PowerWater

Asset Management Plan – Underground cables

Power and Water Corporation

CONTROLLED DOCUMENT

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Executive Summary

Power and Water Corporation (Power and Water) owns and operates the electricity transmission and distribution networks in the Northern Territory of Australia. Included in the networks are underground cable assets performing a critical function in maintaining the business objectives of delivering a safe and reliable supply of electricity to Power and Water's customers'.

Assets contribute a sizeable proportion to the total asset base *– however age compared to expected life is not a great concern.*

Underground cables make up 18% of the total network value of the asset base and contribute to around 11% of the total operating expenditure. The asset fleet has an average age of 25 years, and 0.9%, or 22.8 km of cable (mainly HV, LV and services cable) projected to exceed the standard asset life of 55 years within the next regulatory period. The vast majority, 85% of the asset class is located in the Darwin-Katherine region, with the remainder distributed across the Alice Springs and Tennant Creek regions.

Cable tunnels are uniquely associated with underground cables and are included in the scope of this AMP. The scope does not include other underground network assets such as ground mounted equipment.

Assets operate across a diverse environment *– temperature, humidity, rainfall, termites, soil types present different challenges to managing the assets.*

The Power and Water power network is subject to unique environmental and operational challenges ranging from the coastal tropical environments prone to cyclones, high temperatures and humidity, and high annual rainfall, to desert environments subject to high ambient temperatures, occasional flooding, droughts, dust storms, and surrounding factors including high termite infestation and aggressive soil conditions. This unique environment results in a more rapid rate of asset deterioration, and lower worker productivity compared to peer distribution businesses.

There are three key challenges that require management *– insulation deterioration, earthing screen/system degradation, and specific type defects.*

Key asset challenges include asset type issues related to HV XLPE cables and LV XLPE/PVC cables. Asset condition issues across the fleet of cables are predominantly related to outer sheath damage, water ingress, screen corrosion, which cause cable screen (i.e. earthing system) failures and cable failures.

Assets of particular concern include the HV cables in the northern suburbs of Darwin where investigations confirmed a type issue related to HV XLPE cables following significant cable failure contributions to reliability performance, and consistent reports from field crews on poor cable condition affecting the reparability of these cables.

Investigation initiated by Power and Water on the 11kV Port Feeder cable identified peripheral damage to the cable, damage to the earthing screens, and water ingress. In 2017, the cable experienced five separate in-service failures.

A combination of hazard factors has prompted the need for investment in the replacement of the LV XLPE/PVC cables in the distribution areas of Cullen Bay and Bayview. The cables are in particularly poor condition with consistent sheath and insulation deterioration accelerating the ingress of moisture and the development of calcium adipate leading to accelerated cable insulation and cable termination degradation. The level of deterioration of such a large proportion of cables is unprecedented based on their age and is considered a type issue unique to the cable installed. Other hazard issues identified with these cables include low insulation resistance (IR) in more than 50% of cables tested, compromised LV neutral earthing systems in Cullen Bay area, and inadequate and non-standard earthing system arrangements.

Maturing condition data associated with cable assets is a key asset management challenge. An increased focus on the collection of condition data and analysis are being put into effect to better support asset management decision making. Focused routine inspections and targeted inspections and testing prioritising high risk areas are some of the proposed undertakings aimed at improving data collection and analysis during business as usual activities.

Investment programs are targeted to manage the key challenges *– directed replacement.*

The following asset renewal programs are proposed for the 2019-20 to 2023-24 regulatory period to address key asset challenges:

- Darwin northern suburbs HV XLPE cables (non “TR” XLPE type) replacement program
- 11kV Port Feeder replacement (11BE18)
- LV mains cables – Cullen Bay and Bayview cable replacement program
- Pooled asset replacement program- captures those cable assets that fail in service.

The renewal programs have been developed with the objective of maintaining risk over time. To achieve this, an asset health and criticality framework was developed that provides for a consistent method of assessing assets and making value based investment decisions. The health and criticality framework was central to establishing the targeted cable investment programs focusing on the highest risk assets as a priority.

The cable investment programs are summarised as follows:

Investment category	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Renewal plans	$6.08	$8.79	$5.59	$3.59	$4.41	**$28.46**
Maintenance plans	$2.45	$2.45	$2.45	$2.45	$2.45	**$12.25**
Total	**$8.53**	**$11.24**	**$8.04**	**$6.04**	**$6.86**	**$40.71**

The forecast investment over the regulatory period has been compared to the Australian Energy Regulator’s (AER’s) repex model output. As shown in Figure 1, the proposed investment is under the repex model’s projection for replacement expenditure over the 2019-24 regulatory period and beyond.

The step-change from historic expenditure levels is due to the HV XLPE cable replacement projects planned for the first two years of the regulatory period. Following the completion of these projects, the forecast for the remainder of the regulatory period is generally consistent with historic investment levels. It is anticipated that investment in the future regulatory periods may increase in line with the repex model projections as the condition of the cables continue to deteriorate over time.

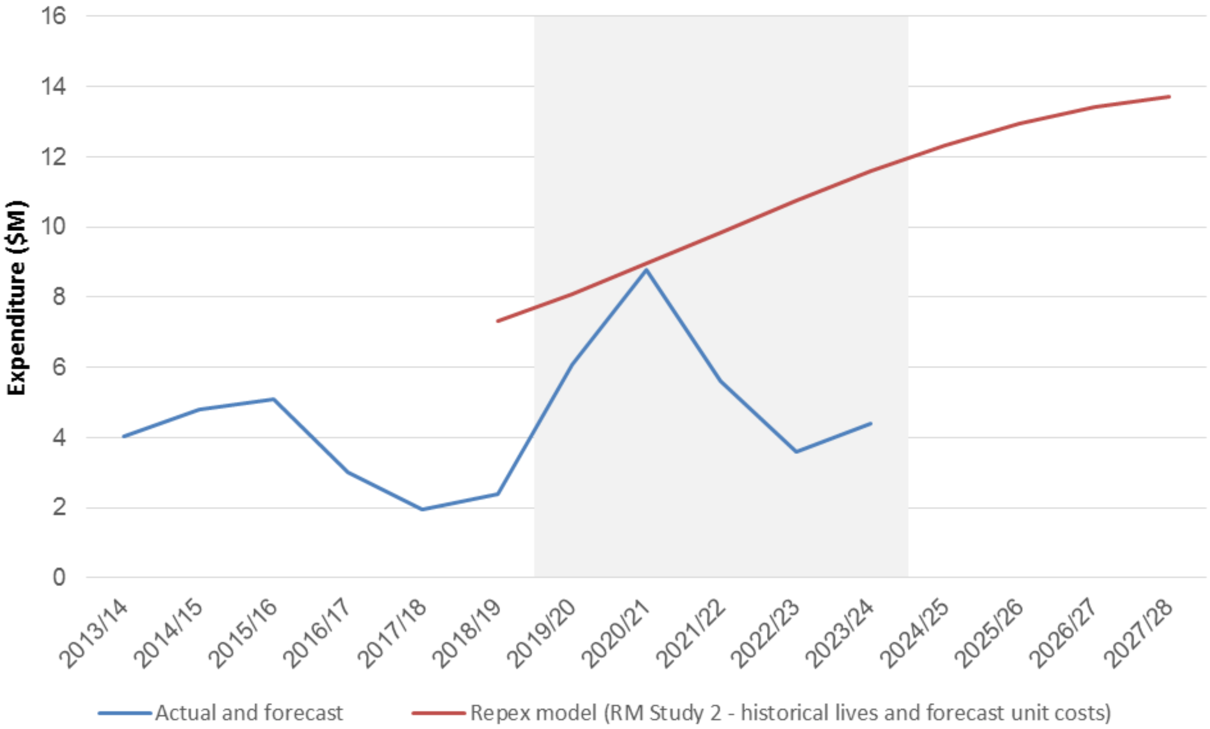

Figure 1: Investment in underground cables over the regulatory period

Benefits from the investment program *– reliability improvement*

The investments are expected to impact on the system performance with an improvement of around 0.5% in SAIDI performance by 2023/24 and an improvement in system SAIFI of around 0.2%. These projected improvements are mainly the result of HV cable investment programs. No investment in the transmission and services cable networks has been identified at this time, apart from in-service failure replacements from the pooled expenditure forecast. The proposed investments in the LV network address public and worker safety risk and manage the risk of increases in reliability impacts.

The investment program targets the highest risk assets with consideration of other works as appropriate to optimise workforce scheduling and address priority defects. The program is expected to materially impact the risk profile of the underground cable assets.

Transmission cable

With only in-service failure replacements over the next five year regulatory period the health and criticality profile is expected to change to that shown in the second table below. The change in risk is demonstrated in the number of assets that enter or exit the H2 health category.

For the transmission cable assets a reduced risk is reflected in a 3% reduction in the number of average health assets in the H2.

Transmission underground cable health-criticality matrix (qty) by 2023-24, with no investment

	H1	H2	H3
C1	6.9 km	8.0 km	
C2	0.8 km	2.5 km	
C3	11.0 km		

Transmission underground cable health-criticality matrix (qty) by 2023-24, with in service failure replacements only

	H1	H2	H3
C1	7.1 km	7.8 km	
C2	0.9 km	2.5 km	
C3	11.0 km		

HV Distribution cable

With investment and including for growth over the next five year regulatory period the health and criticality profile is expected to change to that shown in the second table below. The mitigated risk is demonstrated in the number of assets that transfer from the H3 health category to the H1 health category.

For the HV distribution cable assets a reduced risk is reflected in a 94% reduction in the number of poor health assets in the H3 category, and a 3% reduction in the number of average health assets in the H2 category.

HV Distribution cable health-criticality matrix (qty) by 2023-24, with no investment

	H1	H2	H3
C1	48 km	75 km	10 km
C2	366 km	224 km	19 km
C3	93 km	42 km	15 km

HV Distribution cable health-criticality matrix (qty) by 2023-24, with investment

	H1	H2	H3
C1	55 km	75 km	3 km
C2	386 km	223 km	
C3	118 km	32 km	

LV Distribution cable

With investment and including for growth over the next five year regulatory period the health and criticality profile is expected to change to that shown in the second table below. The mitigated risk is demonstrated in the number of assets that transfer from the H3 health category to the H1 health category. For the LV distribution cable assets a reduced risk is reflected in a 100% reduction in the number of poor health assets in the H3 category, and a 20% reduction in the number of average health assets in the H2 category.

LV Distribution cable health-criticality matrix (qty) by 2023-24, with no investment

	H1	H2	H3
C1	9 km	19 km	0.2 km
C2	478 km	209 km	9 km
C3	44 km	10 km	0.03 km

LV Distribution cable health-criticality matrix (qty) by 2023-24, with investment

	H1	H2	H3
C1	14 km	15 km	
C2	532 km	164 km	
C3	44 km	11 km	

The movement in risk demonstrated by the movement of assets predominantly from the poor health and applicable criticality zones across the sub-asset classes (transmission, HV, and LV) substantiates Power and Water's investment strategy that targets the highest risk assets.

The risk profile snapshots have been based on the current understanding of the underground cable asset class age, condition, and operating environment. The risk profile is expected to evolve as ongoing condition and performance monitoring, methodical inspections, and improved data collection practices provide for better quality data and asset insights.

1 Purpose

The purpose of this asset management plan (AMP) is to define Power and Water's approach to managing the life-cycle activities for underground cables. It frames the rationale and direction that underpins the management of these assets into the future:

- Short Term (0-2 years): Detailed maintenance and capital works plans for the upcoming financial year based on current asset condition.
- Medium Term (2-5 years) 2019-24 Regulatory Period: Strategies and plans based on trends in performance and health indicators.
- Long Term (5-10 years) 2024-29 Regulatory Period: Qualitative articulation of the expected long-term outcomes.

Underground cable assets are managed to comply with the broad external requirements of legislation, codes and standards. This is achieved within an internal framework of policy, strategy and plans that are enabled through interrelated documents, systems and processes that establish the Power Networks asset management practices. The asset management system is summarised in Figure 2.

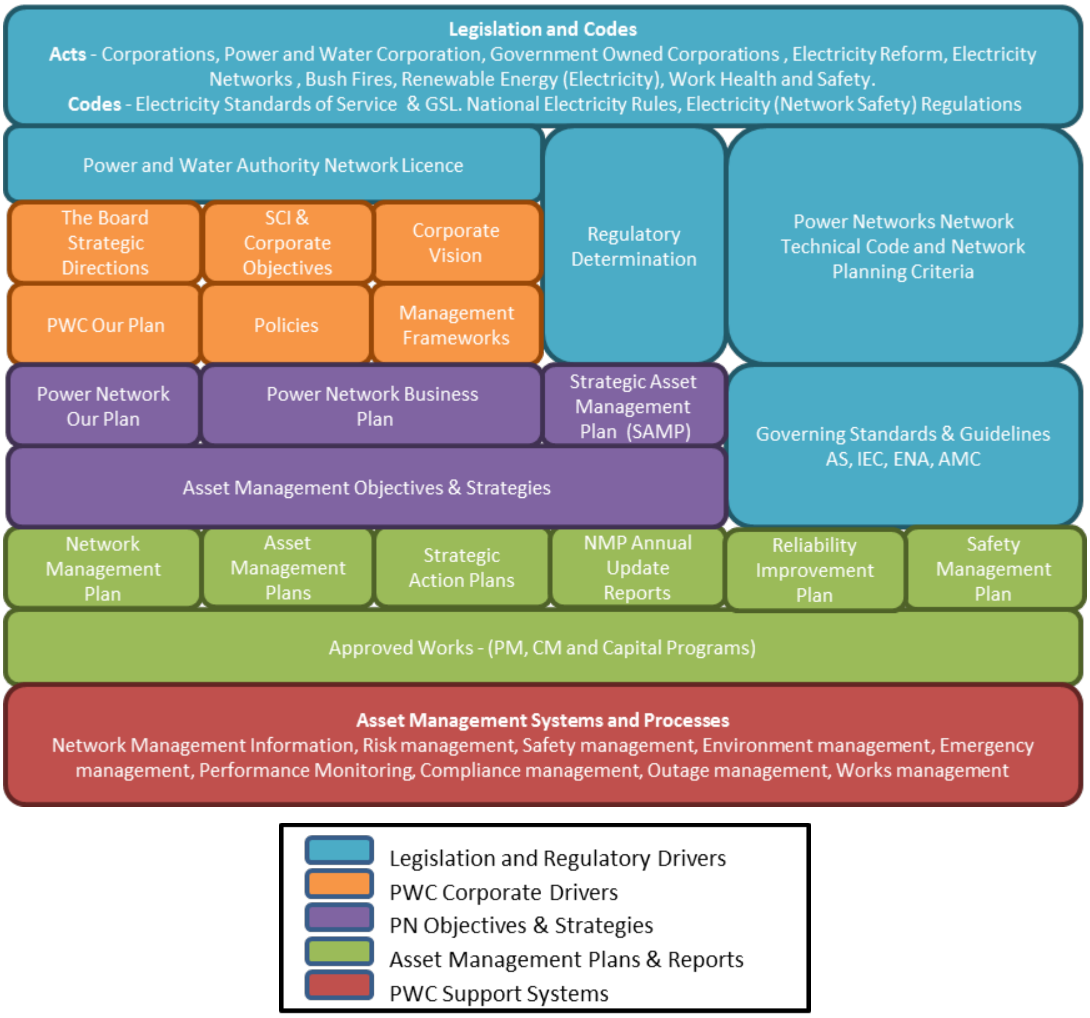

Figure 2: Asset management system

2 Scope and objectives

2.1 Asset class overview

In-scope assets include Power and Water's transmission, high-voltage (HV), low-voltage (LV), and service cables. Table 1 provides an overview of the asset class. Included in the scope are cable tunnels that are uniquely associated with underground cables. The scope does not include other underground network assets such as ground mounted equipment.

Table 1: Overview of in-scope assets

Asset type[1]	Quantity	Voltage	Average Age	Nominal Lifespan	% exceeding lifespan in reg. period	Key points
Transmission cables	29 km	66 kV	17 years	55 years	0.0%	• Predominantly located in Alice Springs and Darwin. • Dating from the 1950s. • 66kV undersea and oil filled cable technology in Darwin region a key challenge
HV cables (distribution feeders)	856 km	6.35-22 kV	24 years	55 years	0.8%	• Predominantly located in Alice Springs and Darwin. • Dating from the 1950s. • Non-"TR-XLPE" cables a key challenge[2]
LV mains cables	712 km	415 V	23 years	55 years	1.0%	• Predominantly located in Alice Springs and Darwin. • Majority date from the 1990s. • Renewal of poor health, high criticality LV cables
LV service cables	932 km	240/415 V	27 years	55[3] years	1.0%	• Predominantly located in Alice Springs and Darwin. • Dating from the 1950s. • No major investment in the forecast reg. period.
Total	**2,530 km**	-	**25 years**	**55 years**	**0.9%**	

The underground cable asset class is increasing in overall significance as proportion of Power and Water's assets and activities. This is because much of the growth in new areas is supplied using underground assets. Currently, the underground cable asset class comprises:

- 18% of the network by replacement value;
- 11% of operational expenditure (opex);
- 14% of capital expenditure (capex), including:

[1] Streetlight assets and associated underground cables have been handed over to city councils and are not included in Power and Water's regulated asset base

[2] "TR-XLPE": Tree Retardant-XLPE insulation technology designed to overcome water treeing deficiencies

[3] Service cables currently a financial life of 35 years however this is under review. For the purposes of this document service cables have been grouped with LV cables and given the same nominal lifespan

- o 11% of replacement expenditure (repex); and
- o 21% of augmentation expenditure (augex).

Power and Water's underground cable assets are distributed throughout its network footprint which covers the Northern Territory (NT).

2.2 Asset Class Function

Underground cables transfer electric power between two termination points at transmission and distribution. They interface with other equipment such as transformers, switchgear, and overhead lines. They also provide services to Power and Water customers up to the point of connection.

Individual circuits can comprise a combination of overhead and underground assets. Underground assets are predominantly located in urban and suburban areas. This is because they are comparatively expensive to overhead assets, and hence only used in densely populated areas where safety, reliability and aesthetic benefits provide justification.

Cable tunnels are associated underground infrastructure that allows for improved human access for maintenance and inspection of cables or conduits running through them, as well as improved routing of cables and ingress and exit from zone substations. Often there are series of cable trays mounted along the walls on either side of the tunnel where the cables run.

The function of underground cables within Power and Water's electricity network is illustrated in Figure 3.

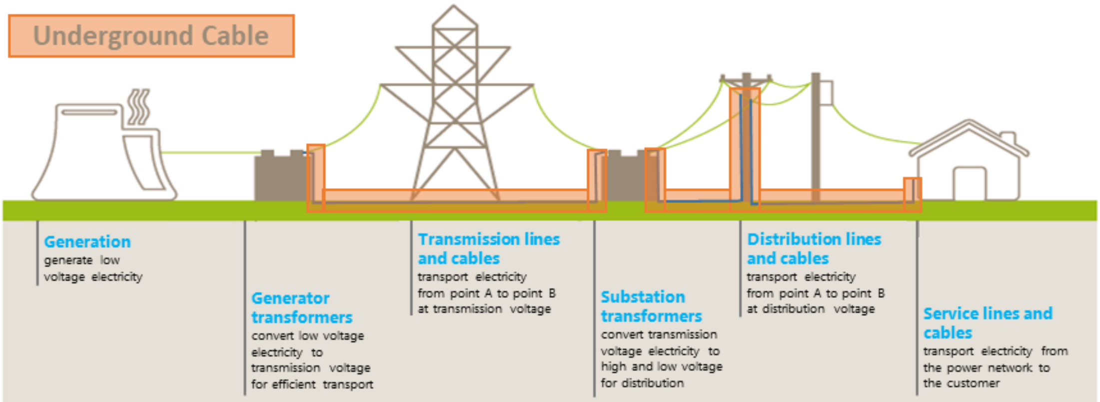

Figure 3: Diagram showing the function of underground cable assets

2.3 Asset Objectives

The AMP provides a framework which steers the management of the asset class in a manner that supports the achievement of Power and Water's broader organisational goals. The Asset Management strategies are listed in the Strategic Asset Management Plan (SAMP) and are aligned to the Asset Management Objectives and implemented in through Asset Management Plans (specific to asset class) or Strategic Asset Plans as shown in Figure 4.

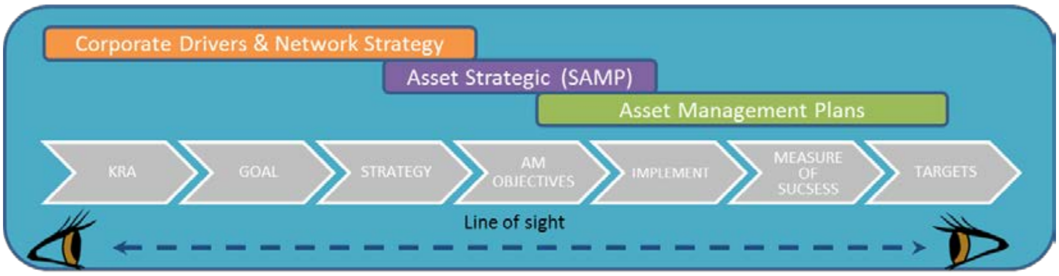

Figure 4: Asset Management Line of sight from Corporate and Network strategies through the Asset Management objective to the targets in the asset management plan.

Table 2 provides the asset management objectives from the strategies that are relevant to this asset class along with the measures of success and the targets. This provides a 'line of sight' between the discrete asset targets and Power and Water corporate Key Result Areas.

Table 2: Asset Management Objectives, Measures of Success and Targets.

