TRANSPOWER

HVDC Link Upgrade Programme
Major Capex Proposal (Stage 1)

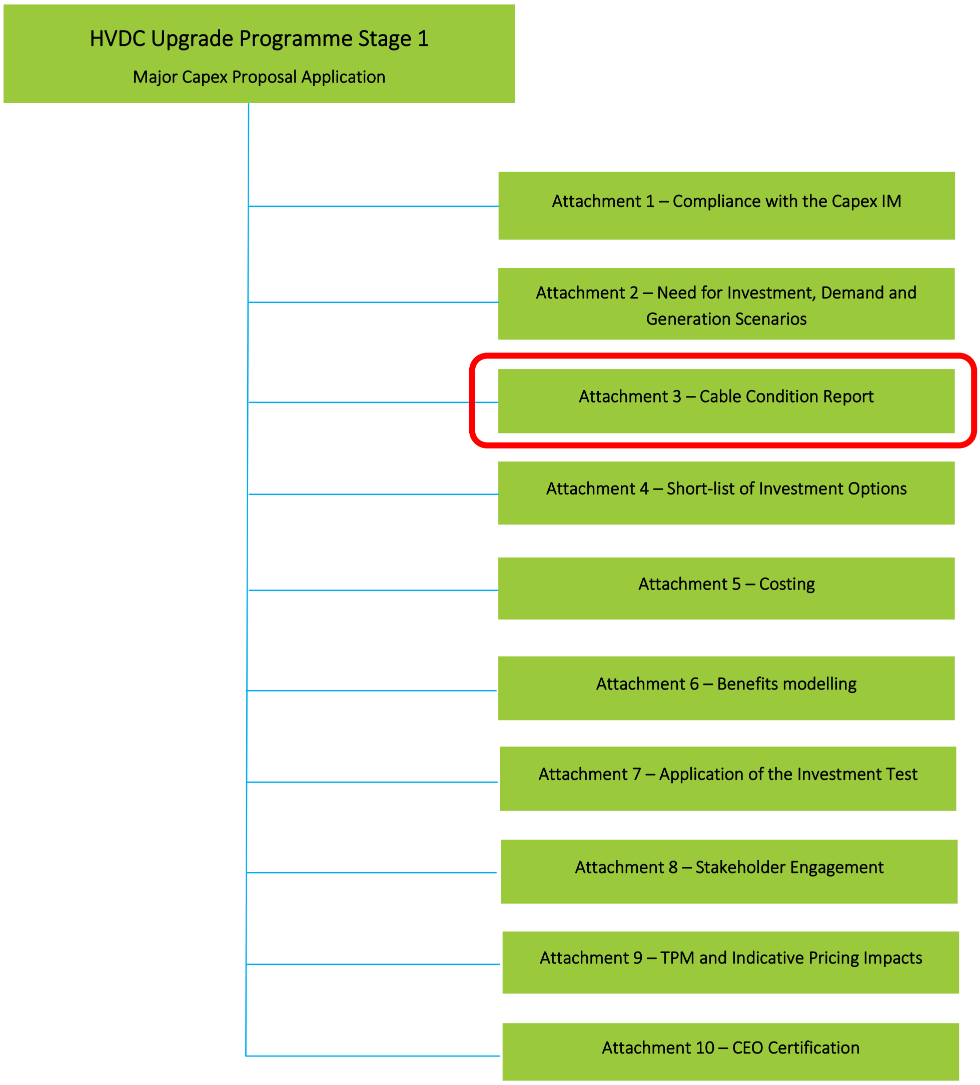
Attachment 3: Cable Condition Assessment Report

September 2025

Contents

Purpose

This document forms part of our HVDC Link Upgrade Programme Stage 1 Major Capex Proposal (MCP). The purpose of this report is to outline condition assessment information, which has informed the need to replace the HVDC submarine cables.



Executive Summary

The HVDC system provides a high-capacity connection between the North Island and South Island electricity systems. The HVDC system will play a key role as an energy market tool, in compensating for intermittent renewable generation, providing system stability and managing changing load patterns going forward. As such, the role and service criticality it plays in connecting New Zealanders will evolve along with electrification.

New Zealand's HVDC system has three submarine power cables. The cables (Cable 4, 5, and 6) are ~40km each in length and were commissioned in 1992.[1] The estimated life expectancy (advised by the manufacturer) is ~40 years. This report discusses the condition-based asset health of the submarine cables.

We have undertaken asset health modelling of our submarine cables to predict the (increasing) risk of failure and to determine when the cables require replacement. Also, we have recently considered capacity increases for the HVDC as part of our Net Zero grid pathway submission.[2]

The asset health model design is informed by a failure mode and effects analysis (FMEA) of the HVDC submarine cables. The model calculates and forecasts asset health using an expected life of 50 years combined with location factors, duty factors and observed and measured condition. Factors include current flow in the Cook Strait, seabed composition, cable depth and cable support (freespans) and the number of voltage polarity reversals. The observed condition is obtained through regular Remotely Operated Vehicle (ROV) and Scuba inspections. Measured condition is obtained through annual electrical testing, specifically Line Impedance Resonance Analysis (LIRA).

The condition of the cable and the submarine environment vary along the length of the cables. The health model recognises this and divides each cable into 1 km sections. The section with the poorest score drives the asset health for the whole cable.

The forecast year for earliest intervention is 2032 for cables 4 and 5, and 2035 for cable 6. The intervention criteria represents an increased likelihood of failure, and as the asset health scores increase further so does the probability of failure at an increasing rate. Replacement of the cables is a risk-based decision. The proposed replacement time is driven by the outputs of our asset health model with an understanding of the consequences of failure including restoration time, the lead times for the design, procurement, installation, and commissioning.

A significant amount of preparation work is required to design and install a cable for Cook Strait including seabed/marine surveys, designing the cable route, risk assessments, cable system designs and cable manufacturing. There is a ~7-year lead time for reserving a cable laying vessel and manufacturing 'slot' for the cables. A further consideration is that a repair following a cable failure is estimated to take at least 6-12 months. Once a single failure occurs it indicates a risk of multiple cable

[1] Cables 1, 2 and 3 are the original cables that are no longer in service.

[2] Net Zero Grid Pathways 1 - Phase 1, Major Capex Proposal 2023

failures within a few years as the cables were laid around the same time and are exposed to same submarine environment, so degradation is expected to be similar.

The length and potential variability of lead times, the increasing probability of failure, the extended restoration times, and the consequence of failure all factored into the proposed cable replacement timing. We proposed the cable replacement program of work as a listed project in RCP4, to adequately manage these uncertainties.

1 Cable history and cable design

The original HVDC 250 kV gas-filed submarine cables installed in 1964 failed in service a number of times due to lead sheath cracking, which contributed to insulation failure of rigid joins or lead sheath creep/fatigue failure. Eighteen failures were repaired between 1964 and 1985. Only one cable was still in service in 1992 (at the time of commissioning of Pole 2), and this cable failed in 1996 due to a gas leak. In summary, the lifetime of the original cables (with numerous repairs) was between 27 and 31 years.

The HVDC link currently has three 350 kV DC submarine cables, connected between the cable terminal stations at Fighting Bay (South Island) and Oteranga Bay (North Island). These cables are of a mass impregnated type, with the minimum number of factory joints and have been in operation for 32 years. The cables were installed in 1991 and commissioned in 1992 during the HVDC upgrade project. Two cables are now connected to Pole 3 (cables 5 and 6) and one cable to Pole 2 (Cable 4).

The length of each undersea cable is approximately 40km. The cables have 1,400 mm^2 copper conductors and are nominally rated for 1430 A at 350 kV. Two of the cables were manufactured by ABB (now NKT) in Sweden and the third by Alcatel/STK (now Nexans) in Norway. They are degasified special viscous compound impregnated, paper insulated, solid type cables known as Mass Impregnated Non Draining (MIND) Cables. The MIND HVDC cables are currently the most used type of cable for HVDC submarine applications; however, recent developments in extruded insulation cables are now making these the preferred cable type. Their compact design makes MIND designs particularly suitable for deep water applications. In contrast, their use for land applications is limited compared to extruded cables.

The cables consist of both round and key stone conductor made of copper, fully degasified special viscous compound impregnated insulation paper, an insulation shield, a sheath of alloyed lead, a waterproof anti-corrosion polyethylene sheath, reinforcement, armouring, and a polypropylene outer serving. HVDC cables 4, 5 and 6 have polypropylene yarn as their outer serving. This is shown in Figure 1.

Figure 1: HVDC Submarine cable Cross-section (key stone conductor), 127mm Outside Diameter.

The armouring provides support for the cable during installation as well as mechanical protection. This includes erosion by the seabed and moving boulders. It comprises two layers of the cross-wound steel armour applied in opposite direction and separated by the bedding tape. Loss of one layer (or significant wire reduction) will introduce additional torsion in the cable.

2 Failure mode and effects

The lifetime of a submarine cable is governed by several factors:

- The cable design, materials, and quality of the manufacturing process and installation
- Electrical operating parameters and lifetime stresses
- Mechanical forces acting on the cable
- Marine and environmental factors.

Electrical stresses are related to how the cable is operated. HVDC interconnectors can only send power in one direction at any point time, however, operational needs may require power to be sent in either direction to balance demand and supply, or to perform functions such as voltage or frequency control. There are times when a reversal of power flow direction is required.

