Asset Management Plan
Underground Cables

Part of the Energy Queensland Group

Executive Summary

This Asset Management Plan (AMP) focuses on the management of underground cable and accessories.

Energy Queensland Limited (EQL) owns and maintains approximately 30,215km of underground cable throughout Queensland at distribution, sub-transmission, and transmission voltages. Approximately 20,790km (69%) of these assets are contained within the Energex networks and 9,425kms (31%) in the Ergon Energy networks.

Underground cable systems are designed and constructed to provide the physical connection and electrical continuity to allow for the safe and reliable transmission and distribution of electrical power. Failure of underground cable assets to perform their function results in negative impacts to the EQL business objectives related to safety, reliability, and compliance.

EQL maintains a diverse population of underground cable types and sizes due to legacy organisation standards, changes in period contracts, and advancement in cable technology. Most cable installed across all voltage designations within EQL use cross-linked polyethylene (XLPE) as the insulation medium. Approximately 66% of underground cable assets are low voltage and 30% are operated at HV distribution voltages. Using current asset quantities and replacement costs, underground cable assets have an undepreciated replacement value of the order of $8.86 billion, approximately 16% of the EQL total asset replacement value.

Predictive CNAIM/CBRM modelling is conducted only for UG cables operating above 33kV covering less than 5% of the entire UG cables asset population. A different SFAIRP approach based on failures, defects and known issues has been implemented for management of remaining <=22kV kV and LV cables. The difference in management strategies is due to a) the cost effectiveness of the process and efforts required for condition data measurements for UG cables, and b) the criticality from a network perspective.

EQL has undertaken proactive replacement programs to remove high risk, aged underground cable assets including cast iron potheads, low voltage Concentric Neutral Solid Aluminium Conductor (CONSAC) and Hochstadter Screened Separately Lead Sheathed (HSL) cable.

A considerable number of defects and in-service failures are attributed to low voltage underground pillars. Routine thermoscanning of underground pillars was trialled and subsequently introduced into both Energex and Ergon Energy.

Ongoing tracking and post fault analysis of cable joint failure is required to enable continuous improvement in this area. A cable pit inspection program has been implemented.

The effective management of underground assets requires specialist technical skills and workforce capability particularly for transmission, submarine and legacy cable types such as lead sheathed or pressure assisted cables. An audit and ongoing monitoring of these skills is continuing.

Underground cables due to their very nature are inherently challenging to access for maintenance or inspection. As such, verification of data to ensure reliable asset population counts, age profiling and asset condition is difficult to accurately determine in-situ. EQL is working to improve its data quality and actively investigating and pursuing advancements in underground cable condition assessment and cable diagnostics that will further assist in the management of this asset class.

1.1.1.1 Revision History

Revision date	Version number	Description of change/revision
31/01/2019	1	Document Initial release
Feb 2021	2	Added V1 End Notes; Updated Action Lists to reflect those in Consolidated Action List; minor edits found during V1 review resolved. Added Document Endorsement Table back in. Updated references to ESCOP to be 2020. Updated Owners and Stakeholders. Added Asset Criticality section. Added Risk Valuation section. Added basic budgets into Section 9.4 and 9.5. Add some comments highlighting a need for Action Reviews
Oct 2021	2.02	Ready for first pass peer review
Nov 2023	2.30	Updated Final Version

1.1.1.2 Document Approvals

Position title	Date
GM Asset Maintenance	Jan 2024
EGM Engineering	Jan 2024

1.1.1.3 Stakeholders / Endorsements

Title	Role
Manager Asset Lifecycle Planning	Endorse
Manager Conductors & Cables	Endorse

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1 Introduction

Energy Queensland Limited (EQL) was formed 1 July 2016. It owns and manages several electrical energy related companies that operate to support energy distribution across Queensland including the Distribution Network Service Providers (DNSPs):

- Energex, covering the area defined by the Distribution Authority for Energex Corporation Limited, and
- Ergon Energy, covering the area defined by the Distribution Authority for Ergon Energy Corporation Limited.

Energy Queensland is committed to maximising value from its assets for the benefits of its customers, stakeholders and the communities in which it operates. In line with our corporate vision and purpose, EQL will look to safely deliver secure, affordable and sustainable energy solutions to its communities and customers by optimally managing its assets throughout life cycle.

There are variations between EQL's operating regions in terms of asset base and management practice, due to geographic influences, market operation influences, and legacy organisation management practices. This Asset Management Plan (AMP) reflects the current practices and strategies for all assets managed by EQL, recognising the differences that have arisen due to legacy organisation management. These variations are expected to diminish over time with the integration of asset management practices.

1.2 Purpose

EQL has shaped the strategic planning approach to consider what we need to do to deliver financial sustainability whilst balancing our ability to transform in an environment of significant market disruption and increased competition as we evolve towards an 'electric life' and renewable targets as described in Queensland Energy and Jobs Plan (QEJP).

The purpose of this document is to guide the responsible and sustainable management of underground cable assets on the EQL network. The objectives of this plan are to:

1. Deliver customer outcomes to the required level of service.
2. Demonstrate alignment of asset management practices with EQL's Strategic Asset Management Plan and business objectives
3. Demonstrate compliance with regulatory requirements.
4. Manage the risks associated with operating the assets over their lifespan.
5. Optimise the value EQL derives from this asset class.

This AMP will be updated periodically to ensure it remains current and relevant to the organisation and its strategic objectives. Full revision of the plan will be completed every five years minimum.

This AMP is guided by the following legislation, regulations, rules, and codes:

- *National Electricity Rules (NER)*
- *Electricity Act 1994 (Qld)*
- *Electrical Safety Act 2002 (Qld)*
- *Electrical Safety Regulation 2013 (Qld)*
- *Queensland Electrical Safety Code of Practice 2020 – Works (ESCOP)*
- *Work Health & Safety Act 2014 (Qld)*
- *Work Health & Safety Regulation 2011 (Qld)*
- Ergon Energy Corporation Limited Distribution Authority No D01/99
- Energex Limited Distribution Authority No. D07/98.

This AMP forms part of EQL's strategic asset management documentation, as shown in Figure 1. It is part of a suite of Asset Management Plans, which collectively describe EQL's approach to the lifecycle management of the various assets which make up the network used to deliver electricity to its customers. Appendix 1 contains references to other documents relevant to the management of the asset class covered in this plan.