AM Objectives	Measures of Success	Targets
• Network related operation and maintenance tasks are quantified in terms of risk and used to inform investment decisions that affect Health and Safety outcomes for the organisation	• Cables damaged by excavations (dig-ins) • Electric Shock due to neutral connection faults • Electric shocks or near misses due to exposed conductors	• Total asset class specific safety incidents not exceeding 0.2 per annum
• All environmental risks have been defined, mitigation controls implemented and responsibility for risk ownership has been assigned to appropriate leaders • Develop Environmental Improvement Plans for significant risks to reduce risk exposures and tracked through a governance framework • Develop performance indicators for intended environmental outcomes.	• Total asset class specific environmental incidents associated. • Oil leaks greater than 100L	• Total asset class specific environmental incidents associated not exceeding TBA
• Ensure that the systems and processes provide sufficient and appropriate data and information to drive optimal asset and operating solutions.	• Asset class contribution to system SAIDI • Asset class contribution to system SAIFI • GSL contribution per year Guaranteed Service Levels	• SAIDI to be no more than 15% for this asset class. • SAIFI to be no more than 8% for this asset class. • GSL contribution per year TBA
• Proactively and systematically measure the network power quality	• Asset class related number of poor power quality incidents.	• TBA
• Ensure that the systems and processes provide sufficient and appropriate financial data • Understand the financial risks associated with asset management	• Variance to AMP forecast CAPEX • Variance to AMP forecast OPEX	• Variance to AMP forecast CAPEX +/-10% • Variance to AMP forecast OPEX +/-10%
• Develop systems and data that facilitate informed risk based decisions • Ensure that works programs optimise the balance between cost, risk and performance • Ensure the effective delivery of the capital investment program	• Network risk index quantified (Y/N) • Health and Criticality Parameters defined (Y/N)	• Annual in-service asset failures not exceeding 5

AM Objectives	Measures of Success	Targets
• Identify, review and manage operational and strategic risks • Prioritise projects, programs and plans to achieve efficient and consistent risk mitigation. • Achieve an appropriate balance between cost, performance and risk consistent with regulatory and stakeholder expectations. • Define and communicate the level of risk associated with the investment program	• Critical spares analysis completed for asset class • Operator/Maintainer risk assessment completed for asset class and risk register updated	• Achieved
• Ensure that electricity network assets are maintained in a serviceable condition, fit for purpose and contributing positively to Power Networks business objectives.	• All staff are trained and hold appropriate qualifications for the tasks they undertake. • Peer benchmarking, i.e. a reasonableness test of underlying unit costs (capex, opex) • Asset class preventative maintenance completion	• Achieved

3 Context

3.1 Roles and Responsibilities

Power and Water operates using an “Asset Owner / Asset Manager / Service Provider” business model. Although there is extensive collaboration and interfacing between the roles, generally speaking:

- The Asset Owner establishes the overall objectives for the assets;
- The Asset Manager develops the strategies and plans to achieve the objectives; and
- The Service Provider performs activities on the ground to deliver the plans.

3.2 RACI

The Responsibility, Accountability, Consulted, Informed (RACI) matrix for the cable asset class is provided in Table 3. This defines the roles and accountabilities for each task by allocating to specific roles/personnel in Power and Water.

Table 3: RACI matrix for underground cables

Process	Exec GM Power Networks	Group Manager Network Assets	Chief Engineer	Network Planning Manager	Major Project Delivery Manager	Southern Delivery Manager	Group Manager Service Delivery	Field Services Manager	Works Management Manager	Strategic Asset Engineering	Asset Quality & Systems
Establish Condition Limits		A	C	C		I	I	C/I	I	R	I
Performance and condition data analysis	I	A	I	I		I	I	I	I	R	I
Plan capital works (Options, costs, BNIs, BCs, etc.)	I	R	A		C/I	R	R	R	R	R	I
Execute maintenance plans	I	I	I			A	A	R	R	C/I	I
Deliver identified major projects and programs of work	I	C	A	C	R	R	R	C/I	C/I		
Manage asset data (data entry, verify data)		A	I	I						C/I	R
Monitor delivery of capital plans and maintenance	I	A	I	I	I	R	R	R	R	R	R

- *Accountable **(A)** means the allocated person has an obligation to ensure that the task is performed appropriately*
- *Responsible **(R)** means the allocated person must ensure the task is completed*
- *Consulted (**C**) means the allocated person must be included in the process for input but do not necessarily have specific tasks to do*
- *Informed (**I**) means this person must be kept up to date with progress as it may impact other parts of their responsibilities or accountabilities.*

4 Asset base

4.1 Overview

Power and Water owns and maintains a portfolio of 2,530km of underground transmission and distribution cables distributed across the four regions of Alice Springs, Darwin, Katherine, and Tennant Creek, with the largest population in the Darwin Region. They operate at voltages including LV (240V, 415V), HV (6.35kV, 11kV, 22kV), and transmission (66kV). The population includes feeders of entirely underground cable as well as mixed overhead and underground feeders.

The portfolio consists of a variety of cable types, with XLPE type cables comprising the majority. Different types have been used depending on the preferred technology at the time of installation, or functional requirements such as different voltage levels. Each cable type presents different challenges, with associated risk and expenditure implications.

Furthermore, Power and Water owns and maintains a portfolio of six kilometres of cable tunnels, mostly located in the Darwin CBD area. The cable tunnels are mainly of box culvert design and follow key cable routes throughout Darwin.

4.2 Asset types

An overview of the different cable types is provided in Table 4.

Table 4: Asset types comprising the underground cable population by region

Cable type	Period of installation	Challenges	Expenditure / risk implications
Oil filled	*1967 - 1981*	• Technology becoming obsolete	• Skill to maintain and repair the cable diminishing. Longer repair times during fault conditions.
XLPE	*1959 – present*	• Prone to water ingress and earthing screen failure.	• Increasing failure rates and increased safety risk during fault conditions. A greater portion will require replacement prior to reaching their nominal lifespan than other types of cables. Note: Standard XLPE insulation type cables have been installed in the Power and Water network to date. Water tree retardant XLPE (TR-XLPE) cables are being considered as a new standard for future installations.
PILC	*1961 – 2013*	• Ageing cable type being phased out in the industry by XLPE type cables	• Loss of jointing skills. Longer repair times during fault conditions. Note: PILC is not a technology considered for new cable installations. Recent installations refer to infills for repair purposes.
PVC	*1961 – present*	• Mostly applied in LV applications • Being phased out in the power distribution industry	• Loss of jointing skills. Longer repair times during fault conditions.
Cable tunnels	*1973 – present*	• Mostly located in the greater Darwin City area • Generally in good health	• Emerging structural degradation, water leaks, and vegetation ingress

4.3 Breakdown of asset population

A detailed breakdown of the transmission underground cable assets is provided in Figure 4. The 66kV oil filled cables are of concern. These cables make up 27% of the transmission cable asset base and covers mainly two feeders, the 66kV Undersea Cable to Mandorah, and the 66kV Darwin to Frances Bay line.

This cable type has reached the end of its economic and technical life with the technology becoming obsolete at 66kV and the skills to maintain and repair the cable diminishing in Australia. Although cable damage and poor insulation results have been recorded these cables supply relatively small loads and do not carry a significant network risk. No capital investment in the oil filled cables has been planned for the next regulatory period. The assets will be closely monitored to identify any increased need as network loads and conditions change.

It is noted that the oil filled cables poses an environmental risk and Power and Water retains a responsibility for ongoing monitoring and maintenance investment during the operational life and following the decommissioning of these cables. Ongoing care and maintenance requirements are included in renewal investment evaluations.

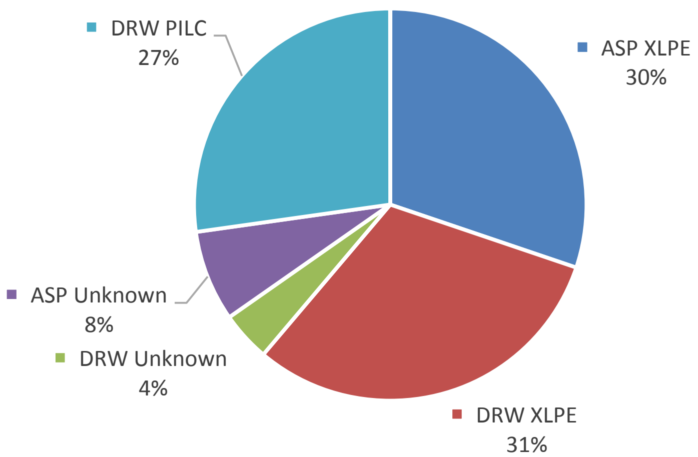

Figure 5: Transmission underground cable by asset type

A detailed breakdown of the distribution HV and LV underground cable assets is provided in Figure 5. At 52%, the XLPE HV and LV cables in Darwin make up a significant portion of the cable fleet. These cables are also of key concern. XLPE cables installed in the Power and Water network are of the standard design type that are known in industry for water treeing, which leads to cable failure. The cables installed prior to the late 1990's do not have water blocking and inconsistent termite protection layers, making them highly susceptible to termite damage, moisture ingress and water treeing. The cables also include aluminium screens that corrode and deteriorate as result of water ingress.

A significant increase in the failure rate of the northern suburb HV XLPE cables have been observed in recent years, with the failure rates nearly doubling over the last nine years, and contributing 5.0% and 2.8% to the Darwin System SAIDI and SAIFI. Investment in the replacement of the northern suburb cables are proposed in the next regulatory period to mitigate safety and reliability risk associated with the degradation of the cables.

Also of key concern are the XLPE/PVC LV cables located in the Cullen Bay and Bayview distribution areas of Darwin. These cables are in poor condition creating a hazardous working environment. Incorrect installation methods, compounded by calcium adipate insulation degradation, non-standard earthing design, and missing neutral conductors collectively contribute to the risks associated with XLPE/PVC LV cables.

The unpredictable operational environment caused by the condition of the cables poses a safety risk to the public as well as Power and Water employees involved in undertaking works on and in the vicinity of the assets and fittings. Although the deterioration in cables and associated replacement works have not impacted system reliability to date. It is expected that the rapid deterioration of the cables will lead to an unpredictable increase in reliability impact at some stage. As the condition of the cables is very poor, when unplanned failures do occur it is likely that they will be extremely difficult to locate using traditional methods, leading to extended outages for customers in these areas. Replacement of the LV cables and coincident refurbishment of the earthing and neutral system are being proposed for the next regulatory period to maintain the safe and reliable operation of the LV cable network.

LV XLPE cable failures due to moisture ingress and LV conductor corrosion (where moisture enters the LV core aluminium strands) have been observed in recent years with increasing frequency. The aluminium strands oxidises to aluminium oxide powder and form high resistance failures causing voltage drop and open circuit faults. At this stage the failures have not been significant enough to initiate a targeted program to address the issues, however a reassessment based on performance over this coming regulatory period will be performed to determine the need for investments in the following regulatory period.

Power Network's insulation specification for XLPE cables is currently being changed and future installations will consist of tree-retardant XLPE (TR-XLPE) cables.

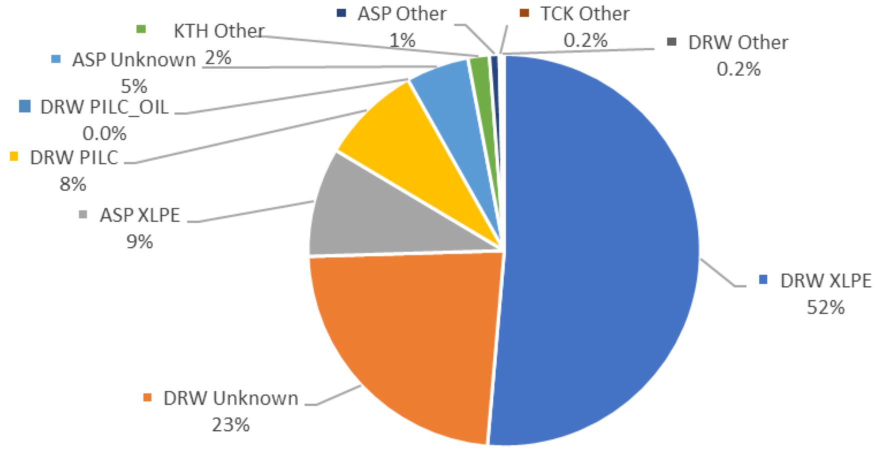

Figure 6: Distribution underground cables by asset type

A breakdown of the cable tunnel assets is provided in Table 5. The cable tunnel assets are generally in good condition and comprise five cable tunnel networks covering a total of 6km. The key challenges in maintaining the condition of the cables tunnels are water and vegetation ingress.

Table 5: Cable tunnels

Distribution area	Length (m)	% of asset population
Archer	231.7	3.8%
Darwin City	4,620.7	76.6%
Driver (associated with Palmerston City tunnel)	259.2	4.3%
Palmerston City	843.3	14.0%
Woolner	80.4	1.3%
Total	**6,035.2**	**100.0%**

4.4 Asset profiles

4.4.1 Transmission Underground Cables

Figure 6 provides a breakdown of the underground transmission cable assets by asset type over time. XLPE cable has grown to become the predominant cable type installed over the last 17 years, replacing PILC cables that were popular in the 1960’s.

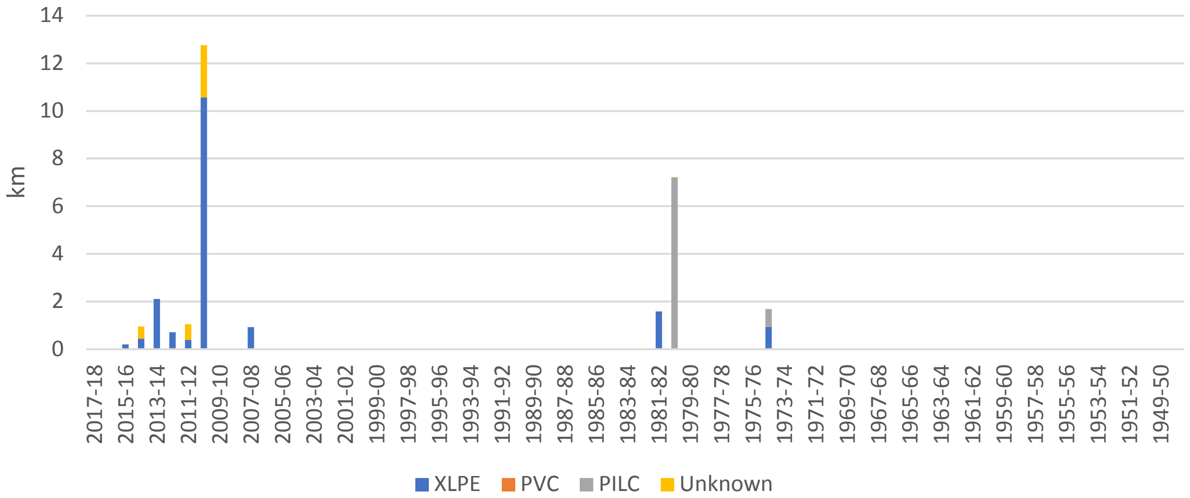

Figure 7: Transmission underground cable by cable type

4.4.2 Distribution Underground Cables

Figure 7 provides a breakdown of the underground distribution cable assets by asset type over time. XLPE cable has grown to be the predominant cable type installed over the last 17 years, phasing out the use of PVC and PILC cables used in earlier years.

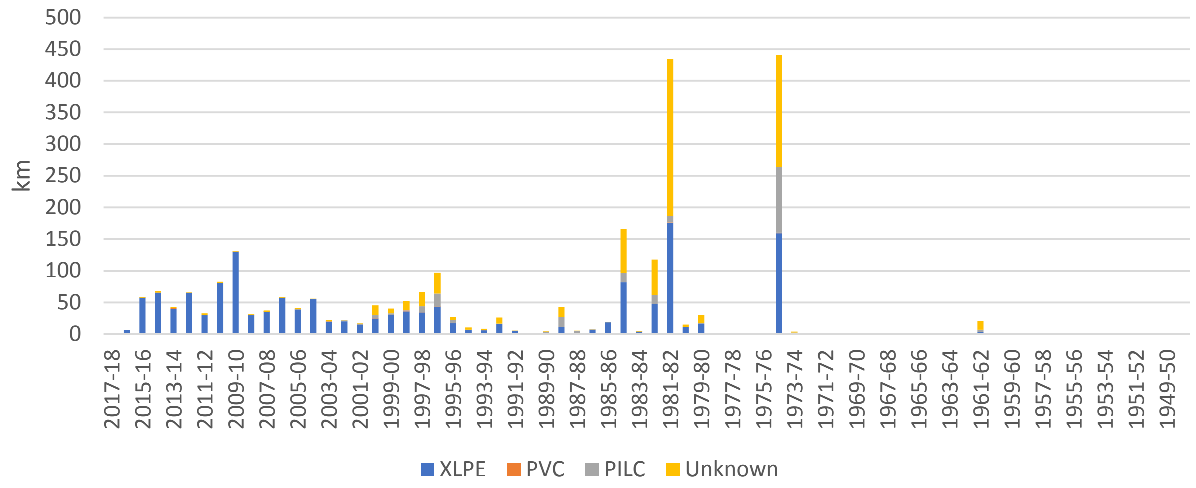

Figure 8: Distribution underground cables by cable type

Figure 8 provides a breakdown of the cable tunnel assets by distribution area over time. The majority tunnels were installed in the mid-1970's in the Darwin city area, with extensions included in the mid-2010's. Further installations are located in the Bellamack, Driver, Woolner and Palmerston city distribution areas of Darwin.

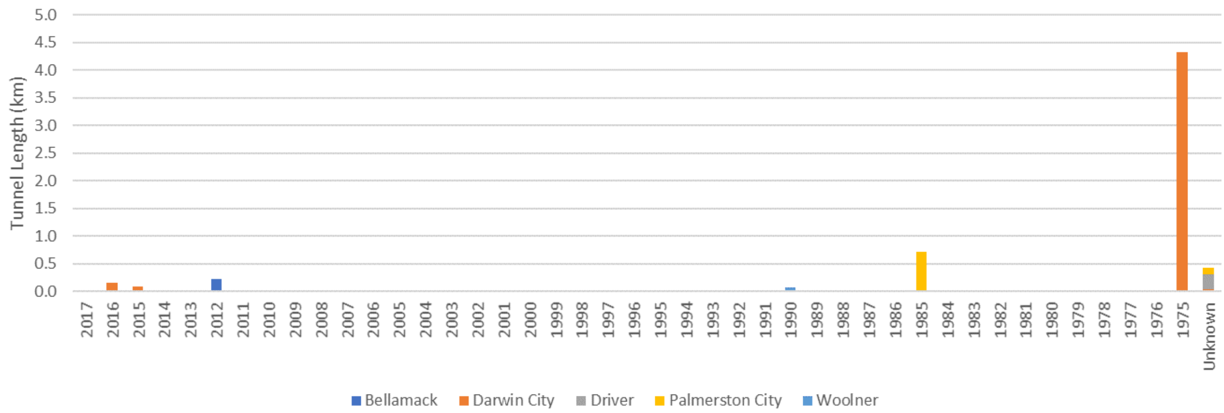

Figure 9: Cable tunnels by distribution area

4.4.3 Standard asset life

The asset life is the period of time that an asset can be expected to reliably and efficiently provide the service capability for which it was designed. Understanding the asset life is important to the establishment of a suitable maintenance regime including a planning and recording system together with its impact on capital and operational expenditure forecasts.

The situation and environment in which an individual asset operates can have a significant impact on both the required level of reliability and the rate of asset deterioration. It is therefore important to note that the asset life represents an average expected life of the asset. Some individual assets will last much longer than the expected asset life and others will fail prematurely. The asset life is generally influenced by:

- the cost of maintenance versus the cost of replacing the asset;

- the maintainability of the asset, particularly if replacement components are no longer available; and
- the risk associated with the failure of the asset, particularly if the consequence of failure increase to unacceptable level.

The asset lives applied by Power and Water as a standard have been based on general industry experience, a consideration of the asset lives used in other Australian and relevant international jurisdictions, and in-house engineering experience and judgement.

The typical asset replacement life applied by Power and Water for transmission and distribution (HV and LV) underground cables is 60 years and 55 years respectively as shown in Figure 10 and Figure 11. The asset lives correspond well with asset lives observed across the National Electricity Market (NEM) as demonstrated in the comparison with peer utilities.