In a Line Commutated Converter (LCC) system, thyristor components that rely on the oscillating voltage of the AC side of the system to turn on or off are utilised. The current flows through the devices in one direction only, so to achieve power flow reversal the polarity of the HVDC voltage is changed. This event is called a voltage polarity reversal (VPR).

The rate and timing of the VPR have an impact on the cable life. A slow VPR is where there is a relaxation time over a number of minutes at zero voltage before ramping to the other polarity. Slow VPR’s allow cool-down before polarity changes and give the oil sufficient time to redistribute, ensuring the insulation is ready to handle the reversed electrical stress. Transpower performs slow VPRs where possible as this is less detrimental for the cable. Under unplanned/transient events (e.g. faults) fast VPRs occur, and these have a greater cumulative effect that is detrimental to the life of the cable.

Our HVDC link also employs round power to minimise electrical stresses. Round power routes return currents through the cables rather than through the ground. This technique helps maintain a baseline temperature in the cables, preventing them from cooling down completely during reduced load periods or outages. Sudden cooling and reheating from temperature cycling can impose additional stress on the insulation. By keeping the cables warm, round power supports the self-healing process and stabilises the cable's dielectric strength.

Mechanical stresses include the abrasion, erosion and corrosion of the cable outer sheath and armouring through ocean velocity and seabed materials such as boulders and gravel moving across the cable. In addition, in long freespan areas where the cable is unsupported, cables can move significantly causing abrasion.

Mechanical stresses can lead to fatigue of the lead sheath through repeated bending and vibrations of the sheath at freespans. This is caused by the forces of tidal currents and the vortex shedding of the water. There are many cable freespan sections and the majority them are in high velocity zones. Overall, there are 114 freespans with 11 of those having an unsupported section of cable greater than 10m. The longest unsupported section is 17.2m. The lead sheath is also vulnerable to fatigue failure from thermal stresses causing contraction and expansion.

The table below outlines how these stresses and failure modes are considered within the Asset Health model, which is used to understand a current and future view of condition-based health.

Table 1: Failure modes and inputs to the cable asset health model.

Component	Failure event	Failure mode	Comments	Factors in Asset Health model
Insulation between copper conductor and lead sheath	Breakdown of insulation - localised heating	Manufacturing defect		LIRA: D-Norm
	Breakdown of insulation - water ingress	Water entering joint or at termination		LIRA: Delta G, depth of ocean
	Breakdown of insulation - high curvature	Trawling/fishing vessels pulls on the cable resulting in reduced thickness of cable insulation (high stress on stretched side).		LIRA: Delta G
	Thermal degradation of insulation	Overloaded operation, design, voltage polarity reversals. Normal aging process.	Thermal model stops overheating. Lightning, harmonics, faults	Polarity reversals, LIRA: Delta G.
Lead Sheath	Failure of submarine cable due to lead sheath being bent (fatigue)	Damage from cable movements	Freespans are the number and distances of cable unsupported	Freespans, Visual inspection report.
	Failure of submarine cable due to lead sheath expansion/contraction (fatigue)	Thermal cycling causing expansion and contraction due to loading cycles		Voltage polarity reversals LIRA: D-Norm
Oversheath - two layers of steel wire armour	Corrosion/erosion of armour results in lead sheath being damaged and sea water entering insulation	Exposure to sea water after propylene yarn is damaged. Contact with acidic seabed material. Presence of anaerobic bacteria.	Includes marine organisms attaching to or eating away sheath materials	Seabed composition, Velocity of ocean current, Freespans. Visual inspection report.
	Abrasion of steel wire armour after polypropylene yarn is damaged eventually leads to sea water entering insulation	Abrasive material moving across galvanised steel wire armouring due to tidal currents	In addition to causing bending forces, freespans create points for abrasion	Seabed composition, Velocity of ocean current, Freespans. Visual inspection report.
Not included in Asset Health model	Seismic displacement or burial, tsunami.	N/A	Natural hazard	N/A
	Cable damage due to ship's anchor or fishing weights puncture the sheath, sinking of a vessel, damage from ROV	N/A	Managed by patrols of cable protection zone and visual inspection.	N/A
	Dragging of cables over each other, slack towing cable, bending cable beyond minimum radius	N/A	Installation fault. Managed through installation and visual inspection	N/A

Internationally, 48% of subsea cable failures are caused by the environmental causes armour abrasion, armour corrosion, and sheath failure.[3]

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[3] Causes of subsea cable failures 1991-2006 SSE (http://sse.com/). Environment 48% third party damage 27%, manufacturing 5%, installation 8% and 12% fault not found,

3 Condition data

3.1 Observed Condition

3.1.1 ROV Survey 2024

Transpower's service provider, Seaworks, undertakes survey inspections using a Remotely Operated Vehicle (ROV). The ROV-20 utilised survey inspection and reporting package (DigitalEdge v5) in conjunction with HD subsea video acquisition. This provides event logging and data recording and reporting process as well as high-definition video footage. Observations from surveys, and categorised defects, are recorded for each kilometre of cable known as a Kilometre Post (KP).

In 2024 the ROV-20 operations commenced on 8 January 2024 and concluded on 30 January 2024. The survey productivity was high despite spells of poor weather. The following coverage was achieved:

- A total of 25.5km was surveyed across the subject cables out of a total scope length of 59.9km, achieving 2km more coverage than the previous ROV campaign.
- Of the cable lengths surveyed, 40% were on high priority items, 25% on medium priority items and 35% on low priority items.
- 100% coverage was achieved on high priority scope items for HVDC cable 6.

Where covered under the priority survey regime, existing sites of known damage or instability were re-inspected, with one case of deterioration observed.

A new anomaly report for the HVDC cable was found: a new free span exceeding 10m along HVDC cable 4, located between KP8.245 – 8.257. Such anomalies can result from seabed changes and highlight the dynamic nature of the environment, where new defects and conditions can emerge over time. The asset health model has been updated to incorporate this free span as a location factor.

3.1.2 Annual Dive Surveys

Dive surveys and maintenance works are carried out on the cables within Oteranga Bay. These dive surveys are done annually. These surveys assess the condition of the cables out to approximately KP 1.2, or 25 metres water depth (beyond this point the ROV is now used). These inspections are carried out to the extent that mobile sand burial and un-burial of the cables permits.

Within Oteranga Bay, there are a few points where HVDC cables cross reefs in shallow water and are subject to surge action in southerly swells. These points on the 1991 cables have been the subject of inspection virtually since installation and require periodic inspection by divers and if found necessary, occasional maintenance attention to the abrasion protection steps that have been taken on earlier surveys.

In March 2015 a dive survey was conducted in Oteranga Bay to monitor points of damage and sites of interest from previous dives. Various new or previously buried outer layer serving damage sites were located and protected.

One dive survey was also conducted in Fighting Bay in 2000, revealing that the cables had all self-buried out to the mouth of the bay. Fighting Bay features a more benign seabed compared to that of Oteranga Bay. Based on these observations, it was seen as unnecessary to include Fighting Bay in the regular survey programme.

In December 2022 a diving-based inspection was conducted in the Oteranga Bay to undertake a continuous video survey of exposed lengths of cables, monitor points of damage / interest from previous surveys, identify any new points of interest, and take protective steps as appropriate. Two new anomalies were observed on the in-service HVDC cables. The first was on HVDC cable 4 where multiple instances of minor serving damage were observed. Repairs were performed at 7 different sections along the offshore length of the cable, with multiple clips installed and poly tape protection added to contain minor serving damage. The second anomaly was on HVDC cable 6 on the Fighting Bay side, where the cable was observed to be in contact with an old chain. No cable damage was apparent at this site, and it appeared the suspected anchor and chain had been there for many years.

The 2024 Scuba dive inspection found some contact damage to the serving on cable 5, and the model was updated for future monitoring. No other new anomalies were found on the remaining cables.

3.2 Cable 4 observations

1. KP 0.567-0.577 – from Scuba report 2021. Armour exposure to underside of cable.

Figure 4: Armour exposure to underside of HVDC#4 KP0.575 beneath clip 113.

2. KP 3.950 – 3.970 – from ROV report 2020. Wide pattern of sliding contact damage from contact with FO9 applying downward pressure on crown of cable 4.

Figure 4: Serving damage - wide pattern KP3.963

3. KP 9.274 – 9.278 – from ROV report 2020. This has been downgraded to a minor defect but is something to note. Protection mats installed to cover bare armour.

Figure 6: West protection mat (damaged outer) KP9.277

4. KP 8.532 – from ROV report 2024. Shows historic serving damage on HVDC cable 4.

Figure 8: Historic serving damage KP8.532

5. KP 8.078 – from ROV report 2024. Shows the cable in freespan, 8m in length.

Figure 3: Freespan KP8.078

6. KP 0.106 – from Scuba report 2015. 9m extensive serving damage and 3m of exposed armour. Burial has since prevented inspection during dive surveys.

There have not been reports on cable 4 for the following KPs since 2018:

KP 14, KP 16, KP 30, KP 31, KP 32, KP 33, KP 34, KP 36, KP 37, KP 38, and KP 39.

3.3 Cable 5 observations

1. Major Defect at KP 3.637 – from ROV report 2020. Area of most severe damage, rupture of serving and wear sleeve, caused by sliding contact abrasion of FO#9.

