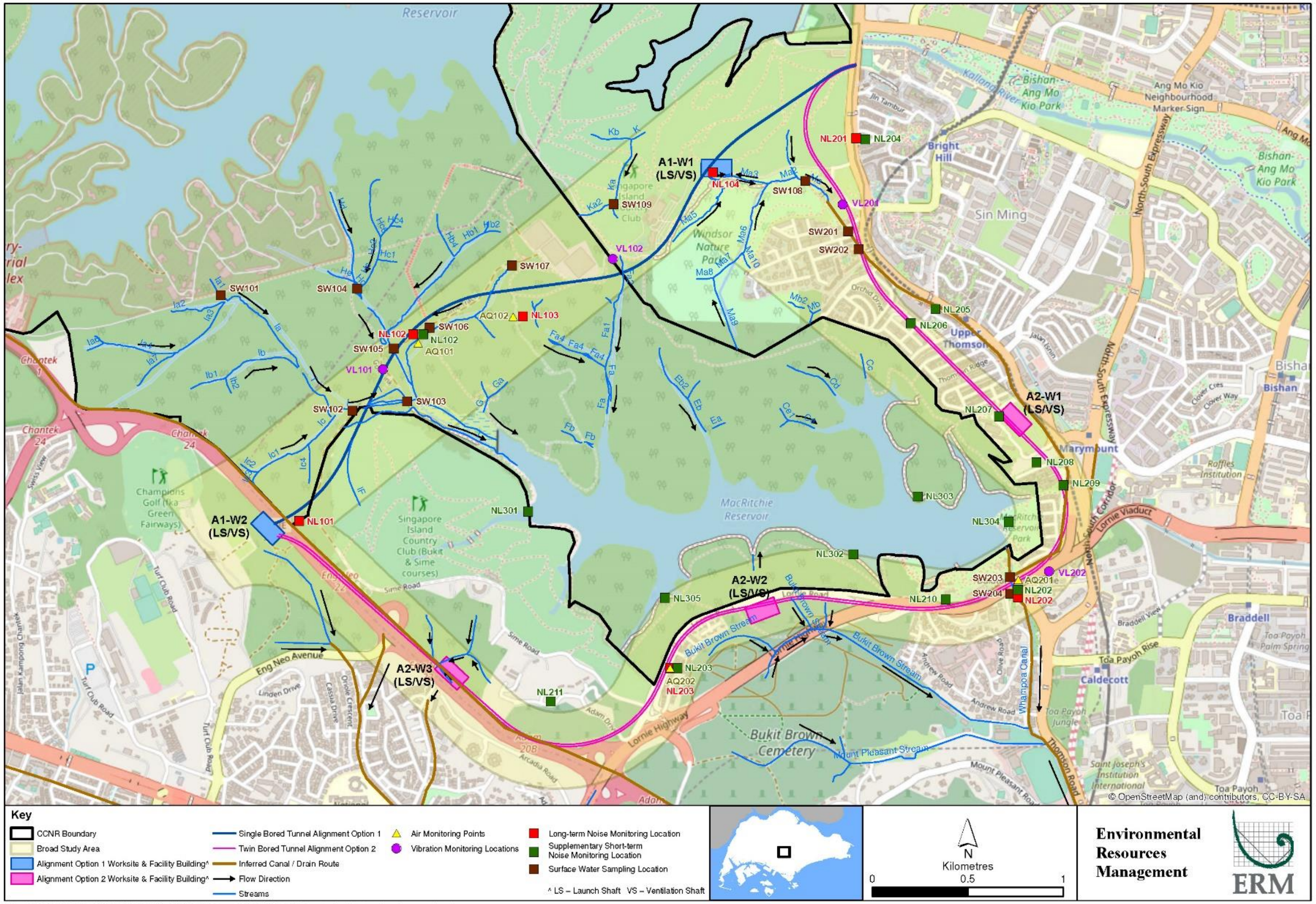

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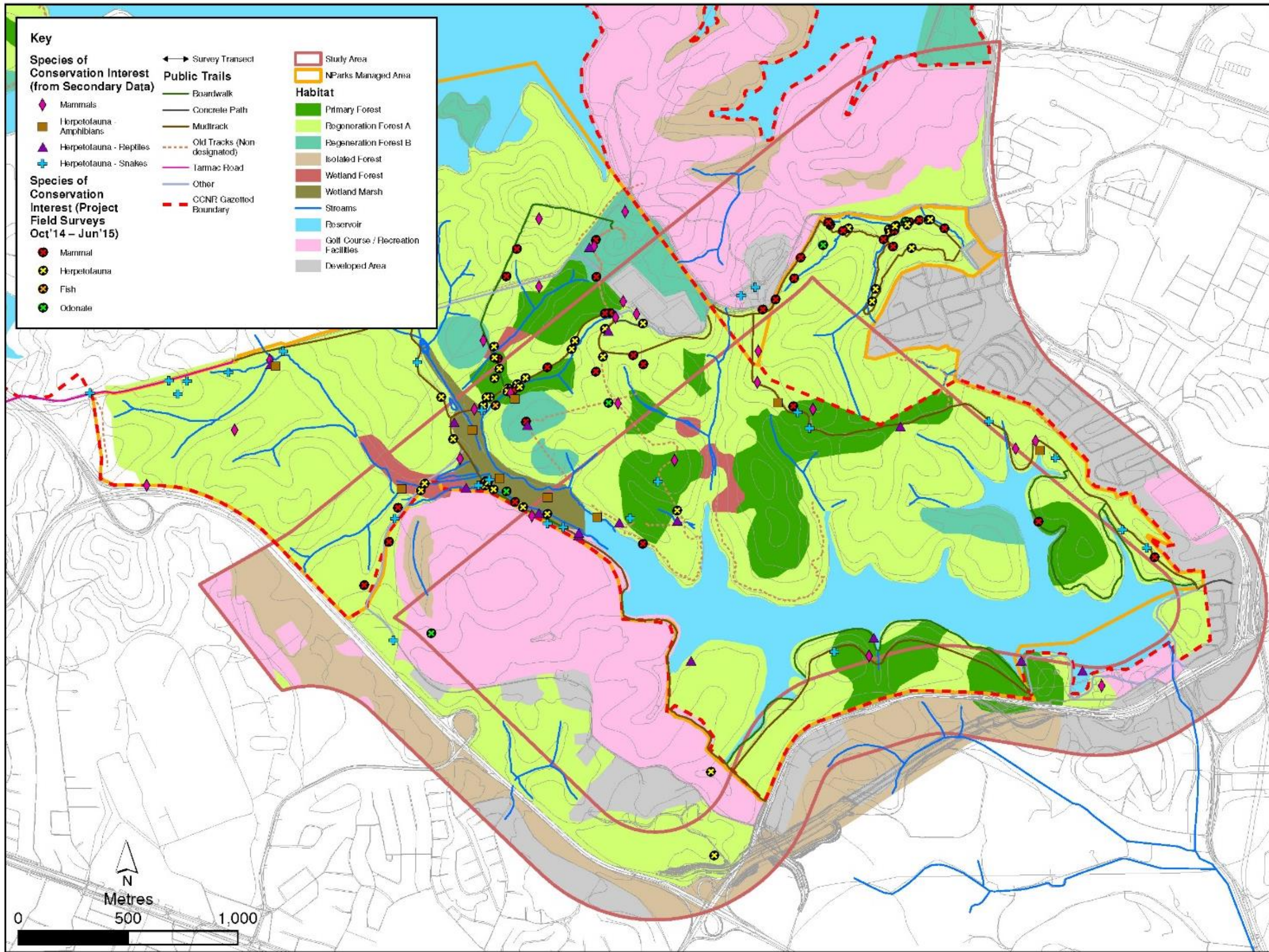
Figure 1.2: Locations of Ecological Surveys



Species of Conservation Interest referring to the symbols on the map

Species	Common Name
Mammal	Horsfield's Flying Squirrel
	Lesser Mousedeer
	Long-tailed Macaque*
	Sunda Pangolin
	Red Muntjac
	Slow Loris
Herpetofauna	Asian Softshell Turtle
	Blue-necked Keelback
	Cinnamon Bush Frog
	Clouded Monitor
	Dusky Earless Agamid, Dusky Earless Agama
	Five-banded Flying Dragon
	Giant Asian Pond Turtle
	Gold Ringed Cat Snake
	Lowland Dwarf Gecko
	Malayan Flat-shelled Terrapin
	Malayan Swamp Skink
	Malayan Water Monitor
	Manthey's Chorus Frog
	Peninsular Rock Gecko
	Reticulated Python
	Spiny Hill Terrapin, Sunburst Turtle
	Spotted Keelback
	Twin-barred Gliding Snake
	Wagler's Pit Viper
	White-bellied Rat Snake
Odonates	Banded Skimmer
	Handsome Grenadier
	Striped Grenadier
	Violet Sprite/ Oval-spotted sprite
	Libellago hyalina
Fish	Harlequin rasbora

Note: Species of conservation interest defined here as those listed as VU, EN or CR in the Singapore Red Data Book (2008), listed as VU, EN or CR on the IUCN Red List of Threatened Species (IUCN 2014.3) or on Appendix I or II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

* Long-tailed Macaque is listed on CITES Appendix II. This species was recorded frequently during surveys. Specific locations where it was recorded are not provided as is considered abundant throughout the Study Area.

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2 SITE SETTING

This chapter of the report presents a description of the existing land uses within the Project Study Area.

2.1 STUDY AREA

The *Study Area* is defined as the area of coverage required to adequately understand and describe the environmental baseline likely to be affected by the CRL C1001 contract. At a minimum, the Study Area will encompass the CRL footprint (for the two alignment options being considered) and its *Area of Influence* (AOI). The footprint will include the alignment itself and any activities or structures associated with the CRL development (see *Vol I, Figure 2.1*). Committed developments that are at or in close proximity to the alignment and surface structures are also considered within the AOI.

It should be noted that the AOI varies across the various environmental receptors (for example, air, water, noise etc), as it takes into account the nature of the affected resource/receptors, the source of impacts and the manner in which the resultant effects are likely to be propagated beyond the CRL footprint. These AOIs are defined in more detail in the respective chapters of *Volume II* of the SI EIA Report for the Project[1] and *Chapters 3* and *4* of this report for each environmental resource considered.

2.2 GENERAL SITE SETTING

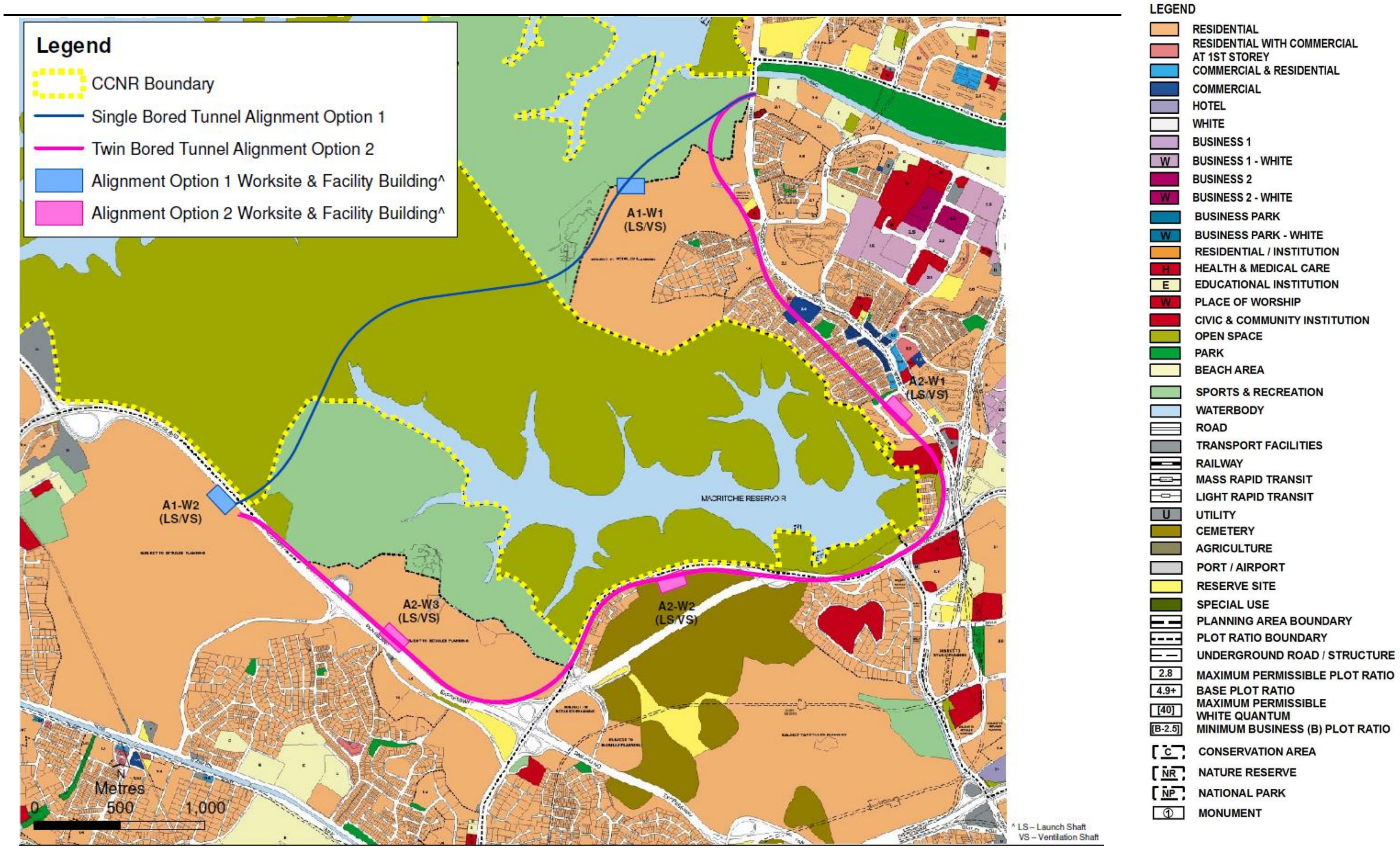
As shown in the *URA Masterplan 2014* (*Figure 2.1*), the Study Area comprises predominantly of the CCNR (categorised as *open space*) and the SICC golf courses located to the east and west (designated for *sports & recreation*). The Study Area also includes densely populated areas characterized by multiple land uses.

Review of maps and satellite imagery updated as of 2017/2018, and reconnaissance undertaken between July and December 2014, highlighted the following existing land uses within the Study Area:

- Ecological areas;
- Recreational areas;
- Residential areas;
- Places of worship;
- Educational institutions;
- Healthcare facilities such as clinics, home for the aged sick and hospitals;
- Utility infrastructure;
- Transport infrastructure; and
- Committed developments[Footnote 1].

[Footnote 1] A development which is under construction and is considered as part of the Project baseline.

Figure 2.1: URA Masterplan of the Study Area



Source: URA, 2014 (http://www.ura.gov.sg)

Ecological areas within the Study Area comprise of the designated CCNR, as well as forested areas *outside the CCNR boundary which serve as ecological buffer zones, eg Windsor Nature Park; the forested area on the northern and western perimeter of SICC's Bukit-Sime golf courses; and the forested area west of the PIE and within the Bukit Brown Cemetery, which are considered ecologically rich sites and fall under the Central Tree Conservation Area (TCA) designated under the *Parks and Trees (Preservation of Trees) Order 1991*[(3)]. It is noted that SICC's Bukit-Sime golf course is home to several mature trees that have been labelled for conservation in accordance with NParks' request. TCAs are defined as areas with a large number of mature trees or extensive greenery, and were designated with the intention of minimizing the felling of mature trees. A review of aerial satellite imagery published by Google Earth[(Footnote 2, Footnote 3, Footnote 4)] confirms that these areas outside the CCNR boundary are largely vegetated with forest and grassland.

Public trails within CCNR, Windsor Nature Park and MacRitchie Reservoir Park serve as key recreational areas within the Study Area for joggers, wildlife photographers and nature lovers, as well as a training and racing ground for cross-country athletes. The trails also provide access to the Tree Top Walk, located north of the Study Area (*Figure 2.2*). The easternmost corner of MacRitchie Reservoir has also been demarcated for recreational activities such as kayaking and fishing. A survey of individuals utilizing key trails in the CCNR was conducted between December 2014 and February 2015. The findings are detailed in the SI EIA Baseline Report[(1)], *Volume II, Annex 1*. In summary, the trails in proximity to the Project alignment within the CCNR are utilized more during the weekends. Extrapolated results indicate that some trails could be utilized by up to 4,100 people during a weekend (rounded value extrapolated for Prunus and Petai Trails as detailed in the SI EIA Baseline Report, *Volume II, Annex 1*) and 1,100 people during a weekday (rounded value extrapolated for MacRitchie Visitor's Centre).

Recreational areas outside the CCNR boundary comprise of the Venus Drive trail connecting Windsor Nature Park and the existing trails within the CCNR (*Figure 2.2*), as well as neighborhood parks along Jupiter Road, Soo Chow Walk and Taman Permata (*Figure 2.1*). Pathways and vehicular access roads within the Bukit Brown Cemetery are also utilized by joggers, dog walkers and horse riders, in addition to visitors to the gravesites.

Residences within the Study Area mostly comprise of black and white colonial-era bungalows, privately owned bungalows, terrace houses, semi-detached houses and low rise and high rise condominiums. These are located along the eastern boundary of the CCNR, south of Lornie Road which borders the south of MacRitchie Reservoir Park, west of SICC's Bukit and Sime golf courses along Adam Drive and Sime Road (*Figure 2.1*) and west of the PIE which borders the west of the CCNR.

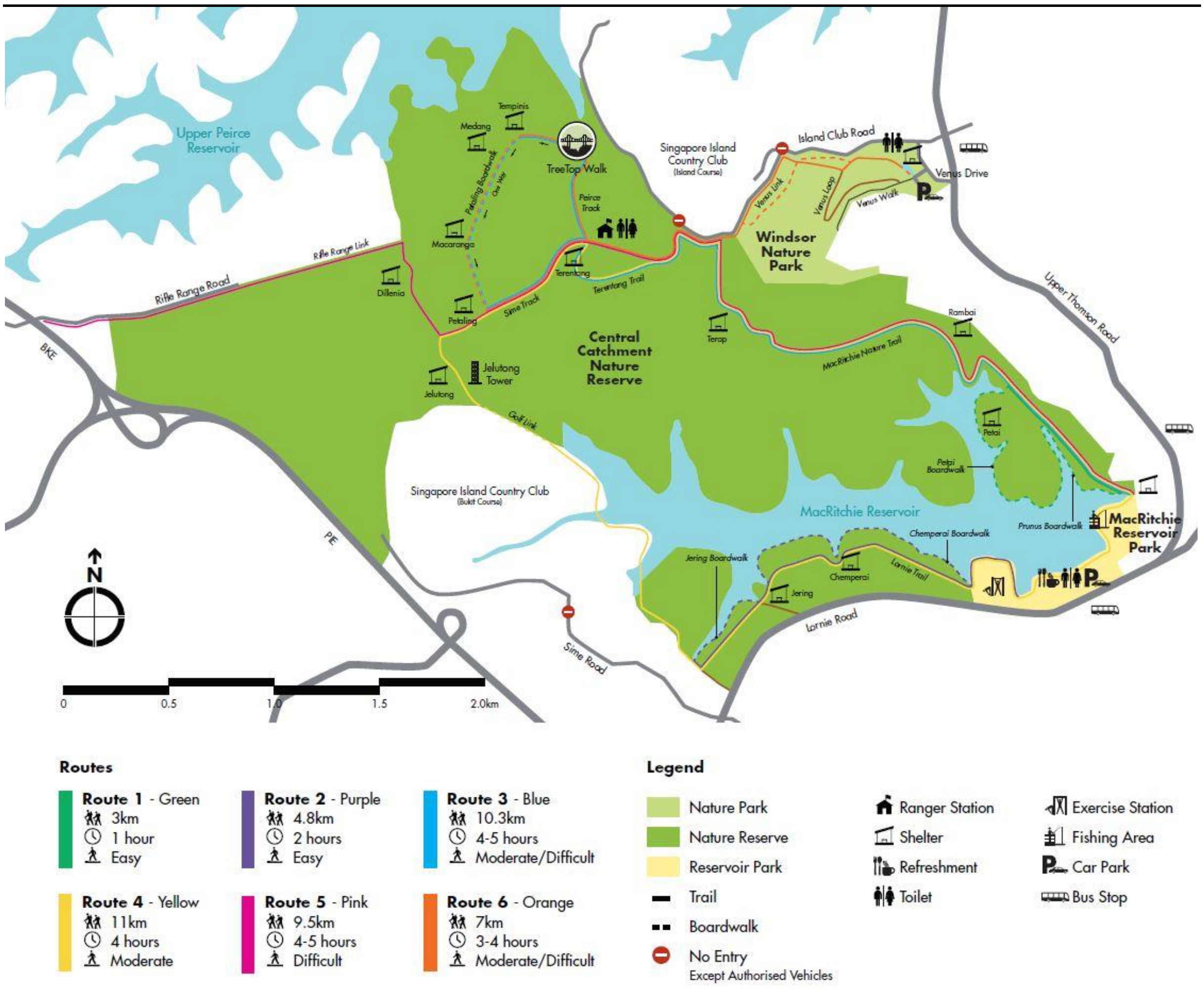
Places of worship within the Study Area include the Hai Lam Sua Tee Kong Toa Temple and St Francis Convent located on the premises of Mount Alvernia Hospital (*Figure 2.3-C*). There is also a chapel located on the ground floor of the Mount Alvernia Hospital, where mass is conducted every morning (except Sundays) for patients, visitors and hospital staff.

[(Footnote 2)] Google Earth Pro 7.1 (22 January 2018) Windsor Nature Park 1°21'18.27"N, 103°49'10.77"E.

[(Footnote 3)] Google Earth Pro 7.1 (22 January 2018) Sime Road 1°20'23.46"N, 103°48'33.17"E.

[(Footnote 4)] Google Earth Pro 7.1 (22 January 2018) Lornie Road 1°20'22.96"N, 103°49'22.33"E.

Figure 2.2: ***Public Trails within the Central Catchment Nature Reserve***



Source: NParks, 2018 (http://www.nparks.gov.sg)

Educational institutions include Raffles' Institution Junior College, located at the cross junction of Marymount Road and Braddell Road, as well as two pre-school facilities located within the private estate along Westlake Avenue (Our Juniors' Schoolhouse[4] and Cherie Hearts Kids-at-Play[5]) (*Figure 2.3-C*).

Healthcare facilities include St Theresa's Home located between the CCNR and Upper Thomson Road, Assisi Hospice and Mount Alvernia Hospital (*Figure 2.3-C*). Thomson Plaza, located along Upper Thomson Road, houses several clinics and dental surgeries (*Figure 2.3-B*).

Utility infrastructure within the Study Area includes MacRitchie Reservoir; the Bukit Kalang Service Reservoir operated by the PUB, pumps and installations for the operation and maintenance of the MacRitchie Reservoir; as well as SP Powergrid 6.6kV substations located within St Theresa's Home, and within private estates lining Upper Thomson Road (*Figure 2.3-A* and *Figure 2.3-C*). Other utility infrastructure such as electricity, gas and water mains, and telecommunication lines are typically installed 1 to 3 m underground, near developed areas outside the CCNR, as well as within or in proximity to the MacRitchie Reservoir Park and the Ranger Station within the CCNR and Windsor Nature Park.

Transportation infrastructure within the Study Area includes the Thomson-East Coast MRT line and the Upper Thomson Station (TE8) along Upper Thomson Road; and the major arterial roads Upper Thomson Road, Lornie Road, and the Lornie Highway which will be fully operational by 2020 (*Figure 2.3-B – Figure 2.3-D*). Upper Thomson Road is a dual three-lane major arterial road that connects the northern and central regions of Singapore. Lornie Road lies along the southern perimeter of the MacRitchie Reservoir and connects the PIE and the Central Expressway (CTE) through the MacRitchie viaduct flyover. Lornie Highway is a dual four-lane road and viaduct linking the MacRitchie Viaduct and the PIE. Once fully operational in 2020, Lornie Highway will serve to ease traffic along Lornie Road. Lornie Road will be converted from a dual four-lane road to a dual two-lane road, and future park connectors skirting the south perimeter of the CCNR will be constructed. A section of the PIE, which is one of two major expressways connecting the eastern and western regions of Singapore, runs along the western boundary of the CCNR. Other supporting transport facilities include bus stops along the aforementioned roads, and petrol kiosks operated by Shell, Esso and Singapore Petroleum Company (*Figure 2.3-B* and *Figure 2.3-C*).

Other landmarks within the Study Area include areas of historical value and/or buildings or structures that have been accorded legal conservation status. These include:

- The water intake tower and connecting bridge at MacRitchie Reservoir, which was conserved as a reflection of late 19th century technology and construction methods *(URA, 13 December 2014*[(6)]*)*;

- The iconic bandstand and bridge at MacRitchie Reservoir Park, which were conserved for nostalgic reasons (*URA, 13 December 2014*[(6)]);

- Syonan Jinja, a Shinto shrine constructed in the forest at MacRitchie Reservoir in honor of fallen Japanese soldiers, and used for ceremonial events during the Japanese occupation of Singapore. Just prior to the surrender of the Japanese forces, the shrine was destroyed to prevent returning British forces from desecrating it. In 2002, the National Heritage Board (NHB) designated the ruins of the Shinto shrine as a historic site (*National Library Board, 2004*[(7)]);

- Bukit Brown Cemetery, a municipal cemetery that belonged to the Hokkien Ong clan when it was first opened in 1922 but later catered to the wider Chinese community in Singapore. In 2011, LTA announced the construction of a dual four-lane road through Bukit Brown i.e. New Lornie Road, and URA and LTA have commissioned the documentation of graves that may be affected by the new road. Bukit Brown cemetery was also included in the World Monuments Watch list[(8)] for 2014 for its symbolic role as a cemetery for pioneering Chinese immigrants from all walks of life (*LTA, 12 September 2011*[(9)]; *National Library Board, 2018*[(10)]);

- Seh Ong cemetery, which lies adjacent to Bukit Brown cemetery within the larger Bukit Brown area. The Seh Ong cemetery site was first a village owned by three wealthy Hokkien entrepreneurs in 1872, and later came to be used solely as a burial ground for the Ong clan. The Seh Ong cemetery is also affected by graves exhumation for the New Lornie Road[(11)];

- Arcadia Road, which was one of five roads gazetted in 2006 by the National Parks Board as Heritage Roads. Mature rain trees (*Samanea saman*) line the two sides of the roads. Located nearby Arcadia Road within the Adam Park Estate are black-and-white colonial bungalows, one of which is Adam Park House Number 7, which was the site of the British 1st Battalion's Headquarters during the Japanese Occupation in 1942. According to the Heritage Road Scheme, a green buffer of 10 m on both sides of the Heritage Road is enforced and the removal of trees or plants is prohibited (*NParks, 2015*[12,13]); and

- Sime Road Camp along Sime Road, which is the site of the former combined Operational Headquarters of the British Army and Royal Air Force during World War II. In 2003, the NHB designated the site of Sime Road Camp as a historic site. It is noted that the buildings associated with the Sime Road Camp no longer exist (*National Library Board, 2011*[14]). Sime Road Machine-Gun Pillbox[15], one of a network of pillboxes that provided fire cover and defence during World War II, is also located along Sime Road in the vicinity of Sime Road Camp.