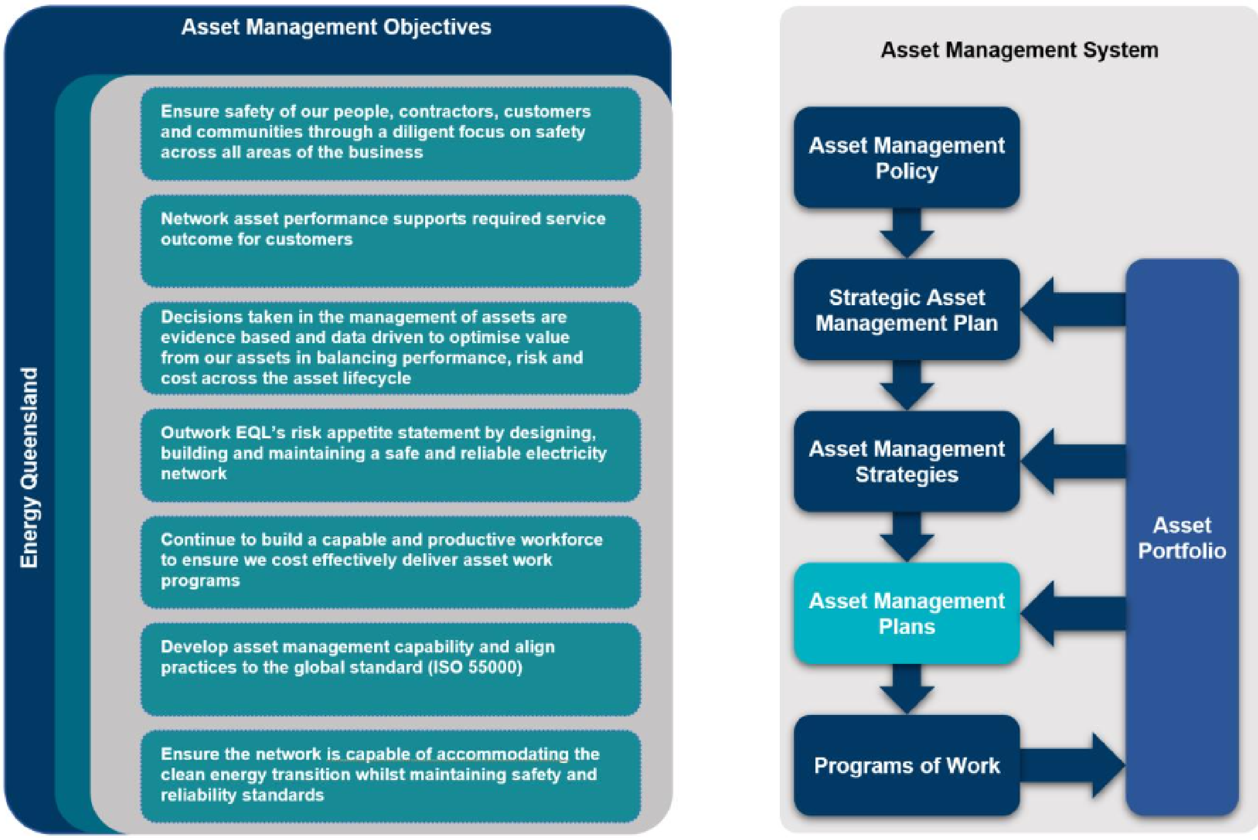

Figure 1: Energy Queensland Asset Management System

1.3 Scope

This AMP plan covers the following assets:

- Impregnated paper, solid dielectric and pressure assisted cable types at voltages up to 220kV.
- Cable accessories including joints and terminations.
- Underground accessories including link boxes, pits, and pillars.

In Queensland, many customers, own and manage their own network assets including underground cables and accessories (typically those with high voltage connections). EQL does not provide condition and maintenance services for third party assets, except as an unregulated and independent service.

The customer's point of connection in the underground low voltage distribution network is the service fuse in the pit/pillar. The underground service (consumer's mains) from the service fuse to the customer's installation is owned and maintained by the customer and is therefore excluded from this document.

1.4 Total Current Replacement Cost

Underground cables are a low cost, high volume linear asset, and are the third largest asset class (by replacement value) of EQL's assets (Figure 2). A large component of asset's replacement cost is attributed to civil works associated with installation and removal.

Figure 2Figure 2 shows that EQL underground cables and accessories have a replacement value in the order of $ 8.86 billion. This valuation is based on typical replacement costs of the assets using the cost of modern equivalents for superseded types on an average per metre basis and excluding savings that may be achieved through quantity replacement optimisation.

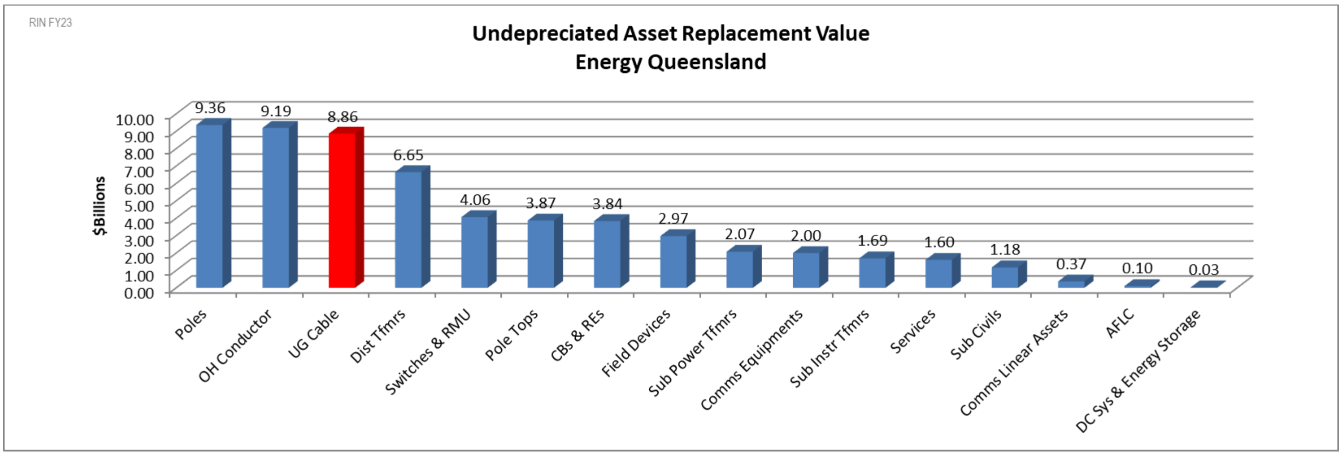

Figure 2: EQL Undepreciated Asset Replacement Value

1.5 Asset Function and Strategic Alignment

Underground cable systems are designed and constructed to provide the physical connection and electrical continuity to allow for the safe and reliable transmission and distribution of electrical power between termination sites for the duration of the asset operational life. The failure of energised underground cable assets can pose a safety risk to EQL employees, contractors, and the public through electrical contact and/or secondary damage due to subsequent fire events. Table 1 details how underground cables contribute to EQL's corporate strategic asset management objectives.

Asset Management Objectives	Relationship of Asset-to-Asset Management Objectives
Ensure network safety for staff, contractors, and the community	Integrity and condition of underground cable assets is a key factor in managing safety hazards and compliance to legislative and regulatory obligations.
Meet customer and stakeholder expectations	The performance of underground cable assets supports the safe, cost effective, secure, and reliable supply of electricity to consumers.
Manage risk, performance standards, and asset investment to deliver balanced commercial outcomes	Performance of underground cable assets is integral in managing the exposure hazard of workers and the public to electrical safety risks and contributes directly to Network Performance MSS and STPIS reliability targets. Prudent management of underground cable assets assists in minimising capital and operational expenditure.
Develop Asset Management capability and align practices to the global ISO55000 standard	This AMP is consistent with ISO55000 objectives and drives asset management capability by promoting a continuous improvement environment.
Modernise the network and facilitate access to innovative energy technologies	This AMP promotes innovation through increased asset utilisation and reliability, and replacement of assets at end of economic life as necessary to suit modern standards and requirements.

Table 1: Asset Function and Strategic Alignment

1.6 Owners and Stakeholders

The ubiquitous nature of the electrical network means that there are many stakeholders that influence or are affected by EQL's operation and performance. Table 2: Stakeholders lists most of the influential stakeholders that have impacted the strategies defined by this asset management plan.

Responsible Party	Role
Queensland Government	Development of legislative framework and environment for operation of EQL and its subsidiaries in Queensland. Development of EQL Distribution Authorities.
Queensland Government as sole shareholder of EQL	Owner of company shares, holding equity in EQL and gaining benefits from EQL financial success.
EQL Board of Directors	Corporate direction, operation, and performance of EQL and its subsidiaries, in compliance with corporate and Queensland law.
Chief Financial officer	Company "Asset Owner" – ensuring all EQL investments are consistent with EQL corporate objectives with balanced commercial outcomes
Chief Operating Officer	Overall operational control of EQL networks including maintenance and operation, and execution of project works
Chief Engineer	Overall strategic control of EQL assets, including asset population performance, network risk and financial management
All employees and contractors of Energy Queensland Limited	Performing all duties as required to achieve EQL corporate objectives
All unions that are party to the EQL Union Collective Agreement	Promotion of safe and fair working conditions for all EQL and subsidiary company employees
Queensland Electrical Safety Office	Regulatory overview and control of electrical safety in Queensland
Australian Energy Regulator	Regulatory overview and control of economic performance of Ergon Energy and Energex to promote the long-term interests of all electrical network customers connected to the National Electricity Market
Powerlink	Queensland Transmission Network Service Provider. Owner and operator transmission grid assets and bulk supply substations that connect and deliver energy to EQL networks
All consumers, prosumers and generators connecting to the Energy Queensland network	Operating within the electrical technical boundaries defined by legislation, regulation, and connection agreements.
All communities and businesses connected to the Energy Queensland network.	Economic prosperity of Queensland

Table 2: Stakeholders

2 Asset Class Information

The following sections provide a summary of the key functions and attributes of the assets covered in this AMP.

