ENVIRONMENTAL VALUATION OF THE CENTRAL CATCHMENT NATURE RESERVE UNDER TWO CONTEXTS: MUTUAL EXCLUSIVITY AND CO-EXISTENCE WITH THE CROSS-ISLAND MASS RAPID TRANSIT LINE

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BY

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A STUDY REPORT SUBMITTED FOR THE DEGREE OF MASTER OF SCIENCE (ENVIRONMENTAL MANAGEMENT)

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Summary

The environmental valuation of ecosystems provides an economic perspective for evaluating urban developments that encroach on natural ecosystems. In 2019, the Cross-Island Line (CRL), Singapore's eighth Mass Rapid Transport Railway network, through and underneath the Central Catchment Nature Reserve (CCNR) was finalized. While an EIA had been conducted and lengthy stakeholder discussions were held, the Land Transport Authority provided no environmental valuation. However, economic feasibility was suggested to play a role in the decision-making process.

According to the Phase 2 EIA, the granite geology underneath CCNR, which the track tunnels traverse, is impermeable. However, the science regarding this is inconclusive. The uncertainty leads to two contexts by which CCNR could be evaluated. In Context 1, the Mutual exclusivity of CCNR with CRL was investigated. Following that, the Co-existence of CCNR with CRL was studied as Context 2. This study report applies the Threshold Value Method and Avoided Cost Method for Context 1 and 2, respectively, under the assumptions of a ten-year construction period and fifty-year operation period. In 2019, the decision to finalize on the direct alignment provided an opportunity for a re-evaluation and added completeness to the decision-making process. The environmental valuation of CCNR could also serve as a guideline for future urban development in land-scarce Singapore.

In Context 1, building on the framework provided by Thampapillai in his 2011 paper "The economic valuation of urban ecosystem services," it is calculated that the Net Present Value of CRL Alignment 1 amounts to $1.27 billion over its life cycle. This opportunity cost is further reduced to $1.45 million per year using the Threshold Value (TV) method. In other words, if the present value of preservation in the initial year is at least equal to the net present value of Cross Island Line at $1.45 million per year, preservation of CCNR should take precedence. Based on the TV theory, the TV value of each cubic meters of water is approximated to be $0.64 cents. This valuation is less than the 2021 lower tier water tariff of $1.21 and suggests that preservation of CCNR could take precedence.

In Context 2, the Avoided Cost Method is applied under the presumption that the groundwater would be polluted above a baseline level as indicated in EIA

Phase 2. The pollution would result in higher water treatment costs from MacRitchie Reservoir and forms the opportunity costs for Alignment 1. This opportunity cost is then compared with Alignment 2 at a $-0.93 B Net Present Value. The OC changes when considering the Avoided Costs of treatment of polluted water. It was shown that if the treatment cost to the baseline level is more than $36.7 million per year, Alignment 2 should be chosen in favor of Alignment 1.

This paper demonstrated that if an economic valuation has been considered in either context, the result could have differed. In either case, regardless of the scientific consensus on granite geology's permeability, there is a case to argue for the alternative alignment.
(Study Report Word Count: 9026)

1. Introduction

Environmental valuations of sensitive ecologies, especially in land-scarce countries like Singapore, play a vital role in guiding sustainable development in a nation. As a case study, the Central Catchment Nature Reserve (CCNR) (28.8 km2) is one of Singapore's largest designated conservational sites with fragile primary and secondary forest patches and reservoirs. In the heart of the CCNR, the Nee Soon freshwater swamp forest (NSSF) (4.8 km2) is Singapore's last freshwater swamp. Furthermore, a complex groundwater system replenishes the MacRitchie, Upper Seletar, Upper Peirce and Lower Peirce reservoirs in CCNR. House to numerous endangered and endemic species, NSSF's biodiversity and hydrology sensitivities to external environmental disturbances are complex and intricate (Nguyen, 2018) and warrant its conservation status as a unique and irreversible environmental resource.

On 17 January 2013, the Land Transport Authority of Singapore announced a Master Plan that included a new Cross Island Mass Rapid Transit Line (CRL) to handle Singapore's increasing need for a more robust transportation system (Land Transport Authority, 2013). Between two alignment options, one would traverse through the CCNR, potentially causing irreversible damage to the CCNR, while the other skirts around the CCNR to keep potential impacts to a minimum, albeit at higher construction costs.

On 4 December 2019, the decision to adopt a direct alignment (Alignment 1) through deep granite hard rock under the CCNR was finalized (Ministry of Transport, 2019). This decision was guided by an EIA (Land Transport Authority, 2019) and extensive consultations with relevant stakeholders. The granite geology which the CRL would traverse is presumably acting as a natural barrier shielding the CCNR and NSSF from tunneling works. Under the above presumption and the premise of CCNR as a unique and irreversible resource, two contexts emerge from the above decision.
Context 1) Mutual exclusivity of CCNR with CRL,
Context 2) Co-existence of CCNR with CRL

A suite of decision-making methods including Environmental Impact Assessments, consideration of alternatives and dialogues with relevant stakeholders are the essential first steps before proceeding with an urban development. Utilizing the information obtained, the use of environmental valuation methods as a follow-up could provide a more comprehensive perspective. The construction of the CRL through the CCNR provides a unique case study opportunity for the environmental valuation of CCNR. As a unique and irreversible natural resource, the use of opportunity cost methods for valuation have fewer limitations than other methods like stated preferences methods. In this report, the threshold value method (Krutilla, 1985) and avoided cost method for the two contexts are applied respectively. Each context will be further analyzed using the alternative alignment to gauge the actual opportunity costs.

2. Background Information and Existing Work

2.1 Unknowns and Gaps in Evaluation of CCNR

The NSSF ecosystem's uniqueness as a water catchment cum biodiversity hotspot is well documented. It plays a critical role in housing rare and endangered species. Some of its rich biodiversity includes native fauna like the Singapore kopsia, kopsia singapurenesis, and the endemic and critically endangered reticulated swamp crab, Parathelphusa reticulata.

Of all its species, one of the most critically endangered organisms, endemic to Singapore, is the reticulated swamp crab named *Parathelphusa reticulata*. Listed in the IUCN red list, the freshwater species is an excellent indicator of terrain and aquatic pollution as they are sensitive to minute changes in their environment (Tan, 2017). Their population has been documented to fluctuate depending on the pollution level and land use in their habitat (Chong, 2018). Yet, despite decades of research, the NSSF still harbors species that are yet to be discovered. In March 2021, a team of researchers from NUS and National Park Boards (NParks) announced a new species of fireflies, Luciola *singapura.* This discovery was significant as it was made more than a century after discovering the last new species of firefly in 1909 (The Straits Times, 2021).

Figure 1 The native Kopsia Singapurenesis

Figure 2 The native Parathelphusa reticulata

Figure 3 Newly discovered firefly species Luciola singapura. Photos by Wan F. A. Jusoh

It highlighted the importance of understanding Singapore's natural heritage by conserving NSSF and enhancing the core habitats of endangered species. As such, the onus of adequate pre-development evaluation lies on the urban planner. While EIAs and stakeholder discussions are helpful prerequisites, environmental valuation provides an alternative perspective. It could be conducted in tandem to measure the true value of an ecosystem. As LTA did not offer an economic evaluation of CCNR, this study report attempts to fill the gap. Hopefully, it could be used as a case study in future urban developments.

According to the position paper by NSS, it is noted that the total damage to the pristine ecosystem of CCNR is valued at its replacement costs. It means that in the case of CCNR as an irreplaceable resource, its valuation tends towards infinity and any development income to be gained is incomparable to its loss. However, such a stand generally proves challenging in persuading the urban planners as it does not allow compromises. The purpose of this study report hopes to address this gap as well.

2.2 Cross Island Line and its Income Generation Opportunity

The Cross-Island Line (CRL) is Singapore's proposed eighth MRT line and will be the longest, fully underground line when completed. The construction of CRL is carried out in phases. While Phase 1 of the CRL began in 2020, Phase 2 (CRL2) had two pending alternatives.

Alignment Option 1 of CRL2 is a direct alignment underground passing the Singapore Island Country Club Island Golf Course to the Pan Island Expressway. About 2km of this underground tunnel would pass 70m underneath the CCNR on average (Refer to Appendix 1). No construction will take place on its direct surface.

An alternative 9km skirting alignment, named Alignment Option 2 (Refer to Appendix 2), around the CCNR and under commercial and residential buildings was added into consideration after the Nature Society (Singapore) published a position paper highlighting the risk of a direct alignment to CCNR's flora and fauna (NSS, 2013).

According to LTA (2019), the direct alignment allows several advantages.
1) About 6 minutes less commuting time between any two CRL stations on either side of the CCNR.
2) About 15% less per trip commuter fare on average
3) Estimated daily ridership of more than 600,000 (lower in Alignment Option 2) across the whole CRL in the initial years and over one million in the longer term under the direct alignment.

As stated in the Phase 2 EIA Report, the key above ground and underground features for construction of CRL2 includes Access Roads, Launch Shaft for Tunnel Boring Machines, tunnels, Cross Passageway, Ventilation Shaft, as well as Facility Buildings. Some of these features will be permanent and are located at the various workstations (refer to Appendix 1 for a detailed description). These features were evaluated by Phase 2 EIA to have varying degrees of impacts on CCNR and hence, require mitigation measures to be in place. The information retrieved from the Phase 2 EIA will be critical in describing the framework in valuating CCNR.