There are a number of committed developments that have been identified within or in proximity to the broad Study Area. The committed developments for which public information is available and are considered further within this EIA are summarised in *Table 2.1*.

Figure 2.3-A: Land Uses within Study Area

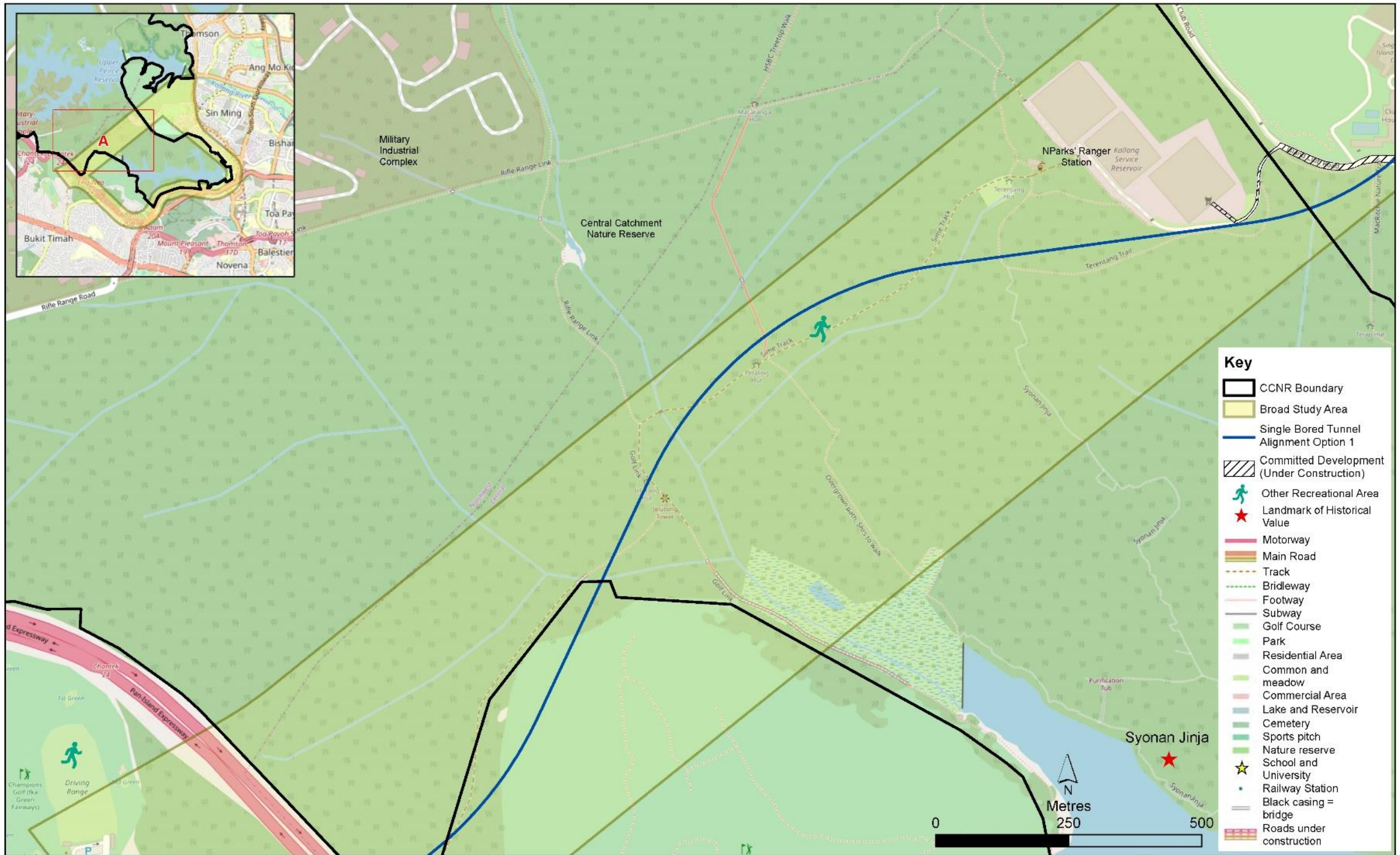


Figure 2.3a
Land Uses within Broad Study Area

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Figure 2.3-B : Land Uses within Study Area

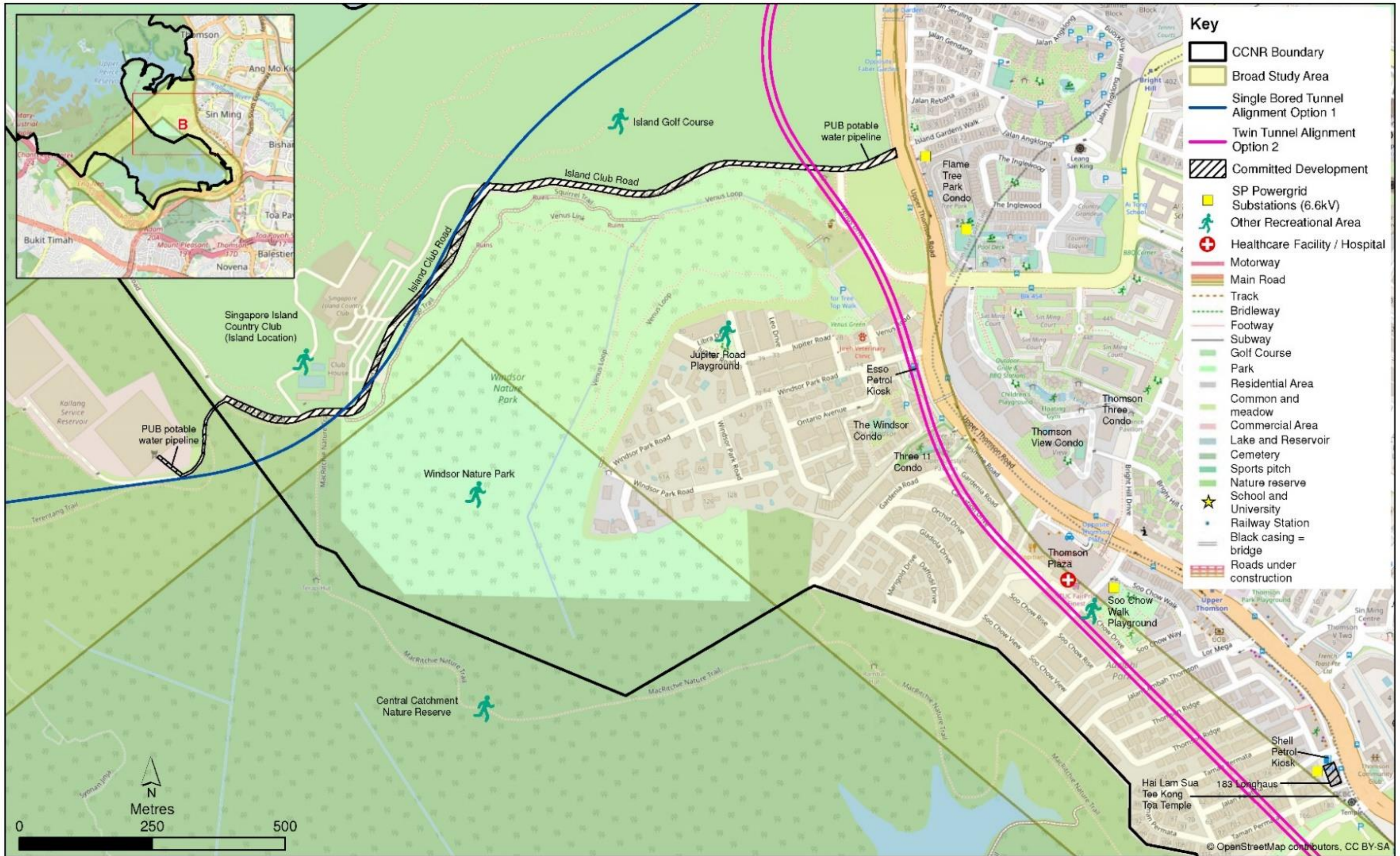

Figure 2.3b
Land Uses within Broad Study Area

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Figure 2.3-C: Land Uses within Study Area

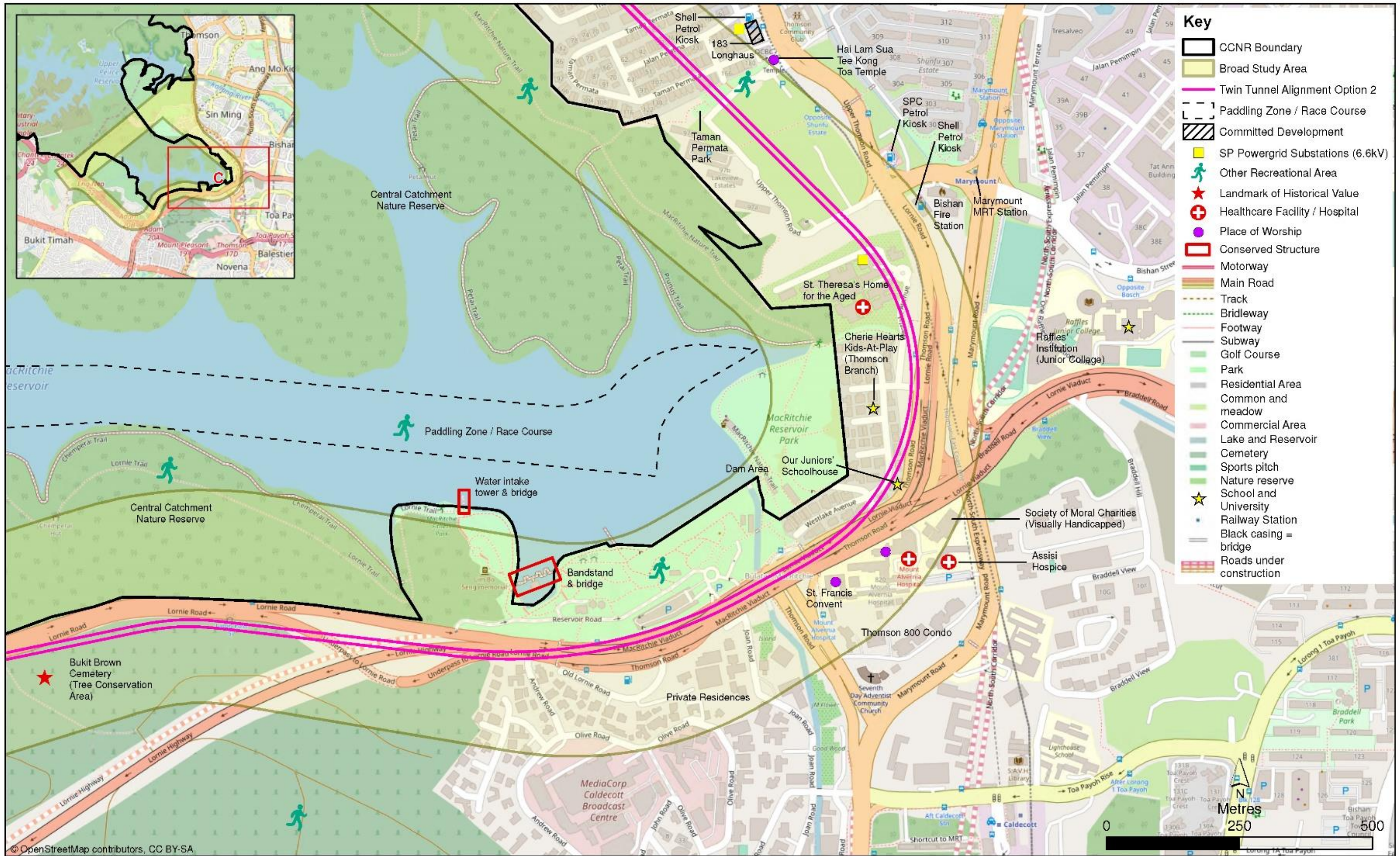

Figure 2.3c
Land Uses within Broad Study Area

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Figure 2.3-D: Land Uses within Study Area

Figure 2.3d
Land Uses within Broad Study Area

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Figure 2.3-E : Land Uses within Study Area

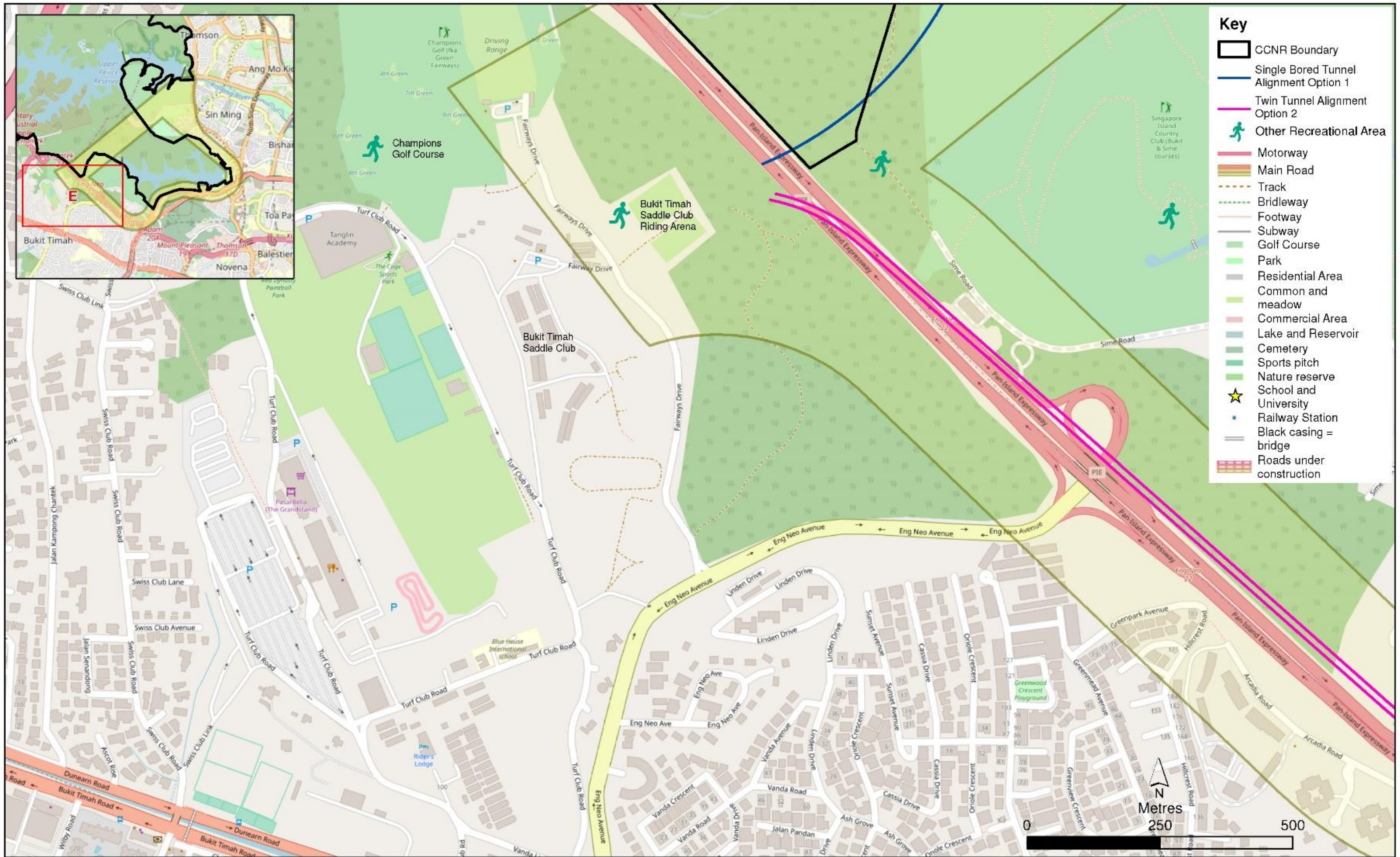

Figure 2.3e
Land Uses within Broad Study Area

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Table 2.1: Committed Developments within the Study Area

No.	Description	Location	Estimated Schedule
Transport Infrastructure			
1	North-South Corridor tunnel section	Between Toa Payoh Rise and Marymount Lane	2018 (Note 1) to 2026 (Note 2)
2	North-South Corridor tunnel section	Between Marymount Road and Pemimpin Place	2019 (Note 3) to 2026
Utility			
3	1,800 mm diameter potable water pipeline jacking project	Between the Bukit Kalang Service Reservoir and Upper Thomson Road, along Island Club Road	3Q2020 to 4Q2023

Note 1: Land Transport Authority (23 May 2018) **LTA awards two civil contracts for the construction of North-South Corridor tunnels.** Available at https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=4eae5958-3802-459b-bf08-f97b1793c9a1

Note 2: Land Transport Authority (28 April 2016) **North-South Corridor.** Available at https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=3581a1a2-2d5e-44d8-a3fe-0093e31d9b07

Note 3: Land Transport Authority (21 December 2018) **LTA awards six contracts for the construction of North-South Corridor Tunnels.** Available at https://www.lta.gov.sg/apps/news/page.aspx?c=2&id=2666f218-c0cf-4603-99d6-1ac1e2f3c682

3 ECOLOGY AND BIODIVERSITY

This chapter of the report presents a recap of the ecology and biodiversity baseline of the Study Area, which was conducted for the purposes of the SI EIA and the C&O EIA. At the time of conducting the baseline study, potential areas that could be impacted by the Project were identified based on preliminary information, as worksite locations have yet to be confirmed at that stage.

For the C&O EIA, additional secondary baseline data specific to the worksite areas has been obtained to supplement the existing data and has been presented below.

3.1 STUDY AREA

The Study Area is defined as the area within which ecological receptors (both terrestrial and aquatic) in and around the CCNR, could potentially be affected from the CRL development activities, i.e. pre-construction SI works, aboveground and underground construction works and operation of the railway.

3.2 DATA COLLECTION

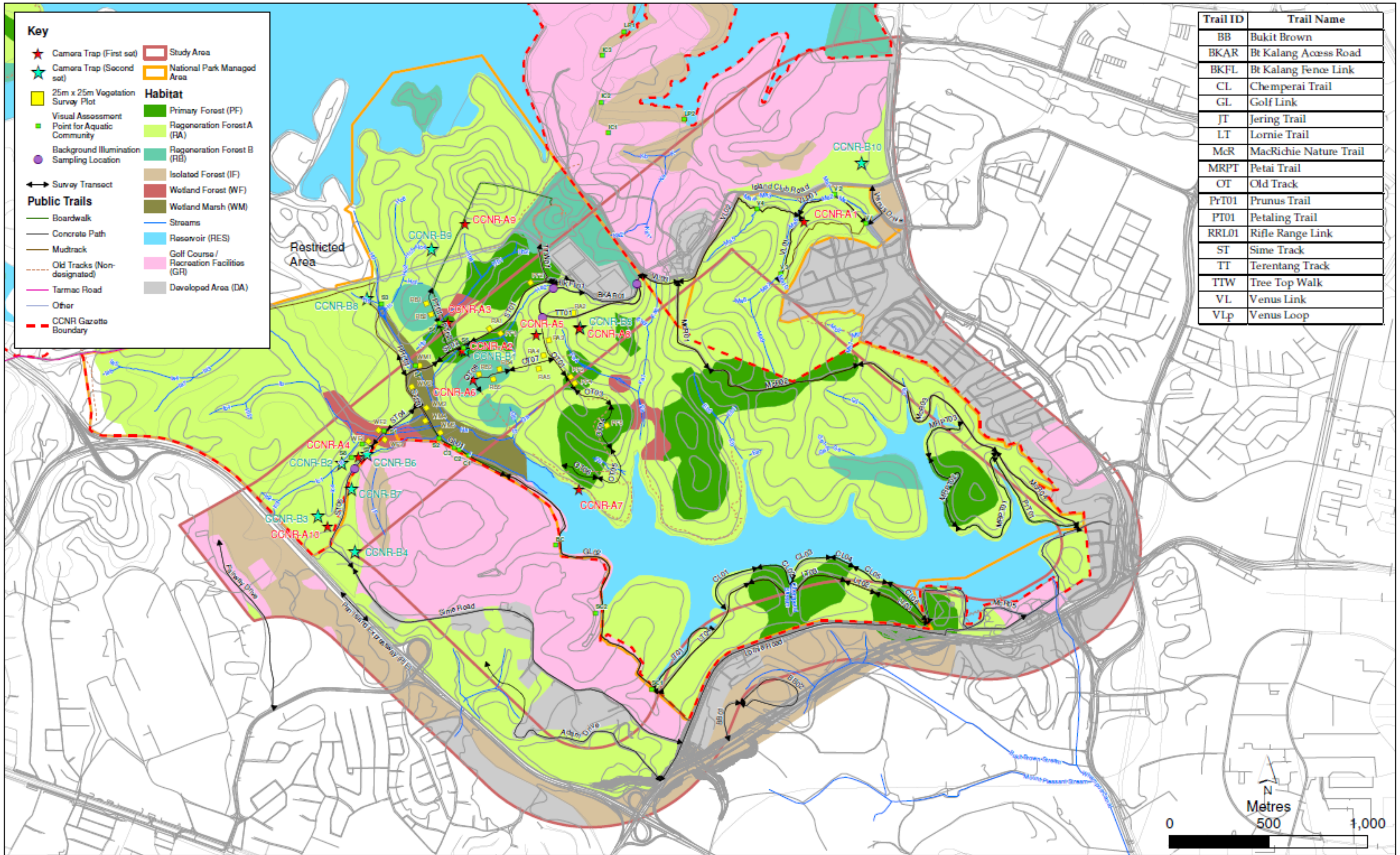
Secondary data review and primary data gathering has been undertaken, including tailored surveys within the Study Area focusing on the habitats and vegetation for a suite of terrestrial vertebrate fauna, as well as specifically targeting avifauna, herpetofauna, butterflies and odonates, and the aquatic community. The ecological surveys covered up to fourteen (14) months of data collection activities covering inter-monsoon period and monsoon periods. The surveys commenced in October 2014 and lasted up to November 2015, as illustrated in *Table 3.1*. Avifauna surveys covered the main breeding season. *Figure 3.1* shows the locations of the survey transects, vegetation plots and camera traps.

Table 3.1: Survey Schedule over the 14-month Survey Period

Survey Elements	Oct '14	Nov '14	Dec '14	Jan '15	Feb '15	Mar '15	Apr '15	May '15	Jun '15	Jul '15	Aug '15	Sep '15	Oct '15	Nov '15
	Inter-Monsoon Period		Northeast Monsoon				Inter-Monsoon Period		Southwest Monsoon				Inter-Monsoon Period	
	Major Bird Migration				Major Bird Migration							Major Bird Migration		
						High Breeding Activity								
Habitat & Vegetation	D	D	D	D	D	D	D	D	D					
Avifauna		D & N	D & N	D & N	D & N	D & N		D	D & N			D & N	D & N	
Butterfly/ Odonate		D		D	D				D			D & N	D & N	
Terrestrial Mammals including Bats		D & N	D & N	D & N	D & N	D & N			D & N			D & N		
Camera trap deployment		D & N	D & N	D & N	D & N							D & N	D & N	D & N
Herpetofauna		D & N	D & N	D & N	D & N	D & N			D & N			D & N		
Aquatic Community including Freshwater fish & Decapod Crustaceans				D	D & N									

Notes:
D = Day Time Survey
N = Night Time Survey

Figure 3.1: Location of Survey Transects, Vegetation Plots and Camera Traps



Trail ID	Trail Name
BB	Bukit Brown
BKAR	Bt Kalang Access Road
BKFL	Bt Kalang Fence Link
CL	Chemperai Trail
GL	Golf Link
JT	Jering Trail
LT	Lornie Trail
McR	MacRichie Nature Trail
MRPT	Petai Trail
OT	Old Track
PrT01	Prunus Trail
PT01	Petaling Trail
RRL01	Rifle Range Link
ST	Sime Track
TT	Terentang Track
TTW	Tree Top Walk
VL	Venus Link
VLp	Venus Loop

Figure A-3 Location of Survey Transects, Vegetation Plots and Camera Traps

File: T:\GIS\CONTRACT\0256660\Mxd\Final_EIA_Report\Appendix\0256660_Appendix_Location_of_ST_VP_CT_v1.mxd
Date: 2/7/2019

Environmental Resources Management

3.2.1 Habitats and Vegetation

All the various classifications of habitat within the Study Area over time have been based on floristic surveys and analysis of structural elements derived from aerial photographs.

The data collection methods included plot sampling and transect surveys, combined with systematic rapid habitat assessments for forests to delineate the forest type with special focus on primary forest, structure and composition. In plot sampling, the forest areas were first classified into strata according to vegetation type namely Primary Forest, Regeneration Forest A, Regeneration Forest B, Wetland Forest and Wetland Marsh.

From each stratum, 25 m x 25 m sampling plots were established independently and placed randomly so that each forest type was well presented. All standing trees with diameter at breast height (DBH) ≥ 5 cm within each plot were assessed. Tree DBH (measured at a point 1.30 m above ground level) was measured over bark, to the nearest cm using a diameter tape. Total tree heights were estimated using Suunto Clinometer and range finder. The identification was based on bark, slash and leaf characteristics. However, trees that could not be identified to species level by non-intrusive approaches (i.e. no collection of fresh plant material) were identified up to genus level.

Transects along the 5 m belt on both sides of designated trails were surveyed to record encountered/ representative trees and other plant species in indicative corridors 1 and 2. Additional focused transects were conducted in sites of high conservation value, e.g., primary forest patches, as well as in habitats of importance to species of conservation interest in indicative corridors 1 and 2. The habitat map is shown in *Figure 3.2*.

The habitats were defined along with their vegetation classification and summary descriptions of each habitat, provided in *Table 3.2*. The summary of the sensitivity of habitats within NParks' Managed Areas and outside of NParks' Managed areas are presented in *Table 3.3* and *Table 3.4* respectively.