There have not been reports on cable 5 for the following KPs since 2018: KP 20, KP 24, KP 25, KP 30, KP 31, KP 32, KP 33, KP 34, KP 36, KP 37, KP 38, and KP 39.

3.4 Cable 6 observations

1. From Scuba report 2022. Cable 6 protected by split-pipe at shoreline.

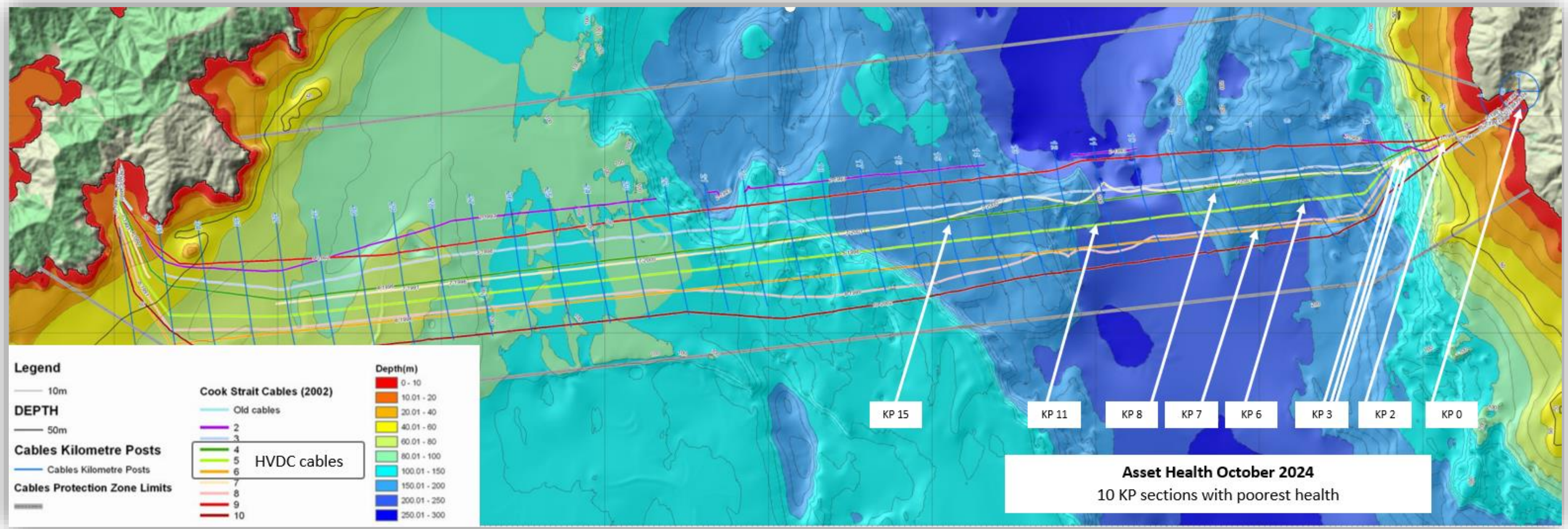
2. KP 1.116 – from Scuba report 2022. Cable with repair bandage.

There are no reported major defects on cable 6.

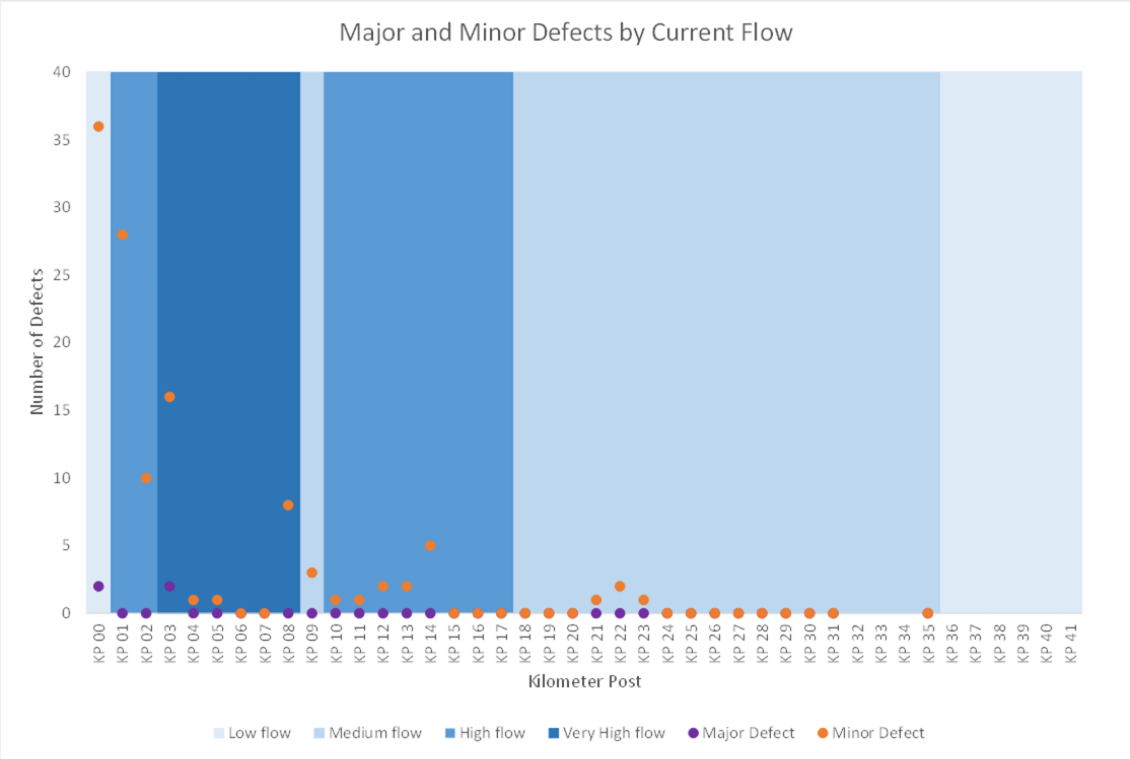
There have not been reports on cable 6 for the following KPs since 2018: KP 23, KP 24, KP 25, KP 26, KP 27, KP 32, KP 33, KP 34, KP 36, KP 37, KP 38, KP 39, KP 40 and KP 41.

3.5 Summary of Major and Minor Defects

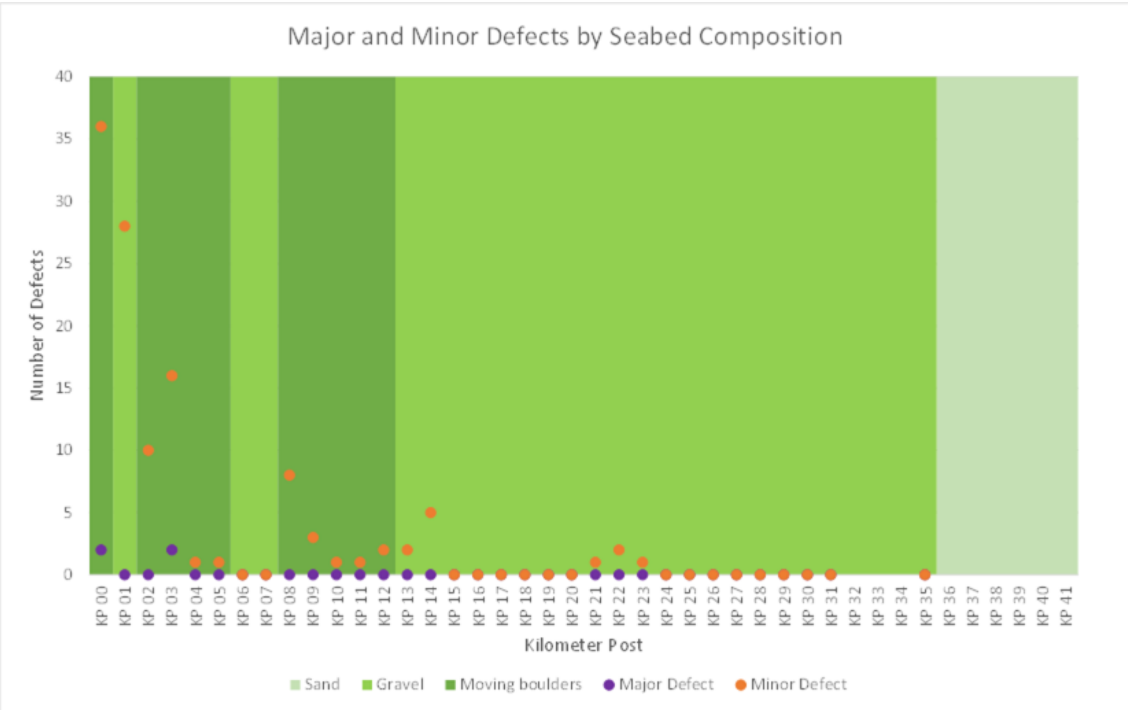
The figure below shows the bathymetry and location of the HVDC cables within Cook Strait. The KPs along the cable are marked out and KP0 is where the cable starts from Oteranga Bay (OTB).



Charts below show the location of defects relative to KP, relative to tidal currents and relative to seabed composition. The majority of defects are at the Oteranga Bay end where tidal current velocities are highest, and where the seabed composition is more aggressive e.g. boulders.



Different coloured dots represent major defects (purple) and minor defects (orange). The shades on the graph indicate the current velocity. Highest currents can reach 3 m/s, this velocity is unique to our NZ situation. A darker shade points to higher current velocity. Note that the end with the higher current velocity had more observed defects.