2.3 Ecological and Hydrogeological Comparison of Worksite Locations in Alignments 1 and 2

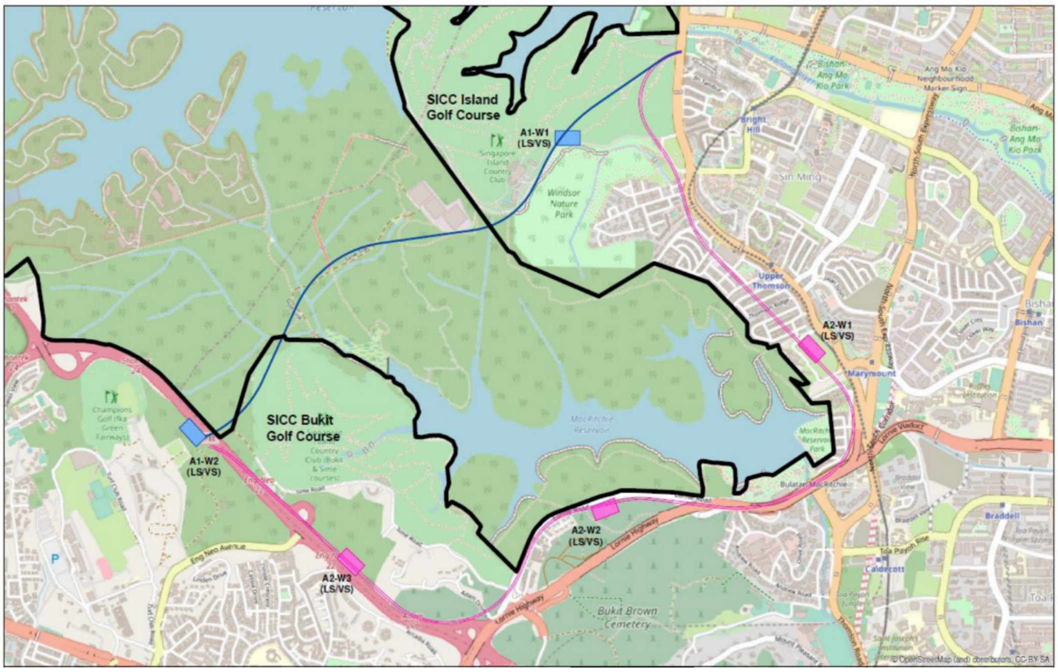


Figure 4 Worksite locations of CRL2. Blue-highlighted worksites A1-W1 and A1-W2 are locations for Alignment 1. Pink-highlighted worksites A2-W1, A2-W2 and A2-W3 are locations for Alignment 2. Retrieved from Phase 2 EIA, LTA (2019).

The figure above shows Alignment Option 1 (in blue) through CCNR. Two aboveground worksites, A1-W1 northwest of Windsor Nature Park, and A1-W2 southwest of SICC Bukit Golf Course, will be erected and used as launch shaft locations. Alignment Option 2 (in pink) has three worksites - A2-W1 along Upper Thomson Road, A2-W2 between the south of MacRitchie Reservoir and Lornie Highway, as well as A2-W3 next to Arcadia Road across the Pan-Island Expressway. All worksites are at least 50 m away from the boundary of the CCNR to minimize any potential environmental impacts to CCNR.

From an ecological and biodiversity standpoint, both options are deemed by Phase 2 EIA to be similar. They will result in a loss of approximately 3 ha of regrowth forest. Nonetheless, from a hydrological point of view, Phase 2 EIA confirmed that Alignment Option 1 poses significant challenges. The reason is that A1-W1 is entirely in the boundary of a natural stream that passes through CCNR and is known to support certain endangered fauna species.

Similarly, A1-W2 is partly within the boundary of a stream system that traverses CCNR. The NSS stressed the importance of protecting such streams from pollution due to its impacts to flora and fauna in CCNR. As such, mitigations in the form of treatment of liquid waste from A1-W1 and A1-W2 to PUB and NEA standards will need to be in place. The treated liquid waste will then be pumped and directed away from the natural streams to a designated PUB drainage system. Alignment Option 2 does not pose the above issues (LTA, 2019).

2.4 Spatial Boundary of Case Study

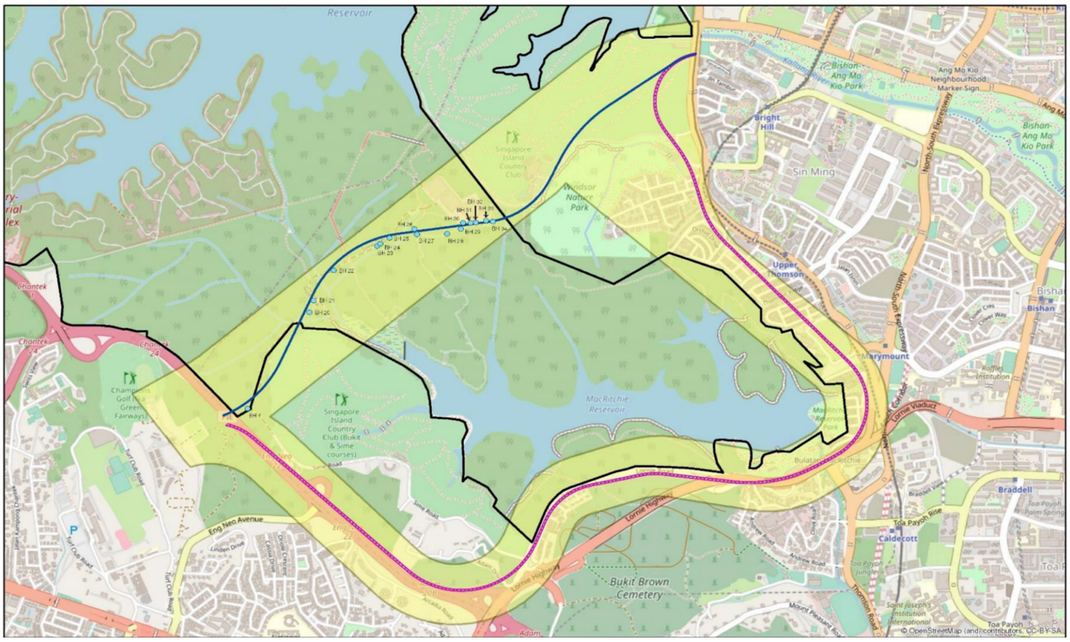


Figure 5 Yellow-highlighted area shows the boundary of CRL2. It bounds the area of site investigation competed in Phase 2 EIA, and will be used as the spatial boundary of this study report. Retrieved from Phase 2 EIA, LTA (2019).

From the bird's eye view, the scope of this case study is defined as the boundary of workstations A1-W1, A1-W2, A2-W1, A2-W2, A2-W3 (shaded in above diagram). This will be in line with the scope of EIA Phase 2. In this shaded region, it encompasses Windsor Nature Park, MacRitchie Reservoir, SICC Bukit Golf Course, and a portion of NSSF. The watershed above CCNR serves as the upper boundary. As defined in Phase 2 EIA, A1 worksites lie in the catchment streams that replenish the CCNR, while A2 worksites do not impact the CCNR.

Based on the bore drilling pre-scoping conducted in the EIA, the average depth from surface to groundwater surface ranges from 110m to 140m for alignment 1, and 110 to 130 m for alignment 2 (Refer to Appendix). This average will serve as the lower boundary of this case study. In between the upper and lower boundary, the groundwater aquifer that replenishes the CCNR watershed is included in the project scope as well.

As defined in this project, the spatial boundary is a simplified model that considers CRL2 and its direct development impacts on CCNR in isolation. However, it is noted that, in reality, the consequences would be expected to be complicated due to the intricate water systems present in CCNR.

2.5 Key Timelines of CRL Project
(Information retrieved from EIA Phase 2, LTA 2019)

17 January 2013: CRL was announced in the Land Transport Master Plan 2013

18 July 2013: NSS releases position paper proposing an alternative alignment

February 2014: LTA awarded tender to Environmental Resources Management for a two-phased EIA

August 2014 – December 2015: Phase 1 EIA (Baseline Evaluation of proposed alignments)

February – October 2017: Phase 2 EIA (Site Investigation Works)

02 September 2019: Phase 2 EIA gazette for public review

4 December 2019: Finalizing of decision on direct alignment (Alignment 1)

2020 – 2030: Construction Phase (Exact Timeline is still open to changes.)

2030 – 2080: Operation Phase (assumed)

2.6 Research Aims and Objectives

This study report aims to evaluate the CCNR under mutual exclusivity and co-existence with the CRL development. The results can aid existing EIAs and stakeholder discussions by providing an economic perspective. As the decision to proceed with Alignment 1 has been made, this study report does not aim to overturn the decision. However, exploring what could have been an alternative analysis through environmental valuation can provide essential insights and reference points for future urban developments in Singapore.

1) Under Context 1, estimate the opportunity costs in Alignment 1 using the opportunity cost framework, and then apply the Threshold Value method to understand if preservation could have taken precedence.

2a) Under Context 2, estimate the opportunity costs in Alignment 1 and then apply the Avoided Cost method to gauge the actual opportunity costs.

2b) Considering the alternative Alignment 2, investigate if the opportunity costs would be reduced or increased, and rationalize the best alignment in Context 2.

3) Understand the limitations in research methodologies in both contexts and explore possible use cases for future urban development in Singapore.

2.7 Research Methodology and Data Collation

This study report describes the valuation of an actual urban development project in Singapore, the CRL, traversing through the CCNR. The primary study materials for this case study are retrieved from the LTA website, which has links to the Phase 1 and Phase 2 EIAs of CRL critical to the arguments made in this report.

In context 1 and 2, for illustrative purposes, several parameters have to be assumed. For example, the income generated from the CRL2 has to be estimated through several assumptions as it requires unpublicized information. These assumptions are listed in their respective calculation tables.