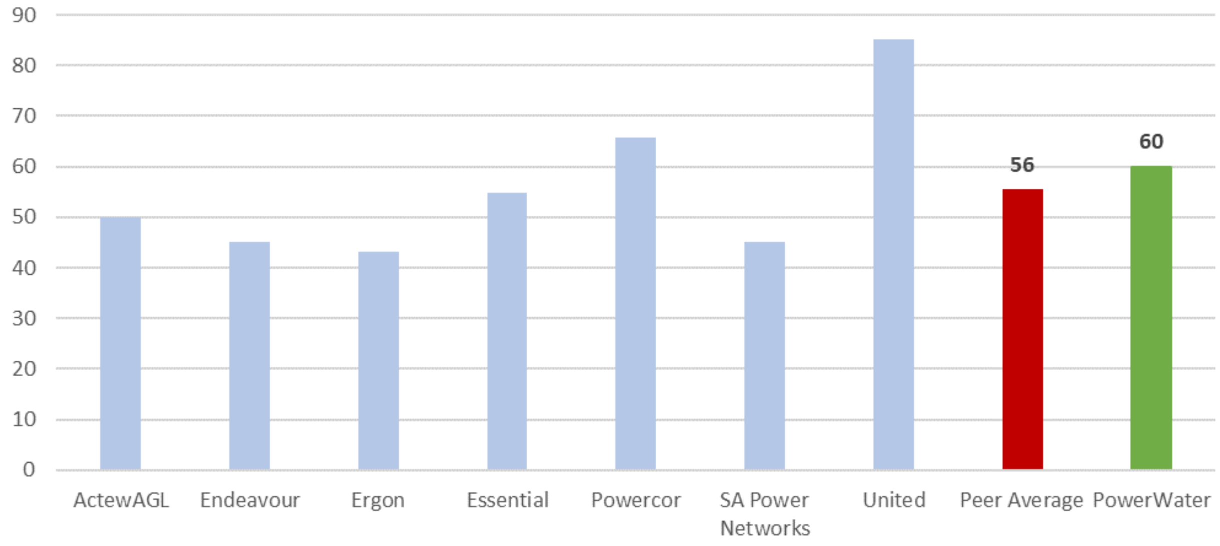

Figure 10: Transmission underground cable replacement life

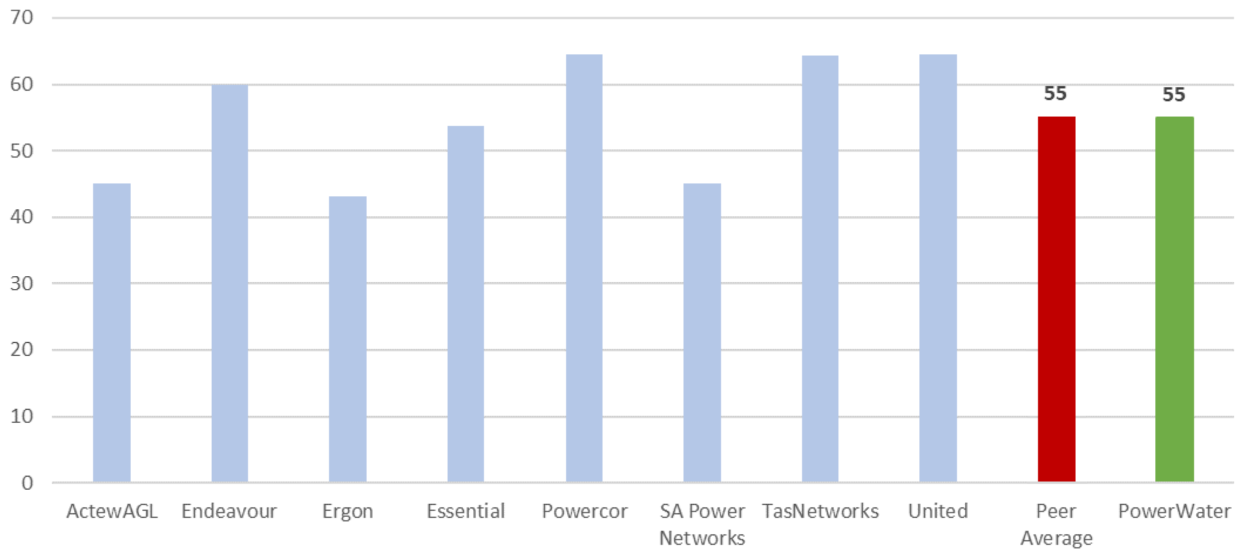

Figure 11: Distribution underground cable replacement life

4.4.4 Age profiles

The age profiles provide an early indication of expected asset condition and potential life extension or renewal investment requirements.

Table 6 and Table 7 provide a summary of asset remaining lives against this industry standard asset life. The tables include an illustration of the expected increase in assets that will be exceeding the asset life over the next two regulatory periods.

The transmission cable age profile shows a relatively young asset group. None of the assets will be exceeding the industry replacement life in the next two regulatory periods. The 66kV oil filled cables are becoming obsolete and are reaching the end of their economic lives; however, these cables are not currently carrying a significant risk to network performance and safety mainly as result of low electricity demands.

No investment requirements have been identified for the next regulatory period and these assets will be monitored closely to assess the need for future investment.

Table 6: Transmission underground cable average age and remaining life

Region	Weighted Average Age (years)	Weighted Average Remaining Life (years)	% of asset population	% exceeding replacement life in 2017	% approaching replacement life by 2024	% approaching replacement life by 2029
Alice Springs	7	48	38%	0%	0%	0%
Darwin	24	31	62%	0%	0%	0%
All transmission	18	37	100%	0%	0%	0%

The distribution underground cable remaining life profile shows a relatively young asset base with around 0.9%, or 23.1km of HV and LV cables (including service cables) projected to exceed the industry standard replacement life within the next two regulatory periods. The age based exceedances are mainly associated with the assets in the Alice Springs, Katherine and Tennant Creek regions.

Although no age based exceedances are forthcoming in the Darwin region, increased failure rates and safety concerns associated with asset condition issues have been identified in the HV cables of the northern suburbs and the LV cables of the Cullen Bay and Bayview distribution areas and have pushed a need for investment.

These cables comprise around a fifth, or 21.6% of the total distribution cable asset base with an average asset age of 47 years and 21 years respectively for the northern suburbs HV cables and the Cullen Bay and Bayview LV cables.

Table 7: Distribution (HV and LV) underground cable average age and remaining life

Region	Weighted Average Age (years)	Weighted Average Remaining Life (years)	% of asset population	% exceeding replacement life in 2017	% approaching replacement life by 2024	% approaching replacement life by 2029
Alice Springs	31	24	15%	5.5%	5.9%	7.1%
Darwin	25	30	83%	0.0%	0.0%	0.0%
Katherine	25	30	2%	1.0%	1.5%	8.0%
Tennant Creek	35	20	0%	0.0%	3.3%	13.8%
All distribution	26	29	100%	0.9%	0.9%	1.3%

4.4.5 Transmission underground cables – Age profiles by region

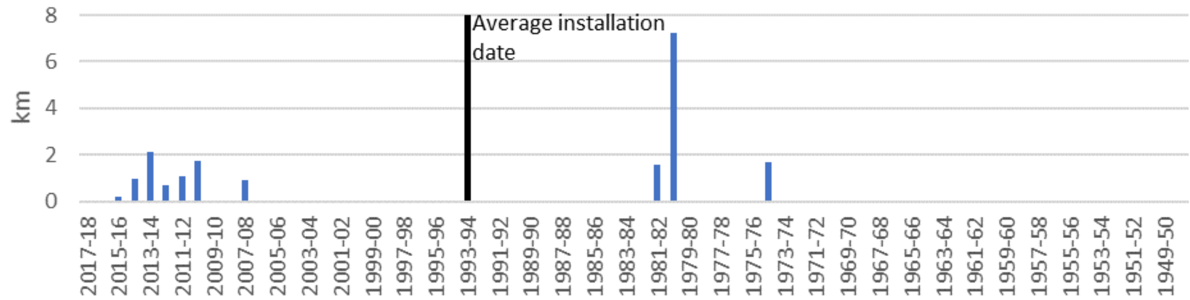

Figure 12: Darwin - Transmission underground cable age profile

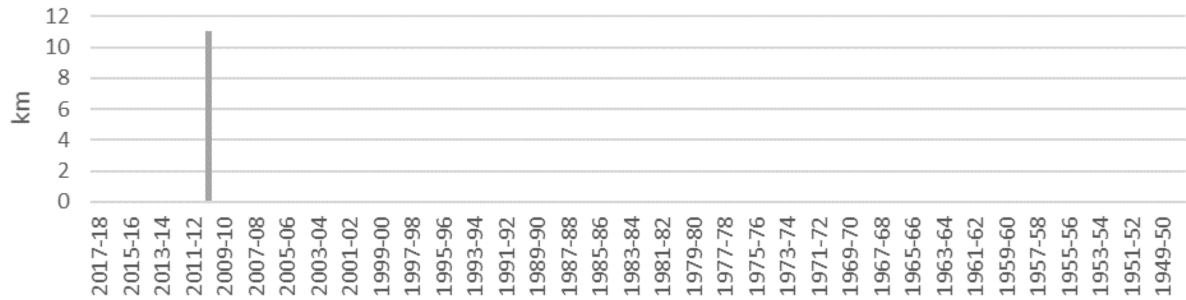

Figure 13: Alice Springs - Transmission underground cables age profile

4.4.6 Distribution underground cables - Age profiles by region

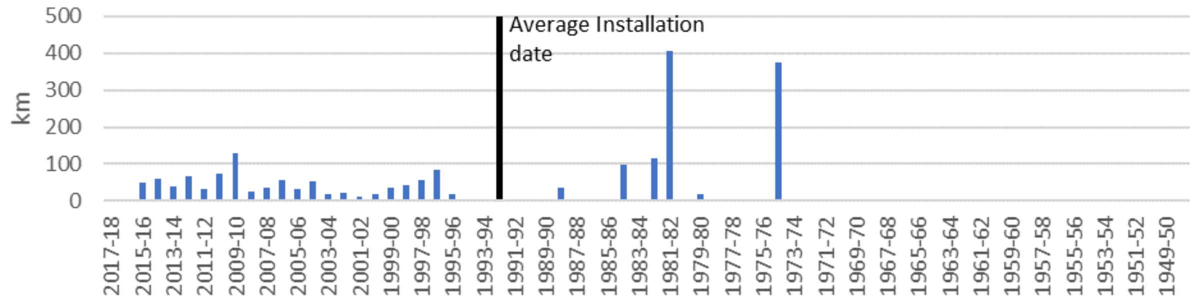

Figure 14: Darwin – Distribution underground cable age profile

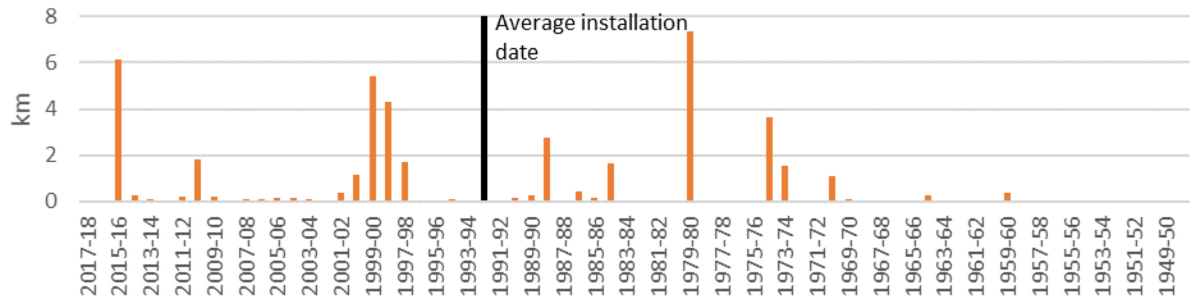

Figure 15: Katherine - Distribution cable age profile

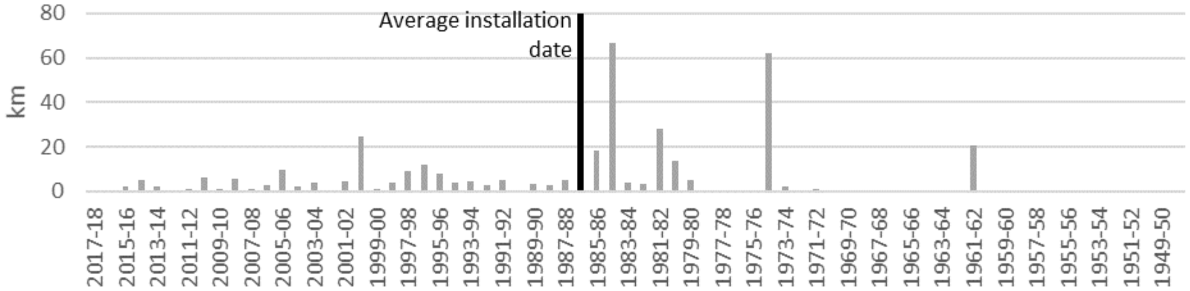

Figure 16: Alice Springs - Distribution cable age profile

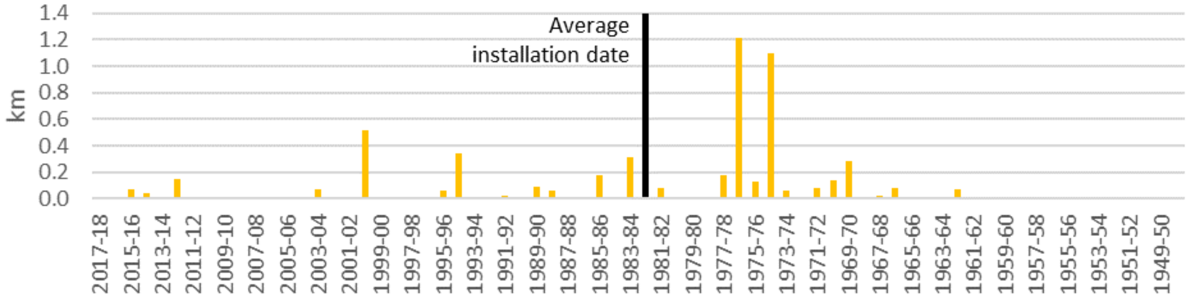

Figure 17: Tennant Creek - Distribution cable age profile

4.4.7 Cable tunnels

The majority of cable tunnels were installed in the mid-1970's. Further installations were made in the mid-1980's and more recently in 2002, and 2015 to 2016. The average age of the tunnels is around 37 years, reflecting a circa 1980 installation date.

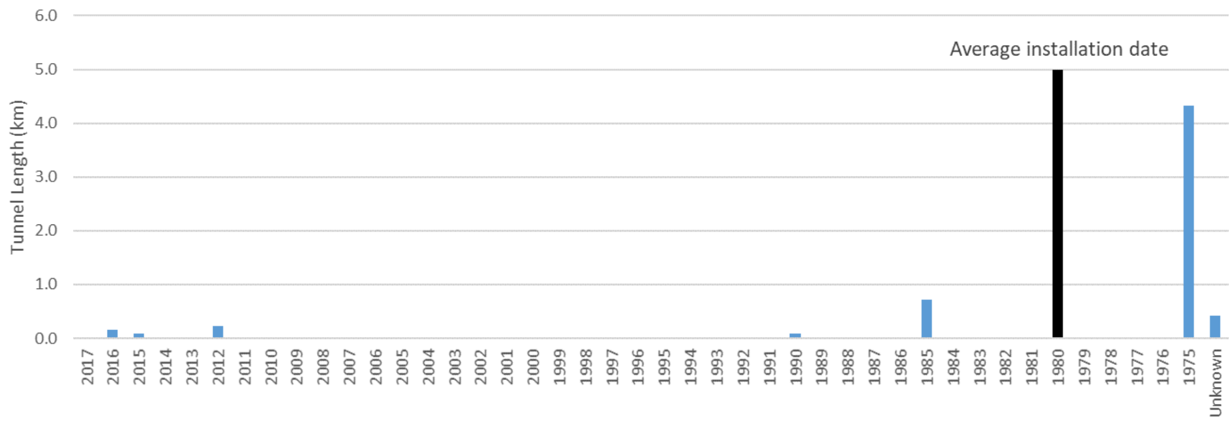

Figure 18: Cable tunnel age profile

5 Health and criticality profiles

5.1 Asset health and criticality indices

Risk is that uncertain event or condition associated with an asset failure that, if it occurs, will affect Power and Water's ability to successfully execute its strategies to achieve its organisational objectives of operating a safe and reliable power network at the lowest cost to the customer. The health and criticality framework[4] provide the basis for calculating the risk associated with the underground cable assets. It combines failure data and recent condition data (IR tests, insulation continuity tests, visual inspection results) to modify the assessment of expected remaining life and the associated likelihood of failure across the fleet of underground cables.

Asset health is a key factor in the likelihood of asset failure, and the asset criticality is a key determinant in quantifying the risk associated with the failure.

It should be noted that the health and criticality indices are evolving as more data regarding asset age, condition, and operating environment become available. It will continue to evolve over time as the asset composition changes with age, investments, and network development. These changes are captured through ongoing improvements in asset data collection practices applied during routine inspections and targeted methodical inspections aimed at recording and updating asset data related to age, condition, and operating environment.

The probability of asset failures and the associated risks are therefore continually refined as routine data, and targeted data is collected across the asset base.

5.1.1 Asset health

Cable systems are generally reliable and perform well. Where cable failures are being observed it is typically a strong indicator to asset health, with the failure mode providing valuable information on the health condition factors.

The underlying failure mode for cables is the degradation of insulation material over time. Asset age, or age based remaining life has therefore in the first instance been used as a proxy for asset health where additional condition data was not available. Degradation is accelerated by aspects such as design defects, outer sheath damage, and thermal loading. These defects are identified and recorded during routine inspections, as part of other works requiring the exposure of the cable, and through targeted methodical inspections and testing. Where available; failure data, inspection findings and test results have been used to inform the cable asset health.

The probability of asset failure is related to the health of the asset and for cable assets has been based on recent fault rates, and test results where these were available.

The main failure modes observed on cable assets are summarised in Table 8.

Table 8: Underground cable failure modes

Failure mode	Description
Insulation degradation	Insulation deterioration as result of age and moisture ingress (particularly in XLPE insulation) ultimately leading to cable failures.
Outer sheath damage	Outer sheath damage either during installation (eg tight bends, sharp backfill, etc), termites or subsequent impacts by excavating tools used in civil works (e.g. other services, road construction, etc). If the damage is not noticed, reported and repaired, moisture ingress leads to screen and sheath corrosion and eventually causes insulation degradation.
Internal failure	Internal failure as result of high thermal load of an otherwise healthy cable. However, joints and terminations are more likely to be the point of failure. Backfill materials or entrapped air in the case of a conduit may limit heat dissipation from the cable creating localised hot spots.
Joint and termination failure	Joint and termination failure primarily due to quality of materials and workmanship,

[4] 'Heath and Criticality decision making process' document

Failure mode	Description
	mechanical stress, moisture ingress and thermal loading or a combination.

5.1.2 Asset criticality

The cable network contributes to both the reliability and safety risk of the power network. Risk quantification undertaken in the industry across asset classes has found reliability risk to routinely be the more prominent risk associated with asset failures. Reliability risk is that risk related to the duration and frequency of outages resulting from asset failures, and is linked to the number of customers impacted by an outage.

The criticality of the cable assets within the network has in the first instance been based on the expected contribution to the system reliability risk resulting from asset failure. Where appropriate and based on inspection and test data, criticality level adjustments have been made to reflect the contribution to public and worker safety risk.

5.2 Transmission cables

For transmission cables the asset **health** has been based on age based remaining life. An expected replacement life of 60 years has been applied for transmission cables and corresponds well with experience observed across the NEM. The health segregation adopted a three-point health index scale used to categorise assets in terms of their expected remaining life where conditional factors were not evident to suggest a different segregation. The approach is described in the Asset Health and Criticality Method discussion paper. The criteria applied to allocate a health score are provided in Table 9. Assets with unknown remaining lives were assigned to the best health category, H1.

Table 9: Health indices criteria

Health score	Description	Criteria
H1	Good	More than 15 years remaining life
H2	Average	Between 5 and 15 years remaining life
H3	Poor	Less than 5 years remaining life

Where poor asset condition issues have been identified through targeted inspection and testing, these cables would typically be included in the overall indices based on a separate assessment. No adjustments have been made for transmission cables.

Criticality ratings have been assigned at feeder level based on the impact of contingencies on the security of supply and system loading conditions. A workshop involving key Power and Water planning and asset management personnel as well as external expertise were undertaken to assess the relative criticality of transmission feeders. The main criteria included an assessment of contingencies resulting in radialisation of the network, system overload conditions, and system critical supply feeders. Allocations were made as shown in Table 10.

Table 10: Transmission feeder criticality assignment

Feeder ID	Description	System radialisation under single contingency *C1 - No radialisation* *C2 – System radialisation* *C3 - Power station link*	System overload under single contingency *C1 - No overload* *C2 - Exceed normal rating but not contingency rating* *C3 – Exceed emergency rating*	Feeder criticality
132 CI-HC A	Channel Island - Hudson Creek	C3	C1	C3
132 CI-HC B	Channel Island - Hudson Creek	C3	C1	C3
132 CI-MT	Channel Island - Manton	C1	C1	C1
132 MT-BA-PK	Manton-Batchelor-Pine Creek	C1	C1	C1
132 PK-KA	Pine Creek - Katherine	C1	C1	C1
66 AR-WD 1	Archer-Weddell	C1	C1	C1
66 AR-WD 2	Archer-Weddell	C1	C1	C1
66 BE-HC 1	Berrimah-Hudson Creek	C1	C1	C1
66 BE-HC 2	Berrimah-Hudson Creek	C1	C1	C1
66 BE-LE	Berrimah-Leanyer	C2	C1	C2
66 CP-DA	Cox Peninsula-Darwin	C1	C1	C1
66 DA-FB	Darwin-Frances Bay	C1	C1	C1
66 HC-AR	Hudson Creek-Archer	C1	C1	C1
66 HC-PA	Hudson Creek-Palmerston	C1	C1	C1
66 LE-CA	Leanyer-Casuarina	C2	C1	C2
66 MR-SY	Mary River-Strangways	C2	C1	C2
66 PA-SY	Palmerston-Strangways	C2	C1	C2
66 WD-SY	Weddell-Strangways	C2	C1	C2
66 WN-CA	Woolner-Casuarina	C2	C1	C2
66 WN-DA	Woolner-Darwin	C1	C1	C1
66 AR-WS	Archer-Wishart	C1	C1	C1
66 HC-DA	Hudson Creek-Darwin	C1	C1	C1
66 HC-WN 1	Hudson Creek-Woolner	C1	C2	C2
66 HC-WN 2	Hudson Creek-Woolner	C1	C2	C2
66 LG-OS 1	Lovegrove-Owen Springs	C3	C1	C3
66 LG-OS 2	Lovegrove-Owen Springs	C3	C1	C3
66 WN-FB	Woolner-Frances Bay	C1	C1	C1

The transmission underground cable asset health and criticality profile is provided in Table 11. It reflects the general good health of the transmission network with no assets in the red and orange zones.