The shades on the graph indicate seabed composition. Darker shades were used for more aggressive seabed. This can move around with the current and the end of the graph with aggressive seabed had more observed defects.

3.6 Measured Condition

3.6.1 Electrical Testing with LIRA – Line Impedance Resonance Analysis

The electrical testing is to measure and verify the insulation integrity in the Cook Straight HVDC cables (4, 5 and 6). This is done as part of regular maintenance on the cables with special emphasis on determining if the cable system (inc. joints and terminations) properties have changed since the last measurements from Oteranga Bay in 2022 and 2024

The Line Impedance Resonance Analysis (LIRA) system provides a unique, comprehensive system for degradation localisation and condition assessment of cables. The system can monitor progressive degradation of cables due to material or environmental conditions. The system can detect and localise defects due to local mechanical effects or local abnormal environmental conditions.

LIRA is based on transmission line theory. Defects are identified by calculations and analysis of the complex line impedance as a function of the applied wide band signals. There is high correlation between the insulation condition and the properties of the insulation's dielectric material. A change in dielectric constant, mainly capacitance, lead to changes in the cable impedance (globally and locally).

A white noise is applied over a wide frequency band (generator) to analyse the input impedance of a transmission line (the cable). A change in the insulation material will cause a change in the dielectric properties of the insulation, the capacitance. This is monitored and analysed as a change in cable impedance.

3.6.2 2024 LIRA test summary

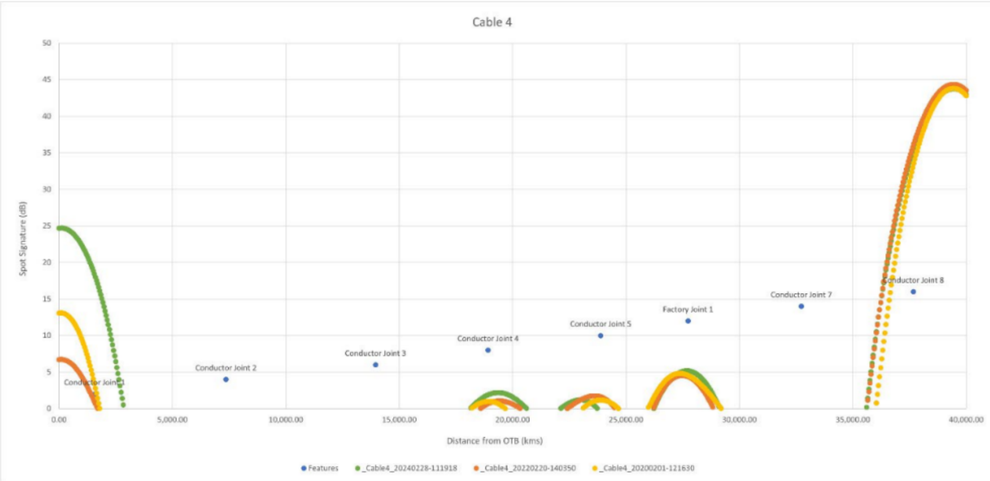
Cook Strait HVDC cable 4 was LIRA tested on 28th Feb 2024 while Cables 5 and 6 were LIRA tested on 25th Feb 2024 from Oteranga Bay. The cable at Fighting Bay cable termination was earthed. Results were compared to previous year's results.

LIRA testing[4] confirmed the following for all cables tested.

- No new spot signature locations.
- No increase in magnitude for known Spot signatures.
- Overall, the cables' insulation is in good condition and there are no areas of concern.

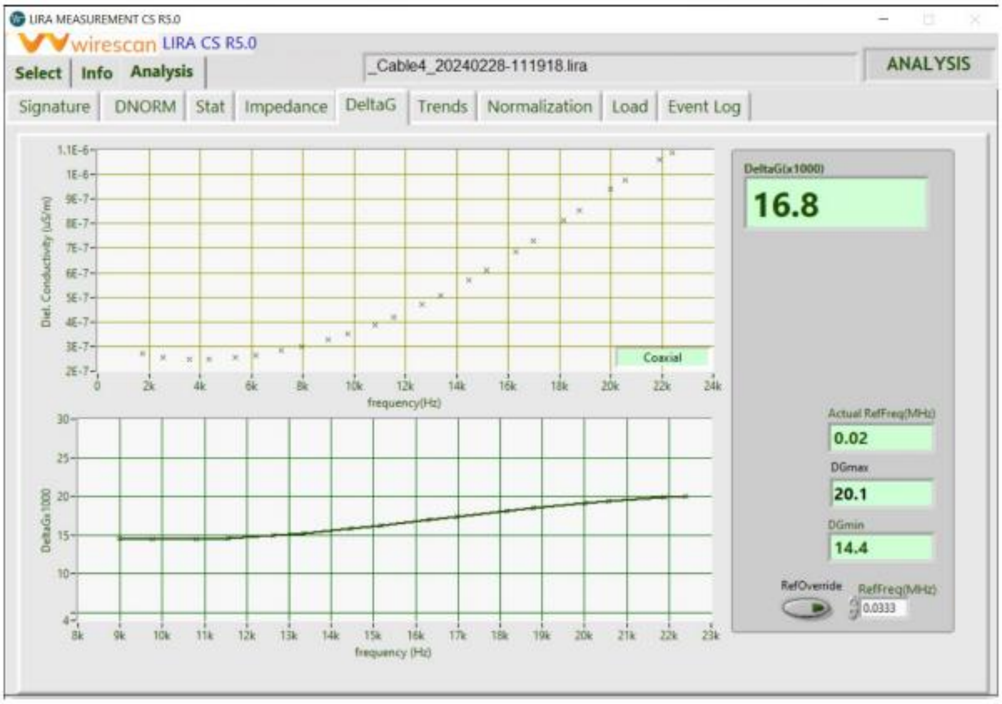
[4] Transpower LIRA Report 2024.pdf

3. Cable 4 LIRA Spot Signature:



4. Cable 4 DNORM:

5. Cable 4 DeltaG



3.6.3 LIRA Comparison with Previous Tests

Results are compared against previous years LIRA results using the same settings.

- Spot signatures found in 2024 are mostly consistent with the Oteranga Bay signatures in 2022 and 2020.
- Table 1 shows all the DeltaG measurements are below 30, which means the overall insulation of the cables are in good condition. The increase of DeltaG of cable 6 in 2020 is due to the high resistance measurement.
- 2024 Results taken from Oteranga Bay are consistent will all other results.

Table 2: DeltaG and BTS measured in 2020-2024.

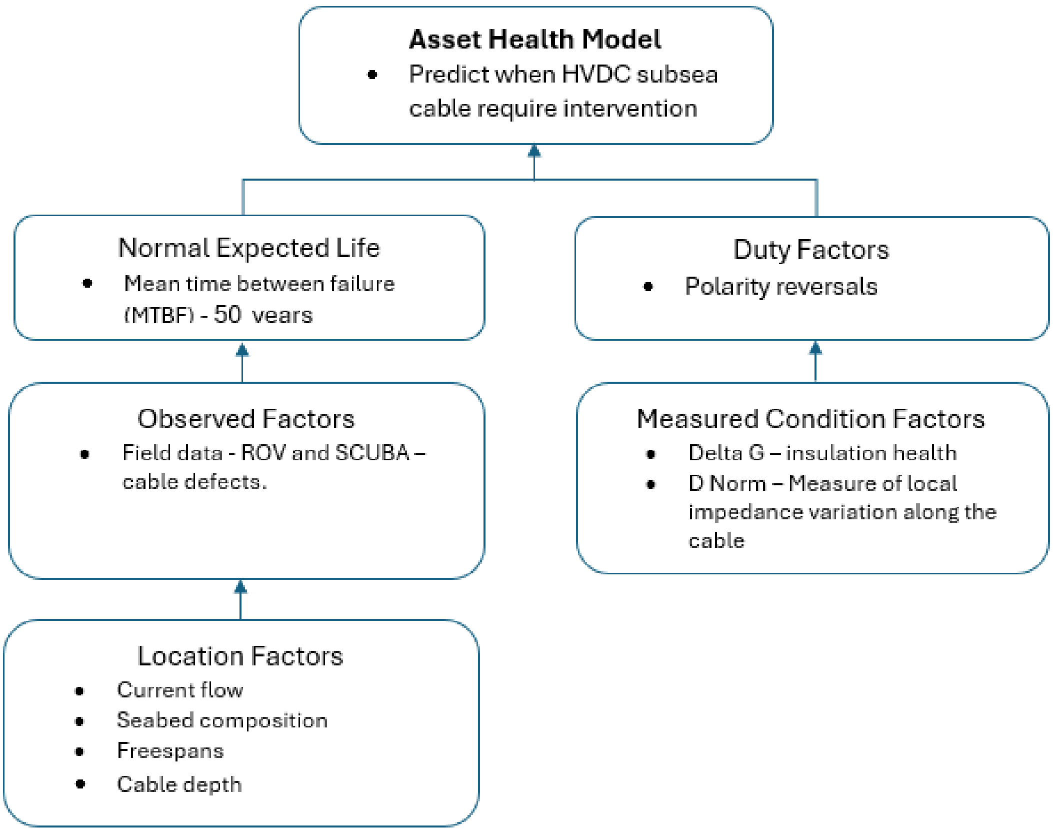
	DeltaG 2020	DeltaG 2021	DeltaG 2022	DeltaG 2023	DeltaG 2024	BTS 2020-2024
Cable 4	23.1	26.1	23.9	17.4	16.8	0.0
Cable 5	20.7	26.5	24.9	20.5	27.6	0.0
Cable 6	39.8	23.2	25.8	24.9	22.6	0.0

4 Asset Health Model Design

The methodology in the asset health modelling for subsea cables uses the common network asset indices methodology. This methodology is used in the UK and internationally for transmission level equipment including subsea cables. Our asset health model is updated annually to include new condition assessments, test results, and operational data. The current health and predicted intervention year can vary with each information update on condition, testing and operational duty.