2.8 Surface, Groundwater and Bedrock Hydrogeology

National Parks extensive research to generate hydrogeological baseline studies of NSSF has been conducted in the last decades. The research methods, objectives, and results were collated, and Cai summarized the conservation recommendations in 2018. Building upon the baseline study above, the Tropical Marine Science Institute developed hydrological models for NSSF, Upper Seletar, Upper Pierce, and Lower Pierce reservoirs. The models were calibrated using field survey data, and remote sensing data from groundwater flow, soil infiltration, channel flows, and overland flows.

TMSI's models were used to demonstrate the impact of rainfall and climate change on reservoir levels. The predictive models show that the hydrogeology is intricately connected and extremely sensitive. Hence, the construction of the workstations A1-W1, W2, and W3 might already impact the baseline surface and ground hydrogeology despite mitigation measures. Besides, it has been shown that the biota in CCNR is highly dependent on the region's geomorphic and hydrological stability (Sun, 2016). This dependence was also noted in a 2011 study by Ting, demonstrating a positive correlation between lower water levels and lower plant biomass in wetlands. As such, contrary to Phase 2 EIA, there might be evidence to show that CRL construction inevitably leads to ecological impacts in CCNR. In addition, the Phase 2 EIA did not consider the inherent time lag of groundwater and surface water should pollution occur. There are also unknown unknowns that need to be considered in sensitive ecosystems. In such cases, it is prudent that urban planners adopt the Precautionary Principle and err on the side of caution.

3. Environmental Valuation of CCNR

3.1 Context 1: Suppose the granite geology is an imperfect shield, the construction of CRL and the conservation of CCNR are mutually exclusive.

3.1.1 Conceptual Framework using Opportunity Costs

Traditional valuation methods like Contingent Valuation Methods, Choice Modelling, and Travel Cost Methods have their limitations in valuing unique ecosystems like CCNR. Using a hypothetical scenario of property development against the preservation of CCNR, Thampapillai (2011) described a conceptual framework to value CCNR using opportunity costs methods in an urban context.

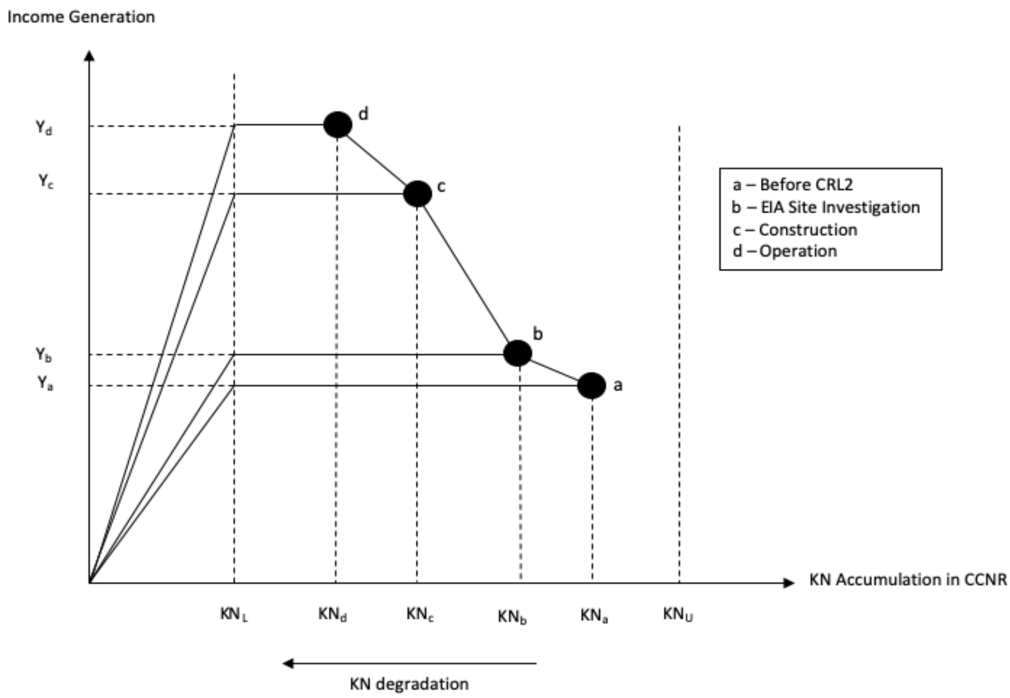
The framework is supported by concepts of entropy and the assimilative ability of environmental ecosystems. As urban ecosystems like Singapore's are highly entropic, the environmental ecosystems have low threshold values and rapidly degrade when developed past a threshold. The figure below shows the conceptual entropy-based framework adapted to CCNR's context.

The use of OC methods for environmental valuation is straightforward and convenient. By estimating the highest net income that has to be foregone in CCNR, the OC of preserving KN at CCNR can be approximated. In this case study, the income generation from CRL serves as the ideal income generation activity as the decision has already been made. However, it is prudent to understand that such a basis for valuation is always an underestimation. The reason is that the threshold value of KN supporting the urban ecosystem has not been considered. Hence, the initial OC will be used as a first step towards more

Figure 6 The increase in Income Generation as KN is degraded from the development of CRL2. Point a refers to CCNR's original state before CRL2. Point b refers to the point when EIA Site Investigation was carried out. As site drilling would have to be conducted, KN is degraded. Point c and d refer to the construction and operation phase of the project and their respective income generation and KN degradation.

accurate estimations of KN.

On the x-axis, KN refers to an aggregated attribute or index of CCNR that accumulates over time in the positive x-axis direction. From the construction of



CRL through CCNR, the attribute or index may degrade and move in the negative direction. In theory, KN could refer to any environmental index of an ecosystem. In this paper, the water quality of groundwater aquifers that replenish the watershed of CCNR could be used as the metric to represent KN. It is noted that KN_U is the maximum accumulation possible when no development has taken place.

On the y-axis, Y refers to the income generated from urban development. Y_a, Y_b, Y_c, Y_d are the amount of income generated, before building CRL construction, during EIA site investigation, during construction and after the building of CRL, respectively. Due to an inevitable impact on CCNR for urban development, there is a degradation of KN from KN_a to KN_d and a corresponding increase in Y_a to Y_d. KN_L refers to the assimilative threshold of CCNR, below which CCNR is no longer able to support Singapore's urban ecosystem and rapidly degrades. As CCNR's resource is utilized and income is generated, the increased entropy results in an increasingly fragile ecosystem.

3.1.2 Calculation of Opportunity Costs for Alignment 1

The net income generation of CRL2 through the CCNR can be simplified into four components. For illustration purposes, it is assumed that CRL2 takes ten years to complete construction with a 50-year operation timeline. In total, CRL2 has a construction and operation life cycle of sixty years.

The four cash flows components used to formulate the net OC of CRL2 are -

1) the construction costs of CRL2 over ten years from 2021 to 2030
2) the maintenance cost of CRL2 over fifty years
3) the mitigation costs pre and post-construction
4) as well as the income generation of CRL2 over fifty years from 2031 to 2080

From the EIA Phase 2 report, pre-construction and post-construction mitigation will be necessary for CRL2. However, their costs are negligible compared to other factors and will not be considered for simplification. A discount rate of 7% is used in this case study.

Based on the above activities and assumptions, the basic opportunity costs of preserving CCNR, (Y_d - Y_a), at net present value is shown by equation (1) below.

$$NPV\ of\ OC = Income\ Generation - Construction\ Cost - Maintenence - Mitigation \ldots(1)$$

The above equation (1) can be simplified into (2) as mitigation costs are negligible.

$$NPV\ of\ OC = Income\ Generation - Construction\ Cost - Maintenence \ldots(2)$$

Table 1 Calculation of PV of Construction Cost of CRL2 (Alignment 1)

Total Construction Costs	\$40.7 Billion
Cost of Construction per km	\$0.7017 Billion
Costs of CRL2 spread over a period of 10 years	\$2.8068 Billion
Annual construction cost (assuming *i* = 7%)	\$0.2084 Billion
Present Value of Total Construction Cost in 2021 (assuming *i* = 7%)	**\$2.08 Billion**

Assumptions
1. There is no huge increase in costs of materials over the construction life cycle and the projected cost of construction is fixed.
2. Costs estimates referred from official reports from LTA are accurate.
3. Unplanned costs like delays or increase in expenditures due to epidemics or other natural/man-made events will be not considered.
4. Each km of railway costs the same amount to construct, for a total length of 58 km for CRL.
5. Alignment 1 has a length of 4 km as stated by LTA.
*Refer to Appendix 4a for calculations.

Table 2 Calculation of PV of Maintenance Cost over 50 years (Alignment 1)

Total Railway Maintenance in 2018 for 203km of railway track.	$425 million
Railway Maintenance for 4km of Railway track in 2018	$8.37 million
Railway Maintenance for 4km of Railway track for the whole life cycle of 50 years from 2031 to 2080 (assuming *i* = 7%)	**$8.20 Billion**

Assumptions
1. According to LTA, the construction costs of CRL2 is estimated to be $40.7B and spread over 10 years from 2021 to 2030 (The Straits Times, 2016).
2. For simplification, it is assumed that there is no increase in maintenance costs over its life cycle.
3. Maintenance cost remains constant over the cost of its operating life cycle.
4. In the 2018 financial year, it is estimated that $425 million were spent on railway maintenance for a total of 203 km of railway track (The Straits Times, 2016).
*Refer to Appendix 4b for calculations.

Table 3 Income Generation of CRL2 over 50 years

PV of Total Revenue from CRL2 from 2031 to 2080 (assuming *i* = 7%)	**$11.55 Billion**

Assumptions
1. Maintenance costs to revenue ratio remain constant at 0.71 during the life cycle of CRL (The Straits Times, 2019.
*Refer to Appendix 4c for calculations.