2.1 Asset Description

EQL owns and maintains approximately 30,215km of underground cable throughout Queensland at distribution, sub-transmission, and transmission voltages. Approximately 9,425km (31%) of these assets are contained with Ergon Energy networks and 20,790km (69%) of these assets are contained within Energex networks.

2.1.1 Underground Cable

An underground cable system is designed and constructed so that it carries electrical energy, up to a rated voltage and current, safely, and reliably between the terminations at each end of the underground circuit.

Cable design varies dependant on the application. However, the design generally consists of a conductor to carry current, and insulation to keep each conductor isolated from its environment and other conductors. Insulation thickness increases with voltage designation. Cables may include screening, a metal sheath to contain pressurised fluid or gas to act as a barrier to moisture ingress, and/or armouring to act as mechanical protection.

In general, underground cables are classified by their voltage rating and construction including:

- Number of cores
- Conductor material, stranding, shape and cross-sectional area
- Insulation material and thickness
- Screen/conductor sheath material
- Armouring if present and protective outer sheath/serving material.

EQL maintains a diverse population of underground cable types and sizes due to legacy organisations standards, changes in period contracts and advancements in cable technology.

2.1.1.1 220/132/110kV (Transmission Cables)

EQL has predominantly copper sheathed, cross-linked polyethylene (XLPE) insulated cables at this voltage designation. XLPE insulated lead alloy (LY) sheathed cable is also present. Due to the required current carrying capacity, copper conductor is typically employed. Approximately 26kms of pressure assisted, oil filled, paper insulated, aluminium sheathed cable (OFPA) remains installed in the Energex network.

2.1.1.2 66kV and 33kV (Sub transmission Cables)

EQL has predominantly copper core, cross-linked polyethylene (XLPE) insulated lead alloy (LY) sheathed cable at this voltage designation. In Energex 33kV networks, a corrugated copper sheathed cable was introduced due to concerns over the ongoing use of lead. More recently, this cable type has been supplanted in designs and replaced with an XLPE insulated, aluminium cored cable with a copper wire screen and laminated aluminium tape (LAT) moisture barrier.

The remaining Energex asset population consists of pressure assisted oil filled, paper insulated, aluminium sheathed cable (OFPA), Hochstadter separately screened lead sheathed (HSL), and paper insulated lead alloy sheathed (PLY) cable types.

The Ergon Energy 33kV and 66kV asset population is predominantly XLPE insulated, with a small quantity of OFPA and PLY cable types.

Due to the unavailability of spare parts for gas insulated cables, all known gas filled cables have been decommissioned from the network.

2.1.1.3 22kV, 11kV, 6.6kV and 3.3kV (HV Distribution Cables)

Cross-linked polyethylene (XLPE) insulated copper wire screened cable is predominantly installed at this voltage designation. Most cables at this voltage employ a copper conductor, although the use of aluminium has increased due to the cost and handling benefits of this material. Cables installed since the late 2000s may contain an improved formulation of XLPE to protect against water tree propagation (TR-XLPE). In recent years, Triplex cable, which consists of three individual single core XLPE insulated copper wire screened cables, laid up and twisted together to form a single cable, has been adopted. There remains a significant population of legacy paper insulated lead alloy sheathed/covered (PLY, PILC) cable at this voltage designation.

There are several submarine feeders installed on the network servicing island communities. These cables are typically paper insulated lead alloy sheathed construction with a double brass tape water seal (PLYDBT) although some XLPE insulated submarine cable is also present.

2.1.1.4 <1kV (LV Distribution Cables)

Most cables in this voltage designation are believed to be cross-linked polyethylene (XLPE) as the insulating medium. Ergon Energy asset records are sparse for this voltage level. The conductor may be copper or aluminium. Small populations of legacy polyvinyl chloride (PVC), paper insulated, lead alloy sheathed (PLY) and concentric neutral, solid aluminium conductor (CONSAC) cable also remain installed.

2.1.2 Cable Joints, Terminations, and Ancillary Equipment

Sections of underground cable are extended and/or repaired using cable joints. At transmission and sub-transmission voltages, cable joints are 'straight through' and used to connect two sections of cable only. Terminations are used to connect sections of cable to plant such as transformers or switchgear or to transition to the overhead system on a hybrid overhead / underground feeder.

Transmission and sub-transmission joints are installed in a concrete jointing pit, which is typically backfilled with the appropriate thermal materials. Link boxes are installed below ground beside the joint bays where required to facilitate cross bonding (a design method to cancel/reduce sheath induction voltages and currents) or other earthing configurations. The pits have lids that allow for access for testing. Sheath Voltage limiters (SVL) are installed at link boxes or on the termination structure where required and can either be in weather resistant boxes or exposed.

At distribution voltages, underground pits are installed to facilitate pulling cables and jointing during installation. Distribution cable pits are fitted with removable covers and not backfilled. In addition to straight through joints, 'branch', 'tee', or 'trouser' joints may also be used to tee sections of cable and provide flexibility in reticulation. Live-end seals are also used at distribution voltages for the safe termination of live cables in the ground or to facilitate future extension of feeders. At voltages below 1kV, terminations may take place in above ground enclosures, link, or service pillars. These enclosures may contain protective devices and provide a safe, weatherproof environment for low voltage service distribution.

2.2 Asset Quantity and Physical Distribution

EQL operates at a wide variety of voltages including 220kV, 132kV, 110kV, 66kV, 33kV, 22kV, 11kV, 6.6kV, 3.3kV and low voltage (LV) (<1kV). A breakdown of the EQL underground cable asset base by voltage designation highlights that 66% of all cables are operated at low voltage, and 30% of all cables are employed in HV distribution (Table 3). Information about cable joints is generally sparse.

Underground Cable	Ergon Energy	Energex	Total
<= 1 kV	6742	13,231	19,973
> 1 kV & <= 11 kV	1865	6595	8,460
> 11 kV & <= 22 kV	725	0	725
> 22 kV & <= 33 kV	58	801	859
> 33 kV & <= 66 kV	19	0	19
> 66 kV & <= 132 kV	15	163	178
> 132 kV (unregulated only)	0		0
Total Route Length (km)	9,424	20,790	30,214

Table 3: EQL Underground Cable Population by Length (Kms)

2.3 Asset Age Distribution

The age profiles for the underground cable asset base in the Ergon Energy and Energex are shown in Figure 3 and Figure 4.