These assessments do not predict an exact year for a failure, rather as cable health deteriorates, the probability of failure increases exponentially. The asset health model provides both current and future asset health information for each kilometre of the cables. The asset health score and predicted intervention year for each cable are determined using the poorest kilometre section on that cable, as it only takes a failure on one point in the cable to remove it from service and necessitate repairs.

4.1 Factors within model



4.1.1 Location Factors

Velocity is a factor in erosion/wear of cable.

Current Velocity	Description
Low flow	< 1.0m/s
Medium flow	1.0m/s ≤ current flow < 2.0m/s
High flow	2.0m/s ≤ current flow < 3.0m/s
Very high flow	≥ 3.0m/s

Cable depth is a factor when there is water ingress in the cable.

Cable Depth	Description
0m to < 50m	Average cable depth per KP
50m to < 100m	Average cable depth per KP
100 to < 200m	Average cable depth per KP
≥ 200m	Average cable depth per KP

Seabed composition is a factor in erosion/wear of cable. The cables are laid directly on the seafloor in diverse conditions, including silt, sand, gravel, and suspension over steep rock outcrops, and are subject to strong tidal and current forces. Moreover, natural burial of the cables has been observed in places consisting of sand and/ or stone, which could directly impact the cable system performance (i.e. rating).

Seabed Composition	Description
Sand	Sand
Gravel	Gravel/ gravel & soft mudstone/ sand & gravel
Moving boulders	Silt, sand & moving boulders/ greywacke rock

Freespans are a factor for wear and bending in the cable.

Freespans	Description
No freespans	Count of freespans
< 5m	Count of freespans
5m to < 10m	Count of freespans
≥ 10m	Count of freespans

4.1.2 Duty Factor

Voltage polarity reversals create internal stresses within the cable.

Reversals	Description
0 to 11 reversals	Max reversals per day
12 to 24 reversals	Max reversals per day
≥ 25 reversals	Max reversals per day

4.1.3 Measured Condition Factors

Delta G is the LIRA global ageing indicator. It quantifies the health of insulation.

LIRA: Delta G	Description
0 to 40	Good condition
> 40 to ≤70	Aging
> 70	Replace

DNorm is the severity assessment tool in LIRA. It is a measure of local impedance variation along the cable.

LIRA: DNorm	Description
< -20	Poor condition
-20 to 20	Good condition
> 20	Poor condition

4.1.4 Observed Condition Factors

The ROV and Scuba inspections identify what defects were observed on the cable.

Minor Defect	Description
No minor defect	Zero minor defect per KP
1 to 5	Count of minor defect per KP
6 to 10	Count of minor defect per KP
> 10	Count of minor defect per KP
Major Defect	**Description**
No major defect	Zero major defect per KP
1 to 5	Count of major defect per KP
6 to 10	Count of major defect per KP
> 10	Count of major defect per KP

4.1.5 Calibration and data source

The current flow velocity is based on the NIWA Current and Tidal Data from (2014-2018). The seabed material can move around so these are updated when Scuba and ROV reports come through. Freespans are also noted in the Scuba and ROV reports.

Our cables were designed for a 40-year lifespan, internationally they would have a base expected life of 50 years in normal conditions. It is important to note that the Cook Strait has some of the strongest tidal flows in the world, and the specific location factors take this into account.

The process of model calibration used the information available through CIGRE and the UK Common Network Asset Indices Methodology (CNAIM), as well as subject matter experts to determine factor weighting for location, duty, observed, and measured condition factors.

Sections already in poor condition are increasingly likely to fail as the cable degrades. Some of the sections at the Fighting Bay end of all three cables have not been inspected in the last few years. We have no recent update of observed condition at the Fighting Bay end; however, the location factors make it more likely the cable is still in good health.

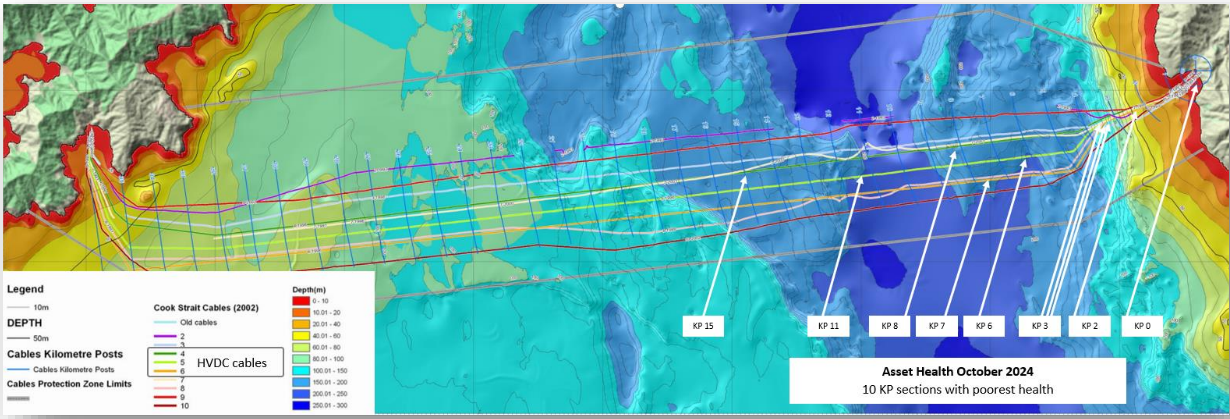
Annual ROV and dive surveys will continue going forward in order to monitor the cables.

5 Asset Health model results

5.1 Current Asset Health

The asset health model considers the duty cycle experienced by each cable, testing results, observed conditions of known defects, and locational factors such as tidal velocity seabed type. Using this data the model determines an asset health score for each kilometre section of each cable. This predicts the deterioration for each kilometre section.

The ten sections of cable with the poorest current asset health score are shown in the diagram and table below. These sections are submerged at a range of depths, mostly in the highest tidal flow areas, with the most aggressive seabed composition (moving boulders). These sections also have a number of major and minor defects.



Sections with Poorest Health

HVDC Cable	km post (KP)	Current Health	Major Defects	Minor Defects	LIRA Delta G	LIRA D Norm[5]	Seabed Composition	Current flow	Depth submerged
W4	3	5.40	1	9	16.8	-	Moving Boulders	Very High	25-150m
W4	8	4.89	0	6	16.8	-	Moving Boulders	Very High	150-200m
W4	0	4.77	2	14	16.8	-	Moving Boulders	Low	0-20m
W4	15	4.25	0	0	16.8	-	Gravel	High	100-250m
W5	3	5.30	1	3	27.6	-	Moving Boulders	Very High	25-150m
W5	6	3.99	0	0	27.6	-	Moving Boulders	Very High	150-200m
W6	11	4.67	0	1	22.6	-	Moving Boulders	High	100-250m
W6	3	4.32	0	4	22.6	-	Moving Boulders	Very High	25-150m
W6	7	3.99	0	0	22.6	-	Moving Boulders	Very High	150-200m
W6	2	4.17	0	6	22.6	-	Moving Boulders	High	25-90m

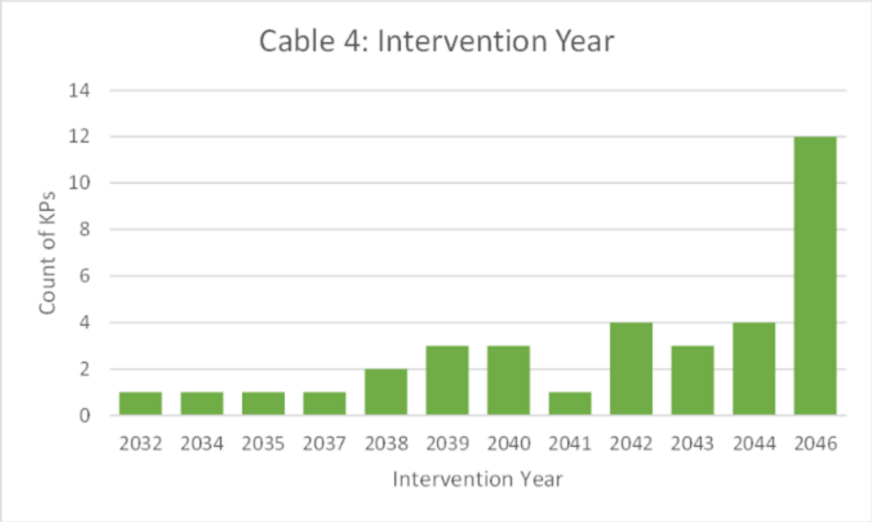
Cable 6 has the best current health, with its poorest section having an asset health index of 4.67. In comparison, both cable 4 and cable 5 are showing more signs of deterioration, with their poorest sections having an asset health index of 5.4 and 5.3 respectively.