Figure 3.2: Habitat Map

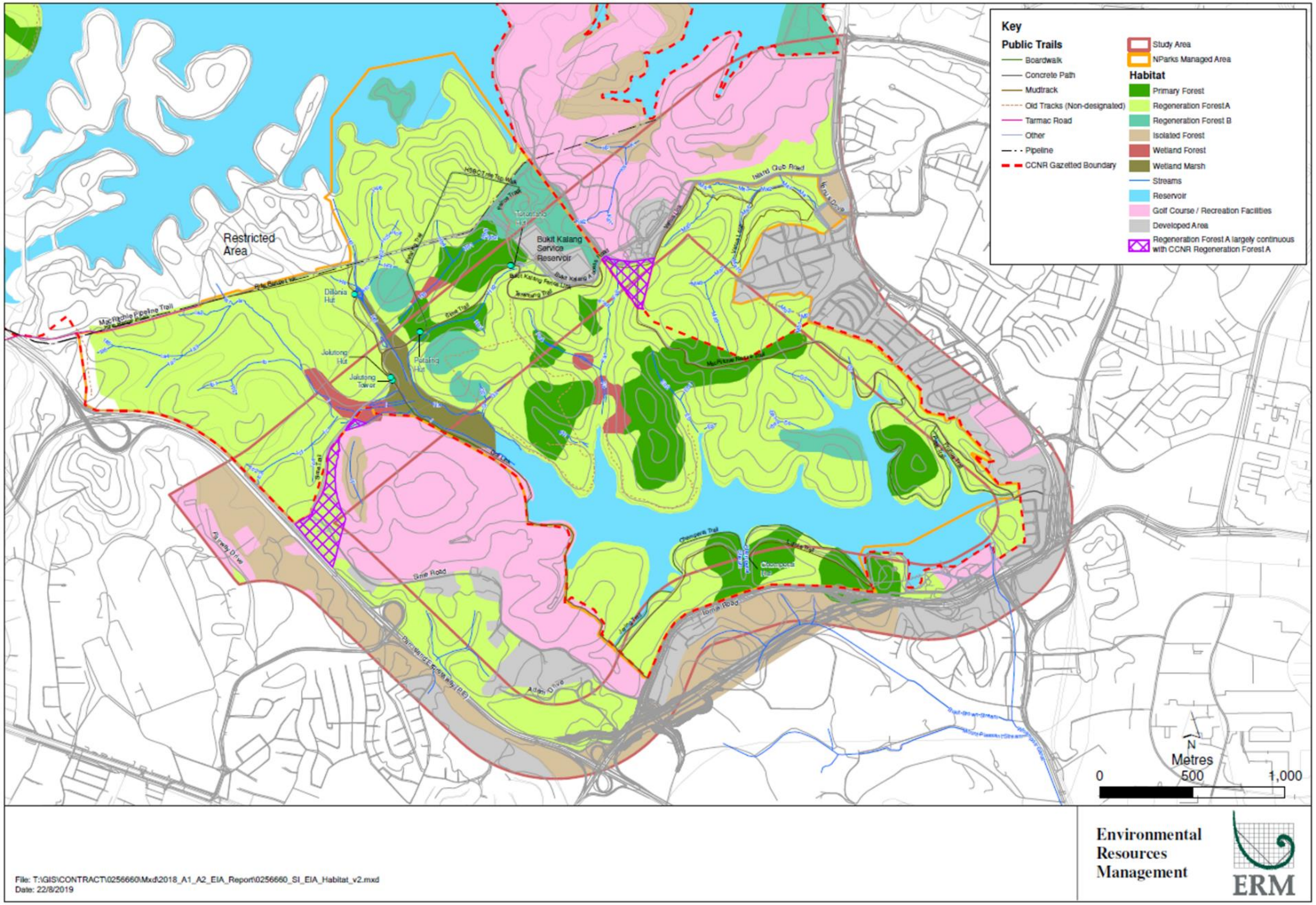


Table 3.2*: *Habitat and Vegetation Classification with Descriptions

Classification	Description
Primary Forest	The canopy cover of this species rich dipterocarp forest was found to be approximately 100%, with emergent trees having DBH[1] 60-90 cm and reaching 40 to 50 m high. Primary species included *Shorea* spp. (*S. gratissima* and *S. pauciflora* are listed as EN while *S. curtisii* as VU by IUCN Red List, the nationally EN *Koompassia malaccensis* and CR *Dipterocapus grandifloras*. Tree fall gaps where the canopy cover was 90-95% were occupied by more light-demanding pioneer species including *Campnosperma auriculatum*, *Dillenia suffruticosa, Rhodamia cinerea, Macaranga gigantean* and *Artocarpus* spp. Primary forest along MacRitchie Trail (Figure 3.1) was considered the most pristine area of this forest type. It was densely stocked with a high diversity of large dipterocarp emergent trees. Species observed were *Shorea curtisii* (the Heritage Tree, Seraya), *S. pauciflora*, *S. gibbosa, S. ovalis, Dipterocarpus apterus* and the internationally VU *Hopea griffithii*, with a DBH of more than 60 cm and reaching 50 m tall. Size of some non-dipterocarps, like *Aquilaria malaccencis* (internationally VU), *K. malaccensis* and *Campnosperma squamatum* were also large, with a DBH 50-60 cm. Forest patches approaching the Shinto Shrine (OT2, OT4, OT6 in Figure 3.1) were well represented by various emerging *Shorea* spp. with a 100% canopy cover. Other common species included *Lithocarpus ewyckii*, *Dyera costulata* and *Pentace triptera*. The transect MRPT02 (Figure 3.1) itself appeared to be in an area of secondary forest at the edge of a forested area, adjacent to Mc Ritchie Reservoir. However a further 10 m into the forest from observation showed that it was primary forest. Species of *Brackenridgea hookeri*, *Carallia brachiate* and *Rhodamnia cinerea* are common along the 5 m edge. Lornie Trail also contained this forest type, dominated by *Dipterocarpus* spp. and *Shorea* spp., with some emergent trees (*Shorea* spp., *D. costulata*, *Sindora leiocarpa* and *K. malaccensis*) having a DBH 70-90 cm and 40-45 m in height. The forest edge along the MacRitchie Reservoir was more open with a canopy cover of 50-70% and the number of *Shorea* spp. reduced.
Regeneration Forest A	Most of the surveyed transects fell within this forest type, which was usually found to be a mix of long-lived and short-lived secondary species. Dipterocarps were not recorded here, except a few individuals which presented along transect MRPT01 and CL03 (Figure 3.1). Canopy coverage was still high as 90-100%. Long-lived secondary species comprised of *Campnosperma auriculatum*, *Alstonia angustifolia*, the nationally VU *A. spatulata*, *Pternandra echinata* and *Cratoxylum arborescens*; while short-lived secondary species, including *Macaranga gigantea*, *Rhodamia cinerea* and *Dillenia suffruticosa*, were confined to more open areas. Some patches were old enough to embrace primary species, including IUCN CR species *Shorea platycarpa, Aquilaria malaccensis*, *Litsea elliptica*, *Dialium platysepalum, Xanthophyllum affine*, *Lophopetalum multinervium* and *Lithocarpus sundaicus*. Over time, these species can grow up to 90 cm at DBH and 45 m tall as emergent trees. Transect ST03 (Figure 3.1) was within the Wetland Marsh area but bordering Regeneration Forest A and was actually located on dry land. Secondary specie s of *Ficus lamponga*, *Dillenia suffruticosa, Macaranga gigantea* and *Symplocos rubiginosa* and the primary species, *Litsea elliptica*, were common in these areas.

[1] DBH – Diameter at Breast Height

Classification	Description
Regeneration Forest A	Transects in Venus Link (VL, Figure 3.1) are part of a former rubber tree (*Hevea brasiliensis*) plantation [17, 18]. Besides rubber trees, the areas were dominated by cultivated crops such as *Nephelium lappaceum*, *Durio zibethinus*, *Cocos nucifera*, *Elaeis guineensis*, *Areca catechu*, *Musa* spp., *Daemocarpus longan*, *Lansium domesticum* and *Artocarpus heterophyllus*. The crops were intermixed with pioneer species like *Rhodamia cinerea, Campnosperma* spp., *Macaranga* spp. Canopy closure was about 90-100%. Resam Fern (*Dicranopteris linearis*) was also scattered in some areas of this habitat.
Regeneration Forest B	Secondary forest with a mixture of ornamental plants and pioneer species. Canopy closure was between 50-70%. There was an abundance of *Caryota mitis*, *Cinnamomum iners, Syzygium cerinum,* and *Rhodamia cinerea* trees and it also included plenty of *Albizia falcataria, Cratoxylum formosum, Pometia pinnata, Alangium nobile, Pternandra echinata* and *Brackenridgea hookeri* trees. Resam Fern (*Dicranopteris linearis*) was also scattered in some areas of this habitat.
Wetland Forest	Flora surviving in this habitat type need to adapt to permanent or seasonal flooding and waterlogged soil. Therefore species diversity recorded here were not as high as other forest types described previously but had a more specific community, with Elaeocarpaceae and Rhizophoraceae having the highest abundance. Most Families were represented by one species only with the top three families (Apocynaceae, Myrtaceae and Phyllanthaceae) represented by three species. Dominant species included *Campnosperma squamatum* and *Elaeocarpus floribundus*; and typical wetland flora like *Ilex cymosa*, *Cratoxylum arborescens* and *Pellacalyx axillaris.*
Wetland Marsh	Most of the species recorded are typical of seasonal wetland flora with small-sized trees. Some can be classified as tree shrubs, for instance *Dillenia suffruticosa* and *Ploiarium alternifolium* which commonly occurred in open places and alluvial soils. Elaeocarpaceae and Euphorbiaceae were found to be the major families in Wetland Marsh represented by four species each. Rhizophoraceae and Dilleniaceae were recorded in the highest abundance in the plots. Other abundant Families included Lauraceae, Phyllanthaceae and Bonnetiaceae. The dominant species were *Gynotroches axillaris*, *Ilex cymosa*, *Alstonia angustifolia, D. suffruticosa* and *P. alternifolium*. Resam Fern (*Dicranopteris linearis*) was also scattered in some areas of this habitat.
Streams	These included Concrete Canals, which were typically found upstream and served to channel water quickly from upstream reservoirs (eg Upper Peirce Reservoir); Rural Streams (all found at the Windsor Interim Green); Forest Streams (observed to be well-shaded, single channel streams); Wetland Forest Streams (relatively flat, low flow gradient streams with muddy substrates which were found in Wetland Forest, experiencing occasional floods when flow volume is high and functioning as habitat for the nationally CR aquatic aroid, *Cryptocoryne griffithii*); and Wetland marsh streams (found in Wetland Marsh – areas with relatively flat environments with low flow gradients and similarly to Wetland Forest Streams, experiencing occasional floods when flow volume is high).
Reservoir	This habitat represents the largest water body in the Study Area, surrounded by various terrestrial habitats described in this table. Water depth ranges from 5-10 m [15]. Streams, many of which feed into the reservoir, have been marked separately on the habitat map (*Figure 3.2*).

Classification	Description
Isolated Forest	This habitat represents the main clusters of trees within Singapore Island and Bukit Golf Course as well as Regeneration Fore st areas which have been disconnected from the main CCNR area by the Pan-Island Expressway and Lornie Road. This includes part of the forest of Bukit Brown Cemetery within the Study Area. The cons truction of a new road within Bukit Brown Cemetery as part of the road system upgrade, will result in the fragmentation of the existing tree conservation area[16].
Golf Course/ Recreational Facilities	This habitat type includes mainly non-forested areas under intensive horticultural maintenance and represents the golf courses and some park areas. Scattered individuals of exotic, ornamental plants and pioneer species were found on grassland or the edge of reservoirs in this habitat. Recorded fl ora was dominated by *Fagraea fragrans*, *Calophyllum innophyllum, Cinnamomum iners* and *Payena lucida*. A number of small rain-fed, landscaped, ornamental ponds, as well as other less managed rain-fed small ponds, were also found in golf course areas of this habitat.
Developed Area	Buildings, developed and densely populated areas within the Study Area, typically outside the CCNR boundary, except the Bukit Kalang Service Reservoir. A variety of ornamental plants can be commonly found within these areas.

***Table 3.3**: Sensitivity Value of Different Habitats within NParks' Managed Area*

Habitat	Description	Sensitivity Value
Primary Forest	These habitats were found important/ significant for various species of flora and fauna, in particular globally Critically Endangered (CR) or Endangered (EN) on the IUCN Red List or the Singapore RDB. All of the habitats identified within NPark's Managed Area are ecologically linked, and therefore their sensitivities are considered together a whole with High Sensitivity Value.	High
Regeneration Forest A		High
Regeneration Forest B		High
Wetland Forest		High
Wetland Marsh		High
Streams		High
Reservoir		High

***Table 3.4**: Sensitivity Value of Different Habitats outside NParks' Managed Area*

Habitat	Description	Sensitivity Value
Regeneration Forest A	Some patches of this habitat type are located outside NParks' Managed Area. Most of these patches are influenced by edge effects due to the highway or moderate traffic on roads or high usage of the adjacent golf courses. Some wildlife and species of conservation interest were found utilizing these areas. It should be noted that these areas were still considered as part of the habitats of significant importance for nationally restricted range species, with mostly avifauna flying over.	Medium
Regeneration Forest A – largely continuous with CCNR Regeneration Forest A	One particular patches of this habitat type which is outside NParks' Managed Area, is only separated by trail from the managed area and is therefore still ecologically linked to the large continuous forest within the NParks' Managed area (demarcated by black dotted boundary in *Figure 3.2*). In addition there is anecdotal evidence of Sunda Pangolins (*Manis javanica*) (CR/RDB; CR/IUCN; CITES-II) using the nearby Bukit Golf course to forage in the evenings, suggesting that this area of Regeneration Forest A may be part of their daytime range. There are also reliable sightings of Slow Lorises (*Nycticebus coucang*) and Malayan Colugos (*Galeopterus variegatus*) from this area.	High
Isolated Forest	Fragmented habitat of medium quality and used by common species. Some located within nationally designated or recognized areas such as the Tree Conservation Area in Bukit Brown Cemetery.	Medium
Golf Course/ Recreational Facilities	Low value habitats of significant importance for nationally restricted range species. This habitat type mainly acts as a green buffer/ corridor connecting forests.	Medium
Developed Area	Disturbed habitats with minimal interest for biodiversity overall.	Low

3.2.2 Birds

Birds were surveyed over transects where any birds encountered were identified and counted. Within the survey period, surveys were planned to be conducted monthly although suitable survey periods had to reflect appropriate weather conditions (e.g. no rain) and times of the day (e.g. dawn, dusk) that corresponded to peak bird activity, as well as migratory season. Qualitative night-time bird surveys were conducted. Any notable behavior such as migration, feeding, roosting or breeding of the birds and the associated habitats and vegetation where they show such behavior were recorded.

3.2.3 *Terrestrial Mammals including Bats*

As most mammals occur at low densities, all sightings, tracks, and signs of mammals (including droppings) were actively searched for (including day and night surveys) along the survey transects. The day transects was walked between 0730 to 1330 hours and 1600 to 1800 hours while night transect was walked between 1830 and 2300 hours to increase the detection probability. A bat detector was employed during night surveys to identify bat activities as well as species composition as far as practical. Any special mammal species-habitat relationships observed (foraging/ breeding ground) during the survey was recorded and marked on the habitat map as far as practical.

Given concerns raised during focus group discussions, camera trapping, using Bushnell camera set-ups, was employed instead of intrusive traditional trapping, to help quantify and identify mammals in the Study Area. The camera trapping targeted medium and large terrestrial animals or arboreal mammals, which spend substantial time on the ground. Camera traps were deployed at 10 locations over two separate periods (November 2014 to February 2015 and September 2015 to November 2015), in various forest types in order to capture species inhabiting different habitats. The setting locations included Primary Forest, Regeneration Forest A and B, Isolated Forest and 100 m vicinity of Wetland Forest, where the forest floor was inaccessible due to occasional flooding. The time delay between photographs was set to a minimum of 30 seconds, to reduce shots of the same individual on a single situation. Consecutive photographs of individuals of the same species taken within one hour were defined as one independent capture to avoid over estimation of the relative abundance. All cameras were operated 24 hours a day with continuous monitoring. The cameras were checked every 40 to 60 days to reload new SD cards and batteries. Rats and mice, and poor photographs of squirrels and tree shrews were pooled together as rodents and squirrels respectively, for the purposes of discussion and because they are often indistinguishable on photographs. Photographs of animals that are only visible partly were categorized as unidentified. Captured images were visualized and quantified with standard indices of animal activity and this data was used to assess mammal relative abundances and diversity in the Study Areas wherever possible.

3.2.4 *Herpetofauna*

Visual encounter transects were used to survey for amphibians and reptiles. Visual encounter transects are the standard sampling technique for herpetofauna and covered a representative sample of the Study Area. Visual encounter transects were both diurnal (0730 to 1330 hours) and nocturnal (1830 to 2300 hours), conducted on foot and consisted of slowly moving through relevant areas (focused on breeding habitats and places where prey are found) and identifying any species observed. The transects focused on the taxa and areas of highest conservation interest identified within the Study Area and included auditory detection of species-specific calls to survey for frogs and toads. Any special species-habitat relationships observed (foraging/ breeding ground) during the survey were recorded and marked on the habitat map as far as practical.

3.2.5 Butterflies and Odonates

Butterflies, dragonflies and damselflies of different habitats within the Study Area were surveyed using transect and MacKinnon List techniques, subject to the on-site conditions. Butterflies, dragonflies and damselflies encountered along transects were identified and counted.

3.2.6 Aquatic Community including Freshwater Fish and Decapod Crustaceans

Bankside visual assessment was undertaken to identify observable aquatic community and their relative abundance. No specimens were collected but species' location was recorded using GPS. The assessment was undertaken during both daytime (0800 to 1700 hours) and at night (2000 to 2130 hours) using headlamps. All fish and decapod crustaceans were identified to species or genus level insofar as possible.

3.3 Additional Baseline Data at Worksites

Additional secondary baseline data specific to the worksites for the C&O EIA are provided below. The data was obtained from past research and projects via Anthony O'Dempsey (representative of the CRL Working Group), NParks and PUB respectively to supplement the existing baseline information.

3.3.1 Flora

Site-specific baseline data on flora species have been obtained for Worksites A1-W1, A1-W2 and A2-W2, provided in *Table 3.5*.

***Table 3.5*: Site-specific Flora Baseline Data**

No.	Scientific Name	Common Name	IUCN Status (Note 1)	National Status (Note 2)
Worksite A1-W1				
1	*Alstonia spatulata*	Marsh Pulai	LC	VU
2	*Aphanamixis polystachya*	Pithraj Tree	LC	EN
3	*Aporosa benthamiana*	Crescent Tree	-	VU
4	*Baccaurea motleyana*	Rambai	-	CR
5	*Bauhinia semibifida*	Common Bauhinia	-	VU
6	*Cinnamomum iners*	Wild Cinnamon	-	-
7	*Ficus fistulosa*	Yellow-stem Fig	-	Common
8	*Ficus variegata*	Red-stem Fig	-	Common
9	*Ficus microcarpa*	Malayan Banyan	-	Common
10	*Ixonanthes reticulata*	10-man Tree	-	Common
11	*Litsea elliptica*	Medang	-	Common
12	*Macaranga griffithiana*	Mahang Bulan	-	VU
13	*Nephelium lappaceum*	Rambutan	LC	Common
14	*Sterculia coccinea*	Scarlet Sterculia	-	-
15	*Syzygium polyanthum*	Salam	-	VU
16	*Syzygium grande*	Sea Apple	-	Common

No.	Scientific Name	Common Name	IUCN Status (Note 1)	National Status (Note 2)
17	*Terminalia catappa*	Sea Almond	-	Common
18	*Hevea brasiliensis*	Rubber Tree	-	Exotic
19	*Elaeis guineensis*	Oil Palm	LC	-
20	*Adinandira dumosa*	Tiup Tiup	-	Common
21	*Alstonia angustiloba*	Common Pulai	-	Common
22	*Calophyllum sp.*	-		-
23	*Campnosperma auriculatum*	Terentang	-	Common
24	*Cinnamonum iners*	Wild Cinnamon	-	-
25	*Elaeocarpus pedunculatus*	Blue-leafed Oil-fruit	-	Common
26	*Fagraea fragrans*	Tembusu	LC	Common
27	*Ficus fistulosa*	Common Yellow Stem-Fig	-	Common
28	*Ficus variegata*	Common Red-stem Fig	-	Common
29	*Ixonanthes reticulata*	Pagar Anak	-	Common
30	*Litsea elliptica*	Medang	-	Common
31	*Macaranga gigantean*	Giant Mahang	-	-
32	*Oncosperma tigillarium*	Nibung Palm	-	-
33	*Palaquium obovatum*	Nyonya Puteh	LC	VU
34	*Pometia pinnata*	Island Lychee	-	EN
35	*Prunus polystachya*	Bat's Laurel	LC	Common
36	*Rhodamnia cinerea*	Silver Back Tree	LC	Common
37	*Aidia densiflora*	Wild Randa	-	VU
38	*Aporosa benthamiana*	Crescent Tree	-	VU
39	*Aporosa fructescens*	Bastard Rukam	-	Common
40	*Carallia brachiata*	Freshwater Mangrove	-	-
41	*Claoxylon indicum*	Laping Budak	-	Common
42	*Cryota mitis*	Fishtail Palm	-	Common
43	*Clerodendrum laevifolium*	Swaddling Flower	-	Common
44	*Dillenia suffruticosa*	Yellow Simpoh	-	-
45	*Elaeocarpus ferrugineus*	Rusty Oil Fruit	-	Common
46	*Elaeocarpus petiolatus*	Broad-leafed Oil Fruit	-	Common
47	*Gionniera nervosa*	Common Rough-Laurel	-	Common
48	*Leea indica*	Common Tree-Vine	-	Common
49	*Strombosia javanica*	Dali-dali	-	VU
50	*Timonius wallichanus*	-	-	-
51	*Ficus glandulifera*	Gaping Fig	-	CR
52	*Radermacheria pinnata subsp. acuminata*	-	LC	CR
53	*Strophanthus caudatas*	Dudur Kijang	-	CR
54	*Cissus rostrata*	-	-	VU
Worksite A1-W2				
1	*Falcataria moluccana*	Albizia	-	-
Worksite A2-W2				
1	*Ficus kurzii*	Burmese Banyan	-	-
2	*Acacia concinna*	Soap Pod	-	-

No.	Scientific Name	Common Name	IUCN Status (Note 1)	National Status (Note 2)

Note 1: IUCN Red List of Threatened Species Categories and Criteria: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), Extinct (EX). Retrieved from https://www.iucnredlist.org/

Note 2: The Singapore Red Data Book of Threatened Plants and Animals of Singapore, and NParks Flora and Fauna Web. Retrieved from: https://florafaunaweb.nparks.gov.sg/

3.3.2 *Fauna*

Site-specific baseline data on fauna species have been obtained for Worksites A1-W1, A1-W2, A2-W2, A2-W3 and Windsor streams provided in *Table 3.6*.

Table 3.6*: *Site-specific Fauna Baseline Data

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
Worksite A1-W1					
1	Bird	*Acridotheres javanicus*	Javan Myna	VU	Common
2	Bird	*Acridotheres tristis*	Common Myna	LC	Common
3	Bird	*Aegithina tiphia*	Common Iora	LC	-
4	Bird	*Aerodramus brevirostris*	Himalayan Swiftlet	LC	-
5	Bird	*Aerodramus germaini*	Germain's Swiftlet		-
6	Bird	*Aerodramus maximus*	Black-Nest Swiftlet	LC	-
7	Bird	*Aethopyga siparaja*	Crimson Sunbird	LC	Common
8	Bird	*Amaurornis phoenicurus*	White-Breasted Waterhen	LC	Common
9	Bird	*Anthreptes malacensis*	Brown-Throated Sunbird	LC	Common
10	Bird	*Aplonis panayensis*	Asian Glossy Starling	LC	Common
11	Bird	*Arachnothera longirostra*	Little Spiderhunter	LC	Common
12	Bird	*Cacomantis sepulcralis*	Banded Bay Cuckoo	LC	VU
13	Bird	*Callocalia affinis*	Plum-Toed Swiftlet	-	CR
14	Bird	*Caprimulgus indicus*	Grey Nightjar	LC	Rare
15	Bird	*Caprimulgus macrurus*	Large-tailed Nightjar	LC	Common
16	Bird	*Centropus sinensis*	Greater Coucal	LC	-
17	Bird	*Chalcophaps indica*	Emerald Dove	LC	-
18	Bird	*Cinnyris jugularis*	Olive-Backed Sunbird	LC	-
19	Bird	*Collocalia esculenta*	Glossy Swiftlet	LC	-
20	Bird	*Copsychus malabaricus*	White-rumped Shama	LC	-
21	Bird	*Copsychus saularis*	Oriental Magpie Robin	LC	EN
22	Bird	*Corvus macrorhynchos*	Southern Jungle Crow	LC	-
23	Bird	*Corvus splendens*	House Crow	LC	Common
24	Bird	*Cypsiurus balasiensis*	Asian-Palm Swift	LC	-
25	Bird	*Dicaeum cruentatum*	Scarlet-backed Flowerpecker	LC	Common

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
26	Bird	*Dicaeum trigonostigma*	Orange-Bellied Flowerpecker	LC	-
27	Bird	*Dicrurus paradiseus*	Greater Racket-tailed Drongo	LC	-
28	Bird	*Dinopium javanense*	Common Flameback	LC	Common
29	Bird	*Ducula bicolor*	Pied Imperial Pigeon	LC	-
30	Bird	*Eudynamys scolopacea*	Asian Koel	LC	Common
31	Bird	*Eurystomus orientalis*	Dollarbird	LC	Common
32	Bird	*Gallus gallus*	Red Junglefowl	LC	EN
33	Bird	*Gracula religiosa*	Hill Myna	LC	-
34	Bird	*Halcyon smyrnensis*	White-Throated Kingfisher	LC	Common
35	Bird	*Haliastur indus*	Brahminy Kite	LC	Common
36	Bird	*Hemiprocne longipennis*	Grey-Rumped Treeswift	LC	-
37	Bird	*Hierococcyx nisicolor*	Large Hawk Cuckoo	LC	-
38	Bird	*Hirundo rustica*	Barn Swallow	LC	-
39	Bird	*Hirundo tahitica*	Pacific Swallow	LC	Common
40	Bird	*Ichthyophaga ichthyaetus*	Grey-Headed Fish-Eagle	NT	CR
41	Bird	*Ketupa ketupu*	Buffy Fish Owl	LC	CR
42	Bird	*Kittacincla malabarica*	White-rumped Shama	LC	-
43	Bird	*Loriculus galgulus*	Blue-Crowned Hanging Parrot	LC	EN
44	Bird	*Macronous gularis*	Pin-Striped Tit-Babbler	LC	Common
45	Bird	*Malacocincla abbotti*	Abbott's Babbler	LC	-
46	Bird	*Merops philippinus*	Blue-Tailed Bee-Eater	LC	-
47	Bird	*Merops viridis*	Blue-throated Bee-eater	LC	-
48	Bird	*Micropternus brachyurus*	Rufous Woodpecker	LC	-
49	Bird	*Muscicapa dauurica*	Asian Brown Flycatcher	LC	-
50	Bird	*Ninox scutulata*	Brown Hawk Owl	LC	-
51	Bird	*Nisaetus cirrhatus*	Changeable Hawk-Eagle	LC	EN
52	Bird	*Nisaetus limnaeetus*	Changeable Hawk-Eagle	LC	-
53	Bird	*Oriolus chinensis*	Black-Naped Oriole	LC	Common
54	Bird	*Orthotomus atrogularis*	Dark-Necked Tailorbird	LC	-
55	Bird	*Orthotomus sericeus*	Rufous-Tailed Tailorbird	LC	-
56	Bird	*Orthotomus sutorius*	Common Tailorbird	LC	-
57	Bird	*Otus Bakkamoena*	Collared Scops Owl	LC	-
58	Bird	*Pericrocotus divaricatus*	Ashy Minivet	LC	-
59	Bird	*Phylloscopus borealis*	Arctic Warbler	LC	-
60	Bird	*Picus vittatus*	Laced Woodpecker	LC	-
61	Bird	*Psilopogon haemacephala*	Coppersmith Barbet	LC	-
62	Bird	*Psilopogon lineata*	Lineated Barbet	LC	Uncommon
63	Bird	*Psittacula krameri*	Rose-Ringed Parakeet	LC	-
64	Bird	*Psittacula longicauda*	Long-Tailed Parakeet	VU	Common
65	Bird	*Psittinus cyanurus*	Blue-Rumped Parrot	NT	CR/GNT