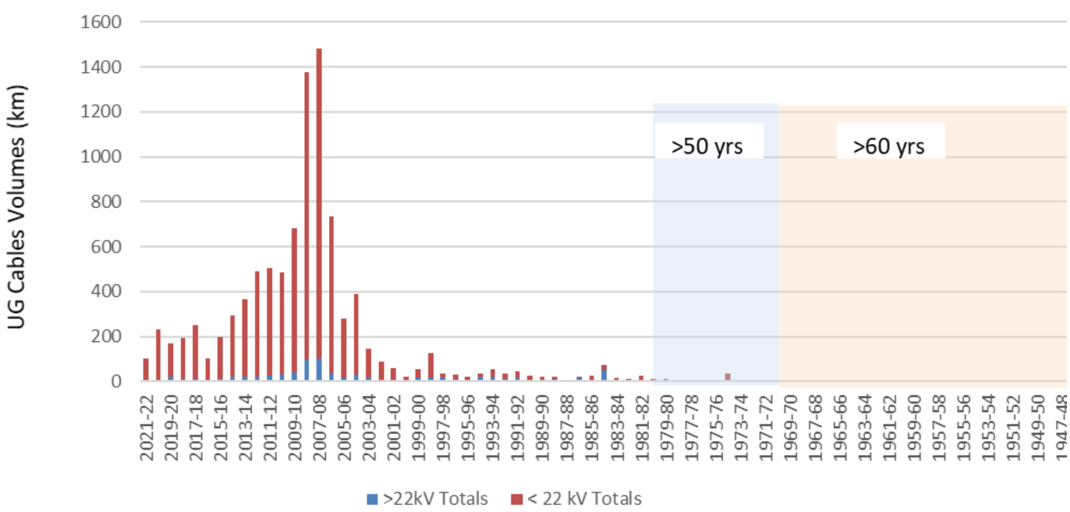

Figure 3: Ergon Energy Underground Cable Age Profile

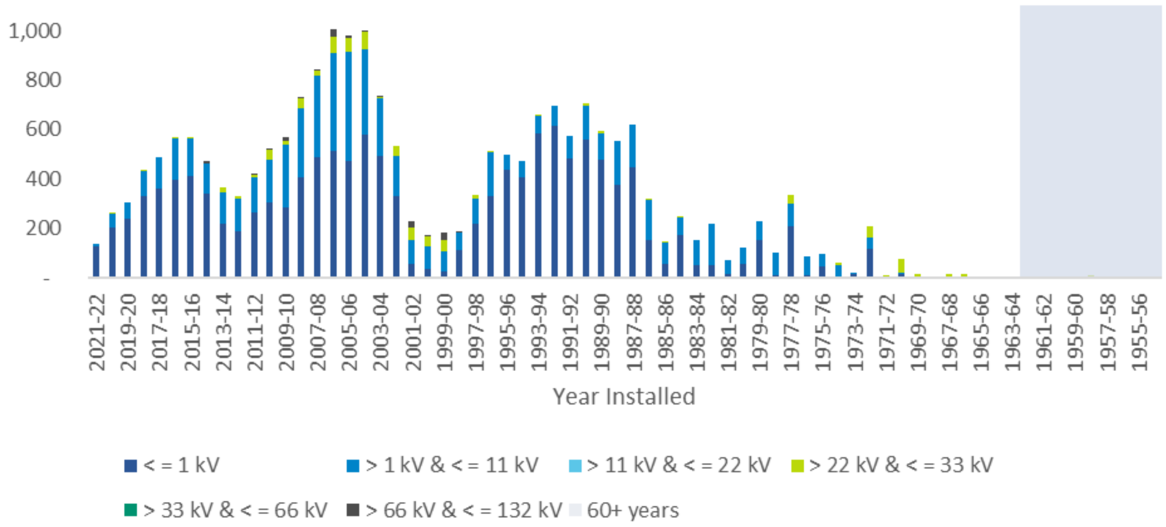

Figure 4: Energex Underground Cable Age Profile

Cable Pit Data

There are 19,363 distribution (HV and LV) cable pits in the Energex area. Accurate information for pit age in unavailable because data was not captured properly when Ellipse it was first implemented. Additionally, there is very little age data available for pits prior to 2001. Pit data captured in some areas commenced in 2001, contributing to age profile analytics reflecting an installation date for most pits between 2001 and 2002 (Figure 5).

Recent pit inspections carried out in the central business district of Brisbane have revealed that most of the cable pits require some form of structural restoration work. This is primarily due to issues such as deterioration of pit walls and roofs.

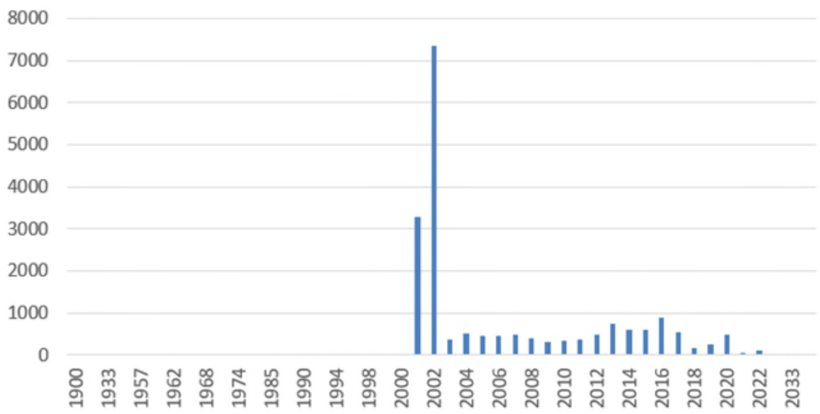

Figure 5: Underground Cable Pits Age Profile

2.4 Population Trends

A breakdown of known cable types installed on the EQL underground network by voltage class is shown in Figure 6 and Figure 7. Most of the cable type installed across all voltage designations (including LV) uses cross-linked polyethylene (XLPE) as the insulation medium. For Energex, where the cable information is far more extensive, 84% of all underground cables comprises XLPE construction. XLPE construction has significant advantages over legacy cable technologies with regards to cost, maintenance, and environmental risk. Globally, the electricity industry has moved to XLPE as the preferred insulation material for all underground cable systems.

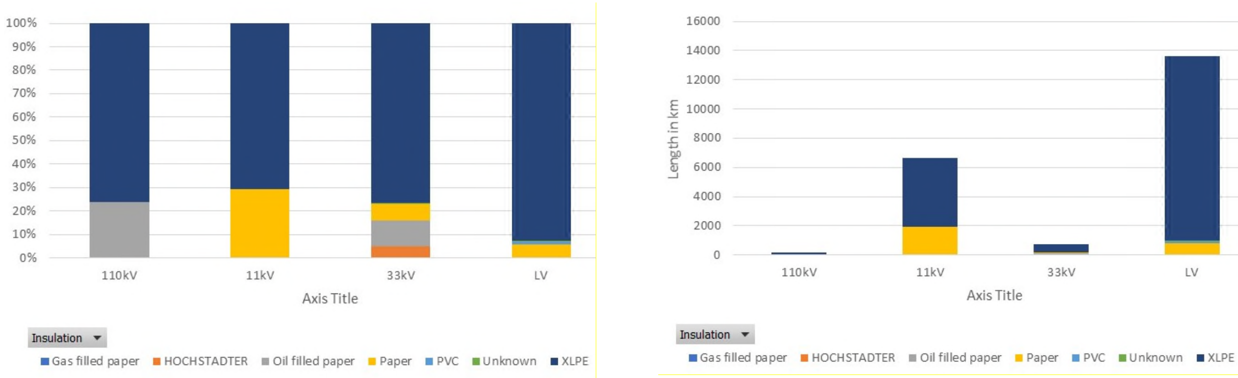

Figure 6: Energex Breakdown Of Cable Type By Voltage Class

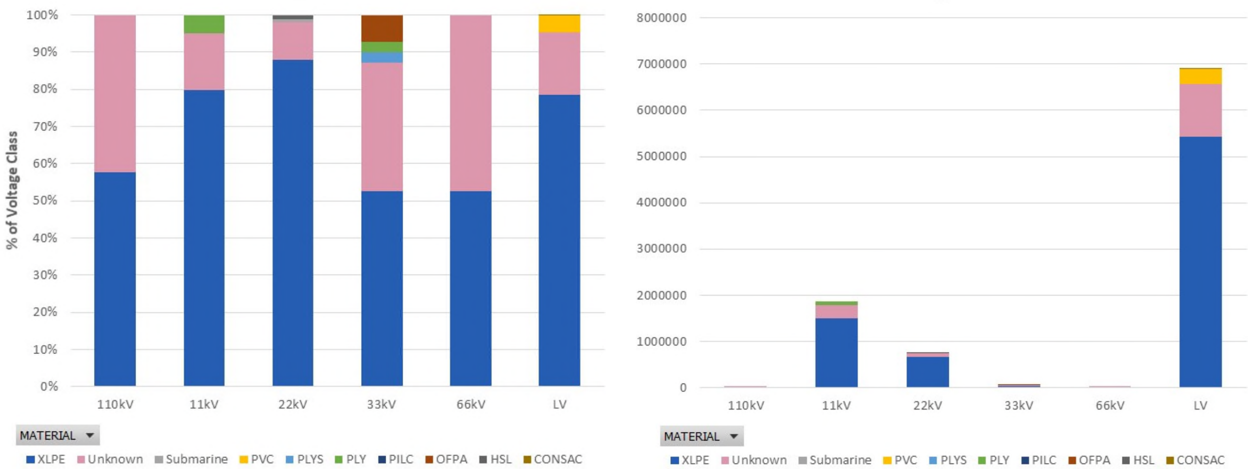

Figure 7: Ergon Energy Breakdown Of Cable Type By Voltage Class

Network reliability, security, and community standards have increased demand for underground. reticulation at all voltage classes. Public safety and joint initiatives with Councils, Main Roads, and other government agencies have also influenced the asset population. The cost difference between overhead line renewal and underground line renewal does not promote a wholesale transition to underground assets. Hence, the undergrounding of existing and established overhead networks is typically limited to high risk, critical, environmentally sensitive, or heritage situations. However, new urban subdivisions employ underground networks, being required by most local councils and/or requested of developers. New rural subdivisions still tend to employ overhead facilities.