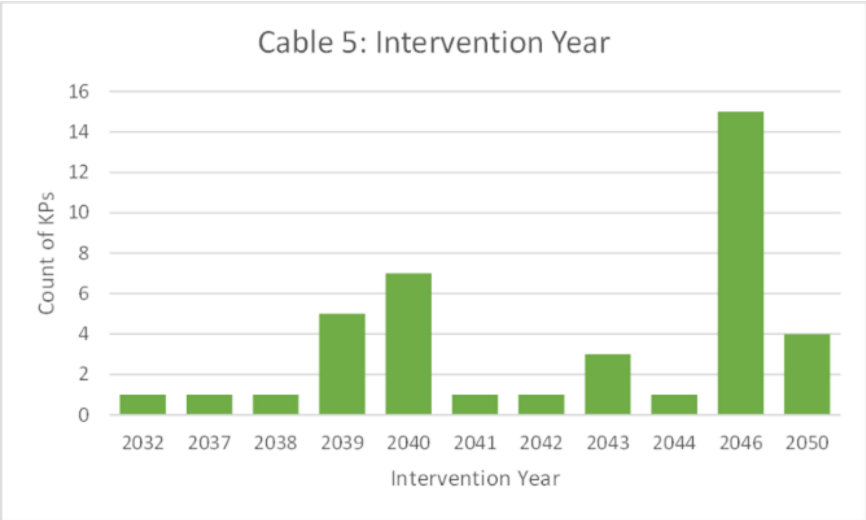
5.2 Future Asset Health and estimated intervention year

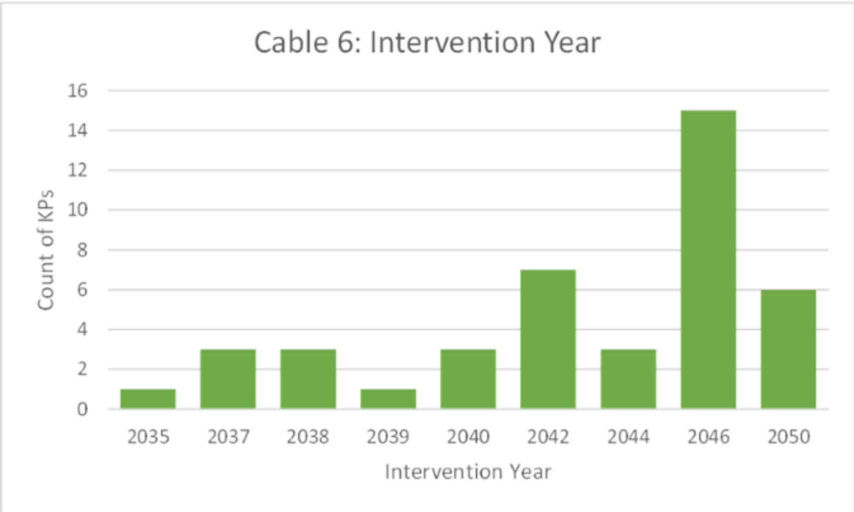
The future health score is projected using the current asset health score, adjusted for location, duty and normal expected life factors using the common network asset indices methodology. An intervention year is then estimated for the point at which the future asset health score reaches 8. The results are shown below.

All KP sections of the cables are expected to reach a score of 8, but at different times. For example, in the first chart below for Cable 4 the earliest is in 2032, with six sections requiring intervention by 2038. Overall cable health is determined by the weakest section, as the failure of a single section would compromise the entire cable.

5 LIRA D Norm measurements are typically taken at 2 or 3 points along the cable. In the case of these sections in poorest health, we have no LIRA D Norm records for 2024.







Cables 4 and 5 have the earliest intervention year in 2032, and cable 6 has the earliest intervention year of 2035. Some sections of the cable are expected to have a much longer service life primarily due to the more benign conditions and lack of defects at the Fighting Bay end.

5.3 Changes in Asset Health over the last 4 years

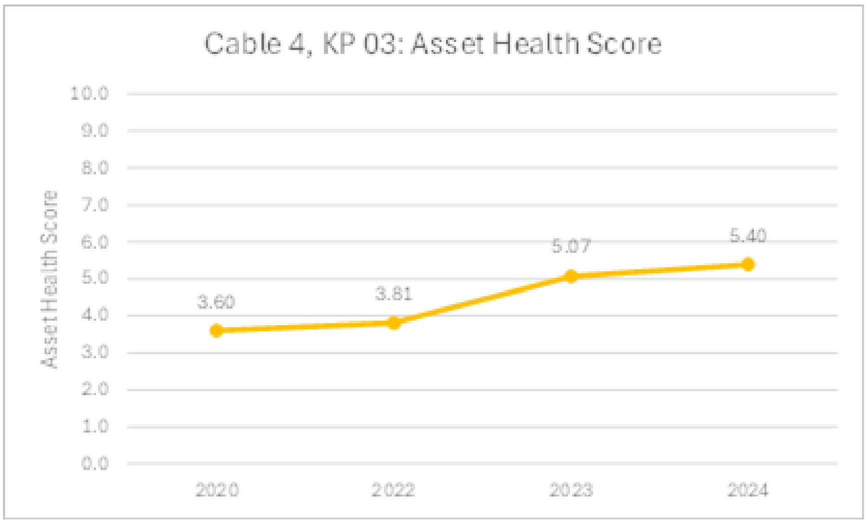
The table below sets out the predicted intervention years based on our 2024 assessment, alongside the projections from the 2020 assessment for comparison.

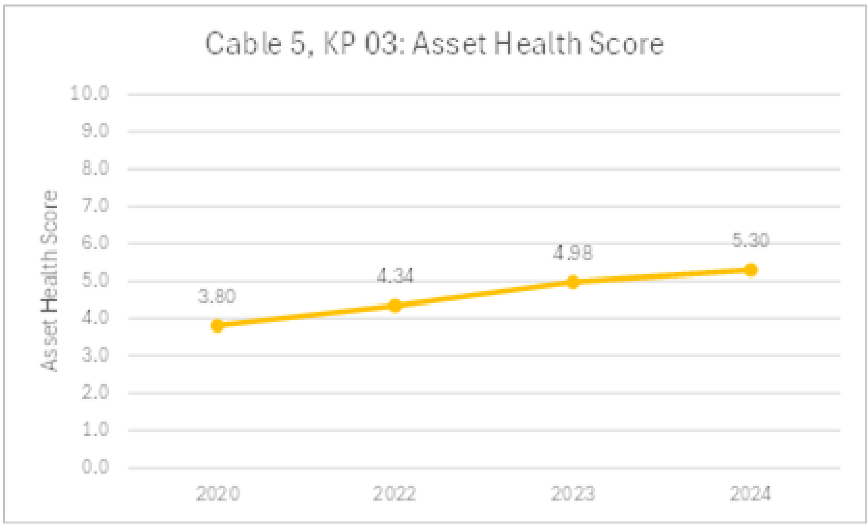
Table 3: Estimated Intervention

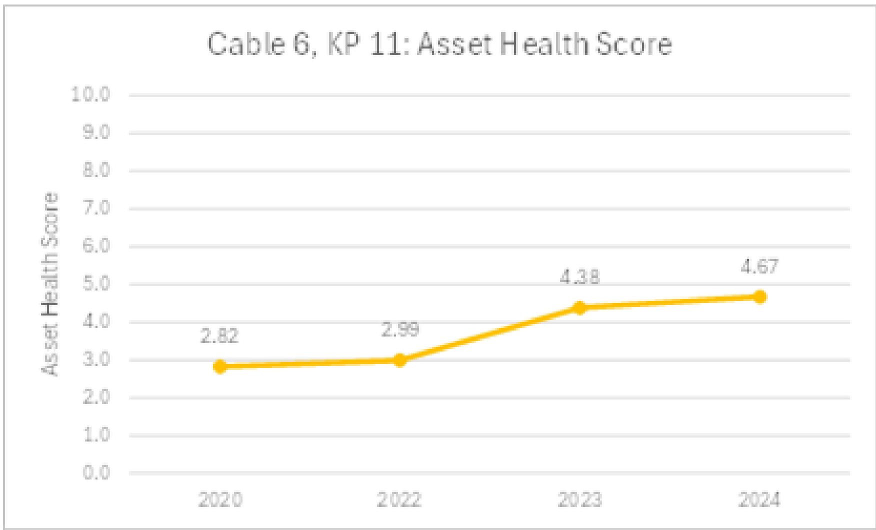
HVDC Subsea Cable	Estimated Intervention Year, 2024 data	Estimated Intervention Year, 2020 data
Cable 4	2032	2035
Cable 5	2032	2036
Cable 6	2035	2038

Our 2024 assessment has resulted in an earlier predicted year for intervention for each of the three cables. This is primarily due to the discovery of additional defects and changes to the seabed close to the North Island end of the cable route in the last few years, as well as the consideration of the cables age.

The changes to the poorest sections are shown year on year in the charts below.







5.4 Predicting end of life

Predicting End-of-Life (EoL) for the cables is difficult as location factors can vary year on year or even within event by event throughout the year. Each year only about one-third of the cable is observed in terms of the ROV and Scuba inspection. This coverage can be reduced further if inspection conditions during the period of inspection are unfavourable (rough seas or high winds). New defects will arise, and this condition information is updated accordingly. Some sections of the cable may be buried during the inspection so the cable condition cannot be observed in this case. External factors beyond Transpower's control also influence the cables condition, especially since the cables are out in an open sea environment.