Table 11: Transmission underground cable health-criticality matrix (qty)

	H1	H2	H3
C1	14.1 km	0.8 km	
C2	2.4 km	0.9 km	
C3	11.0 km		

The asset health and criticality is a function of time and is expected to change as the assets continue to age. With no investment over the next five year regulatory period and no forecast growth, the profile is expected to change to that shown in Table 12. The increase in risk is demonstrated in the increase in the number of assets that entered the H2 health category.

For the transmission cable assets an increase in risk is reflected in a significant increase in the number of average health assets in the H2 category.

Table 12: Transmission underground cable health-criticality matrix (qty) with no investment

	H1	H2	H3
C1	6.9 km	8.0 km	
C2	0.8 km	2.5 km	
C3	11.0 km		

5.3 HV Distribution cables

The HV distribution underground cable **health indices** have in the first instance been based on remaining life applying the standard replacement life of 55 years. Where poor asset condition issues have been identified through targeted inspection and testing, these cables have been included in the overall indices based on a separate assessment. Assets where these adjustments were made included the HV XLPE cables in the northern suburbs of Darwin, and the 11kV Port Feeder. Similar to transmission cables, the three-point health index scale described in the Asset Health and Criticality Method discussion paper was implemented.

Tests were undertaken on 13, or 42% of the Darwin northern suburb cable feeders, and identified a 40% failure rate in XLPE cable screen testing. Visual inspections also identified condition issues with the cables. The northern suburb XLPE cables were allocated into health categories based on the earth screen test findings.

Table 13: Northern suburbs health indices criteria

Health score	Description	Criteria
H1	Good	Earth screen tested fine
H2	Average	Not tested
H3	Poor	Earth screen test failed

Increased failure rates and recent inspection and test results identified the 11kV Port feeder to be of poor health, with consistent peripheral damage, damage to the earthing screen, and water ingress. The cable is around 20 years old but has been categorised as H3 due to the poor inspection and test results.

Asset criticality across the asset class was allocated in the first instance based on the customer density as approximated by the feeder categorisation. Where known feeder performance issues have been identified, adjustments were made to account for these relative performances. Based on good historical performance and a high level of system redundancy CBD feeders were reallocated to C1. Relative low performance had resulted in short rural feeders being reallocated to C3. The underlying criteria applied in allocating cable asset criticality are provided in Table 14.

Table 14: Cable criticality criteria

Criticality score	Description	Criteria
C1	Low	Long rural & CBD
C2	Medium	Urban
C3	High	Short rural

Given the known performance issues associated with the northern suburb HV XLPE cables; these cables were assessed based on historical average customer minutes lost per outage as recorded over the last 10 years.

Table 15: Northern suburb HV cable criticality criteria

Criticality score	Description	Criteria
C1	Low	<5,000 CML per outage
C2	Medium	<15,000 CML, >= 5,000 CML per outage
C3	High	>= 15,000CML per outage

The HV distribution cable health and criticality profile is provided in Table 16 and prioritises 43km of HV cable in the red and orange zones as being of poor health and high criticality.

Table 16: HV Distribution cable health-criticality matrix (qty)

	H1	H2	H3
C1	53 km	68 km	8 km
C2	451 km	113 km	19 km
C3	107 km	21 km	15 km

With no investment and excluding growth over the next five year regulatory period the profile is expected to change to that shown in Table 17. The increase in risk is demonstrated in the increase in the number of assets that entered the H3 health category and the H2/C3 category.

For the HV distribution cable assets, an increase in risk is reflected in a 5% increase in the number of poor health assets in the H3 category, and a 68% increase in the number of average health assets in the H2 category.

Table 17: HV Distribution cable health-criticality matrix (qty) with no investment

	H1	H2	H3
C1	44 km	75 km	10 km
C2	341 km	223 km	20 km
C3	87 km	42 km	15 km

5.4 LV Distribution cables

The LV distribution underground cable health indices have been based on remaining life applying the standard replacement life of 55 years. The three-point health index scale described in the

Asset Health and Criticality Method discussion paper was implemented. Where the age was not known, the cable was assigned to H1.

Similar to HV cables, criticality ratings were assigned by feeder type, adjusted to reflect recent feeder performances.

Through targeted inspection and known operational issues the Cullen Bay and Bayview LV cables have been included in the overall indices based on a separate assessment. The Cullen Bay and Bayview LV cables were categorised for health based on inspection results that recorded the level of adipate observed at cable terminations as shown in Table 18.

Table 18: Cullen Bay and Bayview health criteria

Criticality score	Description	Criteria
H1	Good	No adipate
H2	Average	Adipate observed but not severe
H3	Poor	Severe adipate

Given the small size of the Cullen Bay and Bayview networks and the similarity in customer composition, asset **criticality** was determined to be homogeneous across the networks. Based on customer minutes lost as result of outages, the Cullen Bay and Bayview assets were categorised as a C3 criticality.

The LV distribution cable health and criticality profile is provided in Table 19 and prioritises 9km of LV cable in the red and orange zones as being of poor health and high criticality.

Table 19: LV Distribution cable health-criticality matrix (qty)

	H1	H2	H3
C1	10 km	18 km	0.2 km
C2	522 km	104 km	9.0 km
C3	47 km	2 km	0.02 km

With no investment and excluding growth over the next five year regulatory period the profile is expected to change to that shown in Table 20. The increase in risk is demonstrated in the increase in the number of assets that entered the H3 and H2/C3 zones.

For the LV distribution cable assets, an increase in risk is reflected in a 5% increase in the number of poor health assets in the H3 category, and a 92% increase in the number of average health assets in the H2 category.

Table 20: LV Distribution cable health-criticality matrix (qty) with no investment

	H1	H2	H3
C1	9 km	19 km	0.2 km
C2	417 km	209 km	9.3 km
C3	39 km	10 km	0.03 km

5.5 Service Lines

Power and Water has 932km of service lines. Most service lines serve a single customer and are therefore classified as low criticality. Health levels are not known for service lines.

5.6 Cable tunnels

The replacement life of cable tunnels is expected to be around 60 years. This is based on the economic life applied by Power and Water in recent asset valuations. At an average age of 37 years, and an expected average remaining life of 23 years the cable tunnel assets are considered in good health. However, some general issues around drainage, vegetation ingress, and water leaks are starting to emerge. The cable tunnels will be closely monitored over the next regulatory period to assess the need for future investment.

6 Key challenges

6.1 Environmental challenges

The network covers a range of environments and geographies which present different challenges for the underground cable asset class. Table 21 provides an overview of environmental challenges in relation to managing Power and Water's underground cable assets across its four operating regions.

Approximately 80% of Power and Waters network is coastal tropical environments prone to cyclones, monsoons, high ambient temperatures and humidity, and high annual rainfall. The remainder of the network is desert environments subject to high ambient temperatures, occasional flooding, droughts, dust storms, and aggressive oil conditions.

The unique environment results in a more rapid rate of asset deterioration, and lower worker productivity compared to peer distribution businesses.

Climate change is also expected to further exacerbate the environmental conditions over time, resulting in increased asset damage and failure from increase quantity or/and severity of cyclones, storms, lightning activity, dust storms, and droughts.

These factors impact uniquely on the Power and Water network and assets.

Table 21: Environmental challenges in relation to underground cable asset management

Region	Environment	Challenges	Expenditure / risk implications
Alice Springs	Desert	• Dust storms and drought • Occasional flooding after long dry periods.	• Hot desert environment leading to heat related stresses and reduced productivity • Although rare, extreme weather events do occur (e.g. flooding) • Aggressive soil types resulting in high corrosion issues (particularly related to steel assets, e.g. earthing systems, poles) • Climatic change may result in increased asset damage and failure from increase quantity or/and severity of dust storms and drought • No immediate investment programs planned
Darwin	Coastal / Tropical	• Cyclones • Up to 21,924 lightning strikes per year (Global Position And Tracking Systems (GPATS) - 2007 to 2017 Data) • 6-8 Ground strikes per km^2 per year (Bureau of Meteorology (BOM))	• Hot and humid environment leading to heat related stresses and reduced productivity • Extreme weather events (e.g. cyclones, flooding) • Increased asset damage and failure from increased quantity or/and severity of storms and lightning related to climate change • Northern suburbs HV cable replacement

Region	Environment	Challenges	Expenditure / risk implications
		• Tropical storms with winds in excess of 100 kilometres per hour • Long periods of high supply demands • High corrosion rate zone • High termite hazard zone	program • Cullen Bay and Bayview LV cable replacement program
Katherine	Inland Tropical	• Tropical storms and lightning • High termite hazard zone	• Hot and humid environment leading to heat related stresses and reduced productivity • Increased asset damage and failure from increases quantity or/and severity of storms and lightning • No immediate investment programs planned
Tennant Creek	Desert	• Dust storms and drought • Occasional flooding after long dry periods.	• Hot desert environment leading to heat related stresses and reduced productivity • Increased asset damage and failure from increase quantity or/and severity of dust storms and drought related to climate change • No immediate investment programs planned

6.2 Operational challenges

6.2.1 Asset access

Unpredictable weather conditions and extended and high rainfall periods limit the ability to access assets and effectively schedule and undertake operational and construction activities during the wet season. This directly impacts on productivity associated with civil works due to ground water levels filling excavations, trench wall integrity, and cable jointing in extreme conditions that can affect workmanship due to both moisture ingress and the physical stress on field crews. This is exacerbated by the majority of cable faults occurring during the worst working conditions, as shown in Figure 20.

6.2.2 Operational effectiveness

Power and Water operates in hot and humid environments leading to heat related stresses and reduced productivity resulting in increased time to undertake maintenance and inspection tasks. These environments are not comparable to other networks around Australia and have a significant impact on the productivity of the field crews. To assess and quantify the impact of the climatic conditions, Power and Water undertook a study in selected locations across Australia.

Workability is the term used to describe the productivity impact of climate in both Northern and Southern regions. It is the percentage of time for which work of different physical exertion can be effectively undertaken.

Table 22 describes the work rates used in the study along with a description and examples.

Table 22 Work rate descriptions

Work rate	Description	Work examples
Rest	Rest	Lunch and Crib Breaks
Low	Sitting with light manual hand/arm work. Driving. Standing with light arm work, occasional walking.	Driving, work planning, briefings and toolbox meetings, inspections
Moderate	Sustained moderate hand to arm work, moderate arm and truck work. Light pushing and pulling. Normal walking.	Unpacking tools, spare parts, dismantle/ replace small electronic components, general switching from ground
High	Intense arm and truck work, carrying, shovelling, manual sawing, pushing and pulling heavy loads, walking at a fast pace.	Climbing ladders, working in trenches and cabinets, remove replace larger components
Very High	Very intense activity at fast to maximum pace.	Carrying larger tools and replacement components, lifting, carrying up ladders, digging trenches, hauling cables, moving cable, pillars, poles

The outcome of the study is shown in Table 23 with the impact on Power and Water highlighted in orange. It demonstrates that the climatic conditions, particularly in Darwin where the majority of Power and Water's network is located, result in an average Workability of 65% compared to other major cities in Australia. This would equate to a 35% escalation of labour hours compared with the southern states for similar work and therefore an escalation of opex.

This is supported by feedback received via a heat stress survey which identified that approximately 50% of workers report daily or weekly heat-related impacts on their productivity.

Table 23 Workability for selected Australian locations based upon moderate metabolic rate

Location	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Alice Springs	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Adelaide	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Brisbane	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Darwin	41%	44%	45%	60%	100%	100%	100%	100%	74%	46%	34%	32%
Hobart	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Melbourne	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Perth	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Sydney	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

6.2.3 Availability of capability and skills in remote areas

A key operational challenge in relation to underground cables is the scarcity of personnel trained with HV cable jointing qualifications. Power and Waters cable jointing expertise is mostly centred in Darwin, and results in increased time and costs for undertaking maintenance and repair and/or asset installation activities in the regional areas.

Power and Water's low relative fleet size also doesn't allow for maintaining appropriate experience level associate with specialized skill types. For example, highly technical but generally low volume and low frequency repair and maintenance tasks, such as oil filled cable repairs, require original equipment manufacturer (OEM) support and/or a technical specialist and equipment to be brought in from interstate or overseas.

An increased need for skilled technicians and required plant and equipment to be transported to remote sites in other areas of the network that can be up to 1,500km away is required. This is a unique situation to Power and Water and is not experienced by the distribution businesses in the eastern states of Australia.

6.2.4 Demand profile

The demand profile across the network is flat and consistent across each day, as shown in Figure 18. The daily peak is fairly flat and consistent between 8am and 10pm, and is driven by the use of air conditioners. This shows that all assets are utilised consistently and therefore it is more difficult to remove assets from service for prolonged periods of time.

During the wet season, November to April, the load profile becomes flatter (more consistent) with less difference between the peak and the trough and the demand is about 10% higher.

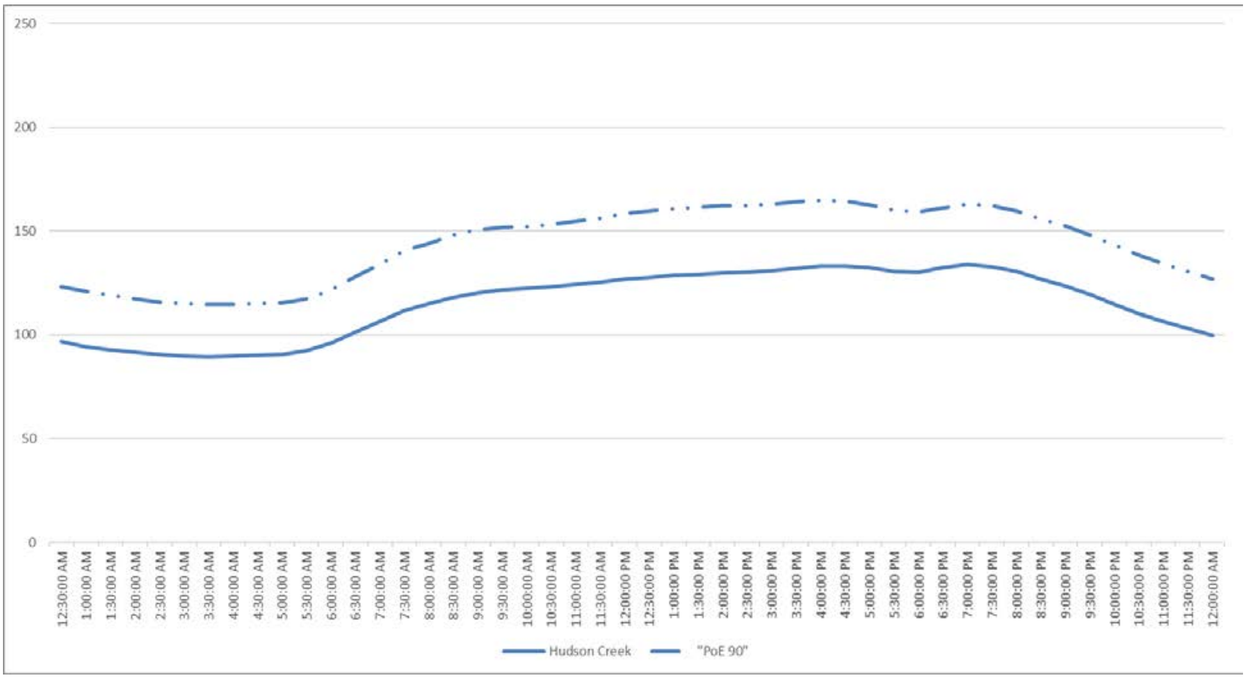

Figure 19: Darwin average daily demand profile (Hudson Creek ZSS) May to October

Figure 20: Darwin average daily demand profile (Hudson Creek ZSS) November to April

The annual maximum shows the demand for the highest half hour interval for the year. This shows that although the average peak was approximately 150MVA, the maximum was 200MVA, or 33% higher.

6.2.5 Seasonal challenges

Darwin has two distinct seasons, the 'wet' and the 'dry'. The wet season runs from November until April, and is characterised by high humidity, monsoonal rains, and storms. Temperatures typically range from a minimum of 20°C to a maximum of 33°C[5] as measured by the Bureau of Meteorology (BOM) over a 77 year period from 1941.

Figure 20 profile shows the 10 year average monthly maximum temperature measured in Darwin indicating the change in season during the year, in comparison with the corresponding average number of cable failures. The ‘dry’ season is characterised by average maximum temperatures dropping to around 31°C and the ‘wet’ season with average maximum temperatures up around 34°C.

The cable failure profile shows a strong correlation between cable failures and the seasonal climate conditions. An increase in asset failures is observed during the time periods when environmental factors, access to assets, workability, and demand profiles presents the highest challenges.

As climate conditions continue to change a corresponding increase in cable failures are expected to be observed during these worst periods of the year, and especially impacting the Darwin region at the Top End of the Northern Territory.

[5] Bureau of Meteorology (BOM), Climate statistics for Australian locations, Darwin

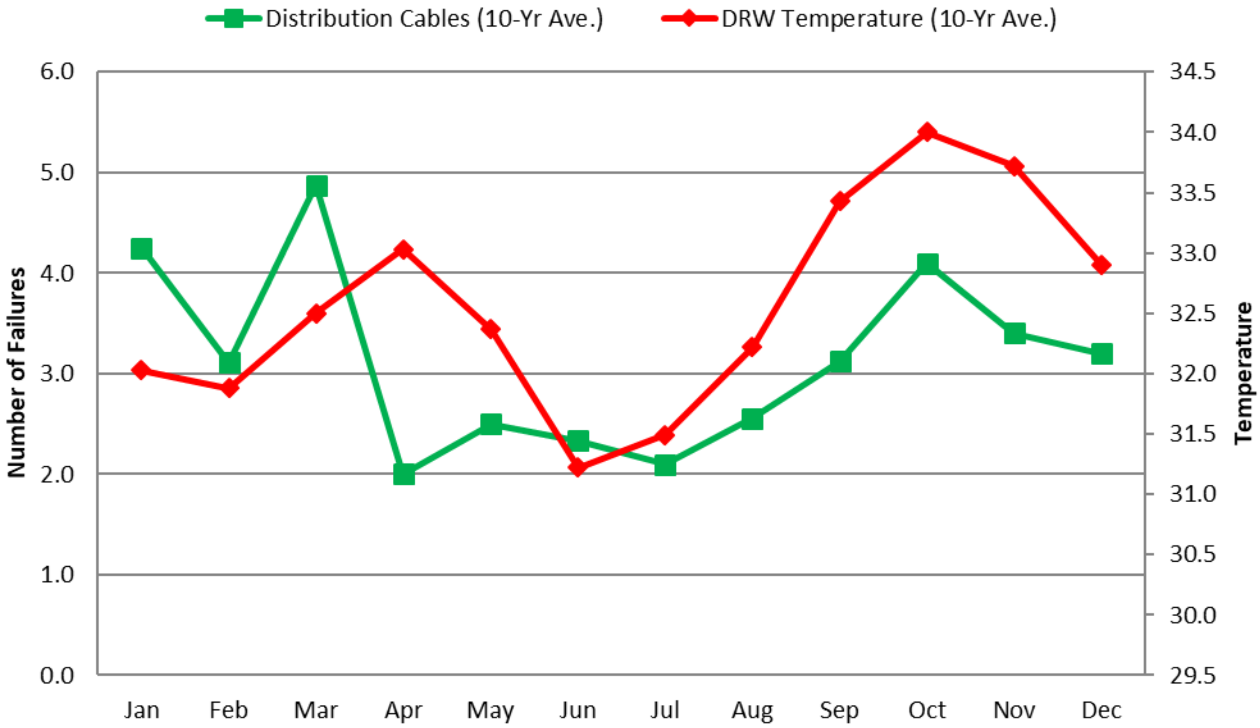

Figure 21: Average annual temperature and cable failure profile

6.3 Asset challenges

The health of cable assets and associated earthing systems are uniquely challenged in the Power and Water network. The key underlying issues relate to moisture ingress in XLPE cables. The cables are subject to persistent wet environments for up to six months of the year resulting in increased levels of moisture ingress, aluminium screen corrosion, water treeing, and ultimately cable screen and cable failure. This issue is mainly as result of the type XLPE cable that has been installed up to recently. The cable specifications are currently being changed and future installations will consist of tree retardant XLPE (TR-XLPE) cable.

Soil conditions distinctly contribute to the cable health and associated system safety issues. During the dry season the soil conditions result in extremely high soil resistivity and during the prolonged wet periods of the wet season results in significantly reduced soil resistivity. Power and Water's earthing systems are designed to cater for these extremes in earthing requirements. An interconnected CMEN earthing system, which relies on cable screens, provides for predictable earthing conditions and design standards. The continuity of the cable screens is pivotal to maintaining the integrity of the earthing system.

Incorrect installation methods resulting in sheath and insulation damage, moisture ingress, and accelerated insulation degradation has also been identified as a key issue in installations within the network.

Technology obsolescence is also emerging as a key issue related to oil filled transmission cables. This cable type has reached the end of its economic life with skills to maintain and repair the cable diminishing.

The northern region of the NT is a high termite hazard zone that provides unique design challenges. These challenges are currently being mitigated through special design specifications requiring termite protection in cables.

These underlying factors are key considerations in the following asset challenges identified in the transmission and distribution cable networks.