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
66	Bird	*Pycnonotus goiavier*	Yellow-Vented Bulbul	LC	Common
67	Bird	*Pycnonotus jocosus*	Red-Whiskered Bulbul	LC	-
68	Bird	*Pycnonotus plumosus*	Olive-winged Bulbul	LC	-
69	Bird	*Spilopelia chinensis*	Spotted Dove	LC	-
70	Bird	*Streptopelia chinensis*	Spotted-Dove	LC	Common
71	Bird	*Sturnus sturninus*	Purple-Backed Starling	LC	-
72	Bird	*Todiramphus chloris*	Collared Kingfisher	LC	Common
73	Bird	*Treron curvirostra*	Thick-Billed Green-Pigeon	LC	EN
74	Bird	*Treron vernans*	Pink-Necked Green-Pigeon	LC	Common
75	Bird	*Trichoglossus moluccanus*	Rainbow Lorikeet	LC	-
76	Bird	*Zosterops palpebrosus*	Oriental White-Eye	LC	Uncommon
77	Butterfly	*Acraea terpsicore*	Tawny Coster	-	-
78	Butterfly	*Ancistroides nigrita*	Chocolate Demon	-	-
79	Butterfly	*Appias libythea*	Striped Albratross	-	-
80	Butterfly	*Catopsilia pomona*	Lemon Emigrant	-	Common
81	Butterfly	*Cethosia sp.*	Unidentified Lacewing Butterfly		-
82	Butterfly	*Delias hyparete*	Painted Jezebel	LC	Common
83	Butterfly	*Elymnias hypermnestra*	Common Palmfly	-	-
84	Butterfly	*Erionota thrax thrax*	Skipper sp	-	-
85	Butterfly	*Euchrysops cnejus*	Gram Blue	-	-
86	Butterfly	*Eurema brigitta*	Grass Yellow	LC	-
87	Butterfly	*Euthalia adonia*	Green Baron	-	Moderately Common
88	Butterfly	*Graphium agamemnon agamemnon*	Tailed Green Jay	-	Common
89	Butterfly	*Graphium evemon*	Blue Jay	LC	-
90	Butterfly	*Graphium Sarpedon*	Common Bluebottle	-	Common
91	Butterfly	*Hypolimnas anomala*	Malayan Eggfly	-	-
92	Butterfly	*Jamides celeno*	Common Caerulean	-	-
93	Butterfly	*Junonia almanac*	Peacok Pansy	-	-
94	Butterfly	*Junonia atlites atlites*	Grey Pansy butterfly	-	-
95	Butterfly	*Junonia hedonia*	Chocolate Pansy	-	-
96	Butterfly	*Lambrix salsala*	Chestnut Bob	-	-
97	Butterfly	*Lasippa heliodore dorelia*	Lascar sp.	-	-
98	Butterfly	*Lebadea martha*	Knight	-	Rare
99	Butterfly	*Lexias pardalis*	Archduke	-	-
100	Butterfly	*Mycalesis fusca fusca*	Bush Brown Sp	-	-
101	Butterfly	*Mycalesis mineus*	Dark Brand Bush Brown	-	-
102	Butterfly	*Mycalesis perseoides*	Burmese Bush Brown	-	-
103	Butterfly	*Mycalesis perseus*	Dingy Bush Brown	-	-
104	Butterfly	*Neptis harita harita*	Sailor sp.	VU	Rare
105	Butterfly	*Neptis hylas*	Common Sailor	-	-
106	Butterfly	*Oriens gola*	Common Dartlet	-	-

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
107	Butterfly	*Papilio polytes*	Common Mormon	-	Common
108	Butterfly	*Parantica agleoides*	**Dark Glassy Tiger**	-	-
109	Butterfly	*Pelopidas mathias*	Small Branded Swift	-	-
110	Butterfly	*Phaedyma columella*	Short-banded Sailor	-	-
111	Butterfly	*Potanthus omaha*	Lesser Dart	-	-
112	Butterfly	*Taractrocera archias*	Yellow Grass Dart	-	-
113	Butterfly	*Troides helena cerberus*	Common Birdwing	LC	VU
114	Butterfly	*Vindula dejone*	Cruiser	LC	-
115	Butterfly	*Ypthima baldus*	Common 5 Ring	-	-
116	Butterfly	*Ypthima huebneri*	Common 4 Ring	-	-
117	Butterfly	*Zizina otis lampa*	Lesser Grass Blue	-	-
118	Butterfly	*Zizula hylax*	Pygmy Grass Blue	-	Common
119	Mammal	*Callosciurus notatus*	Plantain Squirrel	LC	Common
120	Mammal	*Cynopterus brachyotis*	Common Fruit Bat	LC	Common
121	Mammal	*Galeopterus variegatus*	Malayan Colugo	LC	Common
122	Mammal	*Iomys horsfieldii*	Horsfield's Flying Squirrel	LC	EN
123	Mammal	*Macaca fascicularis*	Long-tailed Macaque	LC	Common
124	Mammal	*Manis javanica*	Sunda Pangolin	CR	CR
125	Mammal	*Myotis muricola*	Whiskered Bat	LC	-
126	Mammal	*Nycticebus coucang*	Sunda Slow Loris	VU	CR
127	Mammal	*Paradoxurus hermaphroditus*	Common Palm Civet	LC	Common
128	Mammal	*Pipistrellus javanicus*	Javan Pipistrelle	LC	-
129	Mammal	*Presbytis femoralis*	Raffles' Banded Langur	NT	CR
130	Mammal	*Rattus annandalei*	Singapore Rat	LC	-
131	Mammal	*Rattus sp.*	Oriental House Rat/ Malaysian Wood Rat	LC	-
132	Mammal	*Scotophilus kuhlii*	Asiatic Lesser Yellow House Bat	LC	-
133	Mammal	*Sundasciurus tenuis*	Slender Squirrel	LC	Not Threatened
134	Mammal	*Sus scrofa*	Wild Pig	LC	Not Threatened
135	Mammal	*Tragulus kanchil*	Lesser Mousedeer	LC	CR
136	Mammal	*Tupaia glis*	Common Treeshrew	LC	-
137	Mammal	*Tylonycteris robustula*	Greater Bamboo Bat	LC	-
138	Odonate	*Agrionoptera insignis*	Grenadier	LC	Common
139	Odonate	*Brachydiplax chalybea*	Blue Dasher	LC	-
140	Odonate	*Ceriagrion cerinorubellum*	Ornate Coraltail	LC	Common
141	Odonate	*Cratilla metallica*	Dark-tipped Forest-Skimmer	LC	Common
142	Odonate	*Crocothemis servilia*	Common Scarlet	LC	Common
143	Odonate	*Eooxylides tharis distanti*	Branded Imperial	-	-
144	Odonate	*Gynacantha immaculifrons*	Duskhawker Sp	LC	-
145	Odonate	*Hydrobasileus croceus*	Water Monarch	LC	Common
146	Odonate	*Junonia hedonia ida*	Chocolate Pansy	-	-
147	Odonate	*Lathrecista asiatica*	Scarlet Grenadier	LC	Common

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
148	Odonate	*Macrodiplax cora*	Coastal Glider	LC	Common
149	Odonate	*Neurothemis fluctuans*	Common Parasol	LC	Common
150	Odonate	*Orthetrum chrysis*	Spine-tufted Skimmer	LC	Common
151	Odonate	*Orthetrum luzonicum*	Slender Blue Skimmer	LC	Common
152	Odonate	*Orthetrum sabina*	Variegated Green Skimmer	LC	Common
153	Odonate	*Orthetrum testaceum*	Scarlet Skimmer	LC	Common
154	Odonate	*Pantala flavescens*	Wandering Glider	LC	Common
155	Odonate	*Pantoporia sp.*	Common Lascar	-	-
156	Odonate	*Prodasineura humeralis*	Orange-striped Threadtail	-	-
157	Odonate	*Pseudothemis jorina*	Banded Skimmers	LC	Common
158		*Rhyothemis phyllis*	Yellow-barred Flutterer	LC	Common
159	Odonate	*Semanga superba deliciosa*	-	-	-
160	Odonate	*Tholymis tillarga*	White-barred Duskhawker Sp	LC	Common
161	Odonate	*Trithemis festiva*	Indigo Dropwing	LC	Common
162	Odonate	*Trithemis aurora*	Crimson Dropwing	LC	Common
163		*Tyriobapta torrida*	Treehugger	LC	Common
164	Odonate	*Ypthima baldus newboldi*	Common Five Ring	-	-
165	Reptile	*Ahaetulla prasina*	Oriental Whip Snake	LC	Common
166	Reptile	*Bronchocela cristatella*	Green Crested Lizard	-	Uncommon
167	Reptile	*Calliophis bivirgatus*	Blue Malayan Coral Snake	-	VU
168	Reptile	*Chrysopelea paradisi*	Paradise Tree Snake	LC	Common
169	Reptile	*Draco melanopogon*	Black-bearded Flying Dragon	-	VU
170	Reptile	*Draco sumatranus*	Common Flying Dragon	-	Common
171	Reptile	*Eutropis multifasciata*	Common Sun Skink	-	CommonEN
172	Reptile	*Gonyosoma oxycephalum*	Red-tailed Racer	LC	EN
173	Reptile	*Hemidactylus frenatus*	Common House Gecko	LC	-
174	Reptile	*Lycodon capucinus*	House Wolf Snake	LC	Common
175	Reptile	*Malayopython reticulatus*	Reticulated Python	LC	Common
176	Reptile	*Tropidolaemus wagleri*	Wagler's Pit Viper	LC	EN
177	Reptile	*Varanus nebulosus*	Clouded Monitor	-	-
178	Reptile	*Varanus salvator*	Malayan Water Monitor	LC	Common
179	Amphibians	*Duttaphrynus melanostictus*	Asian Toad	LC	Common
180	Amphibians	*Hylarana laterimaculata*	Masked Rough-sided Frog	LC	Uncommon
181	Amphibians	*Hylarana raniceps*	Copper-cheeked Frog	LC	-
182	Amphibians	*Limnonectes blythii*	Malayan Giant Frog	NT	Common
183	Amphibians	*Microhyla heymonsi*	Dark-sided Chorus Frog	LC	-
184	Amphibians	*Nyctixalus pictus*	Spotted Tree Frog	NT	VU
185	Amphibians	*Polypedates leucomystax*	Common Tree Frog	LC	Common

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
186	Fish	*Barbodes banksi*	Barbodes sp.	-	-
187	Fish	*Barbodes rhombeus*	Indochinese Spotted Barb	LC	-
188	Fish	*Clarias batrachus*	Common Walking Catfish	LC	Common
189	Fish	*Dermogenys collettei*	Malayan Pygmy Halfbeak	-	Common
190	Fish	*Poecilia reticulata*	Common Guppy	-	-
191	Fish	*Rasbora elegans*	Two-spot Rasbora	LC	Common
Worksite A1-W2					
1	Bird	*Caprimulgus macrurus*	Large-tailed Nightjar	LC	Common
2	Bird	*Anthracoceros albirostris*	Oriental Pied Hornbill	LC	Rare
3	Bird	*Pycnonotus zeylanicus*	Straw-headed Bulbul	LC	EN
4	Bird	*Spizaetus cirrhatus*	Changeable Hawk-eagle	LC	EN
5	Bird	*Psilopogon lineatus*	Lineated Barbet	LC	-
6	Bird	*Buceros rhinoceros*	Rhinoceros Hornbill	LC	-
7	Mammal	*Pipistrellus stenopterus*	Narrow-winged pipistrelle	LC	-
8	Mammal	*Manis javanica*	Sunda Pangolin	LC	CR
9	Mammal	*Galeopterus variegatus*	Malayan Colugo	VU	-
10	Odonate	*Rhyothemis triangularis*	Sapphire Flutterer	LC	Uncommon
11	Odonate	*Pseudothemis jorina*	Banded Skimmer	LC	Common
Worksite A2-W2					
1	Butterfly	*Prosotas aluta*	Banded Line Blue Butterfly	-	-
2	Damselfly	*Prodasineura collaris*	Collared Threadtail	LC	-
3	Fish	*Trichopsis vittata*	Croaking Gouramy	LC	-
4	Fish	*Poecilia reticulata*	Guppy	-	-
5	Fish	*Poecilia sp.*	Molley	LC	-
6	Fish	*Gambusia holbrookii*	Mosquito Fish	-	
7	Fish	*Danio rerio*	Zebra Danio	-	-
8	Fish	*Systomus rhombeus*	Indochinese Spotted Barb	LC	-
9	Fish	*Monopterus javaensis*	Asian Swamp-eel	-	-
10	Fish	*Oxyeleotris marmorata*	Marbled Gudgeon	LC	Common
11	Fish	*Betta pugnax*	Malayan Forest Betta	LC	-
12	Fish	*Macropodus opercularis*	Paradise Fish	-	-
13	Fish	*Danio albolineatus*	Pearl Danio	LC	-
14	Fish	*Xiphophorus Maculatus*	Platy	-	-
15	Fish	*Clarias batrachus*	Common Walking Catfish	LC	Common
16	Fish	*Xiphophorus variatus*	Variatus platy	-	-
17	Mollusc	*Melanoides tuberculata (F. Thiaridae)*	Malayan Live-bearing Snail	LC	-
18	Odonate	*Orthetrum sp.*	Dragonfly Nymph	-	-
Worksite A2-W3					
1	Mammal	*Nycticebus coucang*	Slow Loris	VU	CR
Windsor Streams					
1	Amphibian	*Hylarana baramica*	Baram River Frog	LC	VU
2	Amphibian	*Kalophtynus limbooliati*	Lim's Black Spotted Tree Frog	-	VU
3	Amphibian	*Microhyla mantheyi*	Manthey's Chorus Frog	LC	CR

No.	Taxon	Scientific Name	Common Name	IUCN Status (Note 1)	Local Status (Note 2)
4	Amphibian	*Pulchrana laterimaculata*	Masked Rough-sided frog	LC	Uncommon
5	Bird	*Alcedo meninting*	Blue-eared Kingfisher	LC	-
6	Bird	*Ketupa ketupu*	Buffy Fish Owl	LC	CR
7	Fish	*Barbodes banksi*	Saddle Barb	-	Common with a restricted distribution
8	Fish	*Channa lucius*	Forest Snakehead	LC	-
9	Fish	*Channa striata*	Common Snakehead	LC	-
10	Fish	*Dermogenys collettei*	Pygmy Halfback	-	Common
11	Fish	*Rasbora elegans*	Two-spot Rasbora	LC	Common
12	Fish	*Trigonostigma heteromorpha*	Harlequin Rasbora	LC	EN
13	Odonate	*Archibasis viola*	Violet Sprite	LC	LC
14	Odonate	*Gynacantha dohrni*	Spear-tailed Duskhawker	-	LC
15	Odonate	*Pseudothemis jorina*	Banded Skimmer	LC	LC
16	Reptile	*Amyda cartilaginea*	Asiatic Softshell Turtle	VU	EN
17	Reptile	*Boiga dendrophila*	Gold-ringed Cat Snake	-	VU
18	Reptile	*Dogania subplana*	Malayan Forest Softshell Turtle	LC	CR
19	Reptile	*Ptyas fusca*	White-bellied Rat Snake	LC	EN

Note 1: IUCN Red List of Threatened Species Categories and Criteria: Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), Extinct (EX). Retrieved from https://www.iucnredlist.org/

Note 2: The Singapore Red Data Book of Threatened Plants and Animals of Singapore, and NParks Flora and Fauna Web. Retrieved from: https://florafaunaweb.nparks.gov.sg/

4 GEOLOGY

4.1 INTRODUCTION

This Addendum chapter is intended to provide an overview of the regional geological setting of Singapore and further details the geological conditions within the Study Area. Site Investigation boreholes and surveys conducted as part of the Site Investigation Engineering Services have provided additional resolution of the regional and site specific geological trends. This has allowed for a more detailed analysis of localised geology as it pertains to Alignment Options 1 and 2 under consideration. The entire set of borehole and diagnostic data was reviewed by the LTA to form the basis for the additional details and analysis of the localised geology within the Study Area.

This chapter is structured as follows:

- *Section 4.2* defines the Study Area;
- *Section 4.3* presents the sources of information reviewed to develop the geological baseline;
- *Section 4.4* details the regional geology of Singapore;
- *Section 4.5* presents the local geologic overview of the Study Area;
- *Section 4.6* defines the geological profiles identified in the boreholes provided by LTA and Soil Investigation Works Geotechnical Contractors;
- *Section 4.7* presents LTA's findings from site investigation works undertaken for Alignment Option 1;
- *Section 4.8* presents LTA's findings from site investigation works undertaken for Alignment Option 2.

4.2 STUDY AREA

The Study Area for the geological baseline comprises the area of the CCNR and the SICC golf courses located to the east and west through which the Alignment Options 1 and 2 are located. The study area also includes areas adjacent to the east, south and south-west boundaries of the CCNR, extending approximately 400 m outward from the east and south into densely populated areas, and up to 1,200 m outward from the southwest boundary along the PIE (see *Figure 4.2*). The objective of the geological baseline is to provide an understanding of the general geologic profiles and to examine potential concerns with tunneling works associated with the Project.

4.3 SOURCES OF INFORMATION

The CCNR is a designated nature reserve and accordingly there have been limited historical intrusive investigations of the geology. Additionally, the potential for impacts from drilling operations to the nature reserve has limited the number of borings within the reserve boundary. However, along with other borings completed around the reserve boundary (in association with the proposed Alignment Options as well as geophysical surveys), limited boreholes within the CCNR and horizontal directional coring under the CCNR, a considerable amount of data is now available to obtain a clearer understanding of the rock type and weathering profiles at depth, as well as the distribution of the more common Bukit Timah Granite, the overlying Kallang Formation and fill material at the surface.

Geological conditions were primarily determined through Site Investigation Engineering Services conducted by several geotechnical companies:

- Site investigation reports were provided, which include boreholes logs for all works completed as part of the Site Investigation Engineering Services.

- Due to the environmental sensitivity of the CCNR, geophysical surveys were conducted at locations where the alignment departed from trails along which borehole machines could be deployed. The geophysical surveys included gravity surveys, seismic surveys and electrical resistivity surveys, all of which were conducted along the Alignment Option 1 corridor within the CCNR. In some cases geophysical surveys were limited due to the potential impact to ecological habitats associated with worker access to off-trail locations within the CCNR. Where they were completed, the geophysical surveys provided information on the expected rock head, zones of weathering and the presence of increased porosity or unexpected voids along the study transects.

- Horizontal Directional Coring (HDC) was also conducted to test for the presence of rock at depths equivalent to the planned tunnel alignment depths. Information gathered from the HDC works supplemented the data collected from SI and geophysical surveys along Alignment Option 1.

- Additional resources included historical soil investigation works undertaken adjacent to or in the Study Area and a desk top review of available literature sources, including geological reports and presentations, satellite and aerial photographic imagery, historical maps, topographic surveys, field observations and soil investigation borehole data logs undertaken proximal to the CCNR.

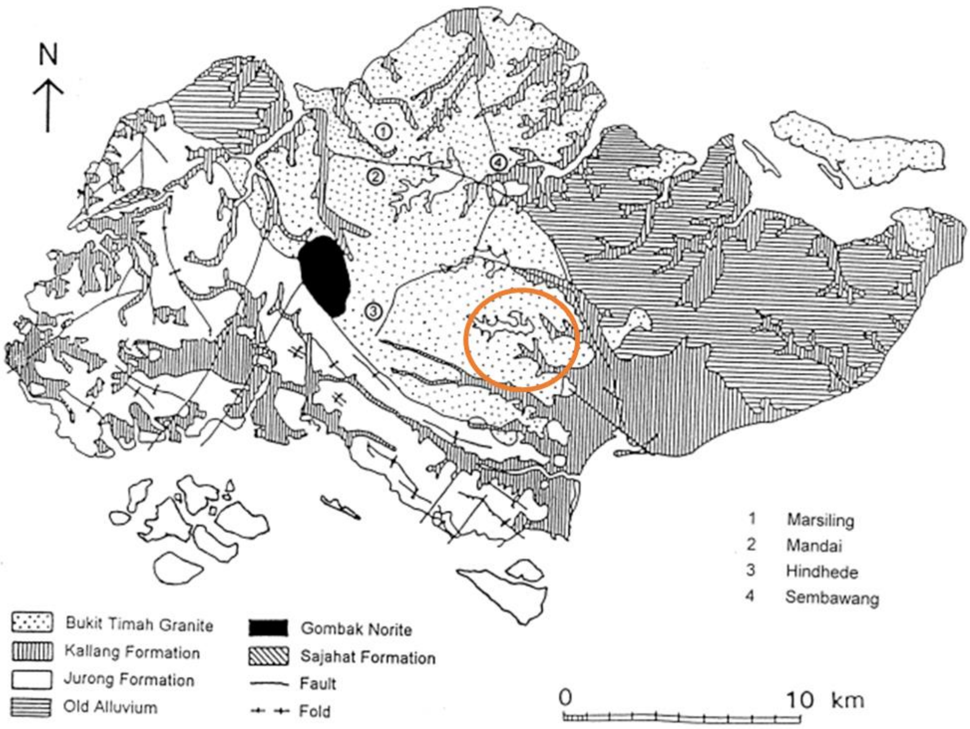
To determine the expected lithology that will be encountered during tunneling, geological profiles from borehole log reports were primarily used to provide an understanding of the geological profile for both Alignment Options with depth. However, not all boreholes are located directly along the alignments. Thus, the geological profile from the closest borehole was applied when determining the expected geological profile along the alignment. Reference was then made to HDC reports and other geophysical surveys on the lithology at specific depths to further confirm the understanding of the geological profile derived from borehole reports. The results from these surveys were analysed as a whole to obtain a more robust understanding of the geological profile along Alignment Options 1 and 2. The interpretation of the geological profile along the two alignments carried out from site investigation works are further discussed in *Section 4.7* and *Section 4.8* respectively.

4.4 Regional Geology and Geomorphology

The land area of Singapore comprises Singapore Island and several smaller islands, with a total land mass of approximately 700 km^2. Singapore Island is low-lying with approximately two-thirds of the island being less than 30 meters above sea level (m asl)[(19)]. It is characterised by several distinctive geomorphic areas which reflect the underlying geology. The primary geological regions of Singapore comprise of sedimentary rock formations in the west and igneous rock formations in the east. Older alluvial sediments overlie the igneous rock formations in the east, with more recent alluvial sediments dispersed along the coastal shores and around the island as illustrated on *Figure 4.1*.

The most distinctive topography is found in the central areas of the island, associated with granites and with hills and steep valleys[15] between 60 and 100 m in relief. The western area is also characterised by distinctive topography, with linear ridges defined by the strike of resistant sandstone and conglomerates associated with the sedimentary geology in the west[15]. The topography of the distinctive Old Alluvium on the easternmost areas of the island is characteristically flat with elevations less than 40 m asl. Low lying coastal plains are reportedly coincident with the younger geomorphic sedimentary units of the Tekong and Kallang Formations that formed in response to sea level change[15]. Additionally, these formations are dispersed throughout the higher elevations of Singapore Island as fluvial deposits unrelated to marine and near shore depositional environments.

Figure 4.1: Primary Geological Regions of Singapore (Zhao, 1998) [20]



Note 1: Orange Circle indicates region of Project interest.

4.4.1 *Sedimentary Rocks, West*

The sedimentary rocks in the western region consist primarily of purple to black mudstone, black shale, yellow sandstone, limestone and minor conglomerates[21]. Overlying the sedimentary rocks are weathered soils which are generally fine grained (silts and clays) in the south-eastern portion of this region with coarser grained sands in the north-west reflecting the parent rocks from which they were derived[17]. There are no known deposits of these sedimentary rocks within the Study Area and therefore the subdivision of these sediments is not discussed further.

4.4.2 *Igneous Rocks, Central*

The central portion of Singapore Island includes the highest summit, the Bukit Timah Hill, with an elevation of 163 m asl. The igneous host rock is predominantly the Bukit Timah Granite which forms the Bukit Timah Hill and other nearby hills in an area of rugged terrain. Soils in the area are primarily derived from this igneous host rock. The Bukit Timah Granite underlies approximately one-third of Singapore Island and is considered the base bedrock of the island[(22)].

The Study Area is contained entirely within this central area and its known geology is discussed further in *Section 4.5*.

4.4.3 *Older Alluvial Sediments, East*

The eastern part of the island is a low plateau characterised by erosion resulting in hills and valleys. The sediments consist of clayey sand with pebbles, generally becoming coarser grained with depth[(17)]. The sediments typically are not cemented but can be quite dense; they form part of a group of sediments aptly named 'Older Alluvial Sediments'. There are no known deposits of Older Alluvial Sediments within the Study Area and therefore the subdivision of these sediments is not discussed further.

4.4.4 *Younger Alluvial Sediments, Entire Island*

Sediments of alluvial and marine origin are dispersed primarily throughout low lying areas, typically along the coast and river valleys. These younger sediments were deposited during periods of sea level change and major fluvial erosional events. The primary member of this group of sediments is the Kallang Formation. The Tekong Formation is a less common secondary member of sediments comprising terrestrial and alluvial deposits[(23)]. Alluvial sediments belonging to the Kallang Formation are present in the Study Area and are discussed further in *Section 4.5*.

The approximate extents of Singapore's geological formations as summarised above is presented spatially in *Figure 4.1.*

4.5 GEOLOGIC FORMATIONS PRESENT IN THE STUDY AREA

4.5.1 *Bukit Timah Granite*

The Bukit Timah Granite is the principal parent rock of Singapore, predominantly underlying the center and north of Singapore and underlying the entirety of the Study Area[(15)]. The Bukit Timah Granite has been dated to the late Permian to middle Triassic period, approximately 200 to 250 million years ago. The principal minerals include quartz (30%), feldspar (60-65%), biotite and hornblende, with mineralogical variations from adamelite to granodiorite. Typically, the Bukit Timah Granite is rich in ferromagnesian minerals resulting in a more acidic composition. Individual minerals are medium to coarse grained, usually light grey and sometimes pinkish[(18)].