2.5 Asset Life Limiting Factors

Table 4 describes the key factors that influence the life of underground cable assets, and as a result, have a significant bearing on the programs of work implemented to manage the lifecycle.

Factor	Influence	Impact
Aging	Cable insulation and sheathing materials lose mechanical and electrical strength through natural aging and thermal cycling under normal operation.	Cable material degradation and ultimate failure of the asset.
Overloading	The expected service life of underground cables can be significantly reduced if cables are loaded to operate at temperatures that exceed their design criteria.	Accelerated aging and poor electrical performance due to insulation damage.
Environmental Overheating	Excessive heating due to nearby cables, other heat sources, or cables buried in materials with high thermal resistivity leading to thermal runaway.	Insulation damage and premature failure of all affected underground cables in the vicinity.
Ferroresonance	Very high voltages and currents due to capacitive/reactive harmonic interactions following single phase switching	Accelerated aging and poor electrical performance due to insulation damage.
Sheath Corrosion	Sheath corrosion can lead to moisture migration In-to the core main insulation. Concentric neutral wires in the presence of moisture or direct contact with the soil are susceptible to corrosion.	Sheath corrosion can cause degradation of insulation including water tree/ electrical tree formation inside main insulation for XLPE cables. Increased ground circuit impedance may affect protection clearing times and result in fault or unbalanced neutral current flowing in alternate paths. This may decrease the safety of workers and the public due to increased step and touch potentials.
Oil Leaks	The solid concentric aluminium sheath of oil filled cables serves to maintain pressure on the oil impregnated paper within the cable. Mechanical damage, corrosion, fatigue, or other age-based deterioration to the aluminium sheath can lead to oil leakage and directly affect electrical performance of the insulation.	Reduced electrical performance of the insulation. Environmental impacts of oil leaks such as soil or waterway contamination.
Environmental/ Mechanical damage	UV degradation of above ground cable terminations, mechanical damage to the cable during installation, inadequate structural support or third-party damage, land erosion leading to cable exposure.	Damage to the outer serving that allows moisture to enter the cable. Damage to the insulation leading to reduced electrical performance.
Water Trees	Moisture ingress in the presence of electrical stress promotes the growth of tree like defects through the extruded cable insulation (i.e., XLPE).	Reduced electrical performance of the insulation leading to premature failure.

Factor	Influence	Impact
Electrical Trees	As per Water Trees, however, formed in the absence of water due to contaminants, voids, or impurities in the insulation.	Reduced electrical performance of the insulation leading to premature and sudden failure.
Vermin	Termites, rodents, and other vermin can attack the outer sheath and insulation of cables leading to premature cable failure.	Damage to cable materials leading to reduced electrical and mechanical performance.
Workmanship	Poor workmanship or materials can lead to the premature failure of joints and terminations.	Poor electrical stress control, increased mechanical stresses, thermal damage due to high impedance connections and moisture ingress leading to reduced asset life.

Table 4: Underground Cable Life Limiting Factors

3 Levels of Service

The following sections define the level of performance required from the asset class, measures used to determine the effectiveness of delivering corporate objectives, and any known or likely future changes in requirements.

3.1 Desired Levels of Service

This asset class is managed, consistent with corporate asset management policy, to achieve all legislated obligations and any specifically defined corporate key performance indicators, and to support all associated key result areas as reported in the Statement of Corporate Intent (SCI).

Safety risks associated with this asset class will be eliminated "so far as is reasonably practicable" (SFAIRP), and if not able to be eliminated, mitigated SFAIRP. All other risks associated with this asset class will be managed to "as low as reasonably practicable" (ALARP).

This asset class consists of a functionally alike population differing in age, brand, technology, material, construction design, technical performance, purchase price and maintenance requirements. The population is managed consistently based upon generic performance outcomes, with an implicit aim to achieve the intended and optimised life cycle costs contemplated for the asset class and application.

All inspection and maintenance activities are performed consistent with manufacturers' advice, good engineering operating practice, and historical performance, with intent to achieve the longest practical asset life overall.

Problematic assets such as very high maintenance or high safety risk assets in the population are considered for early retirement.

Assets of this class are managed by population trends, inspected regularly (to the extent of above ground sections and pit inspections) and CBRM modelling, and allowed to operate as close as practical to end of life before replacement. End of asset life is determined by reference to the benchmark standards defined in the Defect Classification Manuals and or Maintenance Acceptability Criteria.

3.2 Legislative Requirements

EQL, and its subsidiary companies Ergon Energy and Energex, are deemed electricity entities. As such, these companies have a duty to comply with all current legislation, regulations, rules, and codes outlined in Section 1.1 of this AMP. For example, electricity entities must comply with the following:

- ***Electrical Safety Act 2002 (Qld)* s29**
  An electricity entity must ensure that its works are electrically safe and operated in an electrically safe manner. This includes the requirement that the electricity entity inspects, tests, and maintains the works.
- ***Electricity Regulation 2006 (Qld)***
  An electricity entity must, in accordance with recognised practice in the electricity industry, periodically inspect and maintain its works to ensure the works remain in good working order and condition.
- ***Electricity Safety Regulations 2013 (Qld)***
  EQL is required to notify the Electrical Safety Office in the event of any Serious Electrical Incident (SEI) or Dangerous Electrical Event (DEE).
- ***Queensland Coastal Protection and Management Act***
  EQL is required to abide by controls around infrastructure on and across tidal lands, waterways, and harbours.
- ***Transport Infrastructure Act 1994 (Qld)*** (specifically Division 3)
  EQL is required to abide by controls around assets within a carriage way boundary of all state roads.
- ***The Marine Parks Act 1982 (Cth) (Moreton Bay areas)***
- EQL is required to abide by controls around infrastructure such as cables to Russell Island and Bribie Island.
- ***Commonwealth Great Barrier Reef Marine Park Act 1975***
  This act establishes a framework for protection and management of the reef and its environs. The park includes coastline slightly north of Bundaberg through to Cape York, covering much of the coastal area containing Ergon Energy infrastructure.
- ***The Great Barrier Reef Marine Park Regulations 2019 (Cth)***
  This regulation establishes a permit system for operating, maintaining, and renewing facilities in the park. Ergon Energy has a specific permit to operate submarine cables between the mainland and Magnetic Island, Dunk Island, and Hayman Island which embodies specific environmental conditions upon the operations.

3.3 Performance Requirements

EQL has a strategic objective to ensure a safe, cost effective and reliable network for the community. Performance targets associated with these asset classes therefore aim to reduce in-service failures to levels which deliver a safety risk outcome considered SFAIRP, and as a minimum, maintains current reliability performance standards.

EQL has developed a suite of maintenance programs to identify, prioritise, and remediate underground cable asset defects where visual inspection is achievable. Defects identified via inspection programs are classified and prioritised according to the EQL Lines Defect Classification manual (LDCM), Substation Defect Classification Manual (SDCM) and Maintenance Acceptance Criteria (MAC). The P1 and P2 defect categories relate to priority of repair, which effectively dictates whether normal planning processes are employed (P2), or more urgent repair works are initiated (P1). Additionally, classification of C3 aims to gather information to inform or create a “watching brief” on possible problematic asset conditions.