Table 4 Summary of CRL2 Alignment 1 Total Benefits and Total Costs Over its Life Cycle

Total Present Value of Construction Costs	-$2.08 Billion
Total Present Value of Maintenance Costs	-$8.20 Billion
Total Present Value of Income Generation	$11.55 Billion
NPV of CRL2 Alignment 1	**$1.27 Billion … From equation (2)**

From equation (2), PV of Total Revenue can be estimated to be $1.27 Billion over its lifecycle. With the above summary, the basic direct OC, Y_d - Y_a, of

Alignment 1 is approximated to be $1.27 Billion. This represents the minimum value to be forgone in preference for conservation of CCNR in present value when considering Alignment 1. The urban planner has to decide if $1.27 Billion is an acceptable sacrifice to give up in favor of preservation of CCNR. To further aid the urban planner, the Threshold Value (TV) method could be incorporated.

3.1.3 Threshold Value Method (TV)

TV can be defined as the minimum value of benefits of preserving CCNR (growing at a specific rate r) in the initial year such that the present value of preservation is at least equal to the net present value of CRL2. Data on CRL2's projected income generation, construction costs and maintenance costs from relevant authorities have been collated and estimated above.

From Krutilla and Fisher (1985),

$$TV = \frac{NPV\ of\ Income\ Generating\ Activity}{PV\ of\ \$1\ growing\ at\ the\ rate\ of\ growth\ of\ preservation\ of\ benefits} \ldots (3)$$

The estimation of r is a complicated process as its value will have to be inferred from prior scientific inquiry or estimated if such scientific studies are unavailable. In this case study, r can be assumed to be growing at a minimal rate of 0.0005% per year for illustration purposes. Based on the same discount rate of 7% and a life cycle period of 60 years, the PV of $1 is 14.13.

Table 5 Summary of TV of CRL2 Alignment 1

NPV of CRL2	$1.27 Billion
NPV of CRL2 per year	$21.16 Million
Threshold Value (TV) of CRL2 **(Refer to Appendix 3d for calculations.)**	**$1.45 Million…** **From (3)**

As such, the Opportunity Cost reduces from $21.16 million to $1.45 million per year. This calculated TV represents the minimum value of the benefits of preserving CCNR in the initial year such that the present value of preservation is at least equal to the net present value of CRL2. In other words, if it can be shown that the ecosystem services provided by CCNR is more than $1.45 million annually, preservation of CCNR would take precedence over CRL2.

3.2 Context 2: Suppose that the granite geology indeed acts as an almost perfect shield, then the CCNR and CIL can co-exist.

3.2.1 Avoided Costs Method

Under this context, the Avoided Cost Method can be used to approximate the economic value of CCNR's surface and groundwater KN. Groundwater systems and surface water are generally open and complex interacting systems. As the reservoirs in CCNR form part of Singapore's domestic water resource, the Avoided Costs Method looks at valuing KN through the expenses avoided when treating polluted water to drinking standards.

In Alignment Option 1, the Phase 2 EIA Executive Summary Table 8 (Refer to Appendix 3) indicated that W1 and W2 worksite pollution is a major concern and that mitigation measures are necessary. The costs of these measures could serve as the minimum value placed on the surface and groundwater of CCNR. However, complete mitigation is impossible in practice and the Earth Control Measures aim to reduce the impacts as low as reasonably possible. Hence, the cost of returning the water system to its pristine state should the mitigation measures fail or from unforeseen circumstances needs to be considered as well. Prevailing data of such mitigation measures could be obtained from previous MRT construction works and discounted to present values.

While Singapore does not harvest groundwater directly for consumption, groundwater preservation is critical for its option value. PUB has already recognized groundwater as Singapore's 'fifth tap' to ensure water security (PUB, 2016). Due to limitations in research, developments that may infringe on CCNR's groundwater warrants the Precautionary Principle. The valuation of CCNR helps in this context to check if the value of groundwater may have been underestimated. Hence, a combination of TV and other methods like cost savings leads to less contentious evaluations than just using a just single method (Thampapillai, 2019) and may reveal the actual economic value of CCNR.

3.2.2 Conceptual Framework

Consider a simplified model mapping the concentration of a particular pollutant in a single point of an underground aquifer. The governing advection-diffusion equation (ADE) modeling a tracer's flow in a porous medium with steady flow in one dimension is shown below.

$$D\frac{\partial^2 c(x,t)}{\partial x^2} - v\frac{\partial c(x,t)}{\partial x} - \lambda Rc = R\frac{\partial c(x,t)}{\partial t}$$

where D is the diffusivity coefficient, and v is the seepage velocity vector. c refers to the concentration of the pollutant, while R is the retardation factor (how fast a contaminant moves relative to groundwater).

$$c(x,t) = 0, \qquad t = 0$$
$$c(0,t) = c_0\, exp\, exp\, (-\gamma t) \quad where\ 0 < t \leq t_0$$

The system (CCNR as defined in this case study) contains no pollutant initially, while γ and c_0 are constants representing the initial boundary conditions.

In the past decades, it has been found that fractional differential equations in general model real-world processes more accurately compared to integer-ordered differential equations (Atangana, 2013). Similarly, studies on more complex mediums of transport and initial conditions gave rise to the space-time fractional advection-diffusion equation (FADE), a generalized equation derived from ADE. In the FADE, the first order is replaced with the Caputo or Riemann-Liouville derivative of order $0<\beta<1$. Its second order derivative is replaced with the Caputo or Riemann-Liouville derivative of order $0<\alpha<1$. According to Khalique in a 2014 paper, the new parameters α and β characterize the flow of pollutants through the geological formations in groundwater. In this case study, the flow of a contaminant through groundwater in CCNR is modelled using the FADE as shown below. The left side of the curve shows a point pollutant dispersing from a point source, resulting in a spike in concentration. This is assumed to be true for the worksites A1-W1 and A1-W2 in Alignment 1. Over time, the pollutant disperses into the underground aquifer and surface water described by the FADE equations.

$$D\frac{\partial^{\alpha}c(x,t)}{\partial x^{\alpha}} - v\frac{\partial^{\beta}c(x,t)}{\partial x^{\beta}} - \lambda Rc = R\frac{\partial c(x,t)}{\partial t}$$

$$\frac{\partial^{\beta}c(x,t)}{\partial x^{\beta}} = 0, where\ x \to \infty$$

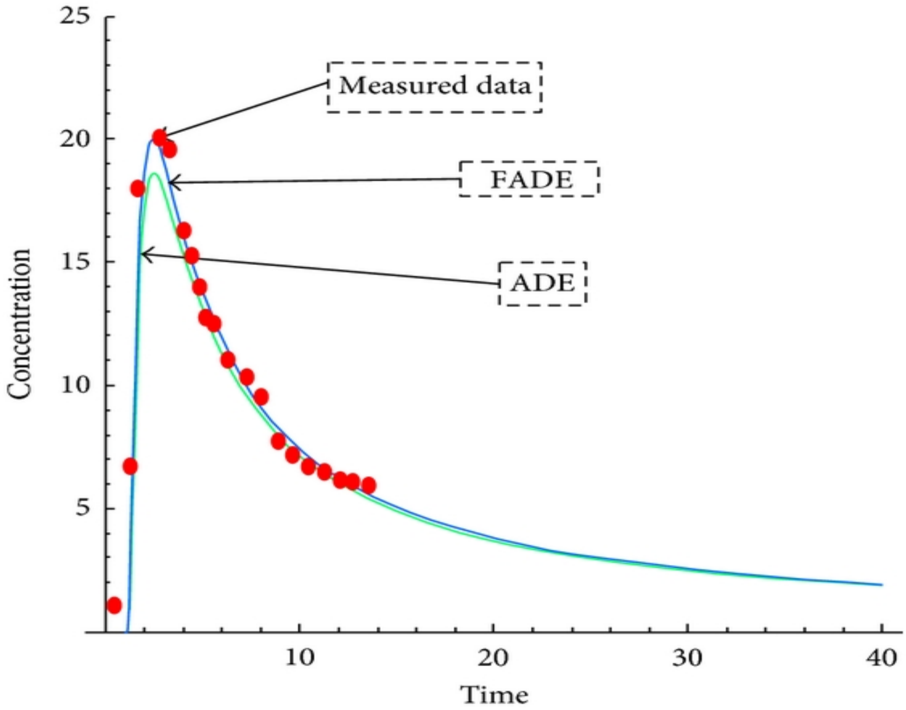


Figure 7 A model using FADE, ADE compared against measured data. FADE provides a better fit as compared to ADE. The shape of a general FADE is also reflected in the above chart, retrieved from Atangana, 2013.

While numerical simulations on FADE have been performed in various earlier studies, analytical solutions are relatively recent owing to the difficulties of solving fractional differential equations. The mathematics is complex and out of bounds of this report. However, the solutions had been found by numerical analysis that yields a general form shown above. In summary, FADE is confirmed to closely match measured real-world data with higher accuracy than ADE.

3.2.3 Baseline Pollution Levels

In a 2018 paper by Tropical Marine Science Institute, high concentrations of heavy metals (e.g., As, Cr, Mn, Ni, Sr, V) are detected in CCNR and more abundant in the lower catchment area than in the upper catchment area. The figure below shows the baseline levels comparison of heavy metals in NSSF and MacRitchie reservoir. It is noted that forest management is being impeded by soil surface erosion due to anthropogenic activities from leisure activities and back-flow of reservoir release water into lower catchment areas (Nguyen, 2018). The introduction of ground-level worksites due to the construction of CRL2 could cause soil erosion to exacerbate and lead to an increase of heavy metal presence in the swamps and reservoirs. Another alternative source that could serve as indexes is the chemical parameters derived from the Baseline Surface Water Quality Sampling from Section 5 of EIA Phase 2 Vol II. Some parameters include the DO, COD, BOD5 at 20°C as well as Oil and Grease.