The degree and depths of weathering of the Bukit Timah granite is influenced by the climatic conditions with the tropical monsoonal rainfall conditions that contribute to surface erosion and weathering. There are six main weathering profiles encountered in the study area, from G(VI), indicative of residual soil, to G(I), indicative of Fresh rock[17]. The residual soil, G(VI), and the completely weathered rock, G(V), of the Bukit Timah Granite are typically characterised as reddish to yellowish brown sandy silt and silty sand. The highly weathered, G(IV), and moderately weathered, G(III), rock of the Bukit Timah Granite are typically characterised as moderately weak to strong granite, with closely spaced fractures. Slightly weathered, G(II), and fresh rock, G(I), of the Bukit Timah Granite are commonly described as moderately strong to very strong massive granites, with widely spaced irregular fractures. The fresh rock, G(I), has an average Uniaxial Compressive Strength of 180 megapascals (MPa), the highest being over 300 MPa; while the weathered rock grades are characterised by much lower strengths.

4.5.2 Kallang Formation

The Kallang Formation originates from sediments deposited over the last 15,000 years, from the Holocene and late Pleistocene to the present. The Kallang Formation can be subdivided into five groups based on the type of depositional environment[18]. The Kallang Formation sub-groups in the vicinity of the Study Area include Estuarine Clay, Fluvial Sand and Fluvial Clay sedimentary units. Estuarine Clay sedimentary units are typically characterised as dark brown to black, cohesive, very soft to soft peat, peaty clay or peaty sand with a high organic content. Fluvial Sand units are typically characterised as very loose brownish grey to grey, slightly gravelly and very silty fine to coarse sand. Fluvial Clay sedimentary units are typically characterised as hard, light yellowish grey to mottled brownish red, slightly gravelly sandy clay[16].

4.6 Definitions of Geologic Profiles identified in Boreholes

All Soil Investigation Contractors followed the definitions of different weathering extents of the Bukit Timah Granite as given by LTA in the *LTA Civil Design Criteria for Road and Rail (Feb 2010)*. For the purposes of this Project, ERM has adopted LTA's definition of weathering extent of the Bukit Timah Granite in the assessment of tunneling impacts on geology.

Table 4.1 Definitions of Weathering Extent by LTA

Weathering Grade	Weathering Extent	Definition by LTA (Note 1)
G(VI)	Residual Soil	Original rock structure completely degraded to a soil, with none of the original fabric remaining. Can be crumbled by hand.
G(V)	Completely Weathered Rock	Original rock texture preserved, can be crumbled by hand. Slakes in water. Completely discoloured.
G(IV)	Highly Weathered Rock	Core can be broken by hand. Does not slake in water. Completely discoloured.
G(III)	Moderately Weathered Rock	Cannot be broken by hand. Easily broken by hammer. Makes a dull or slight ringing sound when struck with hammer. Stained throughout.
G(II)	Slightly Weathered Rock	Not broken easily by hammer – rings when struck. Fresh rock colours generally retained but stained near joint surfaces.

Weathering Grade	Weathering Extent	Definition by LTA (Note 1)
G(I)	Fresh Rock	Intact strength, unaffected by weathering. Not broken easily by hammer – rings when struck. No visible discolouration.

Note 1: **LTA Civil Design Criteria for Road and Rail Transit Systems**, February 2010

4.7 FINDINGS FROM SITE INVESTIGATION WORKS FOR ALIGNMENT OPTION 1

The following sections present the LTA's findings from the site investigation works undertaken for Alignment Option 1, during Phase I of the Project.

4.7.1 Geological Profile Derived from SI Borehole Reports

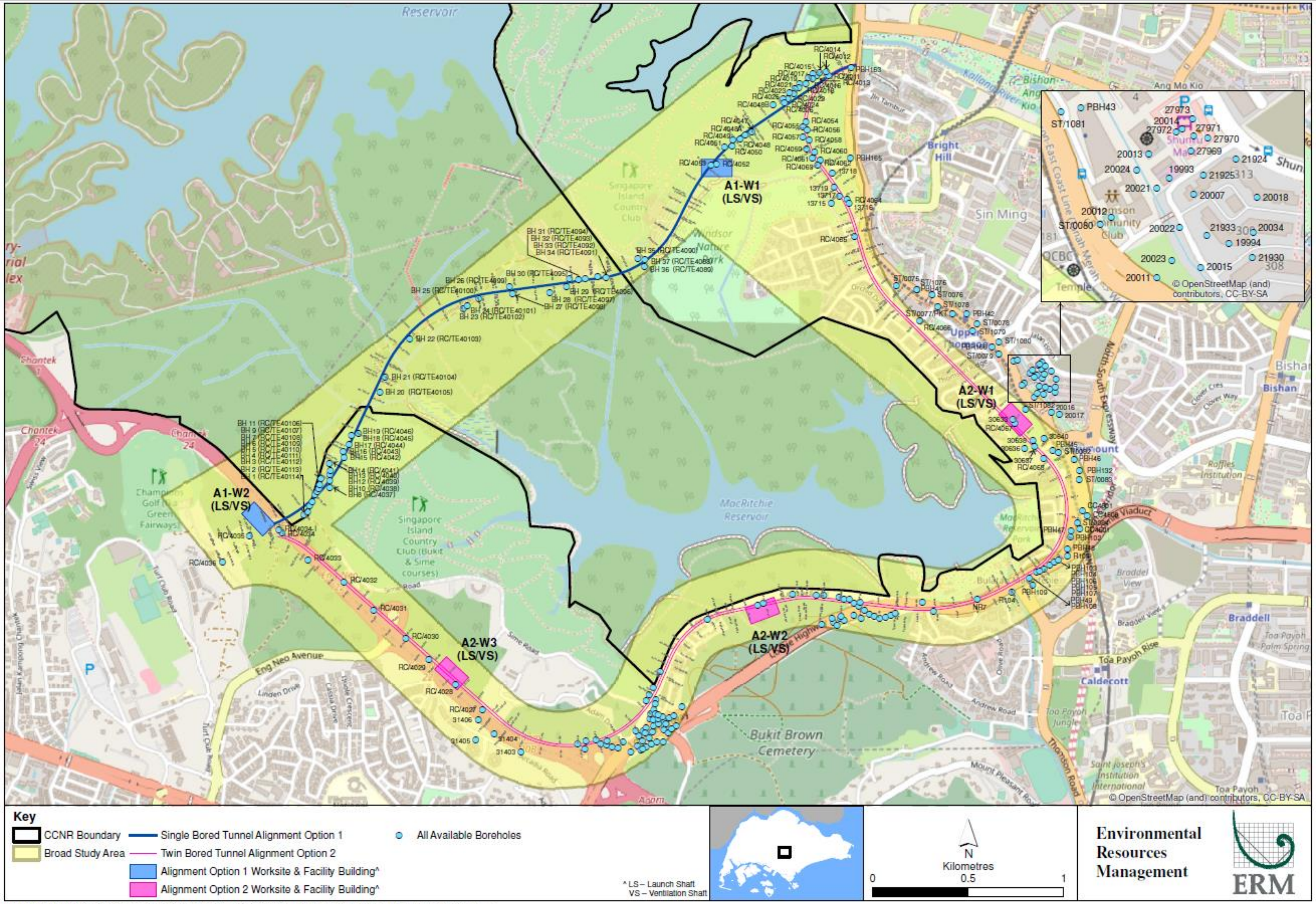
Based on soil investigation works completed as part of Site Investigation Engineering Services along Alignment Option 1, a general overview of the geological profile across the site can be interpreted from the site investigation information[24] available for review as shown spatially in *Figure 4.2*. These boreholes were undertaken under Phase 1 of Site Investigation Works.

Figure 4.3 shows the soil-rock profile under CCNR derived from a total of 37 boreholes, of which 16 boreholes were completed within the CCNR and 21 boreholes were adjacent to the CCNR (see *Figure 4.2*). Rock grades are typically defined as G(I), G(II) and G(III) [25, 26]. Due to the limited extent of G(IV) granite found, the rock head level in *Figure 4.3* was defined as the encounter of G(IV) and better weathering grades of Bukit Timah Granite Formation. Typically, the profile of rock head was derived by linear interpolation between the boreholes near to the alignment. Corrections using linear interpolation technique was used to estimate the rock head levels depending on the horizontal offset of the borehole locations from the tunnel alignment (such as at BH9, BH11, BH14, BH23, BH24 and BH28). For example BH9 is at 24 m offset, BH11 at 38 m offset, BH14 at 48 m offset, BH23 at 45 m offset, BH24 at 38 m offset, BH28 at 40 m offset. This explains why some of the boreholes (such as BH9, BH23, BH24, BH28) are showing lower rock-head than the interpreted rock profile, whilst some are showing higher (such as BH11, BH14) in *Figure 4.3*. The surface ground level was obtained from the land survey data in SLA's Digital Terrain Model.

Figure 4.4 shows how the surface ground level and the rock head level varies across the full tunnel alignment for Alignment Option 1. Whilst the surface ground level ranged from 110mRL to 150mRL, the rock head depth ranged from 20 m to 70 m bgl within the CCNR.

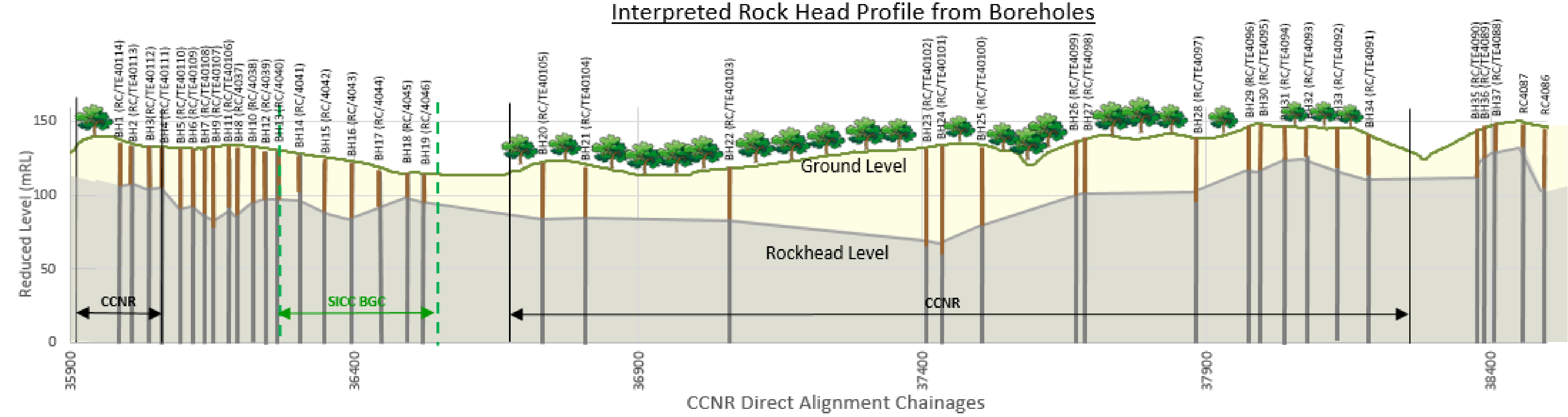
It is also observed that the G(IV) layer is quite thin and even absent in most of the boreholes within the CCNR, and the bedrock is predominantly consisting of G(III) and better weathering grade. The only exception is at the borehole BH 9, which is located just outside the CCNR where about 5 m thick of highly fractured weathering grade of G(IV) granite rock was found above the G(III) rock. Even so, the good quality G(III) granite was found at deeper depth and this was further confirmed by HDC in the vicinity of this location.

Figure 4.2 Map of Boreholes along Alignment Options and Worksites



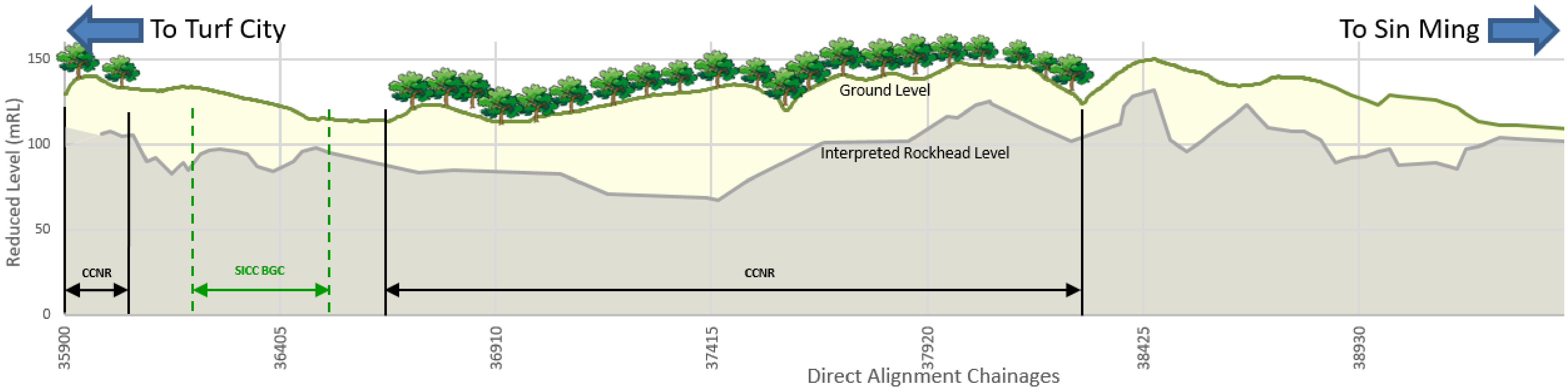
File: T:\GIS\CONTRACT\0256660\Mxd\2018_A1_A2_EIA_Report\0256660_Vol_II_SI_Boreholes_Current_n_Future_a_v2_no_future.mxd
Date: 21/8/2019

Figure 4.3 Interpreted Rock Head Profile Obtained from Boreholes along Alignment Option 1, CCNR Section



Source: LTA

Figure 4.4 Interpreted Rock Head Profile Obtained from Boreholes along Alignment Option 1, Turf City to Bright Hill



Source: LTA

4.7.2 *Findings from Geophysical Surveys*

Geophysical surveys were undertaken to supplement the site investigation works, due to the limited number of SI boreholes that could be drilled along Alignment Option 1. These surveys comprise a 3D seismic survey, gravity survey and electrical resistivity survey. The location of these surveys are presented in *Figure 4.5*. Geophysical surveys were only undertaken at the westernmost section of the alignment near the CCNR, and the findings were extrapolated across the rest of Alignment Option 1. Geophysical surveys were not undertaken at other locations within the CCNR so as to avoid impacts to ecological receptors due to the presence of surveyors.

4.7.2.1 *Seismic Refraction / Reflection Survey*

Seismic Refraction/Reflection Surveys were carried out to identify the horizontal rock layering of geology under CCNR(27). In this geophysical survey method, compression waves generated from a seismic source are refracted or reflected from the ground and picked up by geophones set up at an array of 2.5 m intervals. The compression waves will travel at higher velocity in denser rock material compared to soil layers. Seismic survey methods produce good and reliable results where there is a good contrast in properties across layers such as soil and rock, covered by a multi-layered sequence of strata and particularly in the depth range 30 m to 100 m. The rock head (G(IV) and better) layer was clearly observed in the processed seismic data and calibrated to the borehole logs.

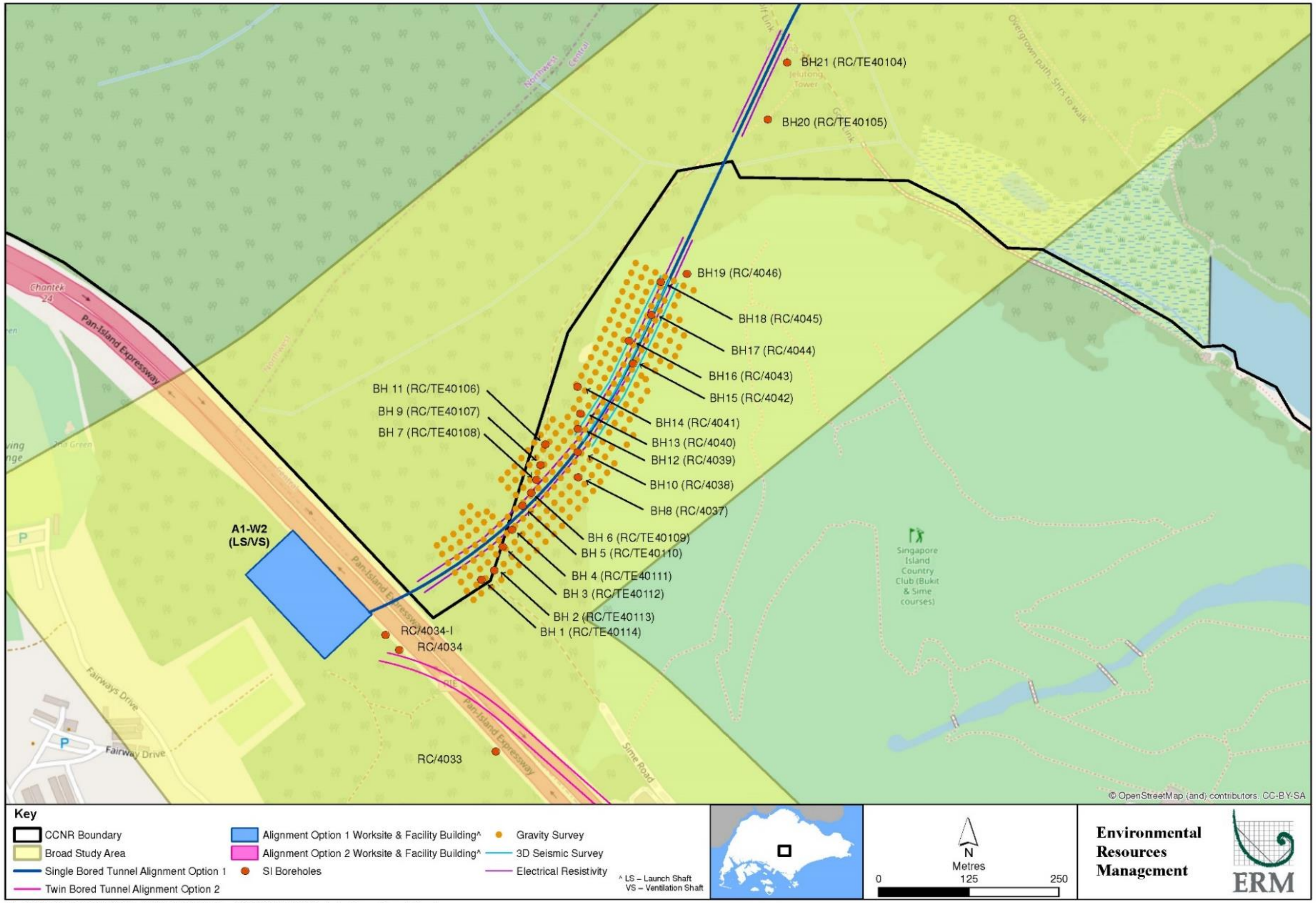
Generally, the rock profile is seen to be undulating, which is consistent with the variability expected in granite rock. The depth of rock head was observed to vary between 54 mRL and 116 mRL, and 14 m to 68 m below ground level across the 3D Horizon. A comparison of the 3D rock head contour model with the boreholes was done and the rock head elevation correlates very closely to the borehole logs where a variation of 0.14 m to 2.1 m is observed. The seismic survey result was later overlaid with the HDC trajectory and the point where HDC transit from soil drilling to rock coring also coincides with the rock head derived from seismic survey with about 1 m deviation. Thereafter, the HDC route was noted to traverse below the seismic derived rock head profile obtained from the seismic survey along Alignment Option 1. This further validates the findings of the seismic survey.

4.7.2.2 *Gravity Survey*

The gravity survey helps to characterise rock profiles around the tunnel alignment. This technique measures minute variations in the gravitational pull of the Earth by using a gravity meter, and interprets the presence of massive objects and of voids in the ground. If there exists some material below the ground having a density that is lower or higher than surrounding ground (such as a cavity or a subsurface cave), the gravity shows a relatively low anomaly and vice versa. Basically, the denser rock material will have more gravitational attraction. In this method, a gravity meter is used to measure the gravity field, which is in gals (1/100 of 1 m/s^2).

Similar to the results from seismic surveys, the gravity survey confirmed that the rock head profile of the Bukit Timah Granite is substantially irregular (36). The results of gravity survey were compared against the boreholes done in the same area. Consistently, the depth of rock head was observed to vary between 54 mRL to 116 mRL, which has the same trend as the seismic survey.

Figure 4.5 Geophysical Survey Locations along Alignment Option 1



File: T:\GIS\CONTRACT\0256660\Mxd\2018_A1_A2_EIA_Report\0256660_Vol_I_SI_Boreholes_Survey_Record_v1.mxd
Date: 27/8/2019

4.7.2.3 Electrical Resistivity Survey

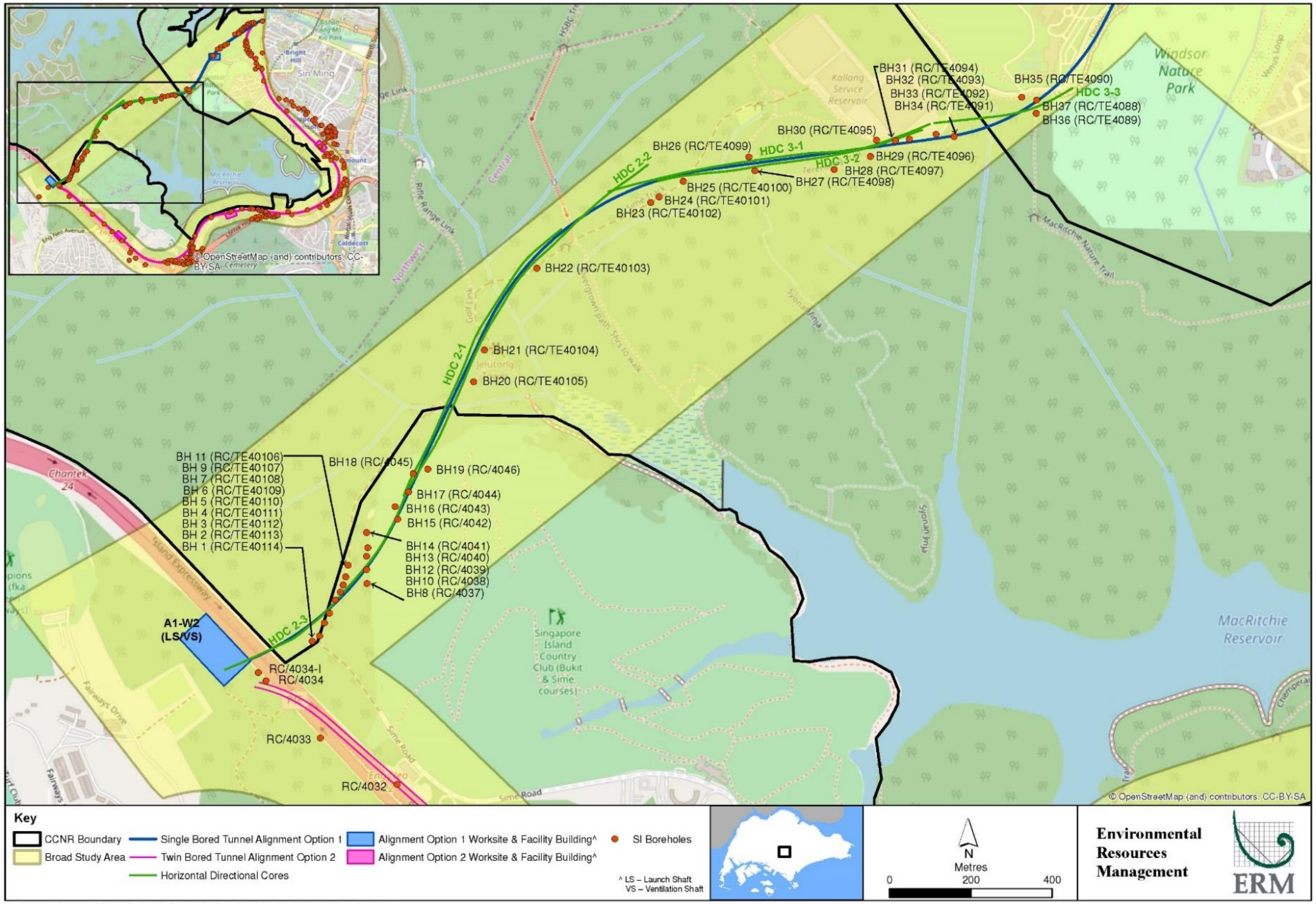
The electrical resistivity survey was undertaken to identify the vertical rock features / fractures underlying the CCNR as denser rock material tend to have a higher electrical resistance (29, 30). This method works by applying electrical current to the ground to measure ground resistivity. The electrical current is passed into the ground through two earth connections (electrodes) and the voltage is measured across a second pair of electrodes. The ratio of voltage to current is the resistance that when multiplied by a factor, which takes into account the spacing between the electrodes, gives a parameter known as the apparent resistivity. When the measurement is made over a homogeneous surface, the apparent resistivity is equal to the true resistivity of the ground. However, when the resistance is measured over a complicated subsurface structure, the apparent resistivity is a weighted average of the resistivities of the various rocks below the surface. A water saturated section of sand or gravel masks interpretation of a resistivity sounding when the strong negative contrast at the water table, combined with the strong positive contrast at the bedrock, may lead to ambiguity. The electrical resistivity results did not identify any vertical fractures or fault zones within the study corridor.

4.7.3 Findings from Horizontal Directional Coring (HDC)

In view of the limited SI locations along Alignment Option 1, horizontal directional coring was undertaken to further confirm the accuracy and reliability of the rock head level developed from the abovementioned SI and geophysical surveys. Six HDC boreholes were drilled along the tunnel alignment under the CCNR (31). The launching sites for the HDC works were located outside of CCNR as shown in *Figure 4.6*. HDC 2-1, HDC 2-2 and HDC 2-3 were launched from the Bukit Golf Course (BGC) of Singapore Island Country Club (SICC). HDC 3-1, HDC 3-2 and HDC 3-3 were launched from the PUB Bukit Kalang Service Reservoir (BKSR), to cover the entire length below the CCNR.

The target depth for the boreholes was selected based on the data from borehole BH 24 that was made available from the completed vertical borehole works. The rock level obtained from this borehole was used as a guide to plan the lower trajectories to ensure that HDC was completed within the rock stratum.