Unassisted asset failures occur where the programs in place to manage the assets do not identify and rectify an issue prior to the asset failing to perform its design function. Failures that are the result of circumstances beyond the reasonable control of any practical management system are deemed assisted failures. Failures typically result in or expose the organisation and the community to risk and represent the point at which asset related risk changes from being proactively managed to retrospectively mitigated. While there are no specific serious SEI or DEE targets, EQL is committed to reduce their occurrence in compliance with our electrical safety obligations under the regulations.

The frequency and duration of outages are tracked and analysed to ensure ongoing compliance with minimum service standards set forth under the Electricity Industry Code. Under the Service Target Performance Incentive Scheme (STPIS), EQL is provided with financial incentive to maintain and improve reliability performance.

3.4 Current Levels of Service

Safety Impact

Many cable failures are underground and hence do not introduce safety issues. However, excavation works (e.g., digging, grading, drilling and boring) have potential to damage underground cabling, and introduce risks of electrical energisation of the excavation equipment. EQL runs regular public awareness campaigns and contributes to the dial-before-you-dig information and promotion systems and offers cable location services on request to mitigate this risk.

EQL records significant material safety events that occur when unassisted conductor failures have resulted in an SEI, involving significant electrical shock leading to hospitalisation or fatality (Figure 8). Most of these events involve root cause conditions that are beyond the ability of any maintenance management system to prevent (e.g., vehicle accident or third-party borer digging into cable) (Table 5). There are no records of any such SEI events within Energex prior 2021. There are no records for either Ergon Energy or Energex where a fatality occurred in relation to underground cable asset failures.

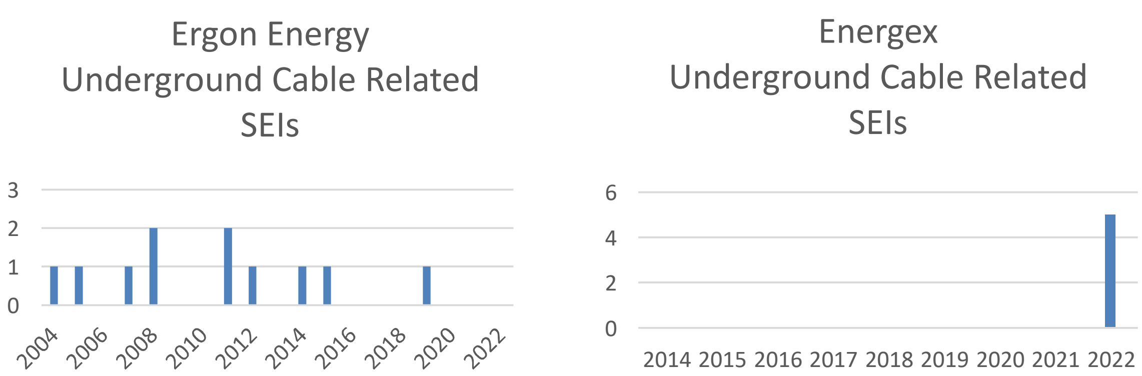

Figure 8 EQL Serious Electrical Incidents

Incident No.	Incident Details
INCD-623188-g	11kV U/G cable contact by a directional borer operator recv'd shoc
INCD -624041-g	LV underground pillar damaged by car, driver recv'd burns from contact.
INCD-598467-g	Fencer hit 11kV UG cable while fencing (post hole digging)
INCD-587400-g	11kV underground cable was damaged by a third party contractor
INCD-560404-g	Excavator dug cables near P68415-b Kremzow Rd

Table 5: Energex Seis - Examples of Third-Party Damages 2022

Reliability Impact

Historical data for underground cable unassisted failures suggests a steady rate for Ergon Energy in recent years with a slight decrease for Energex (Figure 9, Figure 10). The two year moving average performance rate for Ergon Energy is approximately 10.1 failures per 1000 in-service kms, whilst Energex shows 6.4 failures per 1000 in-service kms.

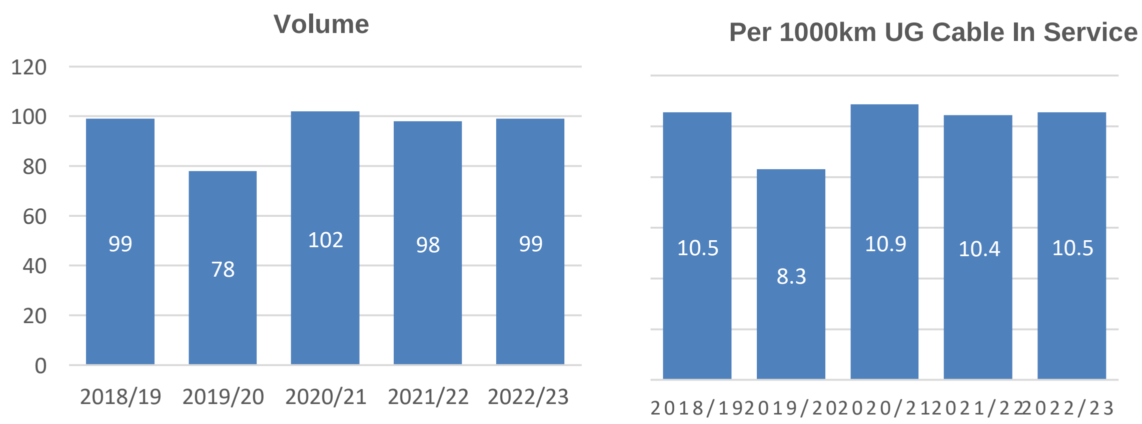

Figure 9: Ergon Energy Underground Cable Unassisted Failures

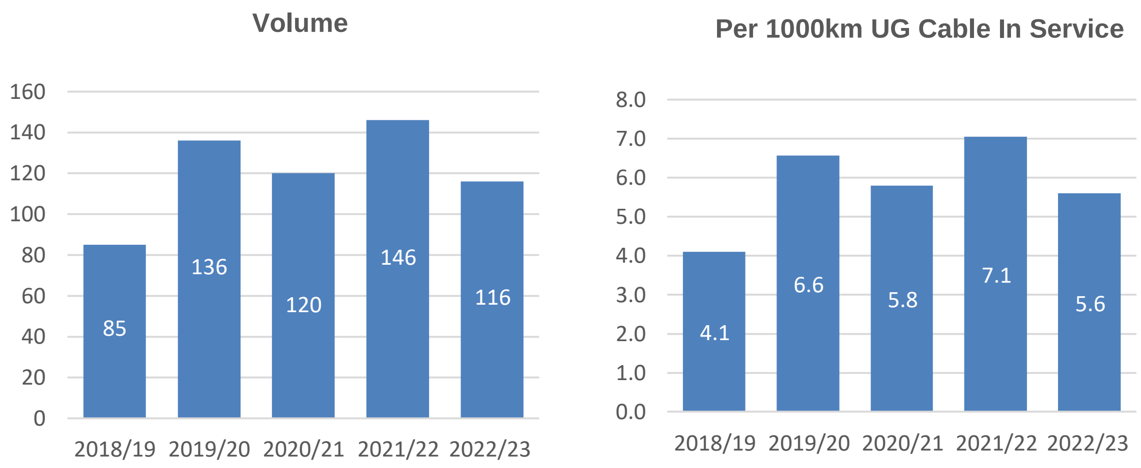

Figure 10: Energex Underground Cable Unassisted Failures

Works Volumes

Ergon Energy underground cable operational performance outcomes show defect work orders for FY18-23 (Figure 11, Figure 12, Figure 13, Figure 14). Volumes represent corrective and forced work orders, as well as urgent maintenance work carried out during this period. Energex pillar defect work order volumes reflect third party damage which is accounted for in corrective budgets.