The decision to replace the cables will ultimately be risk-based, with an asset health score of 8 serving as an indication only. At higher asset health scores, the probability of failure begins to rise significantly and accelerates with further degradation. The proposed replacement timeframes are driven by the outputs of our asset health model, combined with a thorough understanding of the consequences of failure. These include factors such as restoration times and the lead times required for design, procurement, installation, and commissioning.

6 Probability of failure

Alongside condition we also model the probability of failure as a function of asset health. We have used our own experience and industry data to establish failure rates that can be used to estimate the Probability of Failure (PoF) curve. This is shown in table below.

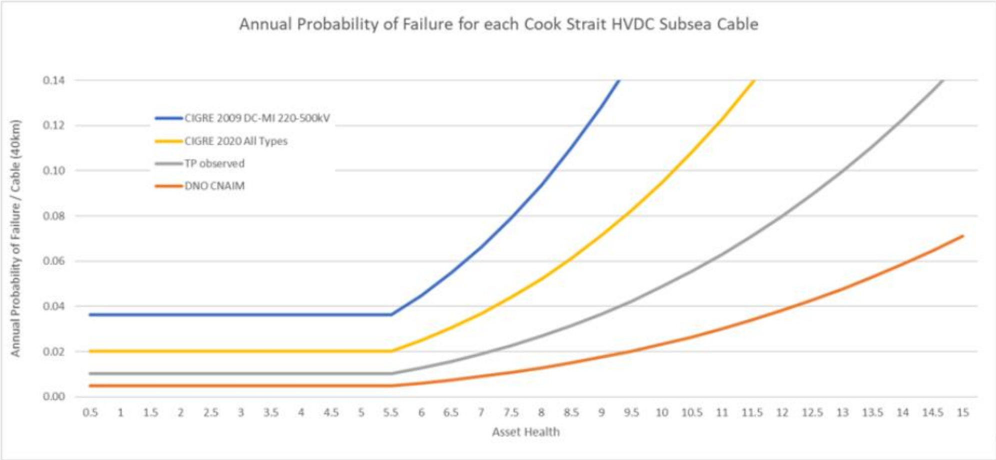
Failure rates from various sources

Study	Details	No. of Failures	λ Failure Rate Failures/100km/yr	Average Outage time (days)
CIGRE TB379 2009	Survey years 1990-2005 - AC & DC types	24	0.1200	60
	220-500kV DC-MI (table 30-32)	11	0.0998	60
	All Voltages DC-MI	18	0.1114	60
CIGRE TB398 2009	Year 2001-2005 220-500kV DC-MI (table 5.6-5.7)	10	0.1000	-
CIGRE WGB1.57 2020	Year 2006-2015 AC & DC types	24	0.0550	105
Transpower	Transpower experience	1	0.0285*	168*

*Note the Transpower failure was in shallow water. Restoration would be longer if an overseas vessel is required.

The CIGRE 2020 survey includes cables of various types and ages, with approximately 65% of the survey installed after 2005, compared with Transpower's cables, which were installed in 1991. The 2009 survey is considered more representative given the age distributions of each survey and considered more representative than Transpower's single data point.

Using the CNAIM methodology the Probability of Failure curves were developed using the failure rates from CIGRE and Transpower operational experiences. These have assumptions about the distribution of asset health within the population at the time the failure rates were assessed. The results are shown in the curve below.



Since Transpower's cables are all the same age and have been exposed to similar conditions and follow adjacent routes, it is credible that subsequent failures can occur within a short period. Such failures may arise within a timeframe shorter than what is required to procure replacement cables, secure the services of a cable-laying ship, and complete the necessary repairs, particularly for deep water faults.

7 Auxiliary systems not within cable asset health

Noteworthy issues - summary of other critical assets associated with HVDC cables

Asset	Summary description and significance (2023)
OTB Cable 6 Termination and Tank	Previous defect resulted in ongoing Nitrogen gas contamination. The gas levels in the oil are improving with flushing new de-gassed oil and we should continue a 6 monthly oil flush and repair to pressure tank until gas levels in the oil stabilise. There is an ongoing defect with the gas valve on the in-service tank. The defect is currently managed with no gas (N2) leaks. We are looking at the option to replace this tank with a good spare tank.
OTB Cable 4 Termination	The gas levels found in the oil and its condition are still showing an indication that the termination insulation is potentially deteriorated or aging (Carbon Monoxide, Di-electric strength and colour). There are still insufficient data points to conclude a more serious intervention at this stage, so more oil samples and flushing should be completed within 6 months to establish if there is a deterioration trend or if the levels will stabilise.

Asset	Summary description and significance (2023)
FTB Cable 4 Termination	The gas levels found in the oil and its condition are still showing an indication that the termination insulation is potentially deteriorated or aging (Carbon Monoxide, Di-electric strength and colour). There are still insufficient data points to conclude a more serious intervention at this stage, so more oil samples and flushing should be completed within 6 months to establish if there is a deterioration trend or if the levels will stabilise.
FTB Spare Tank	It is thought that the condition and availability of this tank and the oil it contains is questionable and may be a risk if used in an emergency unless checked. This should be checked as soon as new oil is available and used to swap in at OTB Cable 6 termination.
HAY Spare Tank	This is the suspect tank with potential burst Bellows that released nitrogen gas into OTB cable 6 termination. Post investigation of this tank showing the tank is in good condition. The condition should be checked and confirmed again as soon as new oil is available. Once condition is confirmed healthy, this tank can be used as an emergency spare.
Cable 5 / Pole 2 Transfer	Cable 5 has been found to be in good / sound condition and can therefore play an essential role supporting 2 poles being available should any of the above issues with cable 4 and 6 develop further and require an extended outage to remediate. The capability to operate Pole 2 via cable 5 is available but needs to be practiced during the next available outages.
Oil Degasifying Plant	Currently oil degasification has been completed using a unit supplied by AIS or a BICC unit from Vector. Transpower has an approved business case to purchase a unit which is planned to be available for the Feb 25 outage.
FTB Cladding Corrosion	Both stations are in extreme marine environments and the integrity of the cladding is essential to the resiliency and operation of the HVDC poles. At FTB there was a noticeable widespread onset of corrosion to the colour-steel panels, and it should be expected that deterioration will accelerate from this point.
FTB Coastline and Stream Erosion	Erosion from the coastline and stream corrosion represent a risk to the cable building foundation. This is worthy of a geotechnical engineer's opinion regarding vulnerability and return period risk from storm event.

Asset	Summary description and significance (2023)
OTB Coastline and storm surge and seismic risk	Oteranga Bay is highly exposed to high winds, storm surge and high waves. In the 2000's swells of 14m and winds of 180kph were experienced. Seismic risks exist at the OTB building. Cable termination at OTB needs to consider these risks.

7.1.1 Cable Termination System

While the cables are a self-contained, mass impregnated, non-draining (MIND) cable system, the cable terminations rely on an oil pressure management (OPM) system to maintain a positive oil pressure within the terminations.

Several defects and deterioration have been observed in the last 10 years.

- Leaking nitrogen gas from the bellows assembly (these are an integral feature of the tanks to ensure a positive oil pressure is maintained through loading cycles) into the oil
- Deteriorated oil condition scores outside established limits
- Discoloured oil
- Low electrical withstand
- High Residual Gas Pressures (RGP), largely due to N2 contamination. This being caused by the rupture of the bellows over the years most likely caused by mechanical fatigue due to lead cycling.
- Elevated carbon monoxide
- Oil condition being actively managed & remediated (flushing)
- Leaking valves, possibly resulting from now regular usage
- Increasing over pressure interventions, because adjustments are required that are dictated by the ambient temperatures to set pre-livening pressure
- High and low temperature remediation, ambient and tank temperature interactions

The operation of each cable termination dictates the availability of each cable. In the case of cable 4, pole 2 is entirely operated via this cable, with an untested ability to run cable 5 as HVDC pole 2, in the event of an extended loss of service for cable 4. Otherwise cables 5 & 6 normally share the function of pole 3.

Currently Transpower has two spare tanks and has attempted to dissemble and refurbish one of these as a trial to develop a rolling refurbishment programme. However, the complexity of the design of the internal pipework and pressure bellows, being operated at the high pressures required has led to Transpower deciding that a new purpose made system is now required. This is essential to ensure the OPM systems last reliably until at least 2033, based on the estimated decommissioning of the existing cable systems in 2031. These dates will be confirmed once the replacement of the existing cable programme is established.

7.1.2 Monitoring of Residual Gas Pressure (RGP)

Measurement of Residual Gas Pressure (RGP) was originally used as a factory test to assess the quality of vacuum impregnation of a cable, but it can also be used for in service cables. For in service cables, RGP can be used to understand if any deterioration is occurring that would result in gas being generated and then absorbed back into the oil.