Table 1. Comparison of the concentrations of selected elements in Nee Soon with those from others studies at MacRitchie and other locations in Singapore.

Site	Description	CR (ppm)	Mn (ppm)	CU (ppm)	Pb (ppm)	Zn (ppm)	(N)
MacRitchie vs Nee Soon (undisturbed lands)							
MacRitchie[1]	Natural Area	14	58	15	28	65	4
Nee Soon[4]	FUC	7	38	5	13	23	86
Nee Soon[4]	FLC	18	160	12	18	33	56
MacRitchie vs Nee Soon (disturbed lands)							
MacRitchie[1]	Industrial Area	47 (3)	146 (3)	47 (3)	71 (2)	268 (4)	8
Nee Soon[4]	ML	35 (5,2)	248 (7,2)	44 (9,4)	56 (4,3)	77 (3,2)	40
MacRitchie[1]	Mixed Disturbance	28 (2)	83 (1)	83 (1)	32 (2)	124 (2)	20
Nee Soon[4]	VDL	23 (3,1)	188 (5,1)	16 (3,1)	24 (2,1)	43 (2,1)	44
Other locations vs Nee Soon							
Unspecified[2]	Residential soil (0-5cm)	–	–	3–93	6–70	89–93	25
Unspecified[2]	Industrial soil (0-5cm)	–	–	1–485	51–235	15–3594	13
Main Island[3]	Main island soils	–	–	5–16	14–26	11–31	6
Nee Soon[4]	FUC (Nee Soon)	2–55	1–11	1–16	3–188	7–65	87
Nee Soon[4]	FLC (Nee Soon)	1–175	30–1184	3–84	3–377	11–98	56
Nee Soon[4]	ML (Nee Soon)	5–224	38–1362	7–632	8–10,000	17–431	40

Figure 8 The Table 1 of Nyugen's 2018 paper where concentrations of selected elements are compared in NSSF and MacRitchie Reservoir. This could be used as a baseline index in the Avoided Cost method.

Hence, by applying FADE to CCNR, the figure below shows a function due to migration of a pollutant with concentration C_{KN} of groundwater due to construction works in A1-W1 and A2-W2, and its resulting level of pollution in the surrounding reservoirs C_{KN} of reservoir. The function follows the shape of a general FADE, but with initial concentration $C(x,t) = C_0$ at $t = 0$. C_0 is the baseline level of pollutants present initially in the reservoirs and can be determined by scientific inquiry. For example, the presence of heavy metals as investigated by Nyugen or EIA Phase 2 baseline sampling and could serve as a baseline pollutant index in this case study.

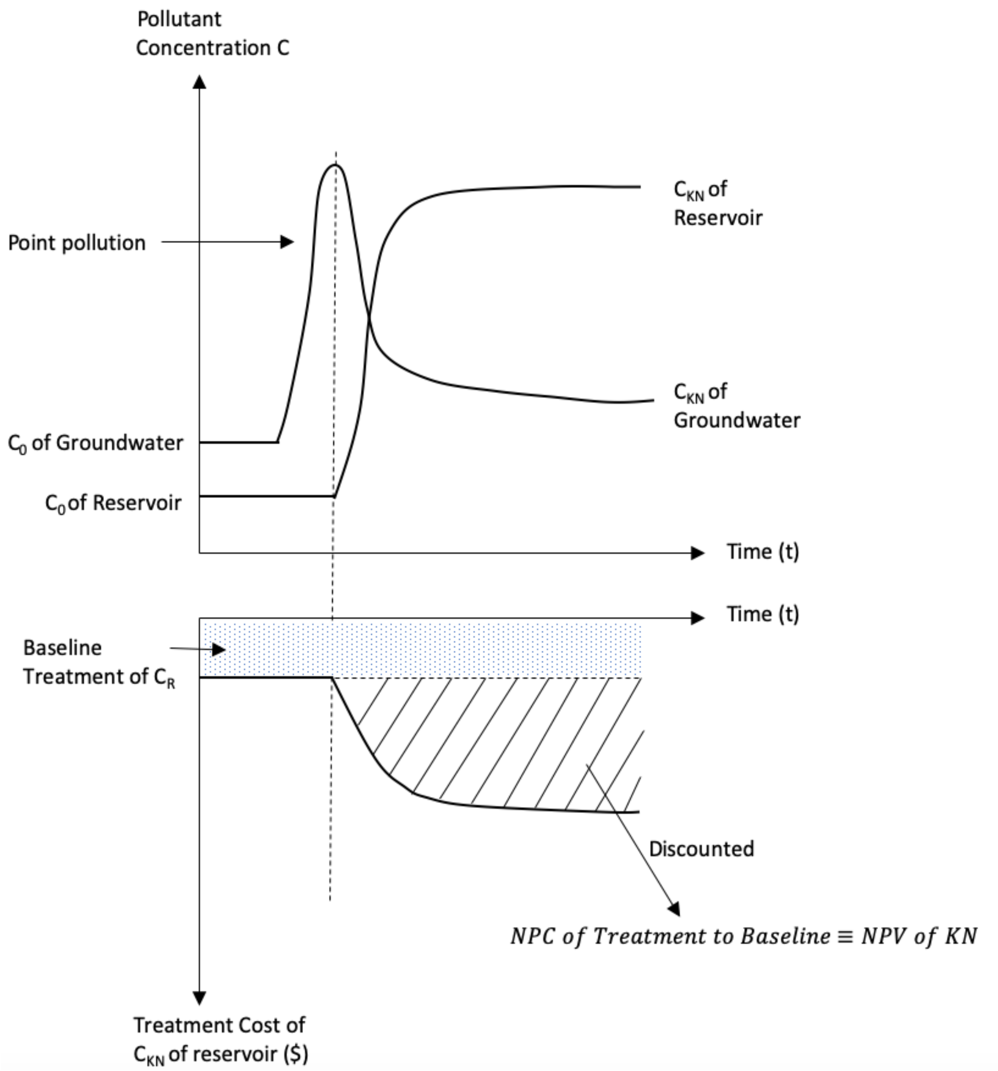


Figure 9 Change in concentration of pollutant in groundwater and reservoir, and the respective cost increase when treating back to baseline levels.

As C_{KN} of groundwater migrates through the underground aquifer, its concentration in a particular point decreases over time due to advection and diffusion. By the law of conservation of mass and assuming no flow of pollutants outside of boundary, C_{KN} of reservoir increases from its baseline level to a higher level as groundwater replenishes the reservoir. Over time, C_{KN} of groundwater and C_{KN} of reservoir decreases due to natural processes like decay, absorption or dispersion, evapotranspiration, etc. With information on the hydraulic topology, soil porosity, and other parameters obtained through detailed sampling and mapping of CCNR, the initial conditions of the FADE can be obtained, and the transport of C_{KN} of groundwater through the underwater aquifer into the reservoirs can be modeled.

Building on the graph shown above, a functional relationship can be derived by plotting the costs of treating reservoir water with increased pollutant concentration C_{KN} of the reservoir. It is expected that the cost of treating reservoir water with increased pollutant concentration will be more expensive than baseline treatment before construction. The total cost difference in treatment of reservoir water, as shaded in the bottom graph, is discounted to present value and represents the Net Present Cost (NPC) of the pollution. The NPC can be equated to the minimum Net Present Value (NPV) placed on KN by urban planners in Alignment Option 1.

3.2.3 Calculation of OC of Alignment 2

The OC calculated above can be further reduced if the alternative is considered. LTA officials evaluated Alignment Option 2 to cost an additional $SGD2 billion due to the extended construction. The three ground sites in Alignment Option 2, W1 W2 and W3, are evaluated by Phase 2 EIA to cause minor impacts to surface and groundwater. In addition, the worksites do not lie in the vicinity of natural streams that recharge CCNR, unlike those in Alignment Option 1. Hence, pre-mitigation measures are deemed sufficient in reducing impacts from minor to negligible, as stated in EIA phase 2. Since the pre-mitigation actions last only the first few months during the initial phase before construction, its costs should be in the range of a hundred thousand to at most millions. This cost would be about three factors of magnitude below $2 billion and can be considered negligible for simplicity.

Table 6 Calculation of PV of Construction Cost of CRL2 (Alignment 2)

Total Construction Costs	$40.7 Billion
Cost of Construction per km	$0.7017 Billion
Costs of CRL2 spread over a period of 10 years	$6.31 Billion
Annual construction cost of CRL 2 spread over 10 years	$0.4571 Billion
Present Total Construction cost of CRL2 in 2021 (assuming *i* = 7%)	**$4.57 Billion**

Assumptions
1. There is no huge increase in costs of materials over the construction life cycle and the projected cost of construction is fixed.
2. Costs estimates referred from official reports from LTA are accurate.
3. Unplanned costs like delays or increase in expenditures due to Covid or other events will be not considered.
4. Each km of railway costs the same amount to construct, for a total length of 58 km for CRL.
5. Alignment 2 has a length of 9 km as stated by LTA.
*Refer to Appendix 5a for calculations.

Table 7 Calculation of PV of Maintenance Cost over 50 years (Alignment 2)

Total Railway Maintenance in 2018 for 203km of railway track.	$425 Million
Railway Maintenance for 4km of Railway track in 2018	$18.84 Million
Railway Maintenance for 4km of Railway track for the whole life cycle of 50 years from 2031 to 2080 (assuming *i* = 7%)	**$18.46 Billion**

Assumptions

1. According to LTA, the construction costs of CRL2 is estimated to be $40.7B and spread over 10 years from 2021 to 2030 (The Straits Times, 2016).
2. For simplification, it is assumed that there is no increase in maintenance costs over its life cycle.
3. Maintenance cost remains constant over the cost of its operating life cycle.
4. In the 2018 financial year, it is estimated that $425 million were spent on railway maintenance for a total of 203 km of railway track (The Straits Times, 2016).