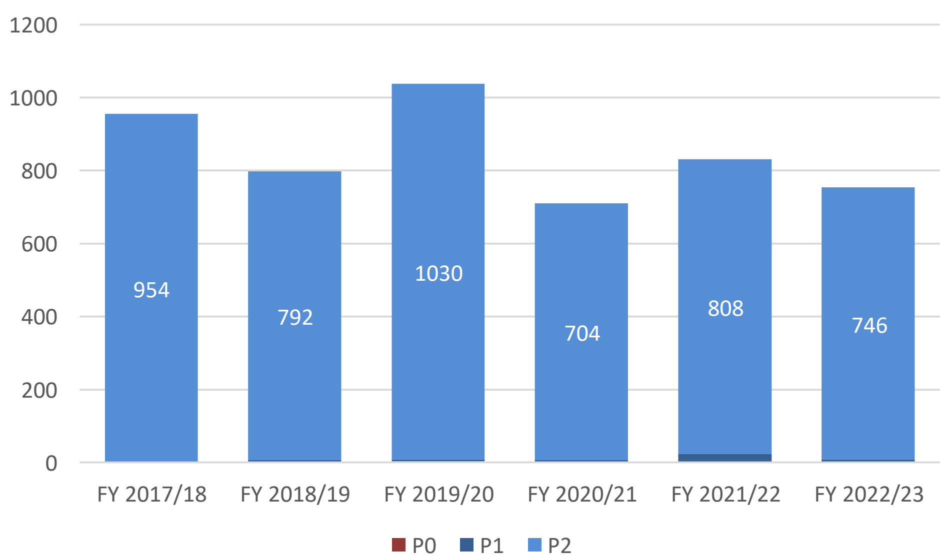

Figure 11: Ergon Energy UG Cable Defect Work Orders

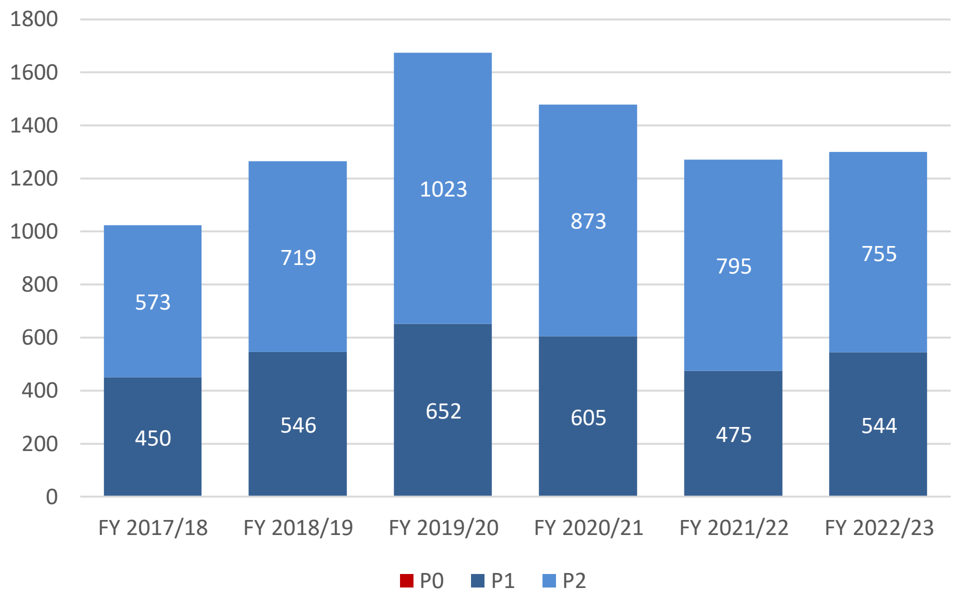

Figure 12: Ergon Energy Pillars Defect Work Orders

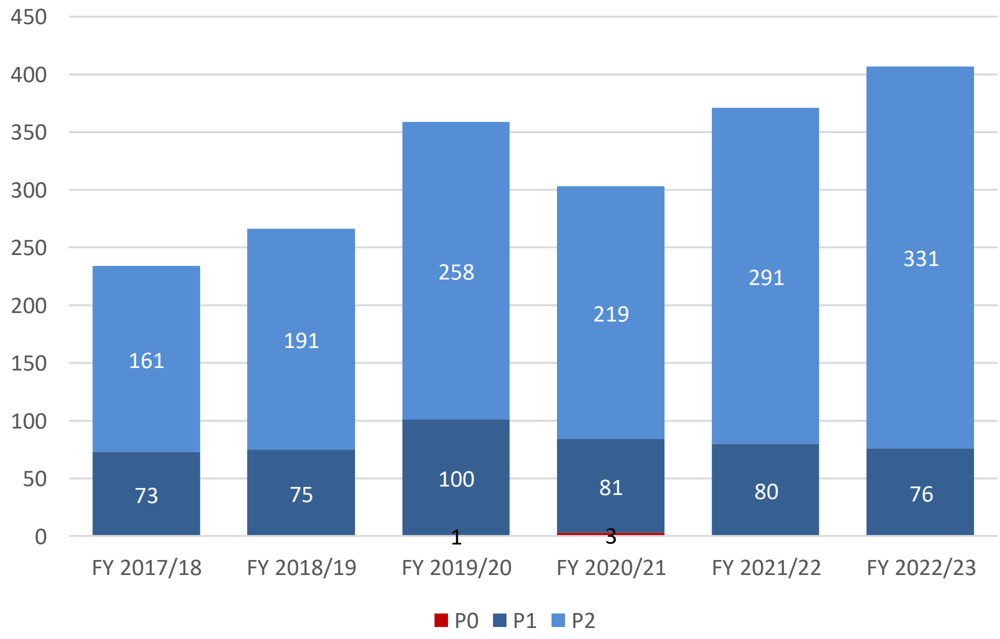

Figure 13: Energex UG Cable Defect Work Orders

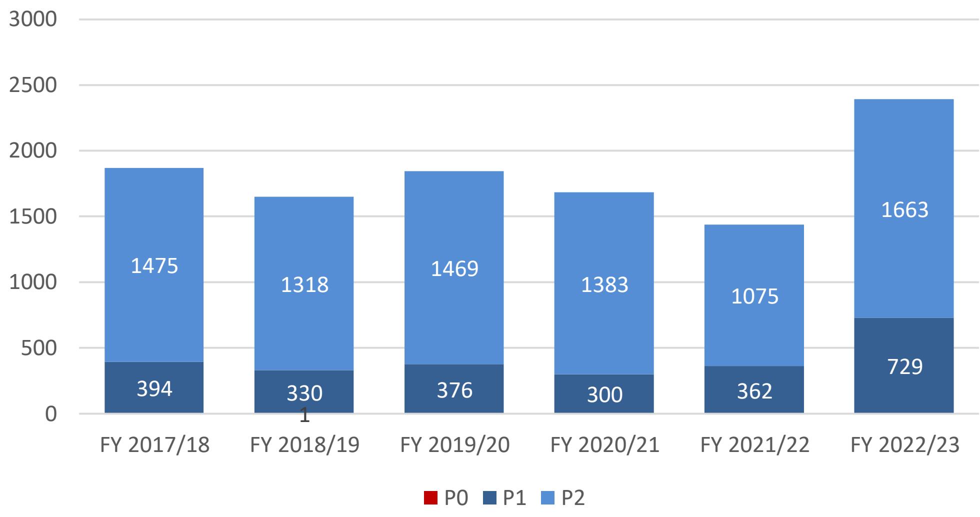

Figure 14: Energex Pillars Defect Work Orders

Polycarbonate pillar boxes are ubiquitous in areas served by underground assets. They are readily accessible by the public, typically located on footpaths and gardens, near driveways and access corridors, and hence are commonly damaged by vandalism, vehicles, and machinery. FY19-23 analytics indicate pillar impact as the leading cause of failure (Figure 15).