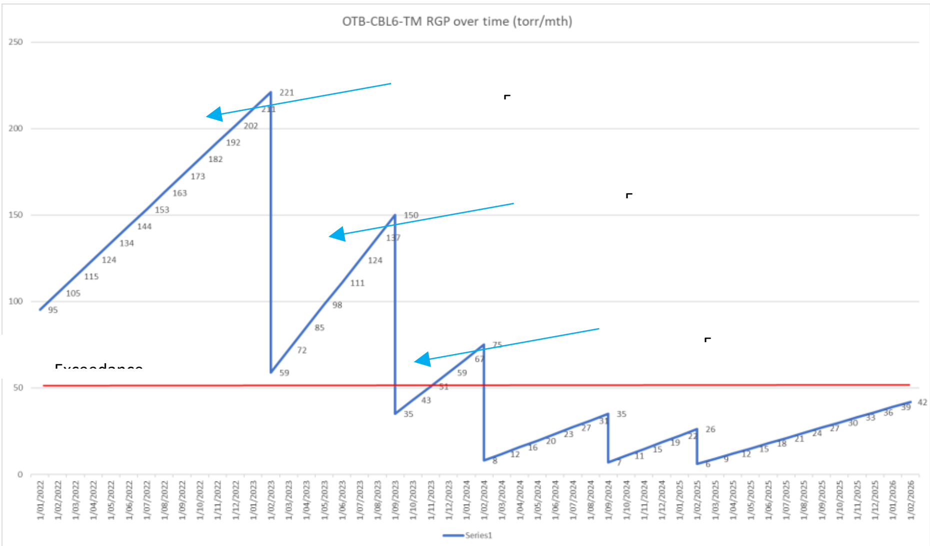
The limits for old installations such as cable 4, 5 and 6 is 50 torr of Residual Gas Pressure as shown in the table below:

The following values should not be exceeded.

System Voltage	Residual Gas Pressure			Maximum Rate of Change
(kV)	New installations (See Note 1) (torr)	Old installations (See Note 2) (torr)	Acceptable after flushing (torr)	(torr per month)
400	10	50	20	2
275	10	50	20	3
132	15	100	30	5
Up to 66	20	150	40	5

(1) New installation, i.e., one ready for commissioning.
(2) Old installation, i.e., one in operational service for a substantial period.

If a high RGP is detected action is recommended to be taken, as we are doing presently, essentially a flushing process. The RGP level for Oteranga Bay Cable 6 Termination is shown below with further predictions.



Given the level of nitrogen saturation, gas will continue to be released into the oil for some time. Periodic RGP or DGA measurements are taken (6 monthly) and if elevated levels are seen the sealing end is flushed under special circumstances.

8 Cable fault 2004

During the energisation of the inverter station on 5 October 2004 the Fighting Bay cable protection detected a ground fault on submarine cable 6.

An initial fault location was estimated using time domain reflectometry on 5 October. On 14 October 2004 a test set and divers were used to locate the fault at the seabed. The divers did report seeing many "white" bubbles rising to the surface but could not directly find the location. The third attempt on 6 November 2004 found the fault location at 345 m from the sealing end of Oteranga Bay, with a stream of very fine bubbles escaping between the servings wrapping the cable.

Figure 2: Cable being hauled aboard during the cable repair at the OTB end in 2004

Initially a cut and cap of the cable was undertaken, this is to prevent water ingress further along the cable. Given the low depth of the fault (12m), Transpower (through Seaworks) sourced an ex-USA Navy tank landing barge, and then designed and constructed cable handling equipment and a relocatable cable jointing building on the barge.

During the initial repair, the first joint had to be redone due to emergency safety action. The safety action was to cut the deployment cables due to rough seas and 80kph winds. This resulted in a bending radius of 1.3m which was below approved specifications and hence a new joint required to remove the bent section. A repair joint was also required closer to the cable sealing end on land. This shows that even a repair in shallow water can prove to be difficult in cook strait. Any deeper repairs would require longer sections of cables that will be heavier and take up more space requiring bigger vessels that would need to be sourced from overseas. Overall cost of the repair in 2005 in shallow water was approximately $13.5M. The repair took 168 days (nearly 6 months).

Weather conditions in Cook Strait are highly variable and can be severe. There are numerous possible combinations of tidal action, sea state and wind, as well as seabed conditions. In addition, water depths for a third of the cable crossing are at depths of 100-250m. A deep-water fault will be much more difficult to locate, to perform a cap and cut, and to repair compared to a shallow water fault.

9 Cable Repair timeframes

Cable repair timeframes are variable depending on the depth, availability of suitable vessels, length of cable required and weather conditions. Estimated cable repair timeframes are shown below:

Activity	Shallow water fault (<12m) (weeks)		Deep water fault (>12m) weeks	
	Earliest	Longest	Earliest	Longest
Identify location proximity	1	1	1	1
Pinpoint fault	2	4	2	6
Mobilise inshore vessel for lift	4	8		
Mobilise large offshore vessel			1	8
Sailing to NZ			4	6
Cut, raise and cap ends	2	4	2	4
Mobilise cable repair team	8	26	8	26
Mobilise inshore repair vessel	12	12		
Mobilise offshore vessel			12	26
Load spare cable (<3km)	1	1	1	0
Manufacture new cable >3km (excludes lead time)				144
Lift and joint	4	8	4	8
Test and commission	1	1	1	1
	27	53	24	204

For a cable failure in deep water, where there is a greater weight to lift the cable to the surface, a large vessel is required for this task. The initial fault response is a locate, cut and cap operation using a large standby vessel in the South Pacific, which also provides standby repair service for Transpower fibre cables and others in the region. Transpower subscribes to the South Pacific Marine Maintenance Agreement (SPMMA) consortium, run by OMS Group. SPMMA are a standby vessel equipped to respond to undersea fibre and power cable faults. This vessel takes 12 hrs to mobilise and would take up to seven days to arrive at the HVDC cables, and the maximum anticipated time for a cut and cap once the vessels arrive is 28 days. Because we share this facility with others in the region, the worst case is a failure on the Bass Link proceeding a Transpower HVDC cable failure, which could add up to a 60-day lead time. The risk of a concurrent failure is low.

The Seaworks ROV (Scorpio 58) is on a 7-day standby period. This has an interface tooling specific to the ROV that allows it to deploy Transpower's WGO135 cable lift clamps and 6" disc cutter for an HVDC cut and cap fault response (excludes cable repair). The 7-day standby does not include a vessel capable of deploying the ROV.

Cable repair can be undertaken using locally available crews and equipment for shallow water repair, or via specialist vessel (likely from Europe) for deep water repair. A cable repair is likely to be in the order of 6-12 months depending on the location of the fault. Once a single failure occurs due to degradation it indicates a risk of further cable failures occurring given the cables were laid around the same time and operate in the same marine environment. If the cable length required by the repair(s) is longer than the spare cable currently held by Transpower, a repair could take as long as four years.

Any cable failure is complex in nature no matter where it is located. Different environments represent different challenges when it comes to locating the fault location. For example, in the shallow water (0-10m) of Oteranga Bay the cable is buried, the sediment has solidified around the cable, and it has rocky outcrops that inhibit access. In deep water a large vessel is required with heavy lifting cranes to lift the cable from great depths. The vessel also needs to maintain a constant position, so it does not drag the damaged cable over the in-service cables and cause undesired damage. In medium depth (10-20m) water the large vessels that can be utilised in deep water cannot operate because of draft and operational constraints due to the size of the vessel. This would require a flat-bottomed vessel to carry out the repair.

Any fault finding and the initial cut would likely be carried out by local operators Seaworks. The SPMMA vessel would not be used for this purpose due to the finite time allocation Transpower has subscribed too. The vessel would need favourable conditions to carry out the lift and cap. In the Cook Strait the conditions are not favourable.

We hold a total of 3.6 km of HVDC submarine cable (in two lengths) as spares at the Miramar cable store. The usefulness of these spares for repair of a cable fault in deep water is dependent on the ability to quickly cut and cap a damaged cable. To limit the requirement for spare cable, it is essential to act promptly and minimise water entry. We also have two spare submarine cable termination kits currently being held at Bunnythorpe.

The direct cost to repair the cables in deep water situations is high and a single localised failure requiring in-situ replacement/repair is expected to be over $50M, excluding any new cable production.

10 Conclusion

Cook Strait has some of the highest ocean current velocities in the world. International studies show the predominant failure modes of subsea power cables are associated with environmental conditions that cause armour abrasion, armour corrosion, and sheath failure.

We have undertaken condition assessments of our three HVDC submarine cables and are planning for their end-of-life replacement assisted by our asset health modelling. Our asset health modelling considers location factors that will accelerate degradation. The cable sections in poorest health are closest to the Oteranga Bay end where the very high current velocities place stresses on the cable and where the seabed is mostly moving boulders. The existing defects in these areas and the location factors in those sections drive the model results to predict that they are likely to fail first. These sections are in water depths of between 25-250m which will require a deep-water repair that will take significantly longer to repair and cost more than the previous shallow water repair in 2004.

Based on the modelling the estimated replacement year is 2032 for cables 4 and 5 and 2035 for cable 6.

At higher asset health scores, the probability of failure begins to increase exponentially. The proposed replacement time frames are driven by the outputs of our asset health model in combination with an understanding of the consequences of failure including restoration time, but also the lead times for the design, procurement, installation, and commissioning. Replacing these heavy subsea cables is a complex and specialist task. The type of cables (MIND) we require are made to order by only two manufacturers worldwide and current global demand is such that the lead times are now approximately seven years. With those considerations, the recommendation is that we commence the process to procure replacement cables so we can ensure a timely replacement of the three cables before 2032.

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