*Refer to Appendix 5b for calculations.

Table 8 Calculation of NPV of CRL2 (Alignment 2)

NPV of Total Revenue from CRL2 from 2031 to 2080	$26 Billion
Adjusted NPV of Total Revenue from CRL2 from 2031 to 2080	$22.1 Billion
NPV of CRL2 Alignment 2	**$-0.93 Billion**

Assumptions

1. Since Alignment 2 takes about 6 minutes less commuting time between any two CRL stations on either side of the CCNR and about 15% less per trip commuter fare on average, this can be assumed to serve as a proxy for the time cost of increased travelling.

2. The revenue from Alignment 2 will be adjusted 15% lower than Alignment 1 to account for the time loss, so as to calculate the Adjusted NPV of Alignment 2.

*Refer to Appendix 5c for calculations.

Table 9 Summary of OC in Context 2 (in Billions $)

	Alignment 1	Alignment 2
Construction	$2.08	$4.57
Operation/Maintenance	$8.20	$18.46
Income Generation	$11.55	$22.10
NPV of CRL 2 in 2021	$1.27	-$0.93
Present Value of Avoided Costs from 2021 to 2080	-NPC of Treatment of Polluted Reservoir Water	N/A
OC	**($1.27 – NPC)**	**-$0.93**

From this case study, it can be shown that Alignment 2 has a $-0.93 B Net Present Value when compared to Alignment 1's $1.27 B throughout the CRL2 life cycle. Hence, without considering avoided costs, the urban planner should choose Alignment 1 as it is economically feasible. However, the OC changes when Avoided Costs of treatment of polluted water is incorporated. Under this situation, the OC of Alignment 1 changes to ($1.27 – NPC).

For Alignment 1 through CCNR to be more feasible

$$\$1.27 - NPC > \$ - 0.93$$

Rearranging,

$$NPC < (\$1.27 + \$0.93) = \$2.2\ Billion$$

$$Avoided\ Costs\ NPC < \$36.7\ Million\ per\ annum$$

Hence, the Avoided Costs of treating polluted reservoir water has to be lower than $36.7 million per year for Alignment 1 to be more economically feasible. In other words, if it can be shown that treatment of polluted water to its baseline costs more than $36.7 million per year, Alignment 2 should be chosen in favor of Alignment 1. Based on information on existing treatment costs from PUB, it is possible to determine which alignment would have been a better option.

4. Discussion of Results and Potential Uses in Future Developments

4.1 Summary of Valuation of CCNR in Context 1 and Context 2

Table 10 Summary of Valuation of CCNR in Context 1 and Context 2

Context	Initial Valuation Methods	Further Reduction of OC	Criteria	Feasible Decision
1. Mutual Exclusivity of CCNR and CRL2	OC	TV	If ecosystem services provided by CCNR > $1.45 million per annum	Preservation of CCNR over CRL2
2. Coexistence of CCNR and CRL2	OC (Avoided Costs of Groundwater Treatment)	Alignment 2 (Skirting Alignment)	Cost of treatment of polluted water > $36.7 million per annum	Alignment 2 chosen over Alignment 1

Depending on the permeability of the granite geology, two different contexts emerged, and their conceptual frameworks for environmental valuation have been derived. The use of OC methods was ideal for urban development in rare ecosystems. After considering TV in Alignment 1 and an alternative Alignment 2 respectively, Context 1 and Context 2 OC have been further reduced.

In Context 1, the following argument could be made. Consider that MacRitchie Reservoir supplies the population with a maximum capacity of 600 million gallons or 2.27 million cubic meters of drinking water. The TV value of each cubic meter of water is deduced to be $0.64. Assuming a lower consumption tier Water Tariff in 2021 at $1.21 per cubic meter, it means that each liter of water has the potential to generate economic benefits of $0.57, that is ($1.21-0.64), at present value. The minimum benefits of preserving CCNR are more than $1.45 million per annum, and preservation could be considered.

In Context 2, if the cost of treating polluted water to its baseline levels exceeds $36.7 per annum, Alignment 2 should take precedence over Alignment 1. It is noted that this value indicates a minimum as there could be other contaminants resulting from Alignment 1. As such, the true OC avoided would likely be higher.

4.2 Limitations of Avoided Cost Method

While prior groundwater and surface water modelling in NSSF are available, the papers focused on the hydrogeological status and biodiversity of CCNR. No prevailing studies are done to model the flow of pollutants through its complex hydrogeology. As such, it is time-consuming and costly to accurately model the flow of a pollutant through CCNR's groundwater system, as a scientific inquiry on hydrogeological parameters and initial conditions is necessary. In this context, tracer studies would need to be conducted and calibrated to real-world data accuracy.

In addition, as groundwater is slow-moving, there is an inherent time lag. It could mean significant time, possibly years before C_{KN} of groundwater and reservoir reach equilibrium for calibration. There is also a chance of irreversible damage due to unknown unknowns, as stated in the Phase 2 EIA. Such occurrences would imply avoided costs that tend towards infinity. Furthermore, use cases in the future, like the extraction of KN as Singapore's reserve water source, are not considered in this scenario. As such, the values calculated above are a minimum of which preservation would take precedence. Lastly, the OCs computed using this method are underestimated. In reality, there could be numerous pollutants increasing above the baseline study. It would be impractical to calculate the actual OCs due to the time required. The more practical method would be to account for the costlier pollutants for treatment to baseline levels for calculation.

4.3 Possible Improvements of Avoided Cost Method

In Context 2, the framework described the minimum OC as only one pollutant is considered in the Avoided Cost Method. Practically, if only one pollutant results in an Avoided Costs higher than that of treatment, it is enough to determine that Alignment 2 would have been a better option.

In reality, a multitude of contaminants is expected to be increased above the baseline levels. Some would be significantly more impactful and hence costlier to treat back to baseline, while others will be negligible even when increased above their baseline levels. It provides an opportunity for future research where the key parameters, for example, those listed in PUB drinking standards, could be considered for analysis and modeled using the framework described. Such a study would provide completeness for all future urban developments that encroach on CCNR.

4.4 Other Alternative Methods for Evaluation of Context 2

The survey-based method, CVM, can be applied to estimate the Willingness-To-Pay (WTP) when an environmental change has been made. By carefully designing a valuation problem to suit CCNR's context, the WTP for the protection of KN in CCNR can be directly estimated. Next, a survey can be crafted explicitly with only yes and no questions to reduce the complexity and save on budget. Lastly, their WTP to protect CCNR will be estimated by asking the first subgroup how much they are willing to pay and using standard statistical analysis. The process can be repeated with other groups while increasing the monetary threshold. A relationship between WTP of the sample and those who replied "yes" can then be obtained. It is used as a proxy for the demand curve of protection of KN.

However, while improvements have been made to CVM over the years, its reputation as a valuation tool for policymaking remains in question. In this context, there is a limited understanding amongst the general public regarding the ecosystem services provided by KN in CCNR and what it means for their interests. As such, the population will have to be equipped with the necessary information. It is not an easy task to decide on the minimum required information required. Hence, the survey will need to be expertly crafted. As this CRL project is complex and considering the unknown future use cases of KN, the scope of the study will be costly.

Another possible method that has been applied for ecosystem valuations is the Travel Cost Method (TCM). The TCM compiles information from the cost incurred by individuals when they travel to KN for recreation. Since this cost is unique to each individual, the sum of the travel cost reveals the combined value of KN placed by the individuals. However, TCM would not be suitable in this context because even though CCNR has recreational attributes, the site where CRL2 traverses has limited access to the public. Hence, while KN does provide in-site services like recharging surface water and supporting groundwater-dependent ecosystems, attributing the portion from traveling to the above uses is challenging.

Compared to TCM, the advantage of using the Avoided Cost Method is that there is no cost aversion bias. As the recharging surface water is currently the only direct use value of CCNR’s KN in Singapore, water has to be treated to drinking water standards. Furthermore, the education of laypeople on groundwater services is not necessary as PUB can monitor the pollution levels in reservoirs. Lastly, there is already an established market in place in valuing the incremental unit treatment costs required for an incremental unit of pollutants due to construction. This allows a convenient and direct OC calculation.

The valuation of CCNR’s groundwater and surface water might not be suitable using the Hedonic Pricing Method (HPM). This valuation method uses the variation of prices of nearby properties as a proxy to estimate the demand for a particular KN. However, the extent of pollution of KN will probably not be isolated in the source location due to the vast network of groundwater systems and its complex interactions with surface water. As such, the impact of a groundwater parameter on the property price may be hard to detect statistically.

4.5 Environmental Valuation of Groundwater and its Importance for Singapore

In environmental valuation, the Total Economic Value (TEV) of CCNR's KN includes both non-use values and use-values, currently and in the future. Non-use values are the most difficult to estimate TEV components as economists' values are subjective. As mentioned above, the use of CVM and TCM to CCNR is not ideal. As such, the use of TVs and Avoided Cost methods could be viable alternatives. The methods hold for the non-use values of KN necessary for supporting the biodiversity in CCNR and for future uses like extracting KN. Furthermore, as Singapore is a resource-scarce country, the protection of unique ecosystems with underground water systems is of utmost importance. The case study provided in this paper could also be applied as a reference for future projects.

Furthermore, as Singapore is a resource-scarce country, the protection of unique ecosystems with underground water systems is of utmost importance. The case study provided in this paper could also be applied as a reference for future projects. In 2016, Singapore began officially exploring the use of groundwater and underground spaces for water security. Due to the nature of the complex groundwater systems, the sensitivity of groundwater to pollutants was high and reflected the need to protect this resource. At present, there is no direct market price for the extraction of groundwater in Singapore. This project provided an opportunistic first point of reference by the TV of groundwater at 0.64 cents in CCNR. It is noted that this TV changes according to the site whereby the groundwater is extracted in Singapore - the more unique and sensitive the ecosystems are to external disturbances, the higher the r value, and the lower the TV is expected. As discussed in the next section, applying the TV to other developments can help understand the risk and payoffs of economic activities in an urban context.