6.3.1 Transmission cables

There are two primary challenges related to Power and Water's transmission underground cable assets as follows.

6.3.2 66kV Undersea Cable to Mandorah

One of the two 66kV undersea oil filled cables supplying Mandorah failed in 2013 and was unable to be repaired. The cable was formally decommissioned in 2016 although Power and Water still retains the liability for the 7,000L of oil contained in the cable. The remaining in-service cable is in good condition for its age however the technology is becoming obsolete and skills to maintain and repair the cable diminishing and Power and Water is fully reliant on interstate and potentially overseas support should a failure occur on this cable. The nature of oil-filled cable construction requires immediate response to maintain oil pressure if a failure occurs. The most prevalent risks to the remaining cable are physical impacts from ship anchors or onshore earthmoving equipment and storm surges associated with high intensity cyclones. Multiple failures of these cables due to these external factors have occurred, the first being Cyclone Tracy in 1974. However the supply risk associated with the cables are low mainly as result of low demands and standby generation permanently installed at the remote end zone substation.

6.3.3 66kV Oil Filled Cable FB replacement (Feeder 66 DA-FB)

The 66kV oil filled cable provides a critical function in maintaining security of supply to Darwin CBD. The cable has reached the end of its economic life with the technology becoming obsolete and skills to maintain and repair the cable diminishing as described above. The replacement of the cable will likely be required in the late 2020's, however the risk associated with the supply risk associated with the cable is currently low mainly as result of system redundancy. If the cable fails in-service it is likely replacement with XLPE would be initiated rather than attempting a repair. Given the reliance on external support and equipment for an oil filled cable repair, a replacement with XLPE cable would likely be the least cost option.

A. Distribution HV cables

There are three key challenges related to the distribution underground cable assets:

6.3.4 Replace Port Feeder

Full details on this asset challenge are available in the BNI document:

- PRD33006 – Preliminary Business Case - Replace Port Feeder

An increase in failure rates have been observed on the 11kV Port Feeder in recent years. An investigation initiated by Power and Water identified consistent sheath damage, damage to the earthing screens, and water ingress. DC Insulation Resistance tests and outer sheath electrical integrity tests further identified the degradation of the internal insulation and the outer sheath. The majority of failures have occurred in two sections of the 8km cable and these sections will be targeted for replacement in 2019 and 2020.

6.3.5 Darwin northern suburbs HV XLPE cables

Full details on this asset challenge are available in the BNI document:

- NMP1 - High Voltage Cable Replacement – Darwin Northern Suburbs

There are unique issues affecting XLPE cables installed in the Power and Water network. XLPE is the abbreviation for cross-linked polyethylene. XLPE started to replace paper cables in the 1960's as a long life alternative with no electrical property degradation. However, towards the end of the 1970's field service performance recognised that XLPE undergo a degradation process called water treeing and an accelerated corrosion of the earth screen when exposed to moisture and electrical stress. In the early 1980's an improved version of XLPE called TR-XLPE was introduced, and has shown much improved field service performance[6 & 7].

This is a particular issue for Power and Water especially in the Darwin region due to the heavy rainfall and prolonged wet periods. Power and Water's XLPE cable fleet consist predominantly of the standard XLPE cable type. These cables are also unique in the fact that the screen conductors are Aluminium.

Significant cable failure contributions to reliability performance from the HV cable network in the northern suburbs of Darwin; combined with consistent reports from field crews on poor cable condition affecting the reparability of these cables resulted in the launch of investigations into the cause of these issues. The investigations confirmed the consistent poor condition of the cables and moisture ingress issues.

Cable tests undertaken as part of the investigations confirmed a widespread issue with cable earth screen continuity failures. Screen corrosion as result of water ingress and oxidisation of the Aluminium screens was identified as the main cause of the screen degradation. A strong correlation was also found between screen corrosion and cable fault events. The extent of the screen degradation will compromise the earthing system integrity in the northern suburbs, of which HV screens are the most critical part.

The cable issues significantly increase reliability and safety risk associated with cable failures and the absence of a reliable low impedance fault current path limiting the risk to people, equipment and system operation to acceptable levels.

A. Distribution LV cables

6.3.6 LV cable network condition at Cullen Bay and Bayview

Full details on this asset challenge are available in the BNI document:

[6] LONG-LIFE XLPE INSULATED POWER CABLE, HAMPTON, NEETRAC, Georgia Tech, USA

[7] Global Trends and Motivation Toward the Adoption of TR-XLPE Cable, The Dow Chemical Company

- NMP2 - Low Voltage Cable Replacement Program Cullen Bay and Bayview

There are unique issues affecting XLPE/PVC cables in the Cullen Bay and Bayview areas. Investigations undertaken during 2016 and 2017 identified that the low voltage cables in the Cullen Bay and Bayview areas were of particularly poor condition with consistent sheath and insulation deterioration. The poor cable insulation condition has accelerated moisture ingress and the incidental development of calcium adipate leading to accelerated cable insulation and cable termination degradation. The level of deterioration of such a large proportion of cables is unprecedented based on their age and is considered a type issue unique to the cable installed.

The LV neutral earthing system in Cullen Bay is also compromised. The LV neutral conductor connection between a substation and the network being supplied is one of the fundamental components of the TN-C-S (Australia's MEN) network configuration as described by AS/NZS 3000. As such an LV neutral conductor is reticulated to all locations of the supplied LV network (Protective Earth and Neutral PEN). Throughout Australian utilities, this is generally achieved through the installation of a neutral conductor with each LV circuit leaving a substation to ensure redundancy and interconnectivity of the MEN system. This is not the case in Cullen Bay where Neutral conductors are "shared", creating many single points of failure. Unlike the rest of Power and Water's LV network, Cullen Bay also lacks a dedicated LV earthing conductor which exacerbates this issue, since in the event of a neutral failure the current return path is restricted to local earth rods resulting in potentially hazardous voltages in the LV earthing system.

6.4 Asset management challenges

Asset management is the application of management, financial, economic, engineering and other practices to infrastructure assets with the objective of providing the required level of service in the most cost-effective manner. It requires the management of the asset condition throughout the asset life cycle, including design, construction, commissioning, operating, maintaining, repairing, modifying, replacing and decommissioning/disposal. A study of condition and performance data captured over time assists in managing the asset to function optimally in a safe and reliable manner throughout its life cycle. The life cycle asset management approach applied by Power Networks is provided in Appendix A.

A key asset management challenge is a lack of comprehensive asset condition assessment data across the network to fully understand and evaluate the health and deterioration of the cable assets.

Improvement in the processes for and quality of data collection is a key focus and is being prioritised. Significant steps have already been taken through the introduction of mobile devices to capture test data in the field at the time of testing. Investment in test equipment and the capability of cable testers has also been a priority to ensure that at a minimum standard industry practices are embedded in our organisation for effectively managing distribution cables. This has been a conscious effort in recognition of the increasing cost, reliability and safety risks associated with the cable portfolio. Similar investment for transmission cables has not been a priority due to the small but generally healthy asset portfolio.

7 Performance indicators

The performance of underground cables against the specific objectives and measures identified in section 2.3 are provided here. The performance shown here represents the historical performance of the asset class to date. It is expected that benefits from investments proposed in the next regulatory period will manifest as benefits in these key objectives. The projected investment outcomes in relation to past performance trends are provided in section 11.

7.1 Operational performance indicators

The performance of the underground cable asset class over the 10 year period from 2006/2007 is provided in Figure 21, and segregated by sub-asset class (i.e. transmission, HV and LV distribution, service cables) in the subsequent charts. The charts show the performance based on sustained outages only, i.e. outages with a duration greater than 1 minute, and excludes major event days (MEDs).

In particular the following events were excluded from the analysis, in calculating the % contribution of the asset class into NT SAIDI/SAIFI:

a) Planned outages
b) Generation-related outages
c) Outages that were internal to customer premises
d) Outages initiated in the interest of public safety
e) Outages related to termination failures (these have been included in the distribution switchgear AMP)

The underground cable contribution to NT system SAIDI under a ‘no investment’ scenario indicates an expected increase in contribution of up to around 17% by the end of the regulatory period, 2023-24, a corresponding increase in SAIFI contribution of up to around 9% is projected. This increase has been projected based on the failure rates observed over the last 10 years and is considered conservative in comparison with failure rates over the last five years.

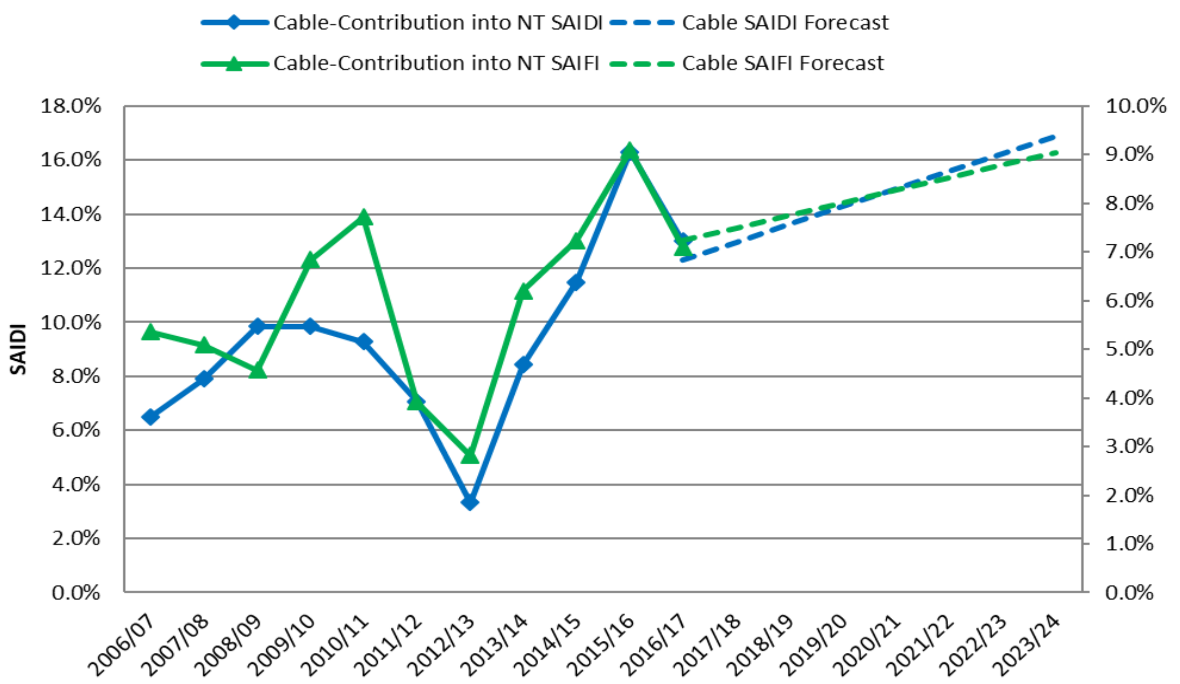

Figure 22: Underground cable contribution into SAIDI/SAIFI

Only 3 outages caused by transmission cables have been recorded over the last seven years. A major contribution was made by an outage of the submarine cable to Mandorah. Based on historical performance the projected contribution to system SAIDI/SAIFI over the next regulatory period under a ‘no investment’ scenario is expected to be flat.

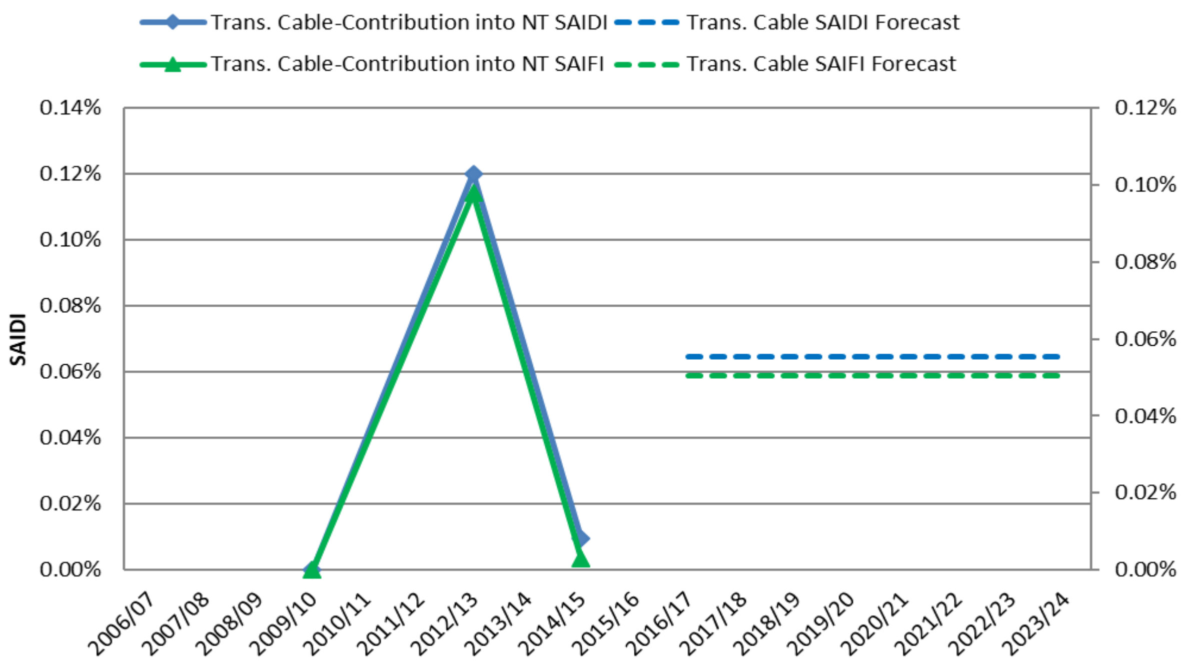

Figure 23: Transmission cable contribution into SAIDI/SAIFI

The projected HV cable contribution to NT system SAIDI under a ‘no investment’ scenario indicates an expected increase in contribution of up to 17% by the end of the regulatory period, 2023-24, a corresponding increase in SAIFI contribution of to 9.5% is projected.

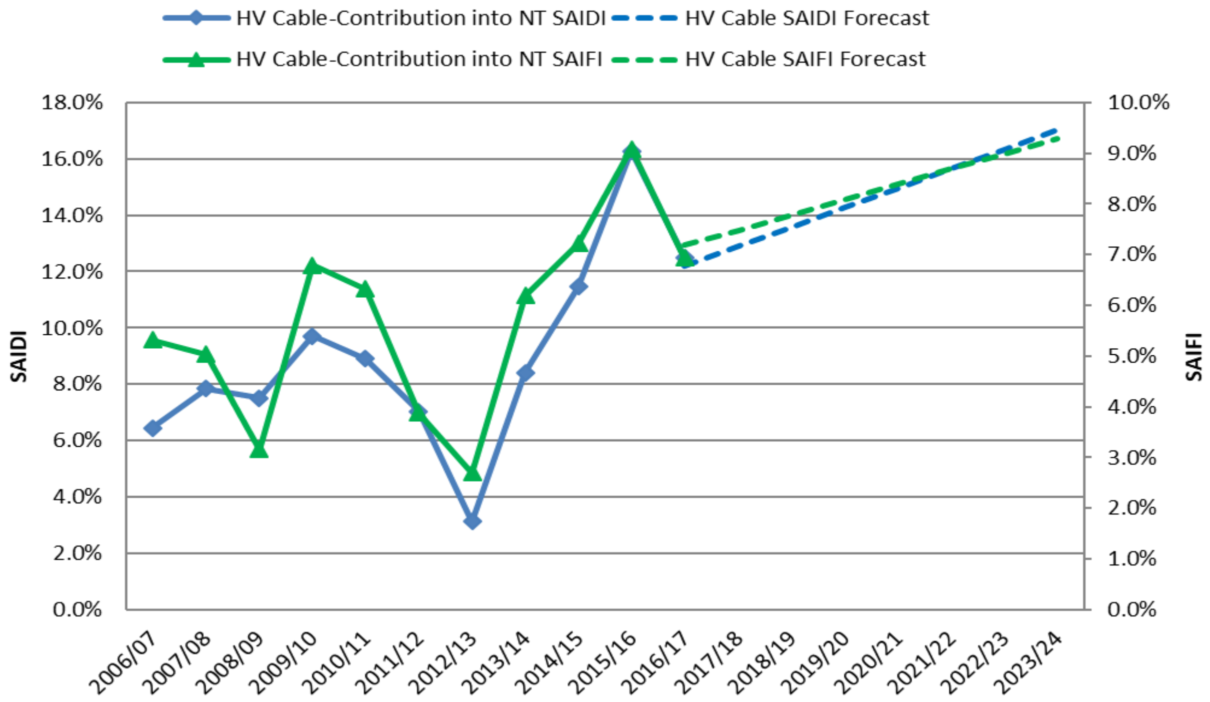

Figure 24: HV Distribution cable contribution into SAIDI/SAIFI

The system SAIDI/SAIFI performance contribution from LV cables is relatively small at a forecast contribution of around 0.1% SAIDI and 0.03% SAIFI over the regulatory period.

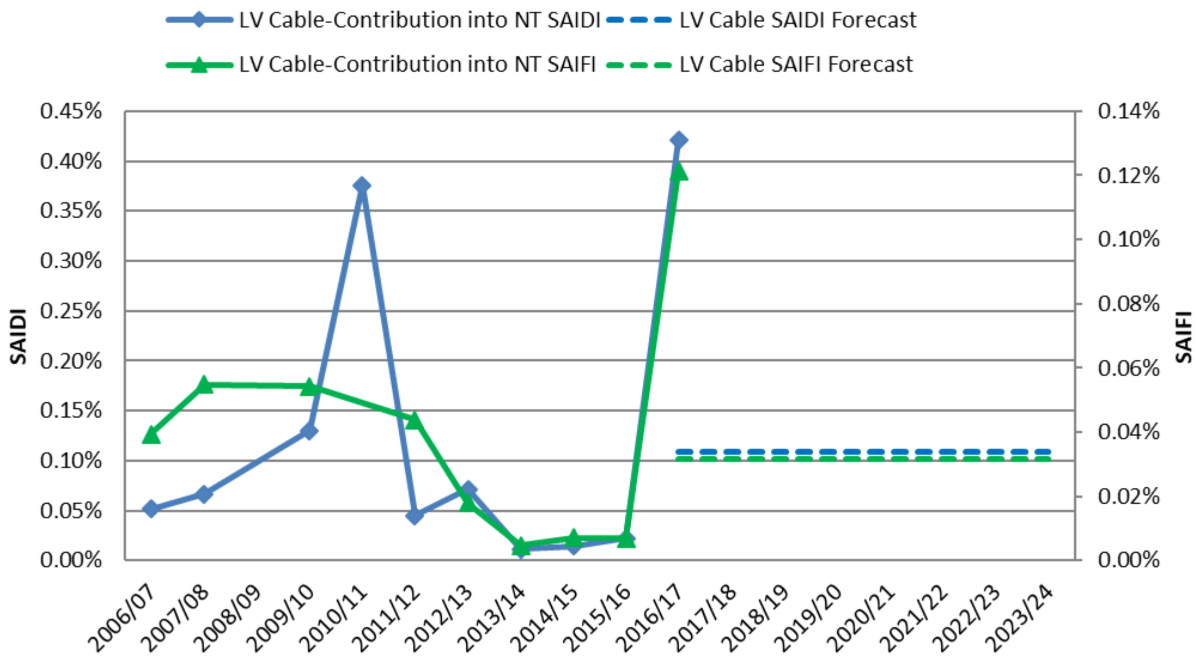

Figure 25: LV Distribution cable contribution into SAIDI/SAIFI

The system SAIDI/SAIFI performance contribution from Service cables is negligible over the regulatory period.

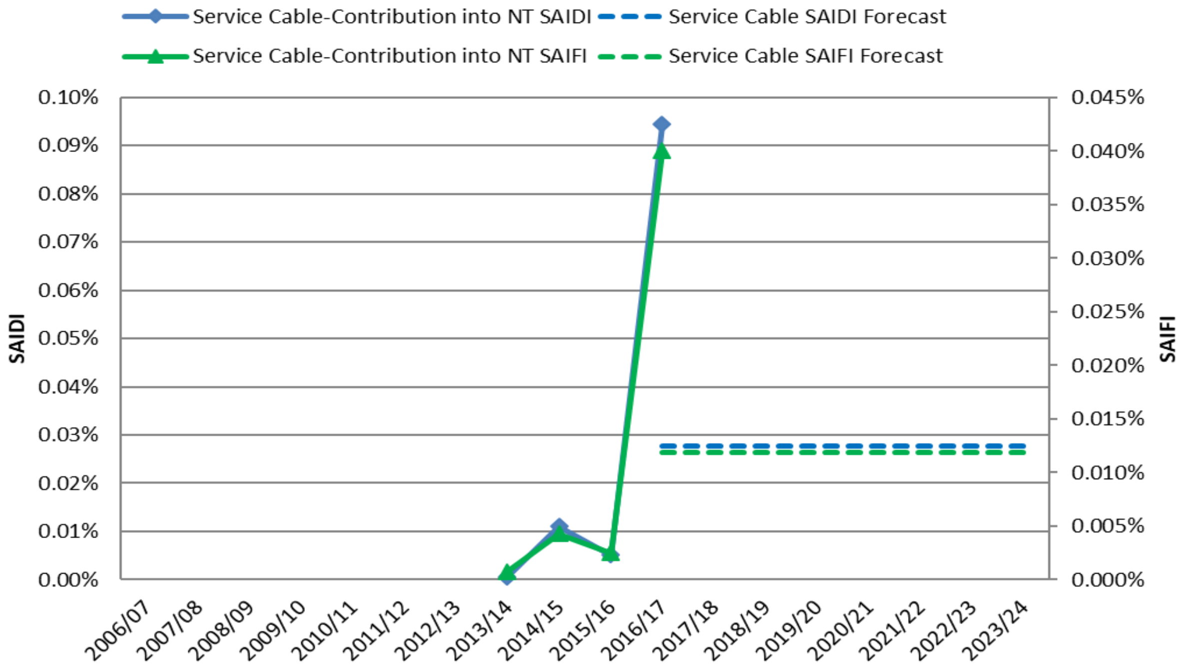

Figure 26: Service cable contribution into SAIDI/SAIFI

7.2 Health and Safety indicators

A key corporate objective is the safe operation of the network. The number of safety related events associated with underground transmission and distribution cables as recorded over the last 10 years are shown in Table 24, Table 25, Table 26, and Table 27. Safety-related incidents includes those outages which were caused by vehicle collision with Power and Water assets, excavation damage to Power and Water assets, public safety-related outages requested for nearby works, and outages to facilitate maintenance and repair works.