Figure 4.6 HDC Locations along Alignment Option 1



File: T:\GIS\CONTRACT\0256660\Mxd\2018_A1_A2_EIA_Report\0256660_Vol_II_HDC_n_Boreholes_v3.mxd
Date: 4/7/2018

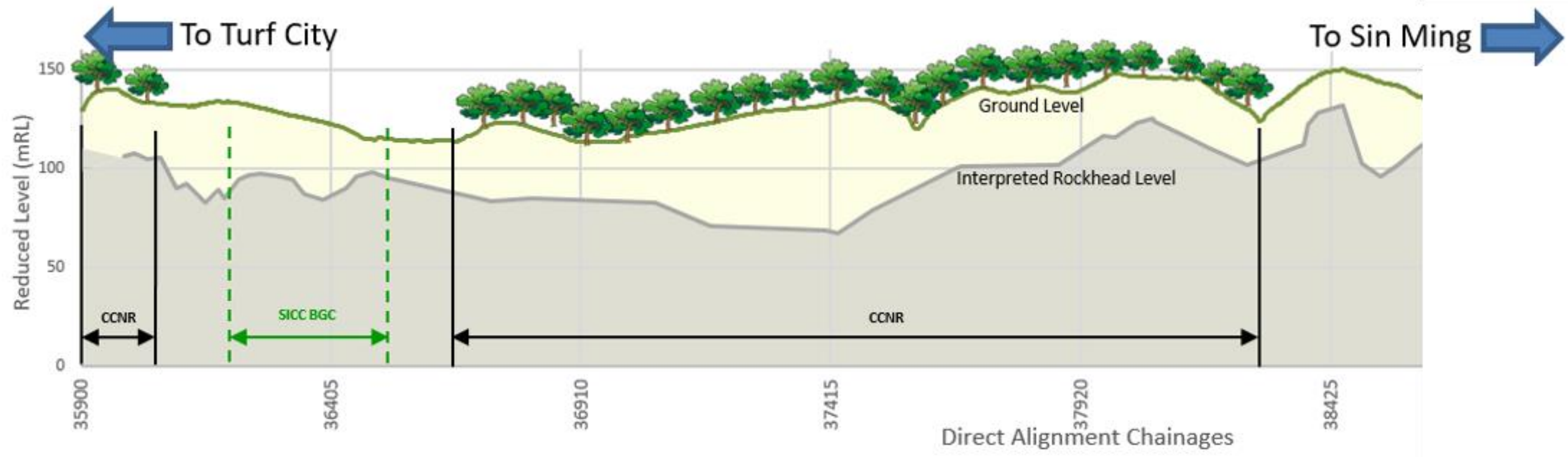
4.7.4 *Interpretation of Soil-Rock Interface Profile for Alignment Option 1*

The derivation of soil-rock interface profile has considered all the investigation methods used within the CCNR. The rock head elevation derived from the boreholes formed the base profile of rock head, which is conventionally the most common method for determining the geological profile. The rock levels estimated from geophysical methods were then compared with the available borehole data and found to be within a 10%-20% variation, understood to be within the normally acceptable range for such studies. The rock head level captured by HDC has been used to fill the gaps between boreholes, especially in the center of the CCNR where the borehole information was more limited.

Figure 4.7 shows the interpreted soil-rock interface profile for the CCNR section of Alignment Option 1, HDC data further confirmed the accuracy and reliability of the rock head level developed along the tunnel alignment. *Figure 4.8* shows the interpreted soil-rock interface profile along the full tunnel alignment from Turf City to Bright Hill. *Figure 4.9* shows the vertical tunnel alignment for Alignment Option 1 plotted against the interpreted soil-rock interface profile.

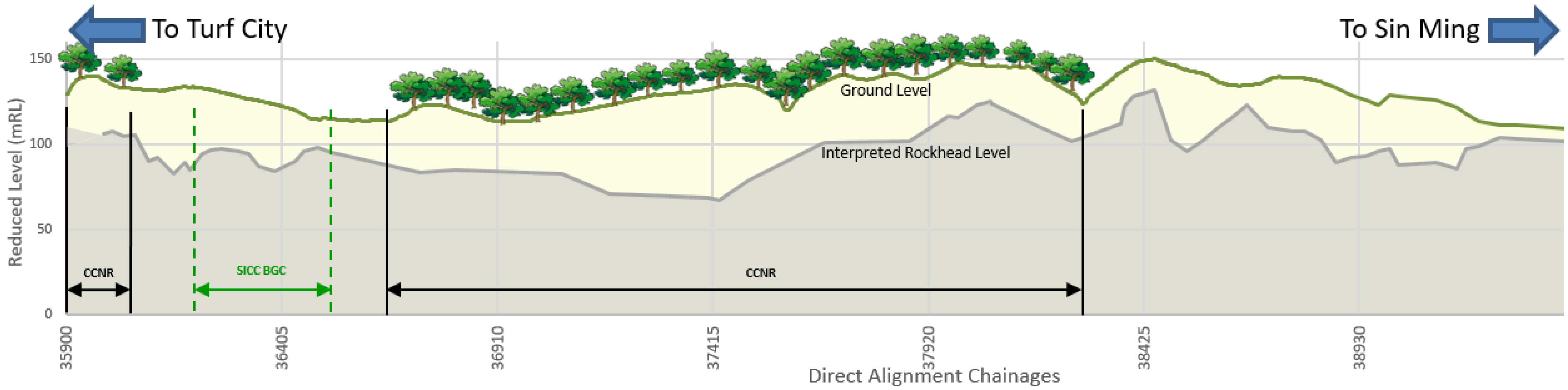
A 3D geological model has been created to simulate the actual geology in CCNR in a three dimensional form as shown in *Figure 4.10*. This uses the Leapfrog software, which applies a geo-statistical method to identify spatial relationships among data points based on statistics before creating the interpretation for the 3D geological profile. As explained before, as the boreholes are not all exactly on the tunnel alignment, the method compensates for borehole offset effects and results in rock head profile being interpreted to the location of tunnel alignment, rather than merely following the rock-head level at boreholes. The interpretation of the geology and model generated by the Leapfrog software is consistent with *Figure 4.7* and *Figure 4.8*. In general, the 3D model indicates that the tunnel crown will be set at a minimum distance of 3 m below the interpreted soil-rock interface profile.

Figure 4.7 Interpreted Soil-Rock Interface Profile for Alignment Option 1, CCNR Section



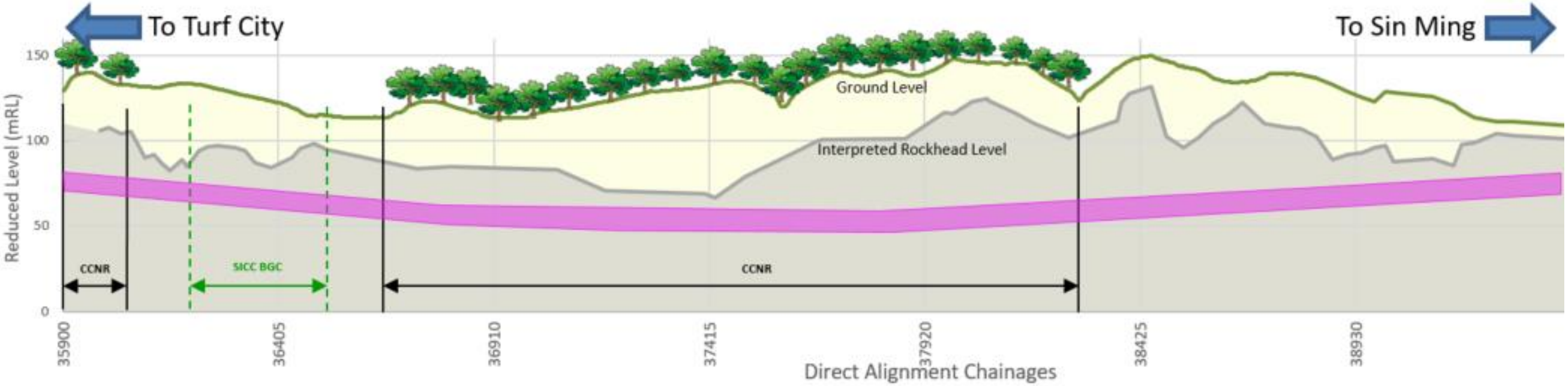
Source: LTA

Figure 4.8 Interpreted Soil-Rock Interface Profile for Alignment Option 1, Turf City to Bright Hill



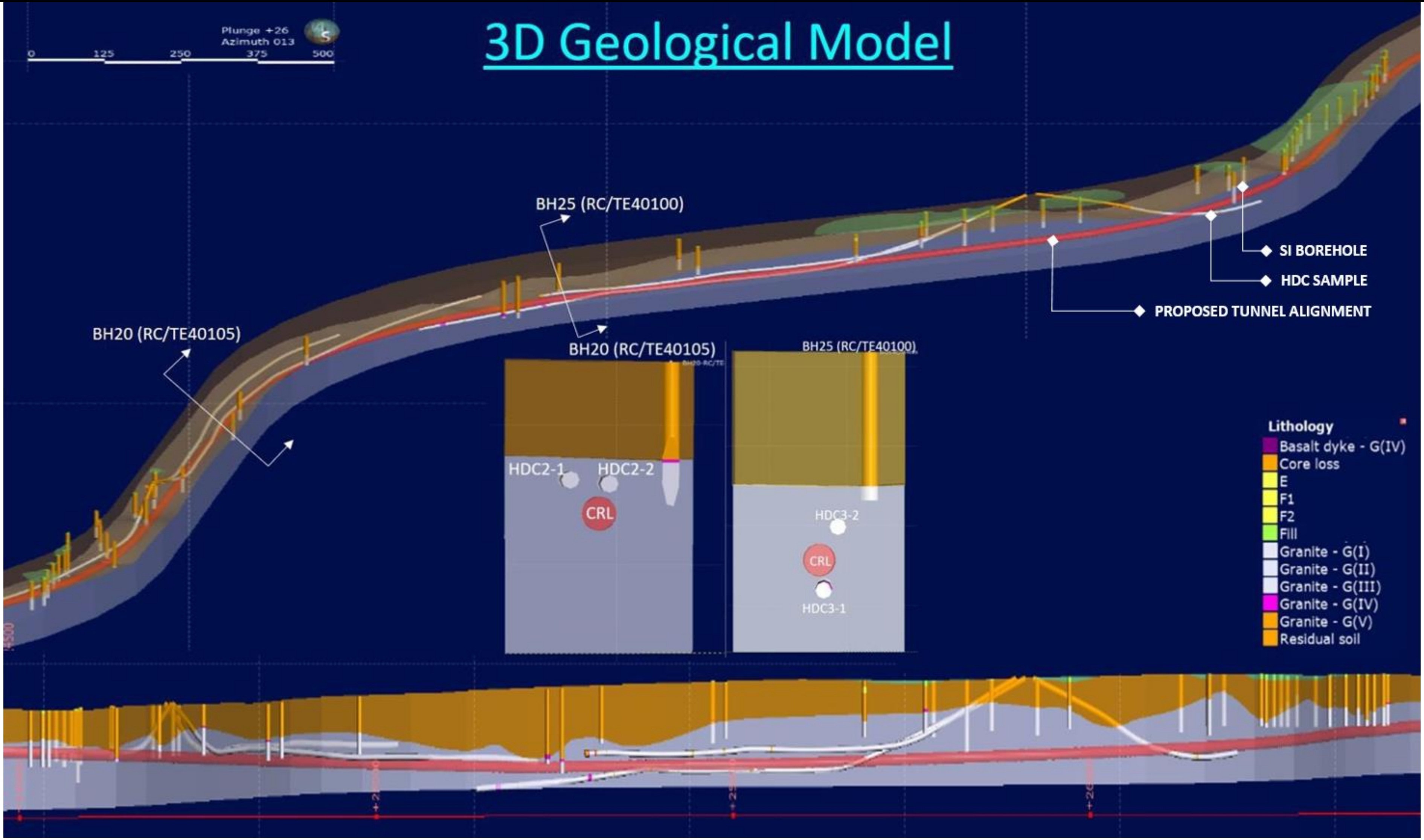
Source: LTA

Figure 4.9 Vertical Tunnel Alignment & Interpreted Soil-Rock Interface Profile along Alignment Option 1, Turf City to Bright Hill



Source: LTA

Figure 4.10 3D Geological Model for Alignment Option 1, CCNR Section



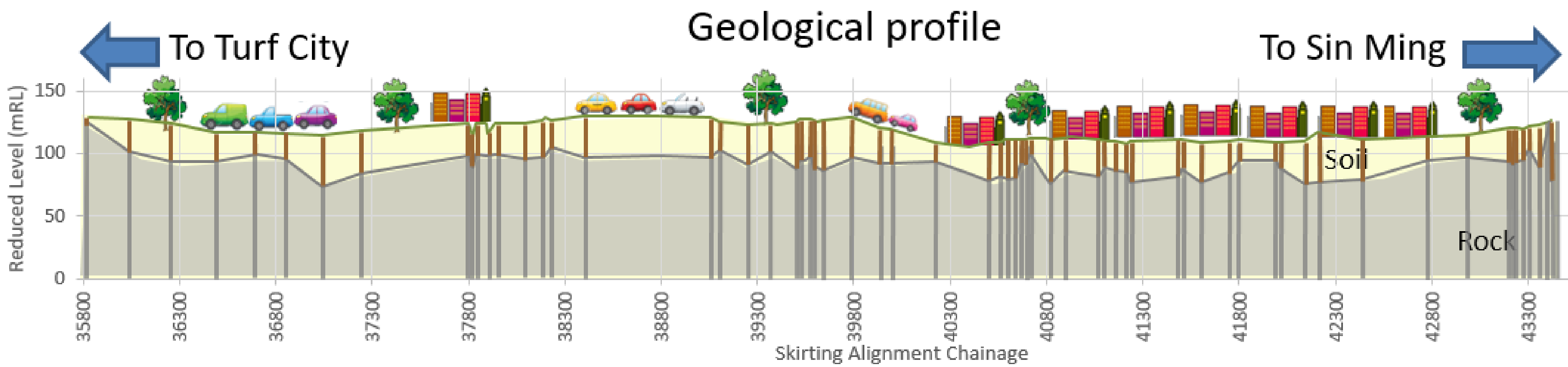
Source: LTA

4.8 FINDINGS FROM SITE INVESTIGATION WORKS FOR ALIGNMENT OPTION 2

Figure 4.11 shows the soil-rock profile derived by the LTA from a total of 77 boreholes, of which 28 boreholes were conducted during Phase 1 SI works and 49 boreholes were obtained from other LTA projects or projects from other agencies' (see Figure 4.2). Rock grades are typically defined as G(I), G(II) and G(III). [21, 22] Due to the limited extent of G(IV) granite found, the rock head level was defined as the rockhead of highly weathered (GIV) or better quality Bukit Timah Granite rock and the rock head level was interpolated linearly between the boreholes. There are a total of 157 boreholes available in the vicinity of the skirting alignment. Another approximately 330 boreholes will be conducted during the next stage of CRL study and the geological profile will be updated accordingly (see Figure 4.2 for indicative locations of future boreholes to be undertaken at 25 m intervals).

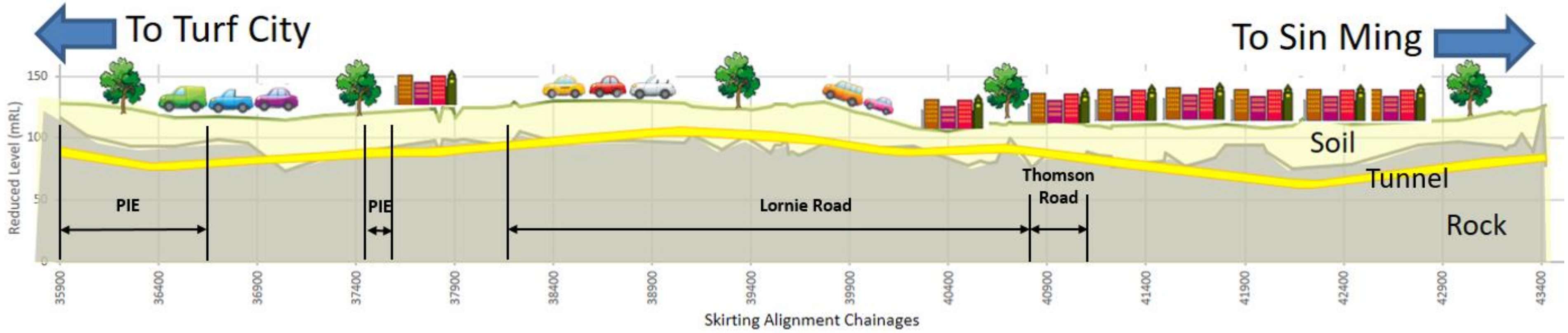
Figure 4.12 shows the vertical tunnel alignment plotted against the interpreted soil-rock interface profile for Alignment Option 2.

Figure 4.11 Interpreted Soil-Rock Interface Profile from Boreholes along Alignment Option 2, Turf City to Bright Hill



Source: LTA

Figure 4.12 Vertical Tunnel Alignment & Interpreted Soil-Rock Interface Profile from Boreholes along Alignment Option 2, Turf City to Bright Hill



Source: LTA

5 WATER ENVIRONMENT

5.1 INTRODUCTION

This Addendum chapter presents the baseline surface and groundwater environment of the Study Area.

The chapter is structured as follows:

- *Section 5.2* provides definition of the Study Area;
- *Section 5.3* lists information used to inform the baseline surface water and groundwater characteristics*;*
- *Section 5.4* provides a summary on the climate, precipitation patterns, humidity and sunlight intensity;
- *Section 5.5* describes the characteristics of MacRitchie Reservoir;
- *Section 5.6* outlines water features within the MacRitchie Reservoir Catchment area, their characteristic and water quality;
- *Section 5.7* summarises the surface water canal data within the Study Area; and
- *Section 5.8* describes the current groundwater regime within the Study Area.

5.2 STUDY AREA

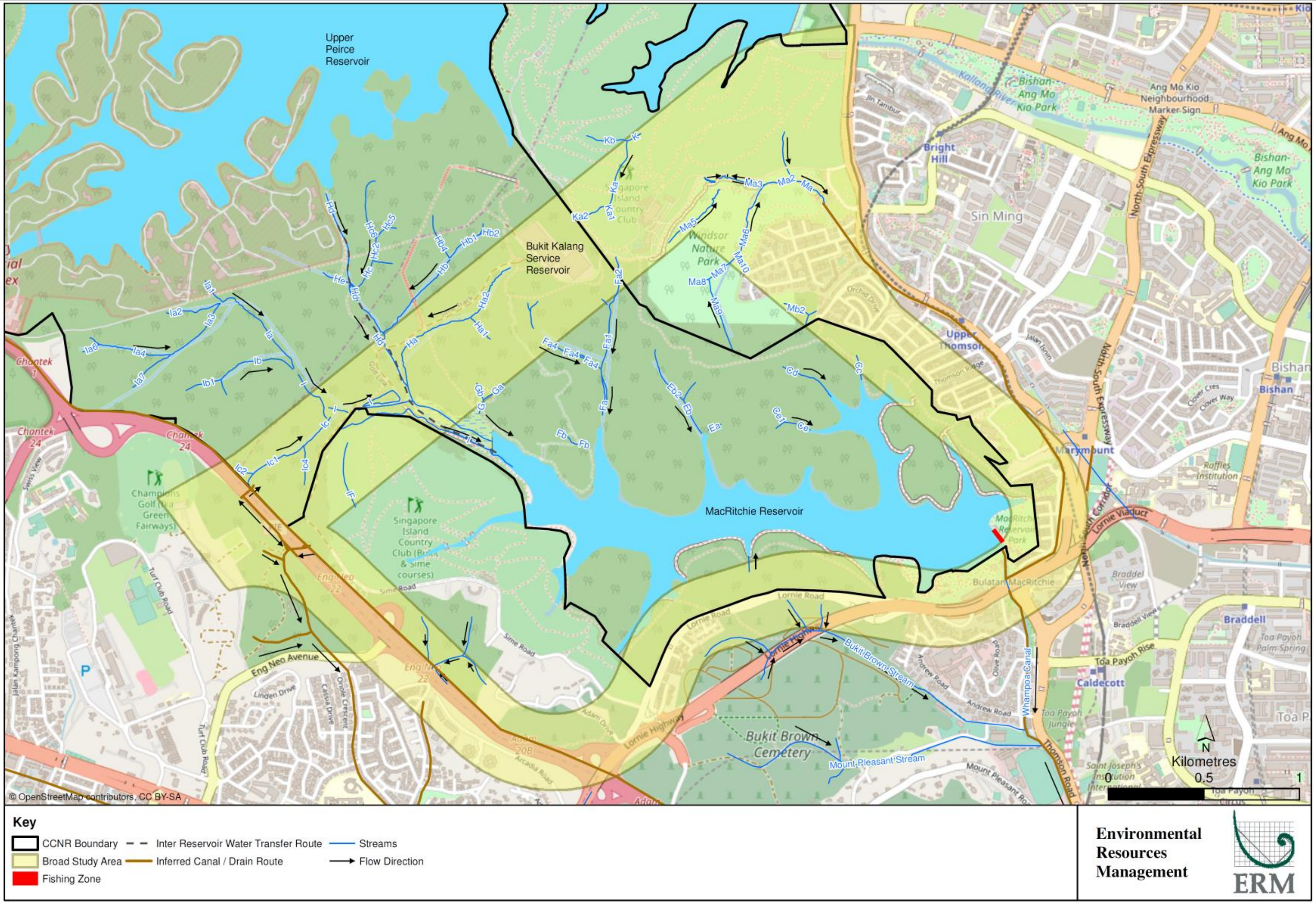
The baseline Study Area is defined as the areas encompassing the water resources (groundwater, streams, reservoirs, canals or other permanent or seasonal water bodies) within and adjacent to the Project. The Study Area also extends to uses immediately downstream or (in the case of groundwater) downgradient of the CRL pre-construction, construction and operational areas.

The Public Utilities Board (PUB) has primary responsibility for managing Singapore's water resources. With limited land to collect water and a high degree of urbanisation with a dense population, Singapore faces challenges to become self-sufficient with regard to water resources and has developed the 'Four National Taps' to ensure sufficient supply for domestic and industrial needs(32). These include water derived from local catchments, imported water, highly-purified reclaimed water (known as NEWater), and desalinated water. The planning by PUB to date has not included the use of groundwater as a direct resource; however, surface water reservoirs across Singapore Island receive inflow from shallow groundwater.

The water resources considered for the Project include: saturated wetland areas and streams within the CCNR immediately above and down hydraulic gradient of the alignment; the MacRitchie Reservoir and its use as a source of water supply to Singapore waterworks; and channelised canals routing stormwater around the urbanised areas surrounding the eastern and southern section of the CCNR as illustrated in *Figure 5.1*.

PUB operates an inland water storage facility known as Bukit Kalang Service Reservoir (BKSR), located to the north east of Study Area, within the CCNR (*Figure 5.1*). It is understood that the water supply to BKSR is from PUB waterworks and is not directly fed from the water bodies identified in this Study Area.

Figure 5.1: Surface Water Features within Study Area



5.3 SOURCES OF INFORMATION

The baseline information presented in this chapter draws upon a number of existing data sources as well as geological, hydrogeological and hydrological data collected during site investigation works. Existing data and information sources includes information that has been provided by nature groups and government agencies of surface water and groundwater features in the Study Area.

In general, the information used to inform the project includes:

- Online publications from local government authorities such as annual reports, guidebooks, climatological monitoring;
- Topographical, geological and hydrogeological maps;
- Satellite and aerial photographic imagery;
- Topographical, geological and hydrogeological maps;
- Water quality data for the streams within the MacRitchie Reservoir catchment area;
- Cross Island Line discussion and position paper published by Nature Society Singapore;
- Soil investigation borehole data logs available for the area surrounding the CCNR; and
- Data provided by respective government agencies.

Primary data has also been collected, including visual inspections of surface water features along with identification of hydrological features, surface water quality sampling, and laboratory analysis of water samples. Thus providing geological profile, groundwater levels and hydraulic conductivity values for the subsurface in the areas of the potential tunnel alignments.

Information from the aforementioned reviews and studies has been summarised and presented below in order to provide an overview of the baseline surface water and groundwater characteristics in the Study Area.

5.4 CLIMATIC SETTING

5.4.1 Overview

Singapore consists of approximately 700 km^2 [33] of land mass consisting mainly of Singapore Island and several smaller islands. Its location at the southern end of the Malay Peninsula, just 1 degree north of the equator, results in a hot, humid climate with extensive rainfall. This equatorial monsoon tropical climate is characterised by a Northeast Monsoon season generally from December to early March and a Southwest Monsoon from June to September. The typical daily temperatures vary throughout the year between 23 ˚C and 34 ˚C, with the extremes ranging from 19.4 ˚C to 36.0 ˚C [34].

5.4.2 Rainfall

The Northeast Monsoon is a relatively wet season with continuous moderate to heavy rainfall in the afternoons and early evenings. December is the month that receives the most rainfall in the year[31]. The Southwest Monsoon is typically characterised by short duration showers and thunderstorm activities between predawn and midday. Sumatra Squalls prevail within this period – these are thunderstorms that develop at night over Sumatra and move to Singapore with heavy rain lasting 1 to 2 hours in the early morning. The two inter-monsoon seasons are generally drier with showers occurring in the afternoon and early evening.

Singapore receives an average annual rainfall of about 2,200 mm [34]. December has the highest monthly mean rainfall while the lowest rainfall occurs in February.

The total amount of rainfall recorded in the Study Area in 2013 falls in a range of 2,900 mm to 3,200 mm and is 15 to 35% above the long-term mean for Singapore[335]**.**

5.4.3 Relative Humidity

Humidity levels remain fairly constant throughout the year. The mean annual relative humidity is 83.9%. The relative humidity typically ranges between 90% in the morning just before sunrise, and around 60% in the mid-afternoon on dry days[32].

5.4.4 Sunlight Intensity

Being located near the equator, Singapore receives ample sunshine that results in daylight of 12 hours and an average sunshine of 5.4 hours every day. On average, 47% of daylight hours are sunny while the remaining 53% of daylight hours experience some percentage of cloud cover resulting in lower solar radiation[36].

The Changi Meteorological Station measures the Ultraviolet Index (UVI) from 7am to 7pm on a daily basis. The UVI is an internationally recognised measure of solar UV radiation at the earth's surface. Typically, the highest UVIs are measured between 11 am and 3 pm, and are noted to be higher during the months where there is less cloud cover or when the position of the sun is directly over the equator (eg February to May and August to September)[37].

Further details on the climatic characteristics local to the Study Area of Singapore are described in *SI EIA Volume II Chapter 6*[1].

5.5 MACRITCHIE RESERVOIR

MacRitchie Reservoir is located in the center of Singapore, within a designated nature reserve as shown in *Figure 5.1*. The reservoir is known as Singapore's first reservoir[38] and was constructed in 1867[39].

The current reservoir features a concrete dam and an outfall near Reservoir Road. Water from the reservoir is treated at a water treatment plant to produce potable water. Water is also transferred to the Marina Reservoir. Major waterworks that are located near the reservoir include the Woodleigh waterworks and Chestnut Avenue waterworks[41]. Prior to discharge to the treatment plant, PUB continuously monitors the water quality from the reservoir to ensure compliance with their treatment system requirements.