Rationalizing backward, one could argue that the urban planner knew about economic payoffs or other intangible factors not considered in this paper. For example, expansion plans for the CRL2 line or other income generation activities based on CRL2 in the future could be one of the factors. The decision to adopt Alignment 1 could also demonstrate the planner’s risk averseness to the value of ecosystem services. The r value of the CCNR’s could have been underestimated resulting in a higher TV value. Hence, it could explain why Alignment 1 was chosen.

4.6 Future Urban Development in Singapore (Tengah Forest)

The calculations in both Context 1 and Context 2 provide valuable reference points for future urban developments that might encroach CCNR. As a formal decision to adopt a direct alignment has been made, environmental valuations of CCNR using CRL2 allow for a direct market valuation instead of indirect markets like house properties. One case in point is illustrated below.

The Singapore URA Master Plan in 2013 revealed that the Tengah forest in Jurong district would be partially developed into public housing. This development encroaches on a 5 km long and 100 m wide green corridor named the "Tengah Nature Way." It forms part of the 360 ha Jurong Lake District mixed-used business district. While this development is a significant undertaking in line with a new transport connecting Singapore and Malaysia (now defunct), critics pointed out that the ecological sustainability plans lack certain areas. In addition to four Globally Threatened Species listed in the Singapore Red Data Book 2008, the Tengah forest also contributes to the Western Catchment areas in Singapore.

Owing to the striking similarities of the nature of the project in the Tengah forest, CCNR's valuation model could serve as a guideline. For illustration purposes, suppose the OC framework was applied to the Tengah forest, with its income generation activity derived from public housing dwellings. An r value could be estimated through scientific inquiry, and the TV of preservation be estimated. The TV will provide a decision framework that allows the urban planner to gauge if preservation should take precedence for the Tengah forest. Furthermore, when applying a similar calculation for the ground and surface water in the Western catchment areas, it is possible to estimate the TV of a cubic meter of water based on this project. With the additional information and, by extension, through the study of other developments in Singapore, planners can now optimize the urban development of public housing dwellings and other infrastructures through threshold analysis. Since such analysis can incorporate other considerations like population dynamics, economic and risk factors, it adds a more holistic approach to evaluating urban developments, in addition to pre-requisites like EIAs and stakeholder discussions.

5. Conclusion

The task of planning urban developments that infringes on sensitive ecologies is not straightforward, and often, different stakeholders evaluate the risks and payoffs subjectively. While the use of EIAs and discussion panels is mandatory and helpful, economic valuations could provide straightforward comparisons. In this study report, the development of CRL2 through CCNR gave rise to an opportunity to evaluate the value of CCNR and whether preservation should have taken precedence.

In Context 1, it is calculated that the Net Present Value of CRL Alignment 1 amounts to $1.27 billion over its life cycle. This opportunity cost is further reduced to $1.45 million per year using the Threshold Value (TV) method. In other words, if the present value of preservation in the initial year is at least equal to the net present value of Cross Island Line at $1.45 million per year, preservation of CCNR should take precedence. Based on the TV theory, the TV value of each cubic meter of water is approximated to be 0.64 cents. This valuation is less than the 2021 lower tier water tariff of $1.21 and suggests that preservation of CCNR could take precedence. The OC framework was applied to Context 1. When incorporated CCNR's growth, it is confirmed that the OC is indeed reduced using the TV method, satisfying Objective 1 of the study report.

In Context 2, the Avoided Cost Method is applied under the presumption that the groundwater would be polluted above a baseline level as indicated in EIA Phase 2. The pollution would result in higher water treatment costs from MacRitchie Reservoir and forms the opportunity costs for Alignment 1. This opportunity cost is then compared with Alignment 2 at a $-0.93 B Net Present Value. The OC changes when considering the Avoided Costs of treatment of polluted water. It was shown that if the treatment cost to the baseline level is more than $36.7 million per year, Alignment 2 should be chosen in favor of Alignment 1. For objectives 2a and 2b, the OC method applied to Context 2 was confirmed to be reduced after considering the alternative alignment. Hence it shows that there is an argument to be made in favor of Alignment 2.

This paper showed that if an economic perspective has been considered in either context, the result could have differed. CRL2 might have adopted a costly alignment (at face value) around CCNR and still reap more economic benefits from that decision. Because the decision to choose Alignment 1 has already been made. In either case, regardless of the scientific consensus granite geology's permeability, there is a case to argue for the alternative alignment.

The study report fulfills Objective 3 of serving as a case study for future developments in Singapore. It does so by allowing a retrospective review of urban planning and risk tolerance in Singapore. This review could serve as a valuable framework and aid future urban developments that encroach ecosystem services, like the Tengah Forest project. Owing to the similarities, urban planners, nature lovers, and the general populace could use the framework described in this study report to evaluate the Tengah Forest project. Together with EIAs and stakeholder discussions, only then can a project be thoroughly reviewed.

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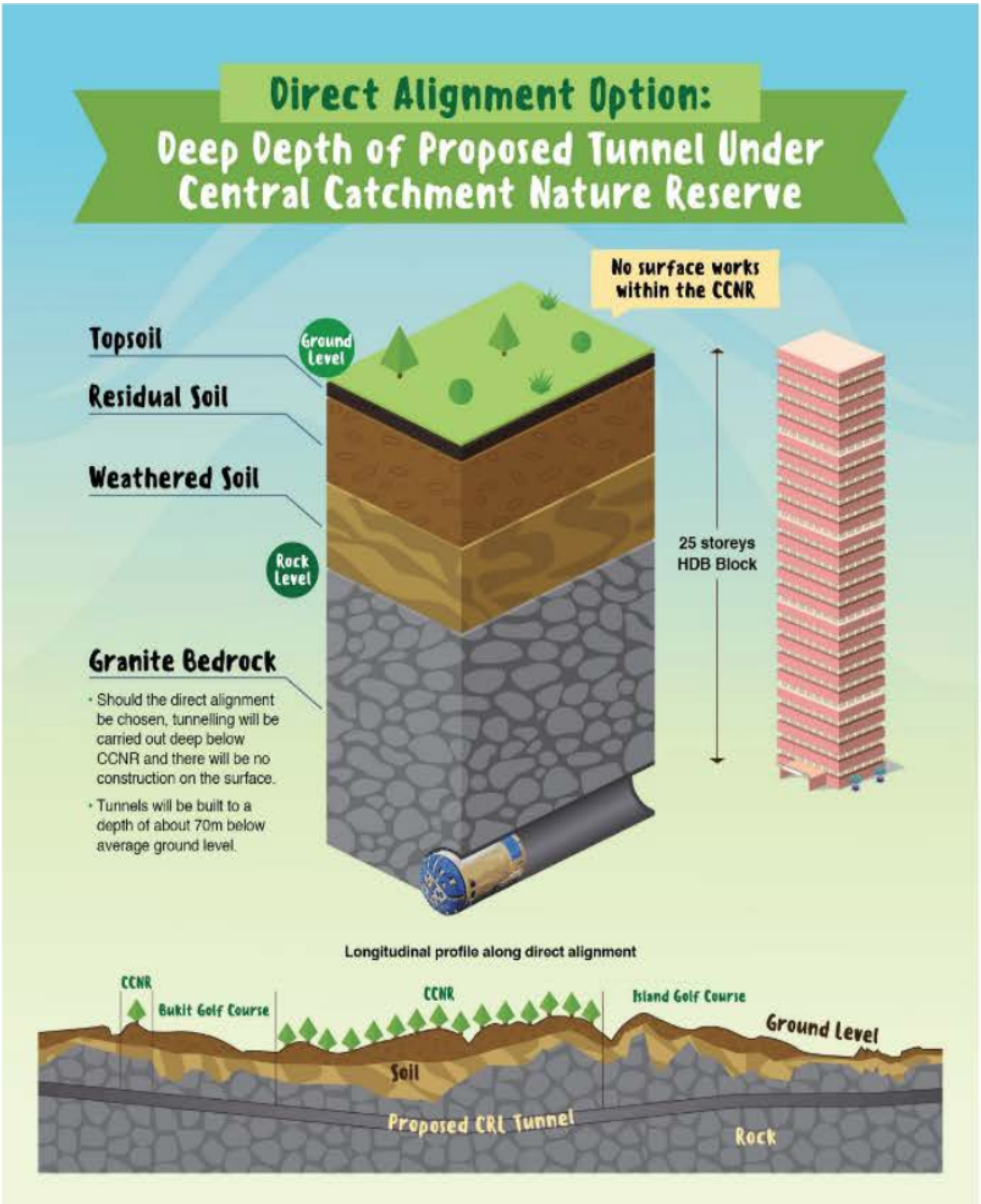
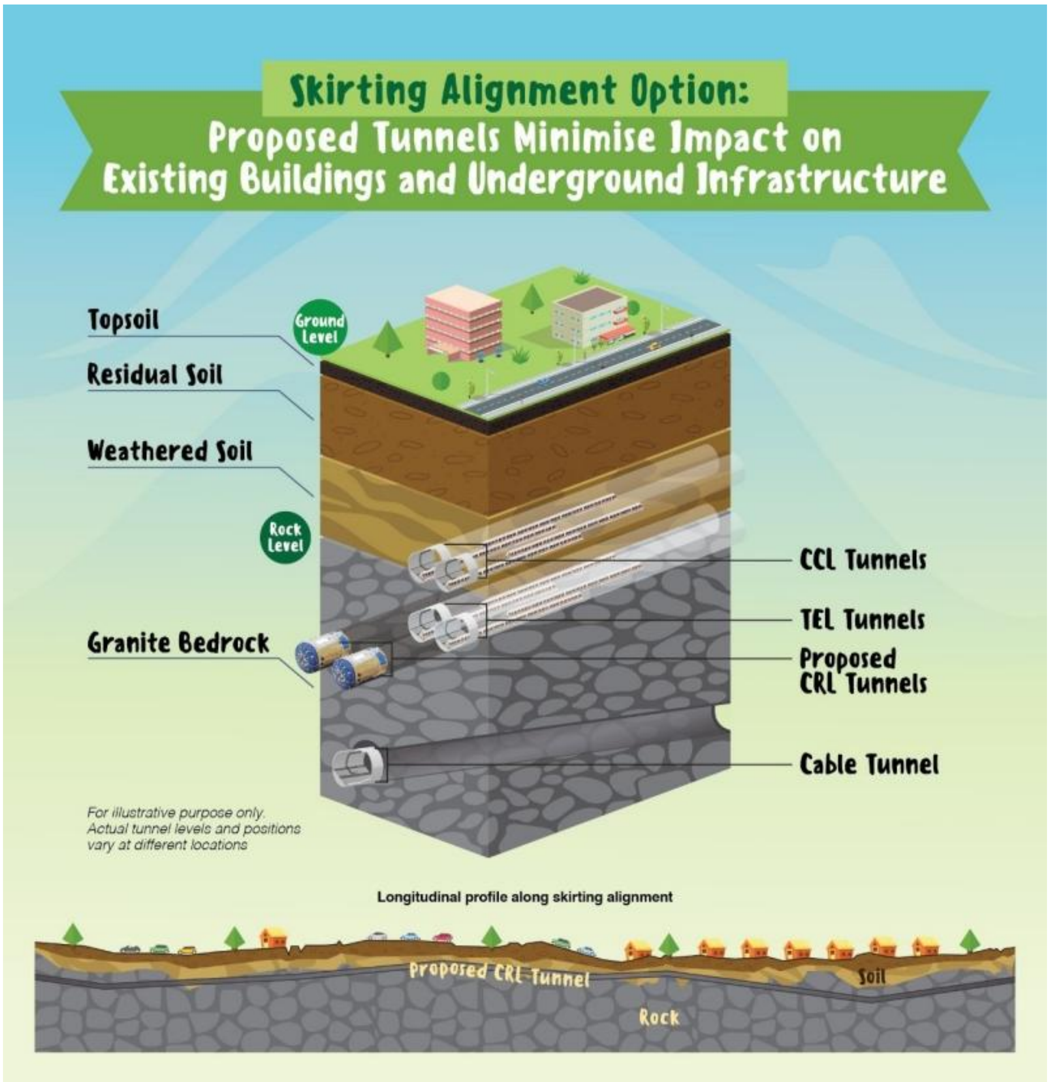
7. Appendix