The frequency of incidents involving cable damage associated with excavations is a key concern relating to the screen deterioration in the Northern Suburbs of Darwin. Cable screens ensure the fault return path is low impedance, enabling protection systems to operate as fast as possible to prevent injury or death to equipment operators, observers, bystanders, etc. Without continuous healthy screens, adjacent equipment or infrastructure are highly likely to become part of the fault return path.

Table 24: Number of safety-related incidents associated transmission underground cables

Financial Year	Number of Outages	Comment
2010/11	1	Outage in the interest of public safety - Feeder opened to allow safe access to 66kV sub marine cable after navy ship in snagged on a cable in the harbour
2015/16	1	Outage in the interest of public safety-Debris blown into beach switchyard

Table 25: Number of safety-related incidents associated with HV distribution underground cables

Financial Year	Number of Outages	Comment
2006-07	4	Cable theft
		Cable damaged during excavations
		Forced outage - Power and Water equipment presents unacceptable risk

Financial Year	Number of Outages	Comment
		Forced outage - Power and Water equipment presents unacceptable risk
2007-08	7	Cable damaged during excavations
		Forced outage - Power and Water equipment presents unacceptable risk
		Outage in the interest of public safety (exposed pillar near school)
		Forced outage - Power and Water equipment presents unacceptable risk
2008-09	9	Forced outage - Power and Water equipment presents unacceptable risk
		Cable damaged during excavations
		Isolation of undersea cable for safety-related reasons
2009-10	6	Forced outage - Power and Water equipment presents unacceptable risk
		Outage in the interest of public safety-Excavations near the cable
		Outage in the interest of public safety-Excavations near the cable
2010-11	4	Forced outage - Power and Water equipment presents unacceptable risk
		Feeder de-energised to allow safe switching of suspect cable.
		Outage in the interest of public safety (vehicle collision with electrical assets)
		Outage in the interest of public safety - Excavations near cable
2011-12	10	Forced outage - Work being done on cable
		Outage in the interest of public safety-Excavations under the cable
		Outage in the interest of public safety-Excavations near the cable
		Forced outage to allow safe switching operations
		Forced outage to repair cable
		Forced outage to facilitate future works
		Forced outage to repair live line clamps
		Forced outage to commission cable
2012-13	2	Forced outage - Power and Water equipment presents unacceptable risk
		Forced outage to repair RMU
2013-14	2	Forced outage to facilitate work on substation's HV cubicle
		Forced outage to repair cable
2015-16	2	Outage in the interest of public safety-Tent blown into beach switchyard
2016-17	5	Forced outage - Power and Water equipment presents unacceptable risk
		Forced outage to facilitate inspections

Table 26: Number of safety-related incidents associated with LV distribution underground cables

Financial Year	Number of Outages	Comment
-	-	-
-	-	-

No safety-related incidents related to LV cables were identified over the last 10 year period.

Table 27: Number of safety-related incidents associated with Service line underground cables

Financial Year	Number of Outages	Comment
2012-13	1	Cable damaged during excavations
2014-15	1	Outage in the interest of public safety (Vandalised power box)
2015-16	1	Cable damaged during excavations
2016-17	1	Cable damaged during excavations

7.3 Financial indicators

Power and Water's long term financial sustainability as underwritten by affordable service and shareholder returns is demonstrated in the efficiency and competitiveness of its capital and operating costs.

The capital expenditure forecast for cable assets has been based on historical unit costs, relying on recent and similarly scoped projects. The approach aligns with industry best practice and relies on data that is continuously validated and updated.

7.3.1 Capital unit costs

The capital unit rates are a significant input towards the capital expenditure forecast and have been calculated and justified to be efficient and prudent.

The cable replacement unit costs applied by Power and Water in establishing the regulatory capital forecast have been compared against similar unit costs observed across the National Electricity Market (NEM). The comparison provided an indicative measure of the reasonableness of Power and Water's costs, and has been based on publicly available data sourced from the AER's Repex modelling and utility Regulatory Information Notice (RIN) submissions.

There are a number of internal and external operational, asset type, and environmental factors that influence the benchmark costs and provide a challenge in respect of the ability to undertake accurate comparisons. Normalisation for these factors has not been undertaken and the benchmark comparisons provided are an indicative measure of reasonableness only.

In undertaking the comparison, Power Networks was considered comparable with six Australian utilities of largely rural type networks. Subject to the availability of appropriate data these utilities included ActewAGL, Endeavour Energy, Essential Energy, Ergon Energy, TasNetworks, Powercor and United Energy.

Where historical unit costs have been utilised as part of the bottom-up estimates or historical analysis, these have been escalated to 2017-18 dollars by CPI only. The CPI escalation factor was derived from indexes published by the Australian Bureau of Statistics for all consumer groups and applicable to the Darwin area.

The unit cost comparison for HV and LV underground cable installation is provided in Figure 26 and Figure 27. Based on the comparison Power and Water's unit costs for HV and LV cable capital work is considered reasonable.

No investments in the transmission cable network is proposed for the next regulatory period and therefore no unit cost comparison was undertaken for the asset class.

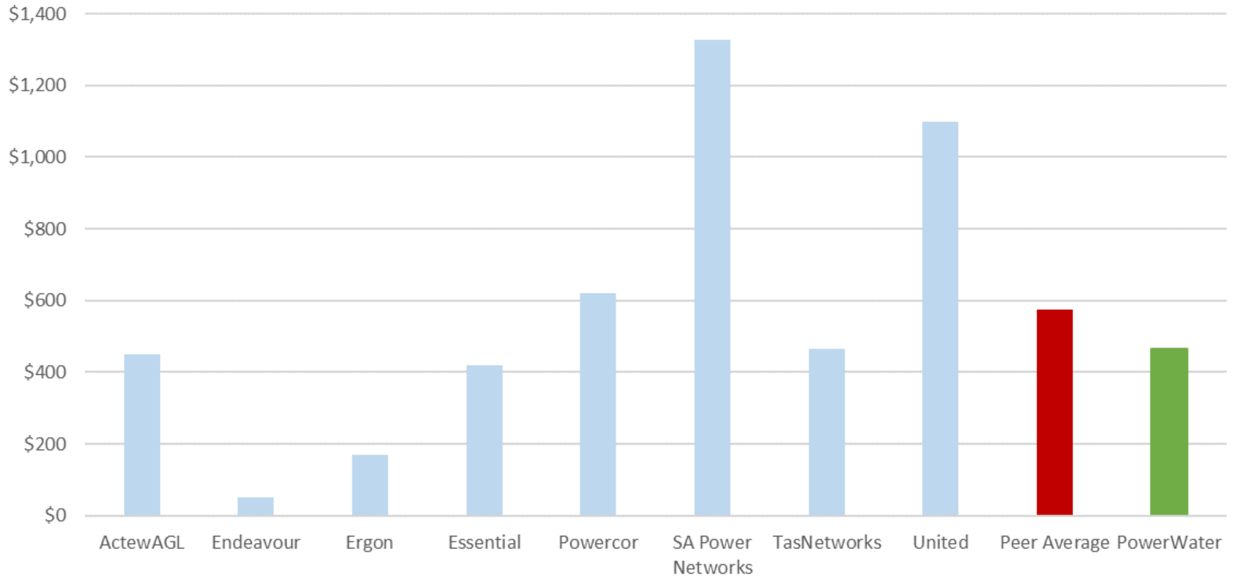

Figure 27: HV underground cable replacement Unit cost comparison

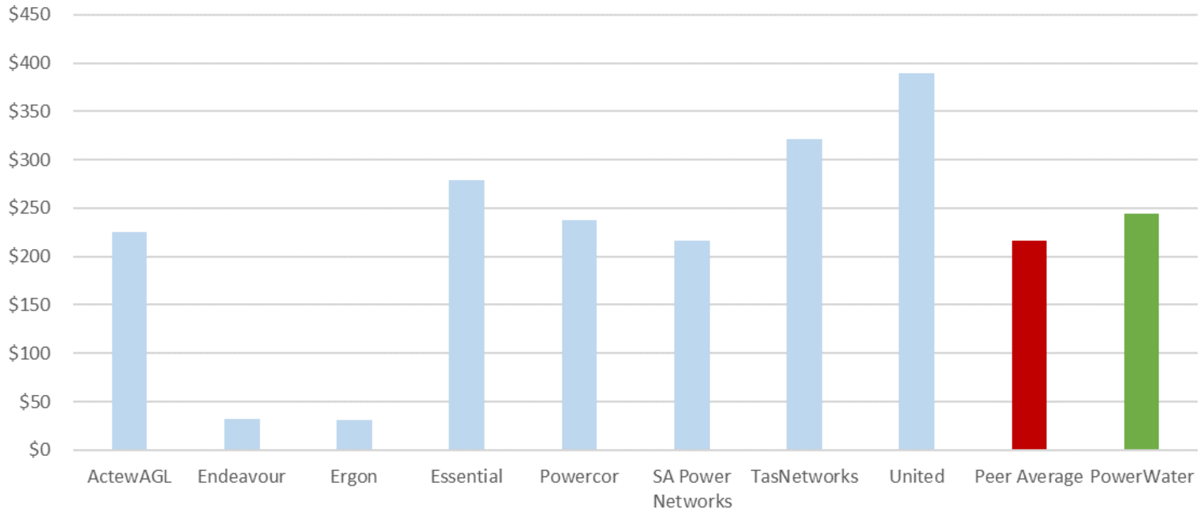

Figure 28: LV underground cable replacement Unit cost comparison

7.3.2 Operating unit costs

The operational expenditures include that expenditure incurred in operating and managing the cable network, ensuring that the assets continue to provide their pre-determined service capacity and quality of service and achieve their useful life. The operating expenditure therefore includes maintenance and direct overhead expenditure associated with the cable network.

Maintenance expenditure includes those costs incurred when:

- an asset is restored to its operational condition; and
- to ensure the asset meets its operational performance, reliability; and
- does not extend the useful life of the asset.

Direct overhead expenditure is expenditure associated with scheduling and planning. These support activities cannot readily be identified as belonging to a particular value adding task/activity and has been allocated on a pro-rata basis.

Similar to the capital cost, a comparison with peer utility expenditures has been applied to provide an indicative measure of the reasonableness of Power and Water's costs, and has been based on publicly available data sourced from the utility Regulatory Information Notice (RIN) submissions.

Insufficient peer utility data was available to allow for a comparison of operations and maintenance costs associated with emergency response works at the asset class level. Emergency response operation and maintenance costs have therefore been excluded from the comparison.

There are internal and external operational, asset type, and environmental factors that influence the benchmark costs and provide a challenge in respect of the ability to undertake accurate comparisons. Normalisation for these factors has not been undertaken and the benchmark comparisons provided here are indicative measures of reasonableness only.

Where historical unit costs have been utilised as part of the analysis, these have been escalated to 2017 dollars by CPI only. The CPI escalation factor was derived from indexes published by the Australian Bureau of Statistics for all consumer groups and applicable to the Darwin area.

A comparison of Power and Water's average annual routine and non-routine maintenance cost in comparison with peer organisations are provided in Figure 28. The Power and Water cost represent the average annual cost over the last five years.

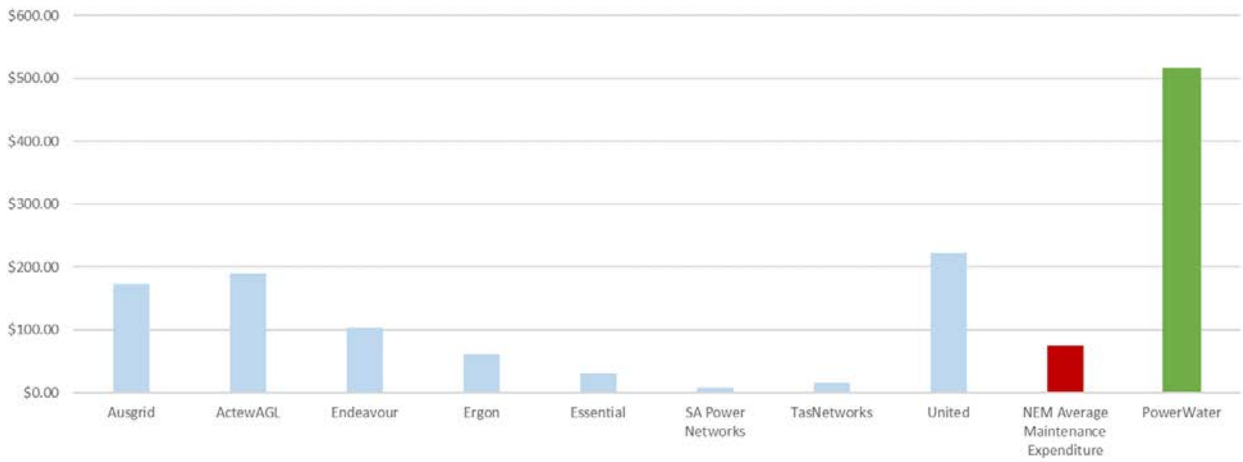

Figure 29: Underground cable routine and non-routine maintenance cost comparison

The high level unnormalised comparison indicates that Power and Water's costs compares with the upper range of costs recorded across the NEM and is reflective of a unique network, unique climate conditions, and unique work environment.

Works undertaken in the Northern Territory are characterised by higher costs than other areas in Australia. This can partly be attributed to the remoteness of the network attracting additional transport and logistic costs, as well as the harsh weather conditions set apart by extended wet and high rainfall periods which impede the effective execution of works; and a tropical climate, which impacts on the productivity that can be achieved during normal work hours. Section 6 provides a discussion on the environmental and operational challenges associated with the Power and Water power network.

Seasonal trends can be seen in the average monthly routine maintenance and emergency response expenditure in Figure 30.

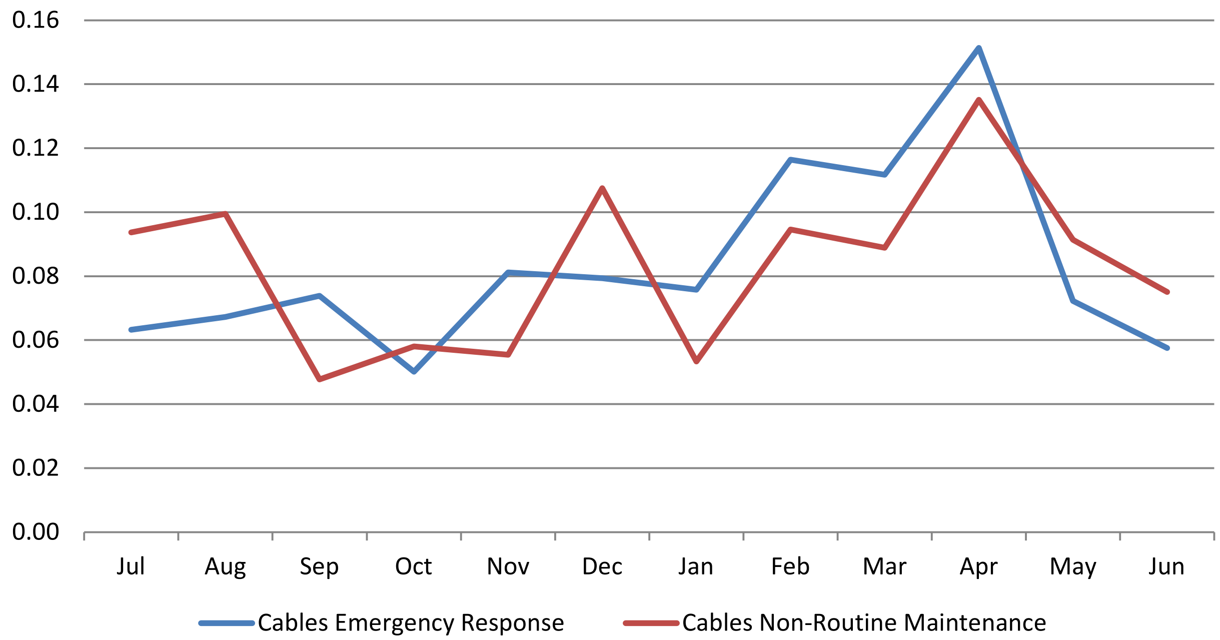

Figure 30: Normalised average monthly maintenance expenditure

As outlined above, there is a distinct increase in cable maintenance in the wet season months of February to April. This highlights that cable maintenance requirements are at their peak during the month during which efficient work is most difficult due to environmental factors.

Power and Water's routine and non-routine maintenance costs associated with underground cables appears high in comparison with peers, however are not considered an outlier given the uniqueness of the operating environment and therefore reasonable.

8 Growth requirements

The demand for power infrastructure is driven mostly by growth in the number of new network connections. To understand this potential growth Power and Water engaged AEMO in 2017 to undertake a demand and connection forecasts for the network regions of Darwin-Katherine, Tennant Creek, and Alice Springs[8]. The study outcome identified relative low customer connection growth across the network with the highest expected average growth in Tennant Creek, 1.0% followed by Darwin, 0.8% and Alice Springs, 0.1%. The outcome of the connection forecast is summarised in Figure 29.

[8] AEMO, Power and Water Maximum Demand, Energy Consumption, and Connections Forecast, September 2017

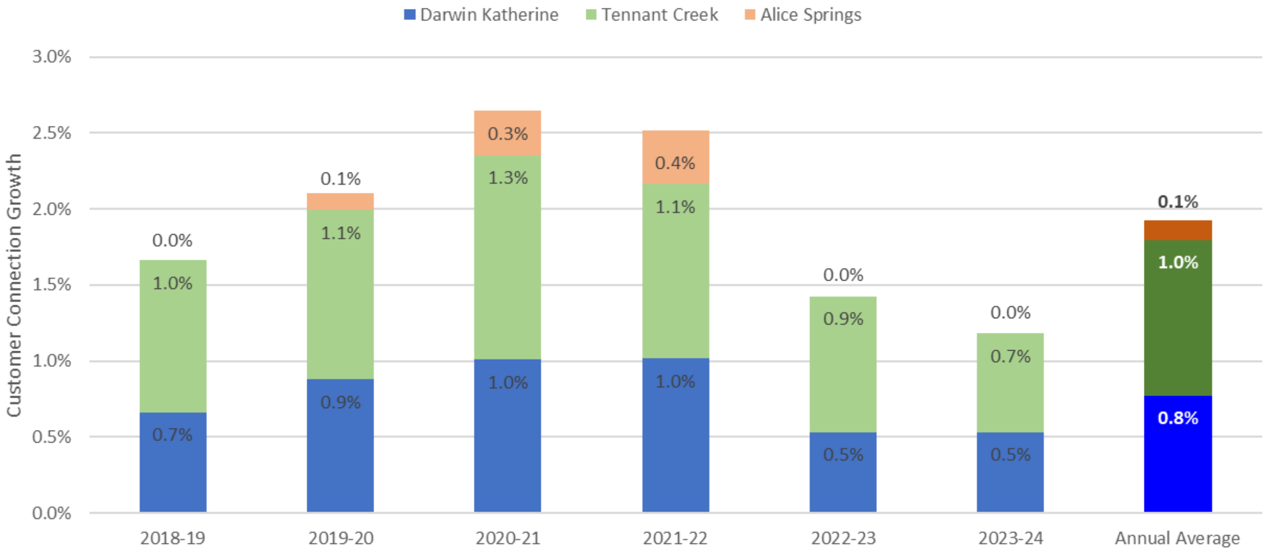

Figure 31: Customer connection growth by region (AEMO 2017 Forecast)

Most new urban and commercial developments in the Power and Water network are designed around the underground distribution of power, making the projected connection growth a reasonable proxy for the expected increase in infrastructure asset requirements over the same period.

It is noted that the AEMO connection growth forecast shows a significantly reduced growth rate in comparison with Power and Water's annual average growth in cable assets over the recent five years from 2012-13 to 2015-16. The changing environment with reducing demand growth is expected to impact on the requirement for network growth and the AEMO forecast has been adopted to project the expected growth in cable assets by the end of the regulatory period, 2023-24.

The projected increase in underground transmission and distribution cable assets is provided in Table 28. In summary the following approach was taken in doing the asset growth projections:

- No growth in transmission cable assets is expected/planned.
- The forecast was based on the customer connection forecasts from AEMO's 2017 report: *Power and Water Corporation Maximum Demand, Energy Consumption, and Connections Forecasts.*
- The current asset base (i.e. lengths of cables) for service cables, LV cables and HV cables were increased each year according to percentage change in the forecast number of connections.
- For periods where this percentage change was negative, the asset base remained the same, under the assumption that the existing network size will not reduce as result of short-to-medium term negative customer growth.