To regulate water levels within the reservoir, PUB transfers water from Upper Peirce Reservoir via a channel (*Figure 5.1*). The channel begins as a concrete and brick-lined waterway from the northwest of MacRitchie Reservoir. It transitions to a natural stream after meeting streams He and Hc at the convergence point east of Dillenia hut. The natural stream then flows southwest and merges with streams Ha at Sime Track and Stream I at Golf Link. Aquatic plants and algal blooms were observed during the field surveys on the reservoir water surface adjacent to the Bukit Golf Course.

In addition to water storage, MacRitchie Reservoir is used for recreational activities such as kayaking, canoeing and fishing. Recreational fishing is also allowed at one designated fishing zone to the southeast of the reservoir, as illustrated on *Figure 5.1*. Fishing is closely regulated by PUB, which enforces strict rules such as restriction of fish type and equipment used; and prohibition of use of live bait to protect water quality[41].

Water from the reservoir is also used for irrigation of the SICC's Bukit-Sime Golf Course located to the west as illustrated on *Figure 5.1*. To protect the water quality of the reservoir, PUB works with the golf club to minimize the use of fertilisers and pesticide used on the golf course and prohibits application of fertilisers and pesticides within 5 m from open waters. PUB also encourages the golf course to the keep the use of fertilisers and pesticides to a minimum.

Dam and outfall of MacRitchie reservoir, near Reservoir Road

Outfall of MacRitchie Reservoir, continue underneath the cross junction of Thomson Road and Upper Thomson Road

View of reservoir's outfall from the dam

Stream Hd and PUB reservoir interchange waterway

Aquatic Plant and Algal Blooms

5.6 MACRITCHIE RESERVOIR CATCHMENT AREA

The main streams and their tributaries of the MacRitchie Reservoir catchment area are illustrated in *Figure 5.1*. The catchment has approximately 68 streams located within, varying in size from small, 6 m long trickles to approximately 1,350 m long and 0.2 m to 6 m wide watercourses. The streams shown in *Figure 5.1* were observed to be shallow with a minimum and maximum depth of 0.02 m and 1 m respectively, during the survey period in October 2014, and were noted to be perennial. In addition to the main streams there are numerous stormwater gullies within the Study Area which channel surface water runoff from the public trails during rainfall events. Some of these have been channelised, such as a gully flowing from northeast to southwest parallel to Sime track.

For ease of reporting, the main streams feeding into the reservoir are labelled I, Ha, Hd, Fa, Eb and Ma. Tributaries of the aforementioned streams are labelled Ia, Ib, Ic, Hb etc as illustrated in *Figure 5.1.*

Visual inspection of the main streams was undertaken in October 2014 and the following parameters were recorded: temperature, pH, total dissolved solids (TDS) and electric conductivity (EC). Field records are presented in *SI EIA Volume II Annex 3.0* [1] and key physical characteristics for the main streams that are located in close proximity to the proposed Alignment Options are summarised in *Table 5.3*.

5.6.1 *Water Quality (Chemical) Survey of MacRitchie Reservoir Catchment Area*

A primary baseline surface water quality (chemical parameters) survey was undertaken at the MacRitchie Reservoir catchment area which could potentially be influenced by the CRL works. Samples were analysed by a laboratory approved by the Singapore Accreditation Council under the Singapore Laboratory Accreditation Scheme (SAC-SINGLAS). The sampling locations were selected to be representative of:

- The location of main streams outlined in *Table 5.3*;
- Their proximity and exposure to potential surface water impacts from activities undertaken during the SI works, pre-construction, construction and operational phases;
- Aquatic sensitivities as identified during the preliminary ecology and biodiversity field surveys; and
- Security and accessibility of each sampling location.

The location of each sampling point is illustrated in *Figure 5.2* and summary presented in *Table 5.4* alongside the rationale for selection of each location.

Table 5.3: Summary of In-situ Parameters and Physical Characteristics of Main Streams (Note 1)

Stream	Temp (˚C)	pH	EC (µS/cm)	TDS (Note 2) (mg/L)	Key observation
I	26.0	5.8	40	26	The section of stream where sampling was undertaken was approximately 2 to 4 m wide with a depth of 0.16 m. Stream flow was fast and smooth and to the south. Stream surface was clear with no sign of woody debris but leaf litter was observed.
Ha	25.7	6.3	100	65	The width of the sampled stream ranged from 1.5 to 3 m with a depth of 0.45 m. Slow moving and stagnant water was observed. Stream surface was generally turbid and stained. Presence of substantial leaf litter and large woody debris was noted.
Hd	27.9	5.9	50	33	The width of the sampled stream ranged from 2 to 3 m and the depth was measured to be 0.3 m. Stream was flowing fast and to the south. Stream surface was slightly turbid with small amounts of leaf litter and woody debris observed.
Fa	25.9	6.2	10	6.5	The sampled stream was 1.0 to 1.5 m wide and 0.05 m deep. Water in the stream was stagnant and stained, and a significant amount of leaf litter was observed.
Ma	26.2	6.3	60	39	The sampled stream width ranged between 1.0 and 2.5 m and was approximately 0.55 m deep. Stream was moving fast and to the southeast. Stream

Stream	Temp (˚C)	pH	EC (µS/cm)	TDS (Note 2) (mg/L)	Key observation
Ma	26.2	6.3	60	39	surface was generally clear but small amounts of leaf litter and trash (e.g. water bottles) were observed.

Note 1: *Field parameter measurements and observations sourced from ERM October 2014 field sampling (See SI EIA Volume II Annex 3.0 [1]).*

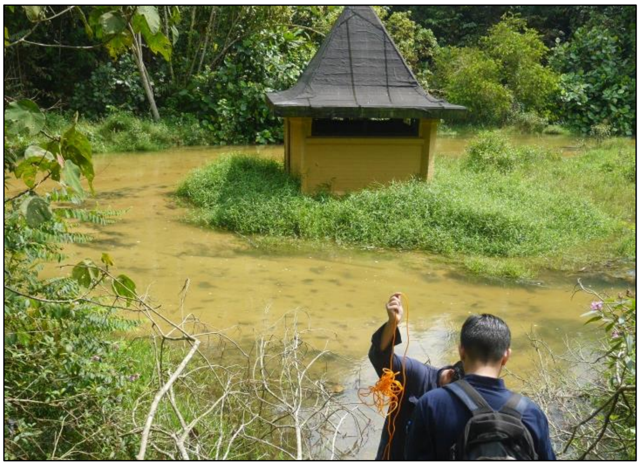
Note 2: TDS derived from EC field measurements using the equation EC (µS/cm) X 0.65 = TDS (mg/L).

Table 5.4: Rationale for Selected Reservoir Catchment Area Surface Water Sampling Points

Sampling Point ID	Location	Rationale
SW 101	Along Rifle Range Link within CCNR	Representative of water quality upstream of stream I
SW 102	At the bridge along Sime Track, near western perimeter of CCNR and SICC Bukit Golf Course	Representative of water quality upstream of proposed SI locations
SW 103	At the bridge next to Golf Link, near western perimeter of CCNR and SICC Bukit Golf Course	Representative of water quality downstream of proposed SI locations, and water quality downstream of stream I
SW 104	Next to Dillenia Hut within CCNR	Representative of water quality upstream of stream Hd
SW 105	At the bridge near the junction of Sime Track and Rifle Range Link (within CCNR)	Representative of water quality downstream of proposed SI locations, and water quality down stream of stream Hd
SW 106	Along Sime Track, near Petaling Hut (within CCNR)	Representative of water quality downstream of proposed SI locations, and water quality downstream of stream Ha
SW 107	Along Sime Track, at the side of Terentang Hut (within CCNR)	Representative of water quality upstream of proposed SI locations, and water quality upstream of stream Ha
SW 108	Along Venus Link	Distinct aquatic environment
SW 109	Within SICC Island Golf Course	Distinct aquatic environment

Surface Water Sampling Location SW101

Surface Water Sampling Location SW102



Surface Water Sampling Location SW103

Surface Water Sampling Location SW104

Surface Water Sampling Location SW105

Surface Water Sampling Location SW106

Surface Water Sampling Location SW107

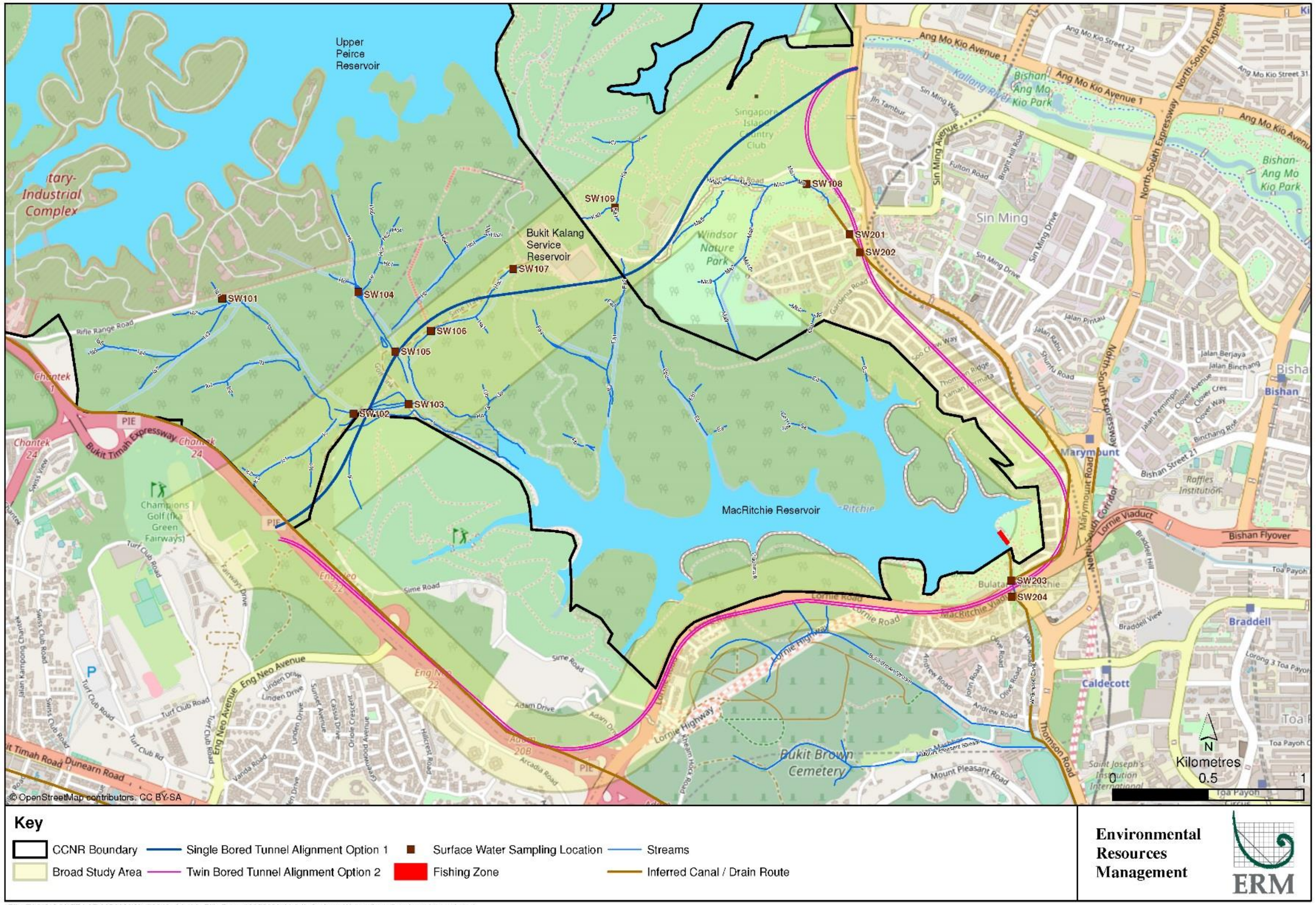
Surface Water Sampling Location SW108

Surface Water Sampling Location SW109

At each location, surface water samples were retrieved by a decontaminated disposable bailer and transported to a SAC-SINGLAS certified laboratory for analysis of the suite of parameters mentioned in *Table 5.5*. Samples were collected from streams or water bodies from existing trails and from the stream bank, i.e. there was no physical entry into streams. Prior to sampling at a new stream/water body, all field equipment was rinsed using water from the sampling site, and clean gloves were worn to avoid potential contamination of the samples.

Two rounds of sampling were undertaken at each location during dry weather, Round 1 in November/December 2014 and Round 2 in January/February 2015. *Table 5.5* presents the results for both rounds of sampling, with the *Environmental Protection and Management (EPM) (Trade Effluent) Regulations*, limits for discharge into a controlled watercourse and the *World Health Organization (WHO) Guidelines for Safe Recreational Water Environment*, included for reference. The full laboratory analysis report is appended in *SI EIA Volume II Annex 4.0*[1].

Figure 5.2: Surface Water Sampling Locations



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5.7 CANALS

There are two canals in the Study Area as illustrated on *Figure 5.1*. Both canals are concrete-lined, 6 to 7 m wide, and were observed to contain a low volume of water during the November 2014 survey period. The canal running along Upper Thomson Road, to the east of the Study Area, was observed to begin from stream Ma, which is located near Venus Drive (see *Figure 5.1*); and the canal that runs along Thomson Road, located to the south of the Study Area was noted to connect to the outlet of MacRitchie Reservoir as shown in *Figure 5.1.* Review of the Singapore Blue Map(42) indicates that, these two canals form part of the central watershed and will ultimately flow to Marina Reservoir located to the south of the Study Area(43). Similar to the MacRitchie Reservoir, water feeding to the Marina Reservoir is monitored and maintained to meet the PUB raw water standard and is treated and used for potable domestic and commercial supply. Marina Reservoir commenced operations in 2008 and has the largest catchment area of all the reservoirs in Singapore.

There is another concrete-lined drain running parallel to the PIE (see *Figure 5.1*). Based on the location it is assumed to be part of the infrastructure for surface water runoff and drainage control of the PIE and the immediately surrounding areas. The outfall location from this concreted drain is unknown.

5.7.1 *Water Quality of Canals*

A primary baseline surface water quality survey was undertaken at the selected locations within the Study Area which would be potential influenced by the CRL works. The sampling locations were selected to be representative of:

- Their proximity and exposure to potential surface water impacts from activities undertaken during the SI works, pre-construction, construction and operational phases; and
- Security and accessibility of each sampling location.

The location of each sampling point is illustrated on *Figure 5.4* and summarised in *Table 5.6* alongside the rationale for the selection of each location. Photographic records of each sampling location are also provided in *SI EIA Volume II Annex 2.0*(1).

Table 5.5: Baseline Surface Water Quality Sampling Results for MacRitchie Catchment Area

Parameter	Unit	LOR	EPM (Note 1)	WHO (Note 2)	SW101		SW102		SW103		SW104		SW105		SW106		SW107		SW108		SW109	
					R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Physical Parameters																						
Temp	˚C	0.1	45	-	24.0	23.0	25.5	25.5	26.5	25.5	30.5	23.0	29.5	26.5	23.0	27.0	33.0	27.5	30.1	22.0	31.1	27.5
pH at 25˚C	-	0.1	6 - 9	-	6.5	6.2	6.7	6.2	6.5	6.3	7.2	7.0	6.7	6.3	6.7	6.4	7.6	7.1	6.7	6.7	6.6	6.5
TSS	mg/L	5	30	-	6	<5	<5	<5	<5	<5	9	6	45	20	7	19	<5	<5	<5	<5	<5	10
TDS	mg/L	5	1,000	-	51	58	33	27	31	27	175	166	121	49	40	36	79	108	32	35	55	67
T	NTU	0.1	-	-	9.2	4.4	5.1	5.6	6.0	9.4	4.0	1.9	7.1	11.0	4.2	12.0	1.1	4.1	8.7	3.5	-	-
Chemical Parameters																						
DO	mg/L	0.1	-	-	6.95	7.2	7.20	7.43	6.78	6.61	7.83	7.4	7.29	7.16	6.96	7.13	8.19	8.22	6.74	7.2	7.94	7.97
COD	mg/L	1	60	-	7	5	4	2	6	2	8	12	11	6	8	6	3	3	7	6	9	<1
BOD_5 at 20˚C	mg/L	2	20	-	5	4	<2	<2	<2	<2	5	7	<2	<2	4	<2	<2	<2	4	5	8	<2
$O\&G_T$	mg/L	5	1	-	<5	<5	<5	<5	<5	6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
$O\&G_H$	mg/L	5	-	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Biological Parameters																						
E.coli	cfu/ 100m	-	-	200	94	<1	17	<1	17	124	9.3	<1	540	90	23	85	17	137	33	25	-	-

Note 1: Limits for discharge into a controlled watercourse from the EPM (Trade Effluent) Regulations, 2008.

Note 2: WHO Guidelines for Safe Recreational Water Environment, 2003.

Note 3: Abbreviations: R1 – Round 1 (December 2014); R2 – Round 2 (January/February 2015); LOR: Level or Reporting; Temp – Temperature; TSS – Total Suspended Solids; TDS – Total Dissolved Solids; T – Turbidity; DO – Dissolved Oxygen; COD – Chemical Oxygen Demand; BOD_5 – Biological Oxygen Demand for 5 days; $O\&G_T$ – Oil & Grease (Total); $O\&G_H$ – Oil & Grease (Hydrocarbon).

Table 5.6: Rationale for Selected Canal Surface Water Sampling Points

Sampling Point ID	Location	Rationale
SW 201	Along Windsor Park Road	Representative of water quality upstream of proposed SI locations
SW 202	Along Upper Thomson Road, between Windsor Park Road and Gardenia Road	Representative of water quality downstream of proposed SI locations
SW 203	Between Island Landscape & Nursery, and the cross junction of Thomson Road and Upper Thomson Road	Representative of water quality downstream of potential SI work and the proposed vent building near the junction of Thomson Road and Upper Thomson Road
SW 204	Between Reservoir Road and the cross junction of Thomson Road and Upper Thomson Road	Representative of water quality upstream of potential SI work and the proposed vent building near the junction of Thomson Road and Upper Thomson Road

Surface Water Sampling Location SW201

Surface Water Sampling Location SW202

Surface Water Sampling Location SW203

Surface Water Sampling Location SW204

At each location, surface water samples were retrieved by a decontaminated bailer and transported to a SAC-SINGLAS certified laboratory for analysis of a suite of parameters outlined in *Section 5.7.* Samples were collected from the canals, while standing near or on the existing trails and from the bank, i.e. there was no entry into the water. Prior to sampling at a new stream/water body, all field equipment was rinsed using water from the sampling site, and clean gloves were worn to avoid potential contamination.

Two rounds of sampling were planned for each location, Round 1 during December 2014 and Round 2 during January/February 2015. The baseline sampling results presented in *Table 5.7* are compared against the water standards within the *Environmental Protection and Management (EPM) (Trade Effluent) Regulations, 2008*, for discharge to a controlled watercourses given the drainage system is connected to Marina Reservoir which does not receive any water supply from PUB.

Table 5.7: Baseline Surface Water Quality Sampling Results for Canals

Parameter	Unit	LOR	EPM (Trade Effluent) Regulations, 2008 (Note 3)	SW201		SW202		SW203		SW204	
				R1	R2	R1	R2	R1	R2	R1	R2
Physical parameters											
Temperature	˚C	0.1	45	26.0	27.0	29.0	29.0	31.5	29.5	30.0	29.0
pH at 25˚C	-	0.1	6 -9	7.0	6.8	7.0	7.0	7.1	7.1	7.1	7.1
TSS	mg/L	5	30	24	10	<5	7	<5	<5	<5	<5
TDS	mg/L	5	1,000	53	48	54	44	113	69	118	55
Chemical Parameters											
DO	mg/L	0.1	-	7.35	6.90	7.98	7.68	7.80	8.05	7.88	8.25
COD	mg/L	1	60	11	5	4	6	5	2	9	<1
BOD_5 at 20˚C	mg/L	2	20	3	4	3	3	3	<2	3	<2
Oil & Grease (Total)	mg/L	5 (Note 4)	1	<5	<5	<5	<5	<5	<5	<5	<5
Oil & Grease (Hydrocarbon)	mg/L	5	-	<5	<5	<5	<5	<5	<5	<5	<5

Note 3: Limits for discharge into a controlled watercourse were adopted for comparison.

Note 4: It is noted that the level of reporting (analytical detection limit) for oil & grease (total) is higher than the limit. However for the purpose of this EIA, oil and grease (hydrocarbons) is more applicable since Marina Bay reservoir is used to supply drinking water which human health will be the main concern.

Note 5: Abbreviations: LOR: Level of Reporting; TSS – Total Suspended Solids; TDS – Total Dissolved Solids; DO – Dissolved Oxygen; COD – Chemical Oxygen Demand; BOD_5 – Biological Oxygen Demand for 5 days; R1 – Round 1 (December 2014); R2 – Round 2 (January/February 2015).

5.8 GROUNDWATER

The description of groundwater baseline conditions is based on available literature sources that are relevant to the Study Area as well as geological and hydrogeological data gathered as part of the intrusive Site Investigation Engineering Services undertaken by several Site Investigation Contractors. The intrusive site investigation works have provided geological profile, groundwater levels and hydraulic conductivity values for the subsurface in the areas of the potential tunnel alignments.

5.8.1 Hydrogeological Framework

The geology underlying the Study Area plays a key role in setting the hydrogeological framework of the subsurface, determining the location and nature of aquifers and aquitards as well as the hydraulic properties of these units.

As described in the geology baseline (*Section 4*), the majority of the Study Area is underlain by the Bukit Timah Granite. The Bukit Timah Granite has six main weathering profiles(23), from residual soil, G(VI), to fresh rock, G(I). The other grades are described as completely weathered rock, G(V), highly weathered rock G(IV), moderately weathered rock , G(III) and slightly weathered rock, G(II). From a hydrostratigraphy perspective these weathering grades can be described as homogeneous to heterogeneous porous media in G(VI) and G(V), fractured porous media, G(IV), and predominantly fractured media, G(III) to G(I)(22). Within the predominantly fractured media, groundwater storage and flow would be controlled by the number and characteristics of the fractures and the connectivity of the fracture network. For the Bukit Timah Granite, groundwater storage and transport is expected to be highest at the interface between the weathered rock and the overlying residual soil within the G(IV) zone where the mass permeability is expected to be highest(22).

The Hydrogeological Map of Singapore published by Pfeiffer (1975) showed that the CCNR, which is founded on the granite rocks, has extremely small groundwater capacity locally of about 1 m^3 per hour(45). He recognized that the central part of Singapore must be regarded as rather short of groundwater as the Bukit Timah granite material is virtually impermeable with permeability coefficient (k-value) in the range of 1.10^{-8} m/s and 1.10^{-10} m/s. Pfeiffer (1975) further reported that only sandstones of the Mesozoic sequence could be considered as possible aquifers and this was not found to be present in the boreholes carried out in CCNR. This is further acknowledged by Forsythe & Pearse-Hawkins(25) which stated that the Bukit Timah Granite rock mass is typically massive and has a low hydraulic conductivity of 10^{-10}m/s to 10^{-8}m/s, with isolated discontinuity zones showing conductivity values of 10^{-8} m/s to 10^{-6} m/s. Forsythe & Pearse-Hawkins also concluded that groundwater flow in the Bukit Timah Granite rock mass is typically via secondary flow i.e. concentrated along the interconnected discontinuities in the rock and each layer or zone exhibit its own hydrogeological parameters. Further conceptualisation of hydraulic conductivities (presence of aquifers, aquitards etc) within the Bukit Timah Granite was undertaken from an interpretation of packer tests conducted at selected SI boreholes, and is described in *Section 5.8.3*.

The Kallang Formation encountered in the Study Area comprises primarily of the Estuarine Clay, Alluvial Sand and the Clay Member. Typically, the Estuarine Clay Member is found above the Alluvial Sand and Clay Member in the 24 boreholes where Kallang Formation was identified. Where present, it is typically encountered in the first 3 – 6 m above the Bukit Timah Granite and occupies the shallow region from the surface downwards or beneath shallow fill layers. Where encountered the Estuarine Clay and Alluvial Clay members would be expected to act as aquitards, while the higher permeability Alluvial Sand Member may present localised aquifers of limited thickness and extent.

As discussed in *Chapter 4 Geology,* the presence of fill material has been identified across the Study Area generally consisting of slightly gravelly, slightly sandy silt with rootlets and crushed stone or in some cases, fine to coarse sand. The fill material was found to cover most of the study area along all Alignment Options as made ground, occupying an average of 4.5 m in depth and in some areas up to 18 m in depth. Fill material is thinner along Alignment Option 1 as compared to Alignment Option 2 as there are more built up areas along Alignment Option 2. Where the fill present highly permeable material such a sands or gravel/crushed stone, this material may present localised water bearing units with high permeability and potentially high through-flow.

5.8.2 Groundwater Levels

Generally, groundwater levels in the Study Area range between 0.5 m below ground level (bgl) to 10 m bgl, with groundwater levels in the 3 to 5 m bgl range being more common[21]. Available data related to groundwater levels for the Study Area are largely limited to water levels measured during the drilling of the site investigation bores. The water level depths are based on measurements recorded with a water level probe and the drilling was undertaken through mud rotary means (with the use of drilling mud as the drilling fluid will likely affect water level measurements within the bore). Water level measurements taken while drilling with mud rotary would have an impact on how reflective the reported values are of aquifer conditions.