Appendix 1. Direct Alignment (Alignment 1) infographic retrieved from LTA website.



Appendix 2. Skirting Alignment Option (Alignment 2) infographic retrieved from LTA website.



Appendix 3. The Table 8 from Phase 2 EIA Executive Summary, LTA (2019), showing that aquatic habitat will be majorly polluted without the necessary measures in place.

Table 8 Alignment Option 1, Pre-Mitigation Impact Significance for Construction Activities (Ecological Resources)

W1 A1-W1 worksite; W2 A1-W2 worksite; Tunnel alignment; [S] – Species [H] Habitat	Sensitivity / Vulnerability / Importance of Ecological Resource or Receptor		
Magnitude of Impact	**Low**	**Medium**	**High**
Negligible	**Negligible**	**Negligible**	**Negligible**
Small	**Negligible**	**Minor** W1 [H] Habitat fragmentation W2 [H] Loss of habitat [H] Habitat fragmentation	**Moderate** W1 [S] Exacerbation of edge effects W2 [H][S] Exacerbation of edge effects [S] Habitat fragmentation Tunnel alignment [S] Disturbance to wildlife
Medium	**Minor**	**Moderate** W1 [H] Loss of habitat	**Major** W1 [S] Loss of habitat [H] Exacerbation of edge effects [S] Habitat fragmentation [S] Disturbance to wildlife [S] Increased injury from vehicle strike W2 [S] Loss of habitat [S] Disturbance to wildlife [S] Increased injury from vehicle strike
Large	**Moderate**	**Major**	**Major / Critical** W1 W2 [H][S] Pollution of aquatic habitat

Appendix 4a. Context 1 – Calculation of Present Total Construction Costs of CRL2 Alignment 1

Total Construction Costs	\$40.7 Billion
Cost of Construction per km	\$40.7 ÷ 58km = \$0.7017 Billion
Costs of CRL2 spread over a period of 10 years	0.7017 × 4km = \$2.8068 Billion
Annual construction cost (assuming *i* = 7%)	\$0.2084 Billion
Present Total Construction Cost in 2021 (assuming *i* = 7%)	\$2.08 Billion

Assumptions

1. There is no huge increase in costs of materials over the construction life cycle and the projected cost of construction is fixed.
2. Costs estimates referred from official reports from LTA are accurate.

3. Unplanned costs like delays or increase in expenditures due to Covid or other events will be not considered. 4. Each km of railway costs the same amount to construct, for a total length of 58 km for CRL. 5. Alignment 1 has a length of 4 km as stated by LTA.

Appendix 4b. Context 1 - Calculation of Present Total Maintenance Costs of CRL2

Total Railway Maintenance in 2018 for 203km of railway track.	$425 million
Railway Maintenance for 4km of Railway track in 2018	425 ÷ 203 × 4 = $8.37 million
Railway Maintenance for 4km of Railway track for the whole life cycle of 50 years from 2031 to 2080 (assuming *i* = 7%)	**$8.20 Billion**

Assumptions

1. According to LTA, the construction costs of CRL2 is estimated to be $40.7B and spread over 10 years from 2021 to 2030 (The Straits Times, 2016).
2. For simplification, it is assumed that there is no increase in maintenance costs over its life cycle.
3. Maintenance cost remains constant over the cost of its operating life cycle.
4. In the 2018 financial year, it is estimated that $425 million were spent on railway maintenance for a total of 203 km of railway track (The Straits Times, 2019).
5. Singapore has a railway network of 203km in 2018.

Appendix 4c. Context 1 - Calculation of Present Value of Total Revenue of CRL2

PV of Total Revenue from CRL2 from 2031 to 2080 (assuming *i* = 7%)	**$11.55 Billion**

Assumptions

1. Maintenance costs to revenue ratio remain constant at 0.71 during the life cycle of CRL.

Appendix 4d. Summary of TV of CRL2 Alignment 1

NPV of CRL2	$1.27 Billion
NPV of CRL2 per year	$1.27 \times 1000 \div 60$ = $21.16 Million
Threshold Value (TV) of CRL2	**$21.16 \div 14.3$ = $1.45 Million**

Appendix 5a. Context 2 – Calculation of Present Total Construction Costs of CRL2 Alignment 2

Total Construction Costs	$40.7 Billion
Cost of Construction per km	\$40.7 x $10^9 \div 58$ = \$0.7017 Billion
Costs of CRL2 spread over a period of 10 years	0.7017 x 10^9 x 9 km = $6.31 Billion
Annual construction cost of CRL 2 spread over 10 years	=$0.4571 Billion
Present Total Construction cost of CRL2 in 2021 (assuming *i* = 7%)	**=$4.57 Billion**

Assumptions

1. There is no huge increase in costs of materials over the construction life cycle and the projected cost of construction is fixed.
2. Costs estimates referred from official reports from LTA are accurate.
3. Unplanned costs like delays or increase in expenditures due to Covid or other events will be not considered.
4. Each km of railway costs the same amount to construct, for a total length of 58 km for CRL.
5. Alignment 2 has a length of 9 km as stated by LTA.

Appendix 5b. Context 2- Calculation of Present Value Total Maintenance Costs of CRL 2 Alignment 2

Total Railway Maintenance in 2018 for 203km of railway track.	$425 million
Railway Maintenance for 4km of Railway track in 2018	$425 × 10^6 ÷ 203 × 9 = $18.84 Million
Railway Maintenance for 4km of Railway track for the whole life cycle of 50 years from 2031 to 2080 (assuming *i* = 7%)	**$18.46 Billion**

Assumptions

1. According to LTA, the construction costs of CRL2 is estimated to be $40.7B and spread over 10 years from 2021 to 2030 (The Straits Times, 2016).
2. For simplification, it is assumed that there is no increase in maintenance costs over its life cycle.
3. Maintenance cost remains constant over the cost of its operating life cycle.
4. In the 2018 financial year, it is estimated that $425 million were spent on railway maintenance for a total of 203 km of railway track (The Straits Times, 2016).

Appendix 5c. Context 2- Calculation of Present Value Total Revenue of CRL2 Alignment 2

NPV of Total Revenue from CRL2 from 2031 to 2080	$26 Billion
Adjusted NPV of Total Revenue from CRL2 from 2031 to 2080	26 × 0.85 = $22.1 Billion
NPV of CRL2 Alignment 2	**22.1- 18.46 -4.57 =** **$-0.93 Billion**

Assumptions

1. Since Alignment 2 takes about 6 minutes less commuting time between any two CRL stations on either side of the CCNR and about 15% less per trip commuter fare on average, this can be assumed to serve as a proxy for the time cost of increased travelling.

2. The revenue from Alignment 2 will be adjusted 15% lower than Alignment 1 to account for the time loss, so as to calculate the Adjusted NPV of Alignment 2.