Table 28 Underground cable forecast growth, qty (FY19 to FY24)

Region	Historical annual asset growth rate (2012/13 to 2015/16)	AEMO annual connection growth rate	Transmission cable increase by 2023/24	HV Distribution cable increase by 2023/24	LV Distribution cable increase by 2023/24	Service cable increase by 2023/24
Darwin-Katherine	3.2%	0.8%	0.0 km	34.1 km	28.4 km	37.6 km
Alice Springs	0.8%	0.1%	0.0 km	1.0 km	0.8 km	1.0 km
Tennant Creek	1.5%	1.0%	0.0 km	0.2 km	0.1 km	0.1 km
Total cable increase	**2.8%**	**0.7%**	**0.0 km**	**35.2 km**	**29.3 km**	**38.7 km**

The growth in assets will impact on the health and criticality profile of the asset class. The new assets are expected to be of good health with a prorate spread across the asset criticalities

The revised forecast health and criticality profiles for each cable class by the end of the regulatory period, assuming no investment and including growth are shown in Table 29 to Table 31. The growth numbers are reflected in the increase in the H1 asset quantities.

Table 29: Transmission cable health-criticality matrix (qty) with growth and no investment

	H1	H2	H3
C1	6.9 km	8.0 km	
C2	0.8 km	2.5 km	
C3	11.0 km		

Table 30: HV Distribution cable health-criticality matrix (qty) with growth and no investment

	H1	H2	H3
C1	48 km	75 km	10 km
C2	366 km	223 km	20 km
C3	93 km	42 km	15 km

Table 31: LV cable health-criticality matrix (qty) with growth and no investment

	H1	H2	H3
C1	10 km	19 km	0.2 km
C2	478 km	209 km	9 km
C3	44 km	10 km	0.03 km

9 Renewal and Maintenance Plans

Power and Water's renewal and maintenance investment plans are aimed at addressing key asset challenges identified within the asset class.

Targeted inspection and testing are undertaken to investigate assets of concern, and a separate assessment applying the asset health and criticality decision making approach[9] is used to

[9] 'Program Replacement Volume Forecast Method' document

understand the risk associated with the assets within the scope of concern and to identify those assets that bear the greater risk.

Opportunities to maintain the safe and reliable operation of the network are then considered and this typically includes assessing options of run-to-failure, test and replace, and targeted pro-active renewal. The outcomes of the assessment manifest in a preferred investment option with a high level scope and cost estimate.

Maintenance activities are crucial in the early identification of asset health and condition issues and the prioritisation of assets for further investigation. Inspection findings, field service feedback, and performance measures are the main inputs used to identify those assets that are of particular concern, or may have a type issue. Routine asset inspections are therefore a fundamental aspect of Power and Water's maintenance regime to ensure prudent and effective investments.

The process and outcomes of the renewal and maintenance requirement assessments are documented in the Business Needs Identification (BNI) documents that are prepared for and approved by the Chief Executive.

The following projects and programs have been evaluated and provide the underground cable renewal and maintenance requirements proposed for the next regulatory period.

9.1 Transmission cable

9.1.1 Transmission cable asset renewal plans

1) 66kV Undersea Cable to Mandorah replacement

The 'do nothing' option was selected and no investment in the renewal of the cables are planned for the forecast regulatory period.

2) 66kV Oil Filled Cable FB replacement (Feeder 66 DA-FB)

The 'do nothing' option was selected and no investment in the renewal of the cables are planned for the forecast regulatory period.

3) Transmission cables – pooled asset replacements

Full details of this program evaluation are available in the document:

- 2019-24 Pooled Asset Replacement Forecasting Model Methodology

The pooled program captures those transmission cable assets that fail in service. These replacements are typically done under emergency conditions and are therefore of limited scope and cost, however impacts positively on the overall health of the network moving assets out of the poor health category. These failures are expected to be mostly associated with poor health and low criticality assets, i.e. those assets that are of poor health but not identified as part of a proactive replacement program.

The expected cable replacements under this program have been projected using a probabilistic approach. The approach forecasts asset failures using a combination of asset age, asset conditional probability of failure, and historical asset failures. A total of 0.3km of transmission cable replacements is forecast over the five year regulatory period. The projected annual replacement volumes are provided in Table 32.

Table 32: Projected pooled transmission cable replacement volumes

Program	2019-20 (km)	2020-21 (km)	2021-22 (km)	2022-23 (km)	2023-24 (km)	Total (km)
Pooled transmission cable replacement volume	0.04	0.05	0.06	0.07	0.09	0.30

The health and criticality assessment of the transmission cable assets expected to be replaced through the pooled replacement program is shown in Table 33.

Table 33: Pooled program transmission cable health-criticality matrix (qty)

	H1	H2	H3
C1		0.23 km	
C2		0.07 km	
C3			

9.1.2 Transmission cable asset maintenance plans

The maintenance plan for transmission cables is to continue with the established maintenance regime, which is based on three-yearly inspections and repair (or replacement) upon failure. Inspections typically involve a ground or aerial based visual assessment of condition. Asset defects are prioritised based on risk of failure and included in the maintenance and defect rectification program.

Defects that cannot be identified through visual inspection eventually result in failure of the asset and are repaired or replaced under the pooled asset replacement program.

9.2 HV Distribution cable

9.2.1 HV distribution cable asset renewal plans

1) Replace Port Feeder

Full details of this program evaluation are available in the PBC document:

- PRD33006 – Preliminary Business Case - Replace Port Feeder

Applying the health and criticality criteria laid out in section 5.3 the assessment of the 11kV Port Feeder is shown in Table 34.

Table 34: 11kV Port Feeder cable health-criticality matrix (qty)

	H1	H2	H3
C1			
C2		8.3 km	2.9 km
C3			

The replacement of 2.9km of the 11kV Port Feeder cable focusing on the cable sections where multiple failures have been observed has been selected as the preferred investment option.

2) High Voltage Cable Replacement Darwin Northern Suburbs

Full details of this program evaluation are available in the BNI document:

- NMP1 - High Voltage Cable Replacement – Darwin Northern Suburbs

Applying the health and criticality criteria laid out in section 5.3 the assessment of the northern suburb XLPE cables is shown in Table 35.

Table 35: Darwin northern suburb cable health-criticality matrix (qty)

	H1	H2	H3
C1	8 km	18 km	8 km
C2		21 km	11 km
C3	12 km	12 km	14 km

A targeted proactive replacement of the select XLPE cables as a concerted approach directed at maintaining the system safety and reliability in a prudent and cost efficient manner has been selected as the preferred investment option. The targeted program will replace 44.2km of XLPE cable, addressing the high-risk cables shown in the red and orange zones as a priority, and continuing with the poor health asset in H3/C1. This accounts for 42.7% of the cables of this type in Darwin's northern suburbs, and 5% of Power and Water's total HV cable population.

The projected annual replacement volumes over the regulatory period are provided in Table 36. This replacement strategy is expected to be continued in future regulatory periods.

Table 36: Projected annual HV XLPE cable replacement volumes

Program	2019-20 (km)	2020-21 (km)	2021-22 (km)	2022-23 (km)	2023-24 (km)	Total (km)
Replacement volume	8.45	14.20	9.76	5.28	6.53	44.23

9.2.2 HV cables – pooled asset replacements

Full details of this program evaluation are available in the document:

- 2019-24 Pooled Asset Replacement Forecasting Model Methodology

The pooled program captures those HV cable assets that fail in service. These replacements are typically done under emergency conditions and are therefore of limited scope and cost, however impacts positively on the overall health of the network moving assets out of the poor health category. These failures are expected to be mostly associated with poor health and low criticality assets, i.e. those assets that are of poor health but not necessarily part a proactive replacement program.

The expected cable replacements under this program have been projected using a probabilistic approach. The approach forecasts asset failures using a combination of asset age, asset conditional probability of failure, and historical asset failures. A total of 6.88km of HV cable replacements is forecast for the next five year regulatory period. The projected annual replacement volumes are provided in Table 37.

Table 37: Projected pooled HC cable replacement volumes

Program	2019-20 (km)	2020-21 (km)	2021-22 (km)	2022-23 (km)	2023-24 (km)	Total (km)
Pooled HV cable replacement volume	0.94	1.12	1.33	1.59	1.91	6.88

The health and criticality assessment of the HV cable assets expected to be replaced through the pooled replacement program is shown in Table 38.

Table 38: Pooled program HV cable health-criticality matrix (qty)

	H1	H2	H3
C1			6.88 km
C2			
C3			

9.2.3 HV distribution cable asset maintenance plans

The maintenance plan for HV cables is to continue with the established maintenance regime, which is based on three-yearly inspections and repair (or replacement) upon failure. Inspections typically involve a ground based visual assessment of condition. Asset defects are prioritised based on risk of failure and included in the maintenance and defect rectification program.

Defects that cannot be identified through visual inspection eventually result in failure of the asset and are repaired or replaced under the pooled asset replacement program.

9.3 LV Distribution cable

9.3.1 LV distribution cable asset renewal plans

A. LV cable network at Cullen Bay and Bayview

Full details of this program evaluation are available in the BNI document:

- NMP2 - Low Voltage Cable Replacement Program Cullen Bay and Bayview

A targeted program is proposed that will replace 6.8km of the LV, XLPE/PVC cables in Cullen Bay and Bayview during the next regulatory period starting with the highest risk assets. The program is a concerted approach directed at addressing asset type and condition issues that cannot be solved through operations and maintenance activities. The replacement program is expected to continue in future regulatory periods.

The projected annual replacement volumes over the regulatory period is provided in Table 39.This replacement strategy is expected to be continued in future regulatory periods.

Table 39: Projected annual Cullen Bay and Bayview LV XLPE/PVC cable replacement volumes

Program	2019-20 (km)	2020-21 (km)	2021-22 (km)	2022-23 (km)	2023-24 (km)	Total (km)
Replacement volume	2.33	2.08	0.93	0.63	0.84	6.81

A risk based prioritisation of the cables applying Power and Water's health and criticality decision making approach was used to inform the replacement program. Applying the health and criticality criteria laid out in section 5.4 the assessment of the Cullen Bay and Bayview LV cables are shown in Table 40. Focused inspection and testing over the next regulatory period will continue to inform the program and an increase of assets in the H2 and H3 categories are expected over the next regulatory period.

Table 40: Cullen Bay and Bayview LV XLPE/PVC cable health-criticality matrix (qty)

	H1	H2	H3
C1			
C2	10 km	0 km	5 km
C3			

B. LV cables – pooled asset replacements

Full details of this program evaluation are available in the document:

- 2019-24 Pooled Asset Replacement Forecasting Model Methodology

Similar to transmission and HV cables the purpose of the pooled program is to capture those LV cable assets that fail in service. Although these replacements are typically of limited scope and low cost they impact positively on the overall health of the LV network moving assets out of the poor health category. These failures are expected to be mostly associated with poor health and low criticality assets, i.e. those assets that are of poor health but not necessarily part a proactive replacement program.

The expected cable replacements under this program have been projected using a probabilistic approach. The approach forecasts asset failures using a combination of asset age, asset conditional probability of failure, and historical asset failures. A total of 4.97km of LV cable replacements is forecast up to the end of the next regulatory period and include for service cable installations.

The projected annual replacement volumes are provided in Table 41.

Table 41: Projected pooled HC cable replacement volumes

Program	2019-20 (km)	2020-21 (km)	2021-22 (km)	2022-23 (km)	2023-24 (km)	Total (km)
Pooled HV cable replacement volume	0.58	0.67	0.78	0.92	1.08	4.04

The health and criticality assessment of the LV cable assets expected to be replaced through the pooled replacement program is shown in Table 42.

Table 42: Pooled program HV cable health-criticality matrix (qty)

	H1	H2	H3
C1			4.04 km
C2			
C3			

9.3.2 LV distribution cable asset maintenance plans

The maintenance plan for LV cables is to continue with the established maintenance regime, which is based on three-yearly inspections and repair (or replacement) upon failure. Inspections typically involve a ground based visual assessment of condition. Asset defects are prioritised based on risk of failure and included in the maintenance and defect rectification program.

Defects that cannot be identified through visual inspection eventually result in failure of the asset and are repaired or replaced under the pooled asset replacement program.

9.4 Service cable

The LV service cables population is generally in good condition, commensurate with its age profile. No current or emerging issues related to LV service cables have been identified at this time.

9.4.1 Service cable asset renewal plans

No capital investment in LV service cables is forecast for the next regulatory period. The renewal plan for LV service cables is to continue with the established renewal regime, which is based on replacement (or repair) upon failure.

These replacements are included in the LV cable replacements forecast in the pooled replacement program.

9.4.2 Service cable asset maintenance plans

The maintenance plan for LV service cables is to continue with the established maintenance, which is based on 10-yearly inspections and repair (or replacement) upon failure.

9.5 Cable Tunnels

In Darwin most electricity is transmitted through underground cables. They are traditionally located beneath sidewalk or road surfaces and work to maintain these cables is carried out on the sidewalk or in the road. By housing electricity cables in tunnels Power and Water achieves a number of advantages compared to the traditional methods:

- Major disruption to the road network is avoided as the need to dig up the streets to lay the cable is removed.
- Overall disruption to road users during cable installations is significantly reduced as the majority works take place underground.
- Repair and maintenance work can be carried out without disrupting traffic, businesses and residents.
- Additional cables can be installed in the tunnels to meet future demand.

The cable tunnels are predominantly located in the Darwin City area and are significant in maintaining the cable network reliability performance.

9.5.1 Cable tunnel asset renewal plans

Currently no requirement to replace or refurbish cable tunnels has been identified. These assets will be monitored closely to assess the need for future investments.

9.5.2 Cable tunnel asset maintenance plans

The maintenance plan for cable tunnel assets is the continuation with the established maintenance regime involving three-yearly inspections with maintenance and repair undertaken as required to address vegetation and water ingress issues.

10 Investment Program Summary

The investment program is developed based on the:

- Continuation of the established lifecycle asset management approaches;
- Specific requirements related to growth in the asset class – outlined in Section 8; and
- Specific requirements related to renewal and maintenance of the asset class – outlined in Section 9.

10.1 Augmentation expenditure (augex)

The augmentation requirements for the underground cable network follows on a relative low demand growth forecast in most existing distribution areas. Power and Water engaged AEMO in 2017 to undertake a demand growth forecast for the network areas. The study identified pocketed areas of significant growth, up to 18% in areas of Darwin, with low growth, up to 2% and 2.5% in other areas of Darwin-Katherine and Tennant Creek and a decline in the remaining areas including Alice Springs.

This changing environment with reducing demand growth is decreasing the need for capital expenditure on augmentation of the cable networks. Where growth is slow, network, non-network, and demand side management support options assist in managing load at risk.

An allowance has been made for a program to augment overloaded underground cable. Full details of this program evaluation are available in the BNI document:

- NFO Overloaded Feeders / Distribution Augmentation Program

Another driver of augmentation expenditure is power quality limitations. An ongoing power quality improvement program has been proposed to address power quality limitations as they arise. Typically this involves the upgrade of distribution transformers or underground cables. Full details of this program evaluation are available in the BNI document:

- NPQ Power quality compliance program

The augmentation expenditure forecast for the above programs are provided in Table 43. It should be noted that not all expenditure in these programs relates to the underground cable asset class.

Table 43: Augmentation expenditure forecast

Program	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Overloaded Feeders/Distribution Augmentation Program	$1.20	$1.20	$1.20	$1.20	$1.20	$6.00
Power Quality Compliance Program	$0.60	$0.60	$0.60	$0.60	$0.60	$3.00
Total	**$1.80**	**$1.80**	**$1.80**	**$1.80**	**$1.80**	**$9.00**

10.2Renewal expenditure (repex)

There are five renewal programs proposed for the asset class over the next regulatory period, 2019-20 to 2023-24. The program is expected to cost $28.46 million over the five-year period and include investment mainly in the HV and LV cable networks.

The renewal expenditure forecast based on the mention programs are provided in Table 44.

Table 44: Renewal expenditure forecast

Program	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Transmission cables – pooled asset replacements	$0.02	$0.02	$0.03	$0.04	$0.05	**$0.16**
Darwin northern suburbs HV XLPE cables and Port Feeder	$1.93	$7.61	$4.54	$2.45	$3.04	**$22.57**
HV cables – pooled asset replacements	$0.42	$0.50	$0.60	$0.72	$0.86	**$3.10**
LV mains cables – Cullen Bay and Bayview cable replacement	$0.57	$0.51	$0.23	$0.15	$0.20	**$1.66**
LV cables – pooled asset replacements	$0.14	$0.16	$0.19	$0.22	$0.26	**$0.97**
Total	**$6.08**	**$8.79**	**$5.59**	**$3.59**	**$4.41**	**$28.46**

The revised five-year forecast health and criticality profiles for each cable class following the proposed investments are shown from Table 45 to Table 47.

The reduction in risk is demonstrated in the number of assets that move from the poor health, H3 category to the good health category, H1 in comparison with the 'current' and 'no investment' risk scenarios provided in section 5.2, section 5.3, and section 5.4.

For the transmission cable assets a reduced risk is reflected in the 3% reduction in the number of average health assets in the H2 category.

Table 45: Transmission cable health-criticality matrix (qty) with investment

	H1	H2	H3
C1	7.1 km	7.8 km	
C2	0.9 km	2.5 km	
C3	11.0 km		

For the HV distribution cable assets a reduced risk is reflected in a 94% reduction in the number of poor health assets in the H3 category, and a 3% reduction in the number of average health assets in the H2 category.

Table 46: HV Distribution cable health-criticality matrix (qty) with investment

	H1	H2	H3
C1	55 km	75 km	3 km
C2	386 km	223 km	
C3	118 km	32 km	

For the LV distribution cable assets a reduced risk is reflected in a 100% reduction in the number of poor health assets in the H3 category, and a 20% reduction in the number of average health assets in the H2 category.

Table 47: LV cable (including services) health-criticality matrix (qty) with investment

	H1	H2	H3
C1	14 km	15 km	
C2	532 km	164 km	
C3	44 km	11 km	

10.3 Historic, forecast and future expenditure comparison

Historic replacement expenditure on underground cables has been predominantly to address conditional and functional failures discussed in Section 6.3.

As outlined in the preceding sections, the forecast expenditure on underground cables is targeted to address the key asset challenges expected to manifest over the regulatory period. As shown in Figure 32 there is a step change increase in the first two years of the regulatory period as compared to historic expenditure to address specific HV XLPE cables. In the final years of the forecast, the investment level is more consistent with historic expenditure levels, and representative of a forecast associated with rectification of in-service failures.

Future expenditure in the asset class has been forecast using the AER's repex model and shows an increasing requirement for investment. As the AER's repex model is primarily an age-based model, it is expected that through continuing to target poor health assets, future investment in the asset class can be managed at a level between $4 million and $10 million per annum.

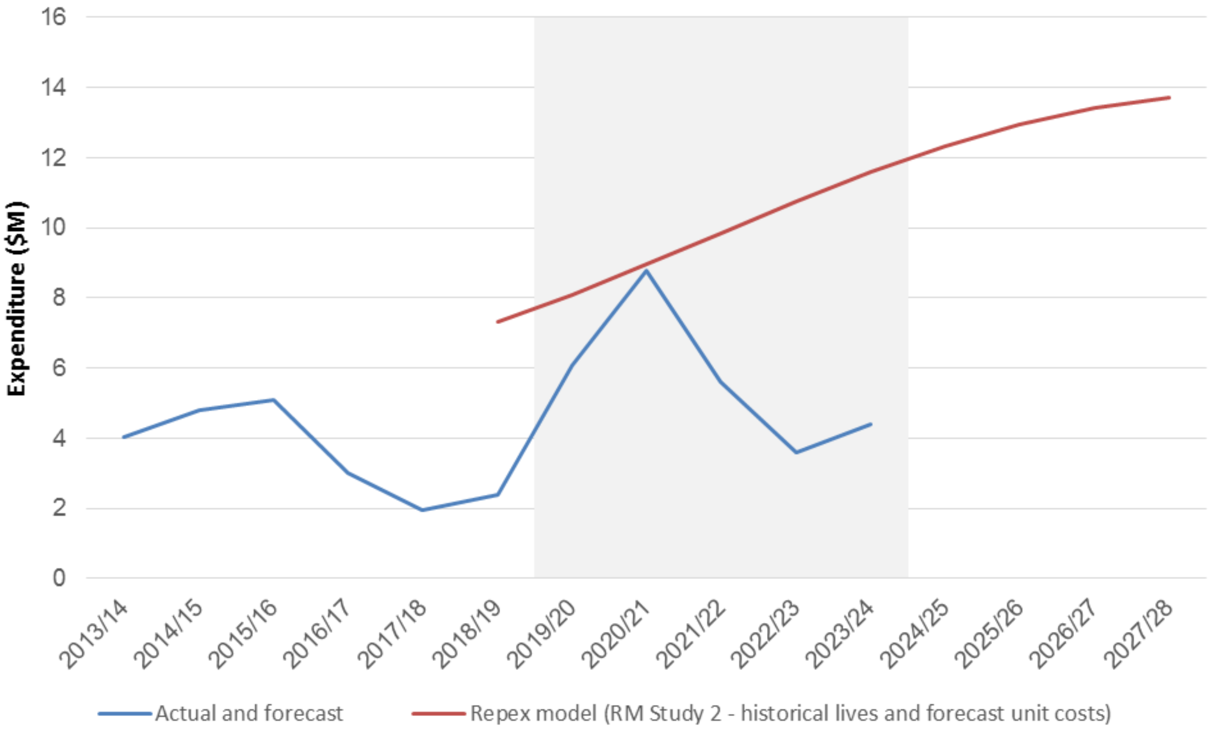

Figure 32: Underground cable investment profile

10.4Operational expenditure (opex)

The operating expenditure for underground cables for the current and next regulatory period is provided in Table 48.