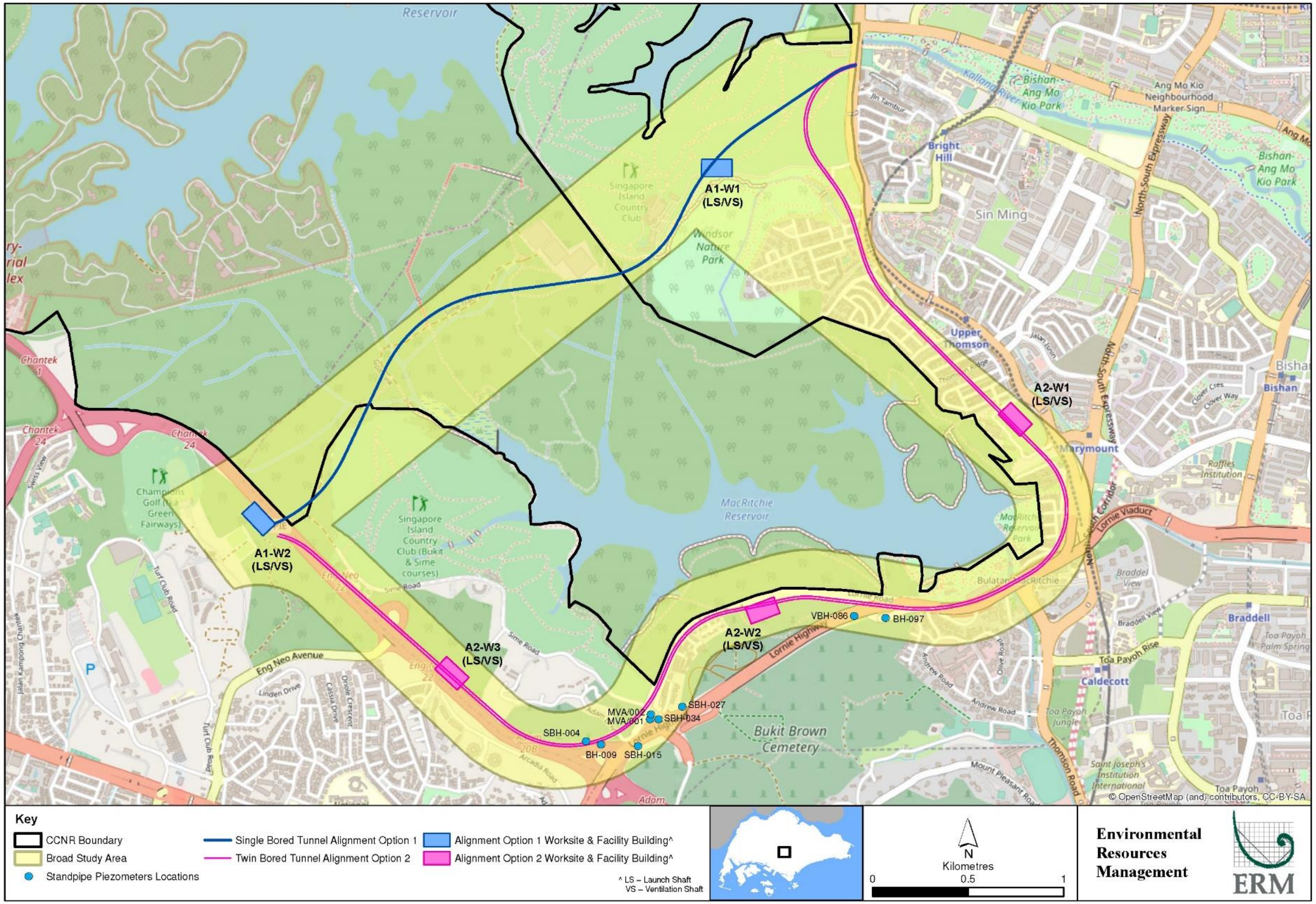
Note that for a number of bores, both morning and afternoon water level measurements are available, and ERM understands that the morning measurements took place before the commencement of drilling for the day. While morning measurements would still potentially have been affected by the use of mud rotary as a drilling method, the morning measurements are expected to be more reflective of groundwater levels compared to afternoon measurements (as a degree of equilibration would have taken place between the drilling fluid and the groundwater overnight when drilling is understood not to have taken place). ERM therefore focused on the morning measurements, and all drilling period related water level measurements presented in this report are based on the morning measurements. Where only one daily measurement was provided, ERM has assumed that these measurements were taken prior to the commencement of drilling for the day and these measurements were grouped with the morning measurements when calculating the minimum, average and maximum depths to water level.

The bores drilled during the site investigation works for which water level data were collected during drilling are presented on *Figure 3.2a and Figure 3.2b*, *Chapter 3*. Altogether, water levels measured between January 2012 and October 2017 are available for the series of boreholes that have been drilled in the Study Area along Alignment Options 1 and 2.

The installation of 13 standpipe piezometers along Alignment Option 2 was conducted to obtain the measurements of groundwater levels from targeted depths following completion of drilling, of which 9 were found within the Study Area. No groundwater level monitoring through the use of standpipe piezometers were conducted along Alignment Option 1. All SI boreholes located within the CCNR were backfilled directly after drilling was completed to avoid the creation of any new and permanent pathways to groundwater resources. The locations of standpipe piezometers with available groundwater level measurements are presented in *Figure 5.3*.

Depth of piezometer installation varied between 5 and 25 m bgl (with the Bukit Timah Granite weathering profiles screened by these piezometers varying from completely weathered rock, G(V), to residual soil, G(VI)). Average groundwater levels for piezometers screening the G(V) weathering profile (all installed to a depth of 25 m bgl) varied from 6.14 to 9.26 m bgl (with gauging undertaken during different periods in 2014 and 2015). Average groundwater levels for piezometer screening the G(VI) weathering profile (with installation depths varying between 5 and 25 m bgl) varied from 2.33 to 12.08 m bgl (with gauging undertaken at different times between 2012 and 2015). Piezometers installed in differing weathering profiles were not located in close enough proximity (or gauged across the same time periods) to facilitate an assessment of hydraulic gradients between the G(V) and G(VI) weathering profiles.

Figure 5.3: Locations of Standpipe Piezometers with Available Groundwater Level Data



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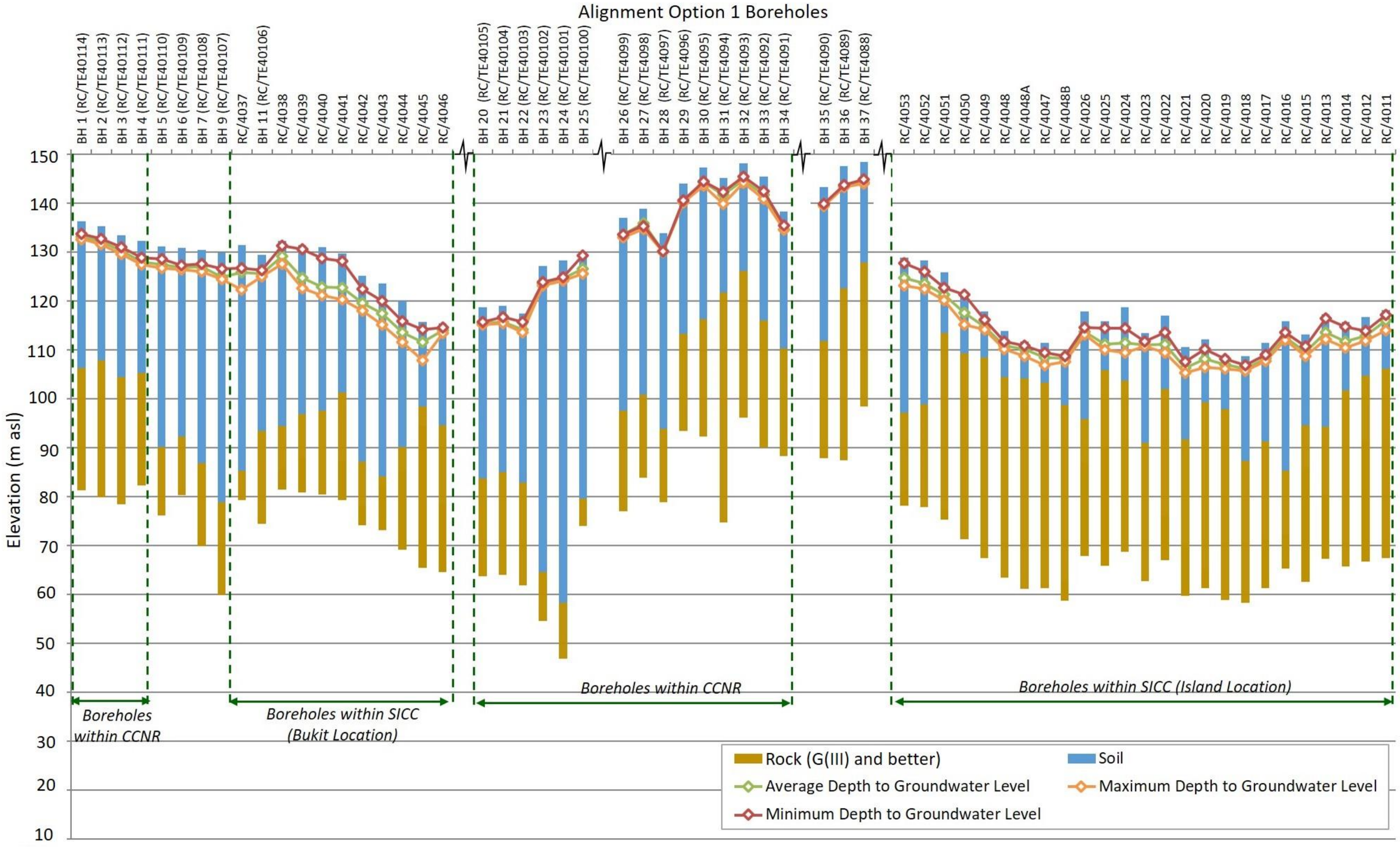
Date: 4/7/2018

The remainder of this section outlines the water level measurements taken during drilling, with this water level dataset covering a much larger spatial area than the groundwater level data available from the standpipe piezometers. Given the restrictions with the drilling period water level data, the drilling period water level data is considered an approximation of actual groundwater conditions at best.

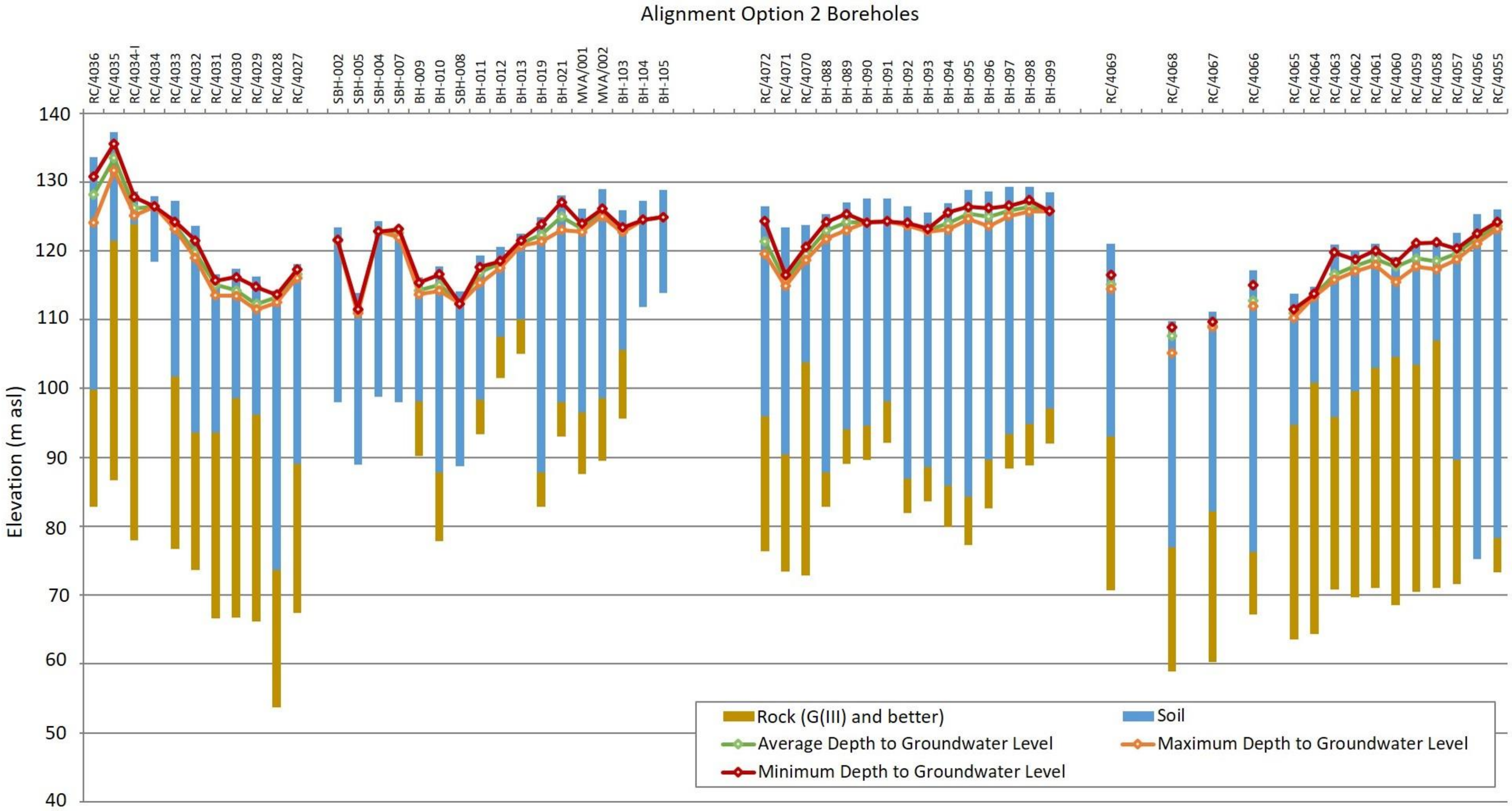
Average, minimum and maximum depth to drilling period water levels for the boreholes located along Alignment Options 1 and 2 (with a summary of lithologies encountered at each bore) are presented in *Figure 5.4* and *Figure 5.5* respectively.

Figure 5.4: Available Water Level Data Collected during Drilling and Lithology Summaries for Boreholes along Alignment Option 1



Note 1: Boreholes are arranged not to horizontal scale and gaps between borehole locations indicate greater than typical distance horizontally between locations.

Figure 5.5: Available Water Level Data Collected during Drilling and Lithology Summaries for Boreholes along Alignment Option 2



Note 1: Boreholes are arranged not to horizontal scale and gaps between borehole locations indicate greater than typical distance horizontally between locations.

Alignment Option 1

Along Alignment Option 1, the average, minimum and maximum depths to drilling period water levels were predominantly within the shallow residual soil horizon, G(VI). Average depth to water varied between 3.0 m bgl and 4.0 m bgl along Alignment Option 1. The lowest minimum depth to water was recorded as 0.48 m bgl and the highest maximum depth to the measured water level 8.2 m bgl.

Review of drilling period groundwater levels across CCNR indicates that along Alignment Option 1, average drilling period water levels ranged from 3 m to 6 m bgl in the west and centre to 1 m to 4 m bgl in the east of alignment. The deepest water level was measured along Alignment Option 1 at 9.8 m bgl, west of the PIE.

With respect to mean sea level (msl) (Footnote 1), drilling period water levels were observed to be highest in the central section of Alignment Option 1 in close proximity to Stream Fa where it is the most forested, with water levels at approximately 40 m above mean sea level (amsl). Water levels in the southwestern area of Alignment Option 1 were higher than in the northeast, thus indicating an overall undulating groundwater surface with respect to mean sea level.

Given the limitations on the spatial and temporal distribution of the available drilling period water level data (with water level data collected during the same time period generally being limited to bores drilled in near linear transects in specific areas), groundwater elevation contours were not generated from the data. In fill material, unconsolidated sediments, Residual soil and Highly weathered to Completely weathered Bukit Timah Granite, G(VI) to G(IV), groundwater flow would be expected to align with the slope of the topography. In the less weathered Bukit Timah Granite, G(III) to G(I), groundwater flow will be governed by the orientation and interconnectivity of the fracture network which could show high localised variability.

Alignment Option 2

Along Alignment Option 2, the average, minimum and maximum depths to water levels during drilling were predominantly within the shallow residual soil horizon, G(VI), and to a lesser extent within the Kallang Formation. Average depth to water varied between 2 m bgl and 3 m bgl along Alignment Option 2. The lowest minimum depth to water was recorded as 0.98 m bgl and the highest maximum depth to the measured water level 7.76 m bgl.

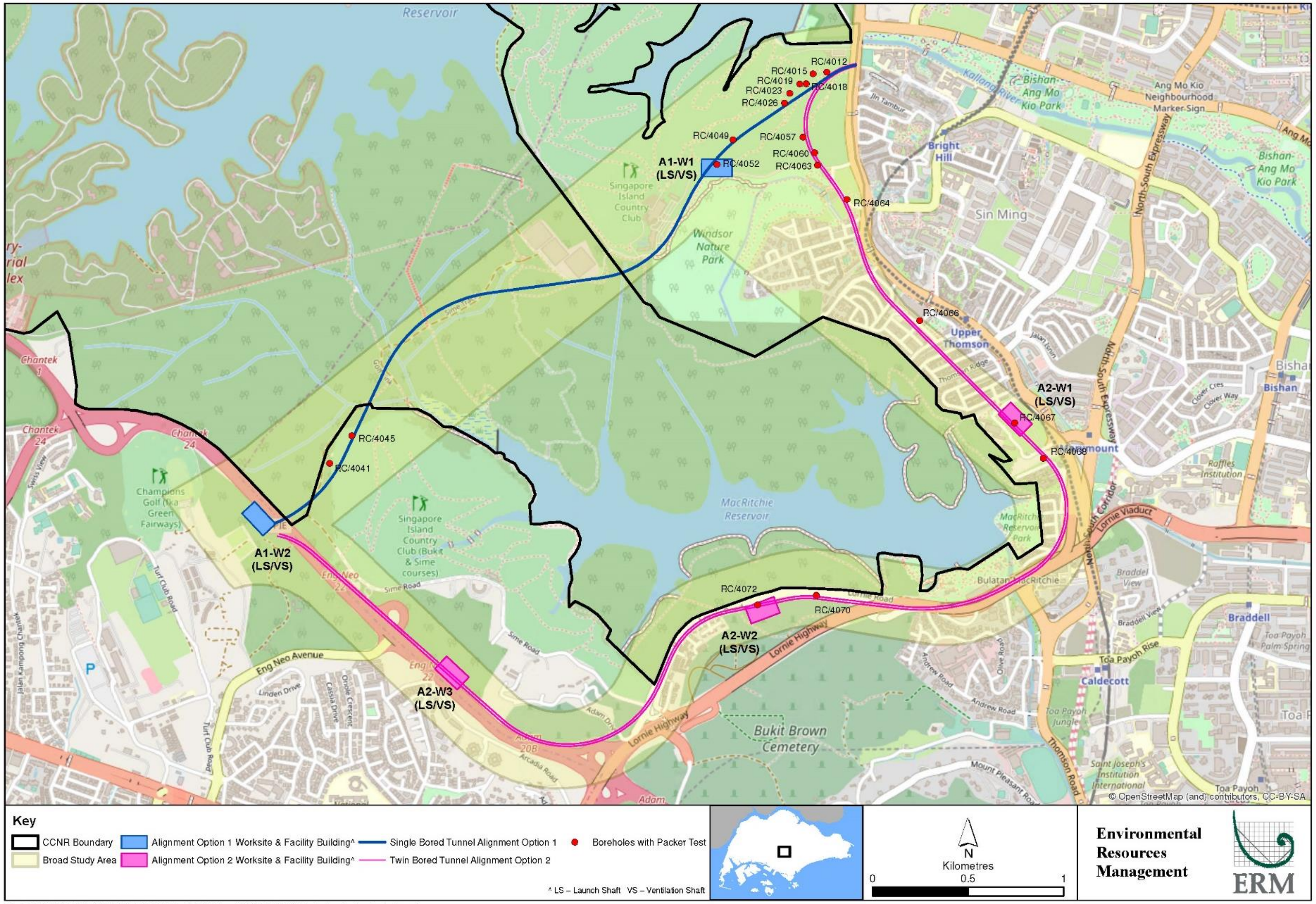
Along Alignment Option 2, bores located within the northwest, northeast and southwest areas had water levels ranging from 1 m to 8 m bgl with the deepest water level measured at 9.5 m bgl which was found in more built-up areas outside of the CCNR. At the southwest portion of Alignment Option 2, water levels were higher with a range of 1 m to 4 m bgl, while the boreholes that are located along Lornie Road towards the southeast had deeper water levels ranging between 3 m to 7 m bgl. There is a general trend where water levels are found deeper in more disturbed built-up areas (along roads and buildings) as compared to forested areas around the CCNR. This differentiation may be due to differences in recharge to groundwater as affected by surface cover in the different landuse areas.

Footnote 1 The mean sea level at Keppel Harbor is equivalent to 100 m RL shown on *Figures 5.4* and *5.5*.

5.8.3 Hydraulic Conductivities

To obtain a Study Area specific understanding of the range of hydraulic conductivities, packer tests were conducted at 19 boreholes between January and December 2016 (*Land Transport Authority, Nov 2016 – June 2017*)[(44)]. The packer tests were conducted to determine the permeability of the rock where significant fractures were encountered. They were conducted on 1-2 m intervals of rock between 20 m to 45 m bgl that intersected Bukit Timah Granite of varying weathering grades ranging from highly weathered rock to fresh rock. Bore locations where packer tests were conducted are presented on *Figure 5.6.*

Figure 5.6: Locations of Boreholes where Packer Tests were conducted



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Date: 4/7/2018

During a packer test, the amount of water injected into a segment of the bored hole is measured under a steady pressure in various stages and the Lugeon value is defined as the loss of water in liters per minute and per meter borehole at an over-pressure of 1 MPa. The Lugeon values derived therefore provide an estimation of the hydraulic conductivity of the tested interval.

Lugeon values with an associated conductivity classification, as developed by Camilo, 2010[45], are presented in *Table 5.8* below. Hydraulic conductivity values in m/s can be estimated by multiplying Lugeon values by a factor of 1.3 X 10^{-7}.

Table 5.8: Lugeon Values and Associated Conductivity Classification

Lugeon Value	Conductivity Classification
<1	Very low
1-5	Low
5-15	Moderate
15-50	Medium
50-100	High
>100	Very high

** French Standard NF P 94-131 (1994) Essais d'eau Lugeon*

The results for the packer testing undertaken in the Study Area are summarised in *Table 5.9.*

Table 5.9: Reported Packer Testing Results (Land Transport Authority, November 2016 – June 2017)[44]

LTA BH ID	Depth of Top of Test Section (m)	Depth of Bottom of Test Section (m)	Geology (Completely, Highly, Moderately, Slightly Weathered & Fresh Rock)	Fracturing Extent (High, Moderate, Slight, Very Close, Closely spaced Fractures)	Recommended Permeability Value (m/s)	Lugeon Value
RC/4012	23	24	High - Mod	High - Mod	9.75E-07	11.2
RC/4015	19.5	20.5	High - Mod	Mod	9.48E-07	10.89
RC/4018	26.4	27.4	Mod - Slight	Slight	1.03E-06	11.8
RC/4019	22	23	Mod - Slight	High - Mod	9.28E-07	10.66
RC/4023	28.6	29.6	High - Slight	Mod	2.49E-09	0.03
RC/4026	29	30	Mod - Slight	High	8.28E-07	9.51
RC/4041	31.4	32.4	Slight - Fresh	Mod	4.26E-06	48.94
RC/4045	23.7	25.7	Slight - Fresh	Mod	3.68E-06	34.86
RC/4049	22.5	23.5	High - Mod	High - Mod	3.86E-07	4.43
RC/4052	41.4	42.4	Mod - Slight	Mod	5.72E-07	6.56
RC/4057	36	37	High - Mod	Mod	3.72E-07	4.27
RC/4060	34.5	35.5	High	High	1.34E-06	15.33

LTA BH ID	Depth of Top of Test Section (m)	Depth of Bottom of Test Section (m)	Geology (Completely, Highly, Moderately, Slightly Weathered & Fresh Rock)	Fracturing Extent (High, Moderate, Slight, Very Close, Closely spaced Fractures)	Recommended Permeability Value (m/s)	Lugeon Value
RC/4063	40	41	Mod - Slight	High - Mod	5.48E-07	6.29
RC/4064	29	31	Mod	Very Close to Close	2.30E-09	0.0217
RC/4066	43.5	46	Mod - Slight	Closely to Medium	9.29E-09	0.0834
RC/4067	35.9	36.9	Mod	Very close to Close	No water flow into the joint due to very tight to tight aperture	
RC/4068	41.5	43.9	Mod	Closely to Medium	1.18E-09	0.0165
RC/4070	24.7	26.9	High - Mod	Very close to Close	5.67E-07	5.2437
RC/4072	35.1	37.2	Mod	Close	No water flow into the joint due to very tight to tight aperture	

The reported Lugeon values range from 0.01 to 49 (equating to a hydraulic conductivity range of 10^{-6} to 10^{-9} m/s), which indicates a range of very low to medium hydraulic conductivity. These ranges represent the considerable variability in permeability of the soils derived from the weathering of the Bukit Timah Granite (described on the borelogs as ranging from slightly weathered to highly weathered rock, G(II) to G(IV).

Packer tests undertaken on the moderately weathered Bukit Timah Granite returned the lowest Lugeon values (ranging between No water flow to a Lugeon value of 0.0217). Packer tests undertaken on slightly to moderately weathered and moderately to highly weathered Bukit Timah Granite returned significantly higher Lugeon values, ranging between 4.27 and 11.8 (with the exception of the tests undertaken on slightly to moderately weathered material at RC/4066 which returned a Lugeon value of 0.0834). The highest Lugeon values were returned for tests undertaken on highly weathered Bukit Timah Granite (with a Lugeon value of 15.3) and fresh to slightly weathered granite (with reported Lugeon vales of 34.89 and 48.94). In general, no clear correlation was apparent between described fracturing extent and the Lugeon values observed. The high Lugeon values reported for tests undertaken on the Fresh Rock to Slightly weathered rock however suggests that these test locations occurred in an area where fracture derived permeability is significant.

The packer test results support the literature review in *Section 5.8.1* which had suggested that the Bukit Timah Granite rock material would be virtually impermeable with isolated discontinuity zones. Groundwater flow in the rock mass, if any, would be typically via secondary flow and concentrated along the interconnected discontinuities in the rock with each layer or zone exhibiting its own hydrogeological parameters.

It is further noted that anecdotal observations were made by the LTA during the site investigation works in 2017. There were reportedly no observation of artesian water pressure conditions during the drilling of vertical and horizontal boreholes. LTA reported that examinations of the HDC rock core samples undertaken along Alignment Option 1 did not yield any observation of interconnected fractures, which is indicative that no significant fault zones were encountered. The site investigation data therefore does not indicate any hydraulic link of groundwater to deeper layers of soil or rock, where the intercepting of ground water to geothermal strata could cause hot water to flow to the surface under artesian conditions, as observed at the Sembawang hot spring [(46)].

5.8.4 Groundwater Quality

For 5 out of the 202 boreholes within the Project area, chemical tests of groundwater were conducted to determine the pH value using the electrometric method, sulphate content, chloride content and Organic content using Dichromate oxidation method. These boreholes are spaced apart along the PIE and along Lornie Road, along Alignment Option 2. However, due to the lack of sufficient results, groundwater quality has not been assessed in the baseline.

5.8.5 Groundwater – Surface Water Interaction

An examination of maps and images of the CCNR, as well as field observations, indicated the presence of water saturated soil conditions at the surface in low lying wetland areas and adjacent to waterways. Consequently, it is expected that shallow groundwater levels (0 m bgl to 1.0 m bgl) would occur in low lying wetland areas and adjacent to the streams and MacRitchie Reservoir. The aforementioned surface water features in the Study Area would be expected to be in hydraulic connection with groundwater in the shallow residual soil, G(VI), horizon of the Bukit Timah Granite as well as shallow sediments of the Kallang Formation where present.

As described in *Section 5.8.3* however*,* site investigation data and field observations by the LTA indicate that there are no major fault lines or fracture zones, and therefore no deep groundwater aquifers that are hydraulically connected to surface reservoirs and waterbodies in and around CCNR. Furthermore, the presence of thick weathered Bukit Timah granite layers (G(VI) and G(V)) that are not permeable, above the granite rock would present a barrier to any movement of groundwater from shallower depths to the bedrock.

The specific dynamics of the groundwater – surface water interaction (and during what periods the surface water features may be gaining or losing water feature) is unverified without having time series surface water elevation and groundwater elevation data to compare.

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