Table 48: Operating expenditure forecast ($M)

Asset type	Expenditure category	FY14 (H)	FY15 (H)	FY16 (H)	FY17 (H)	FY18 (F)	FY19 (F)	FY20 (F)	FY21 (F)	FY22 (F)	FY23 (F)	FY24 (F)
Transmission cables	Routine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Non-routine	$0.0	$0.0	$0.0	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Fault and emergency	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total		$0.1	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
HV cables	Routine	$1.5	$1.4	$0.9	$0.4	$1.0	$0.9	$0.8	$0.8	$0.8	$0.8	$0.8
	Non-routine	$0.0	$0.0	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Fault and emergency	$2.6	$0.6	$0.9	$0.5	$1.1	$1.0	$1.0	$1.0	$1.0	$1.0	$1.0
Total		$4.1	$2.0	$1.8	$0.9	$2.1	$2.0	$1.8	$1.8	$1.8	$1.8	$1.8
LV mains cables	Routine	$0.5	$0.4	$0.1	$0.0	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2	$0.2
	Non-routine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Fault and emergency	$0.3	$0.4	$0.3	$0.4	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3
Total		$0.8	$0.9	$0.3	$0.4	$0.6	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
Service cables	Routine	$0.0	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Non-routine	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Fault and emergency	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Total		$0.0	$0.1	$0.0	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1	$0.1
All cables	Routine	$2.0	$2.0	$1.0	$0.5	$1.3	$1.2	$1.1	$1.1	$1.1	$1.1	$1.1
	Non-routine	$0.0	$0.0	$0.1	$0.1	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
	Fault and emergency	$3.0	$1.1	$1.2	$0.9	$1.4	$1.4	$1.4	$1.4	$1.4	$1.4	$1.4
Total		$5.0	$3.0	$2.2	$1.5	$2.8	$2.6	$2.5	$2.5	$2.5	$2.5	$2.5

11 Asset class outcomes

11.1 Key performance indicators

11.1.1 Reliability indicators

Investments in the cable network are expected to impact on the performance of the asset class, and the contributions made into the system SAIDI/SAIFI performance. The contribution from each investment program was analysed to identify the potential improvements that could be affected.

A. Transmission cables

No investments in the transmission cable network has been proposed for the next regulatory period. No improvements in system SAIDI/SAIFI performance related to transmission cables are therefore projected over the next regulatory period.

The expected contribution from transmission cables into the system SAIDI/SAIFI is provided in Figure 33.

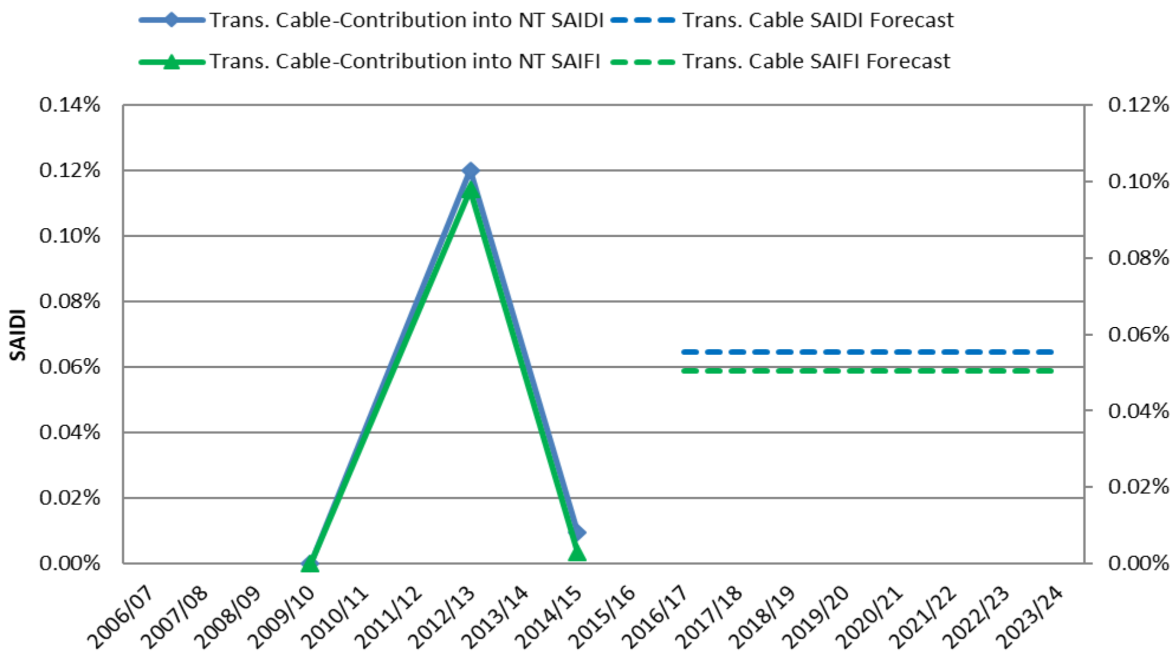

Figure 33: Transmission cable contribution into SAIDI/SAIFI following investment

B. HV Distribution cables

The investments proposed for the HV cable network are expected to impact on the performance of the asset class, and the contributions made into the system SAIDI/SAIFI performance. The expected improvement in performance in relation to system SAIDI and SAIFI is provided in Figure 34 and Figure 35. Improvements were calculated as the percentage contribution to total system performance at an asset level based on historical performance and taking into account existing asset quantities, expected growth rates, and renewal volumes. The SAIDI/SAIFI improvements followed the quantity of assets expected to be replaced or refurbished.

An improvement of around 0.5% in SAIDI performance by 2023-24 is projected and similarly, a reduction in system SAIFI contribution of around 0.3% is projected.

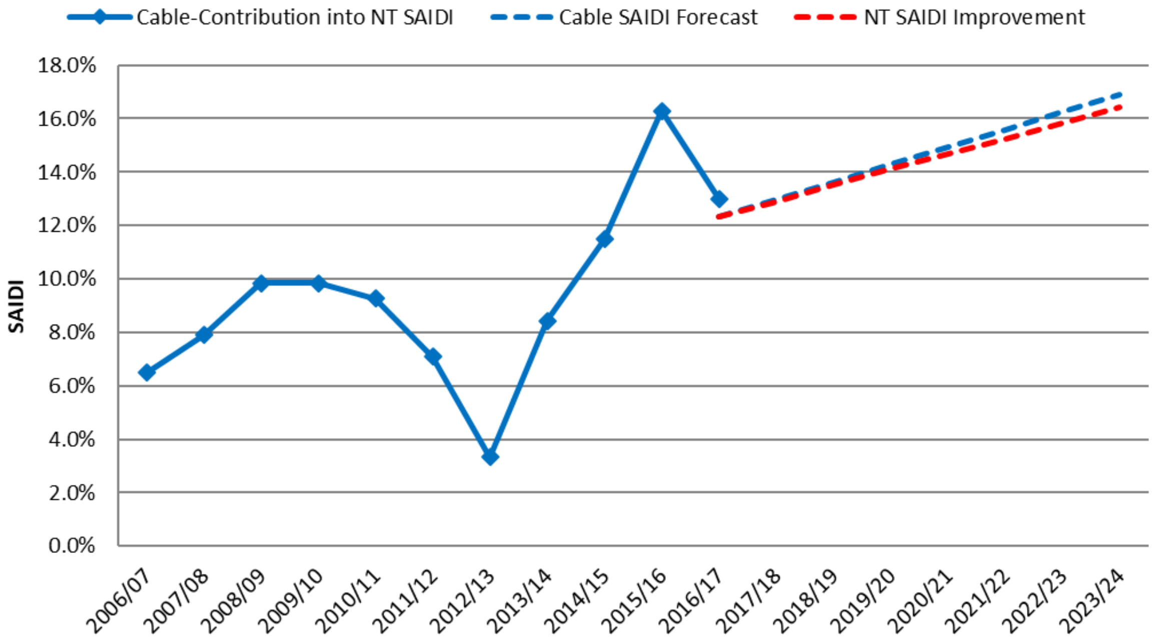

Figure 34: HV Distribution cable contribution into SAIDI following investment

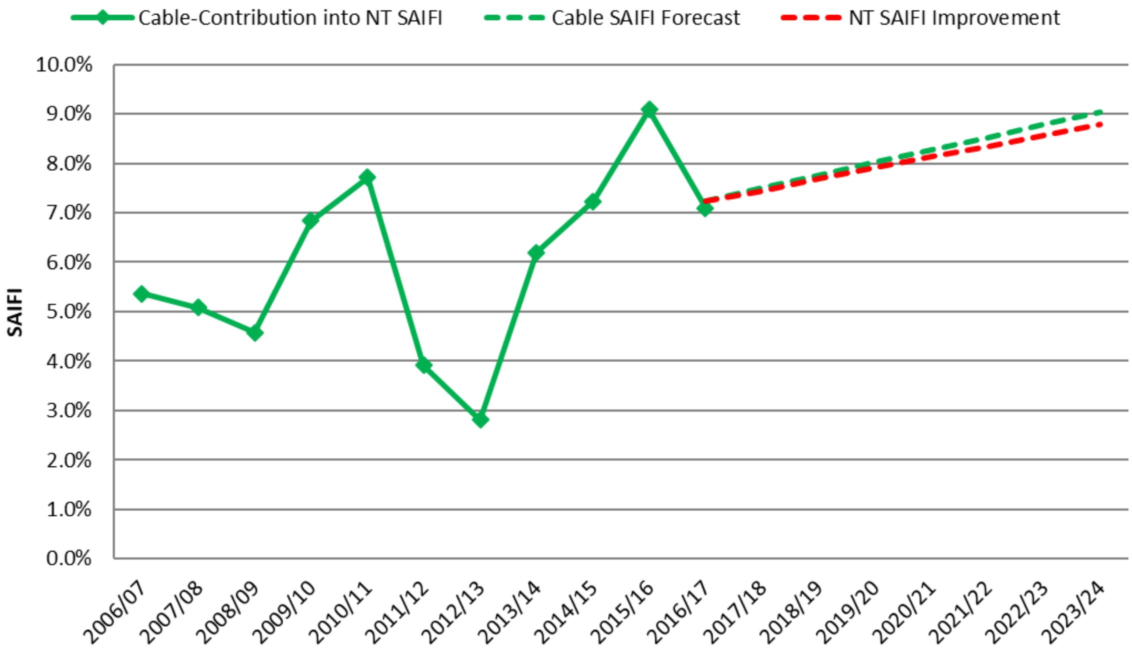

Figure 35: HV Distribution cable contribution into SAIFI following investment

C. LV Distribution cables

The investments proposed for the LV cable network are not expected to impact on the performance of the asset class based on past performance, and the contributions made into the system SAIDI/SAIFI performance. The proposed investments address public and worker safety risk and currently unpredictable future increase in reliability impacts.

The expected contribution from LV cables into the system SAIDI/SAIFI is provided in Figure 36.

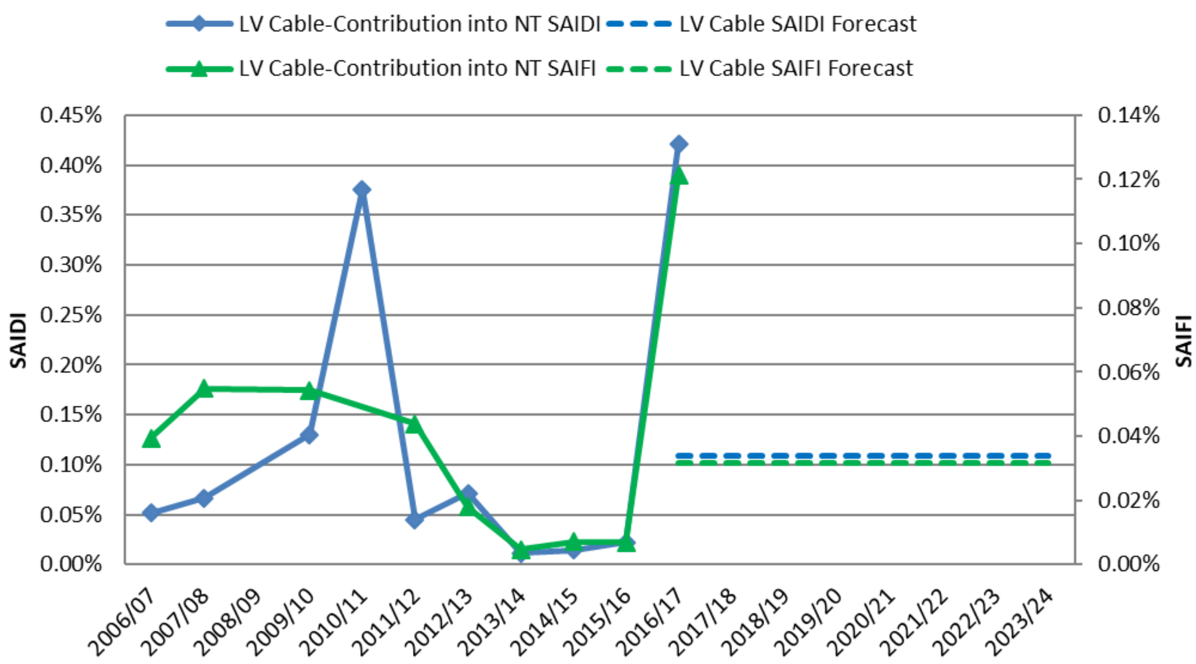

Figure 36: LV Distribution cable contribution into SAIDI/SAIFI following investment

11.1.2 Responsibility indicators

The safety related events associated with underground cables mainly involves vehicle collision with Power and Water assets, excavation damage to Power and Water assets, public safety-related outages to make safe, and outages to facilitate maintenance and repair works. The cable investments proposed for the next regulatory period involves the in situ like-for-new replacement of assets and is unlikely to result in material safety performance improvements.

12 Performance monitoring and improvement

Ongoing condition and performance monitoring is a key part of Power and Water's performance evaluation and improvement strategy. Study of the condition and performance data captured over time assists in developing valuable insights on underground cables defect modes and trends. These insights provide for informed decision making on whether to repair or replace cable assets. It assists in the continuous development of the asset management strategy for underground cables.

This Asset Management Plan will be reviewed at least every two years or when there is a significant driver from the network or other events that requires revision.

Improving data resources, undertaking data analysis and deriving insights will be undertaken as business as usual activities with increased focused. Any improvements in analysis and understanding of the underground cable fleet will be included in this AMP when it is updated.

The RACI model provided in section 3.2 identifies the roles and responsibilities important in the management and the underground cable assets. These responsibilities include ongoing performance monitoring and strategy revisions.

Power and Water has a comprehensive set of guidelines and criteria for the testing of cables that has been developed in conjunction with industry experts and other network service providers. Recognising the increasing reliability issues associated with cable failures, Power and Water continues to invest in the improvement of testing and fault finding capability and to reduce reliance on interstate cable testing expertise. This investment is expected to result in material cost benefits associated with interstate personnel, test equipment, and vehicle transport.

Cable fault finding and repair procedures have been adopted that recognises the differences in cable feeder types and characteristics. In urban areas with short cable runs, multiple faults on the same section typically triggers a condition assessment of the cable including Partial Discharge and Tan Delta testing. The results are then assessed to determine the likelihood of future failures and a decision is then made on whether to leave in service, run-to-failure, or replace. Longer cable sections are treated similarly but are typically not replaced completely unless testing identifies significant deterioration of condition across the entire length of cable. Faults are generally repaired and where sections of the cable have multiple faults then larger sections may be replaced to avoid issues associated with excessive jointing and reliability concerns.

Applicable procedures include:

- D2015/518670 PN Cable Maintenance - Testing Specification
- D2016/470683 Technical Specification 11/22kV Underground Cable Electrical Testing
- D2016/470825 Technical Specification Transmission Underground Cable Electrical Testing

13 Appendix A – Lifecycle asset management

Power and Water make great efforts to be a customer oriented organisation that provides a safe, reliable and efficient electricity supply in the Northern Territory. This is demonstrated in the approach Power Networks take in managing its assets. The life cycle asset management approach applied by Power Networks is aimed at making prudent asset management decisions such that its assets do not cause harm to any person, have minimal environmental impact, and meet agreed service performance outcomes, consistent with current and future needs.

The approach includes:

- Maximising the utilisation of its assets throughout its life cycle
- Optimising life cycle asset management costs
- Reducing asset risks as low as reasonably practical
- Continually improving its knowledge in respect of its assets

The following asset management activities details Power and Water's life cycle management of its underground cable assets.

13.1 Planning (augmentation)

The asset planning stage defines the need for an asset to exist. It also establishes the functional requirements of the assets and ultimately the number of assets, design, function, criticality, configuration, level of redundancy, capability and capacity.

Key criteria to ensure optimal line route selection, establishing prudent, cost efficient, intrinsically safe, and sustainable corridors for the life cycle management of the underground cable assets include consideration of:

- Optimised utilisation of existing infrastructure
- Schedule and cost impacts from existing adjacent infrastructure
- Transport and logistics
- Project cost implications
- Safety and reliability risks
- Environmental and approvals risk
- Stakeholder and community requirements
- Design and execution requirements
- Operation and maintenance requirements

Asset management in the planning phase has been demonstrated by the establishment of cable tunnels achieving safety, reliability, and cost advantages in cable routing, cable installation, and cable maintenance and repairs.

13.2 Design

The design phase is where decisions around the physical characteristics and functioning of the asset are made. This life cycle stage defines the quality and reliability of the asset, and the whole of life cycle costs that can be realised. It influences the total cost and the level of service that the assets can deliver to customers and shareholders.

Power and Water's approach to the whole of life cycle prudent and efficient design of assets includes the standardisation of cable type and size. Standardisation is defined as the process of developing and agreeing on uniform technical design criteria, specifications and processes and is a key aspect of Power and Water's asset management process.

Along with continuity, leverage and scalability, standardisation enables consistent application of best industry practise and continuous performance improvement. It establishes technical commonality that allows for an off-the-shelf, best practice, and fit-for-purpose approach to engineering solutions. It also allows for interchangeability that provides operations and asset management benefits.

Power and Water's underground cable design standardisation offers the following specific benefits to the business. It:

- Helps with the ranking and prioritisation of investment projects
- Gives confidence in the safe and reliable functioning of the assets
- Provides assurance that the assets will do the job they were intended for
- Boost production and productivity
- Encourages higher quality of engineering leveraging specialist knowledge and optimum solutions
- Allows for the uniform execution of projects
- Enables standardisation of construction equipment and processes

Continuous improvement in this design phase has been demonstrated in the change in cable standards and specifications over time to adopt evolving technologies. Power and Water moved away from PILC cable to adopt XLPE cable as the new standard, the later inclusion of water blocking and termite protection layers, the change from aluminium to copper screens around the same time, and the most recent change to water tree retardant XLPE (TR-XLPE).

13.3Operation

Asset operations include activities associated with the monitoring, operation and control of the asset to adapt to changing requirements of the network. This includes:

- Planned switching of the network for scheduled works (e.g. maintenance)
- Emergency switching of the network in response to incidents (e.g. fault events)
- Real time switching to operate the asset within its design parameters (e.g. loading)
- Monitoring of the condition of the asset (e.g. alarms)

Asset operations do not typically apply to underground cables. The main function of underground cables is to safely and reliably transfer electricity from one point to another within the power network. These assets do not need to be operated to adapt to changing network requirements.

13.4Maintenance (opex)

Asset maintenance involves the care of assets to ensure they will function to their required capability in a safe and reliable manner from their commissioning to their disposal. The maintenance requirements evolve as the condition and performance requirements of the assets change through its life. It monitors and provides feedback on asset condition, it incorporates upkeep and repair activities to maintain the condition of the asset, and it also includes the monitoring and management of the deterioration of an asset over time. Power and Water define three main types of maintenance activities: preventative, corrective, and unplanned maintenance.

- Preventative maintenance involves the controlled care and repair activities carried out to reduce the probability of failure or degradation of asset performance. It includes routine inspection and monitoring, upkeep and repair, testing and component replacements. Preventative maintenance expenditure increases over time as assets age.
- Corrective maintenance involves activities to repair asset defects identified as result of condition assessments or failures. Corrective maintenance expenditure increases over time as assets age and deteriorate.
- Unplanned maintenance involves activities to immediately restore supply or make a site safe in response to unplanned failures. Unplanned maintenance expenditure increases over time as asset age and deteriorate.

Power and Water employs a three yearly ground based visual inspection and an annual visual/aerial inspection cycle to assess the health of cable and cable termination. Included in this inspection is an assessment of the above ground and accessible components of the assets. The inspection involves a judgement of condition and risk of failure based on a visual assessment and in conjunction with system performance tracking provides a pointer to potential asset integrity issues. High risk assets are prioritised for further investigation and testing.

Power and Water also applies contemporary testing practices for the location of cable faults and condition assessment after repairs.

13.5 Renewal (repex)

Asset renewal is the establishment of a new asset in response to an existing asset's condition. The need for the renewal of existing assets is identified in the asset maintenance stage and verified in the asset planning stage. Asset renewal aims to optimise the utilisation of an asset whilst managing the safety and reliability risk associated with the failure of the asset.

Power and Water has asset replacement programs in place to renew assets of poor condition as close as possible yet prior to the asset failing.

13.6 Disposal

The decision to reuse or dispose of an asset is made with consideration of the potential to:

- reuse the asset
- utilise the asset as an emergency spare
- salvage asset components as strategic spare parts.

The remaining asset is disposed of in an environmentally responsible manner.