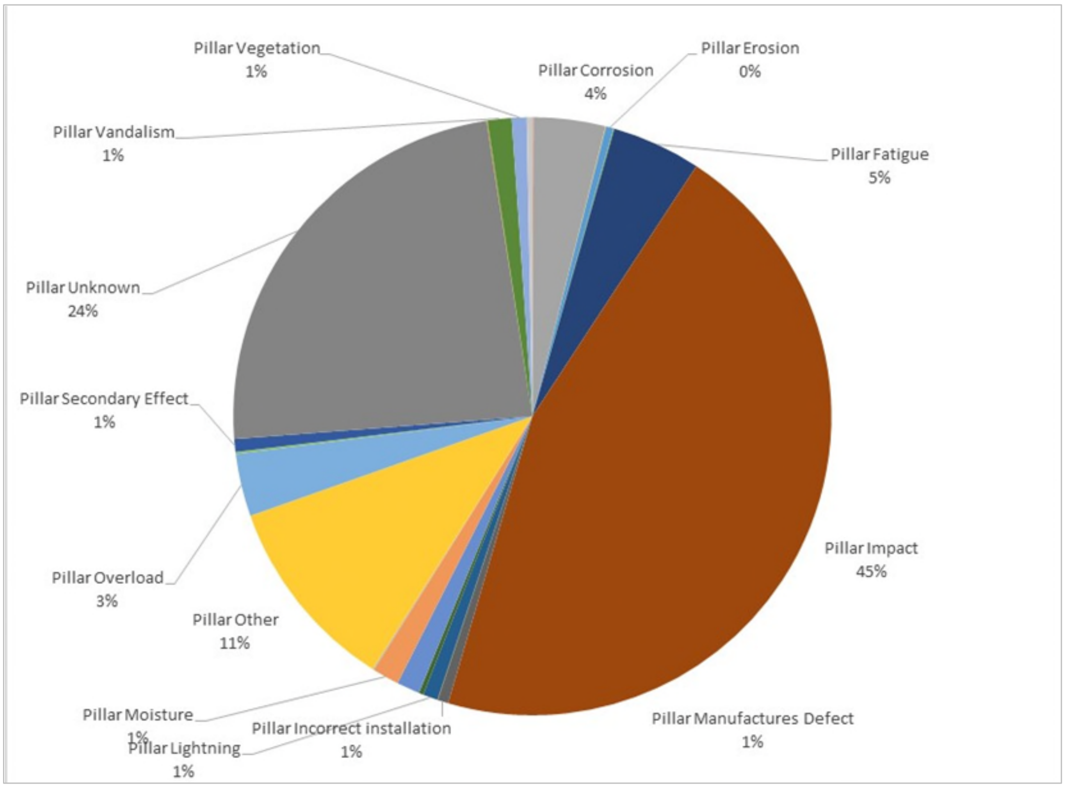

Figure 15: Energex Pillar Failure Causes FY19-FY23

3.5 Risk Valuation

Valuing the consequences of manifested risk supports understanding and comparison of ongoing and potential asset management strategies. Valuing the consequences of safety related risks is also an essential part of EQL's compliance with the Queensland Electrical Safety Act.[1]

[1] A consequence of Electrical Safety Act (Qld) s28 requiring a decision about whether a safety remediation/mitigation cost is "grossly disproportionate" to the risk.

4 Asset Related Corporate Risk

As detailed in Section 3.2, EQL has a duty to ensure its assets are electrically safe. This safety duty requires EQL to act So Far as is Reasonably Practicable (SFAIRP) to eliminate safety related risks, and where it is not possible to eliminate these risks, to mitigate them SFAIRP. Risks in all other categories are managed to levels as low as reasonably practicable (ALARP).

EQL undertakes several actions to eliminate or mitigate the risks SFAIRP/ALARP, such as inspections and maintenance (Figure 16). This safety duty results in most inspection, maintenance and replacement works and expenditure related to underground cables being entirely focused upon preventing and mitigating failures.

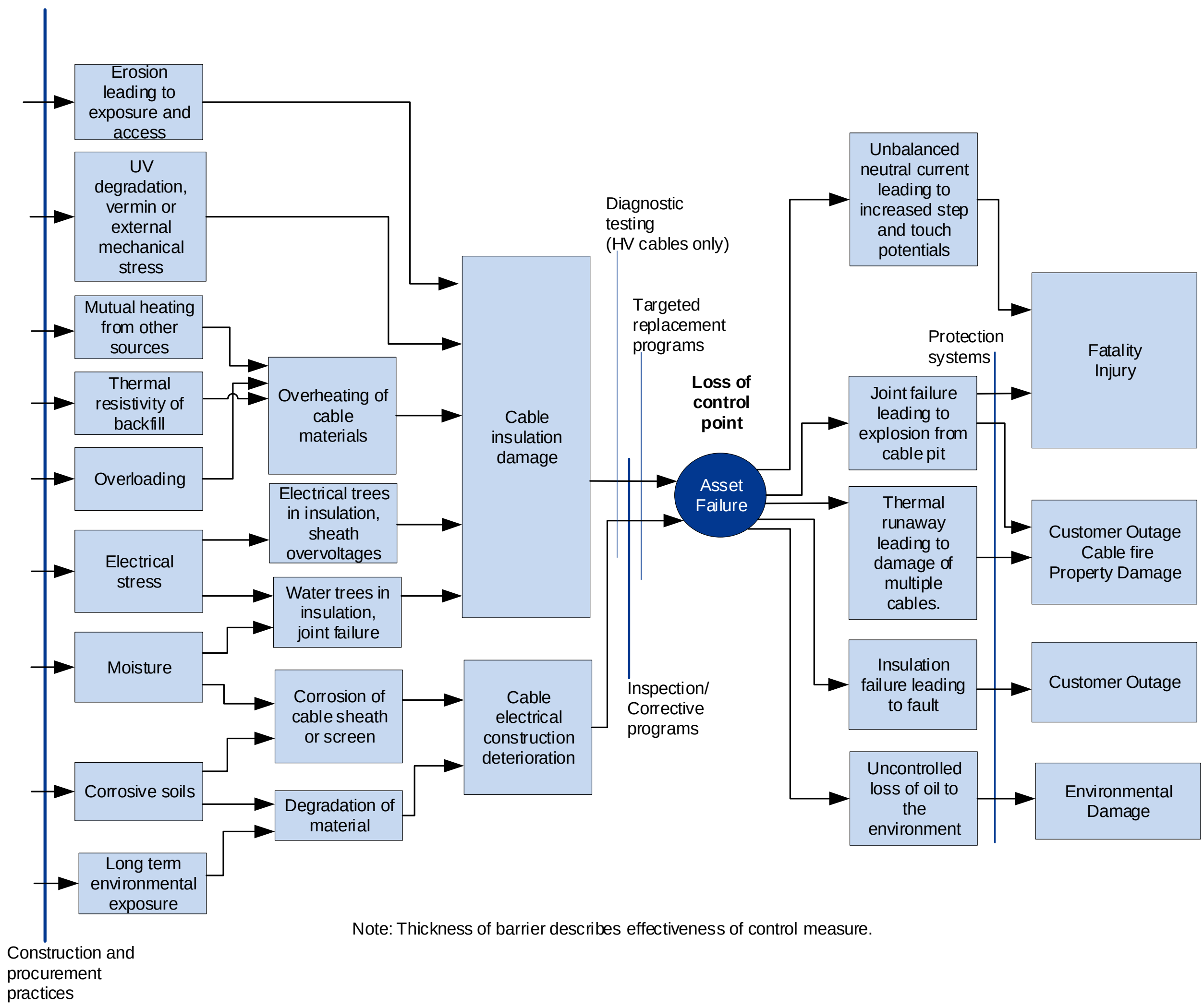

Figure 16: Underground Cable Threat Barrier Diagram

5 Health, Safety & Environment

5.1 Electromagnetic Fields (EMF)

While there is no scientific evidence supporting a hypothesis that Electromagnetic fields (EMF) are harmful to human health, EQL has adopted a policy of prudent avoidance for the design, construction, and operation of its facilities with regards to electromagnetic fields. Most high voltage cables employ sheaths and mechanical metallic protection in the outer layers of the insulation. This effectively eliminates electric fields outside of the cable. Based on current industry guidelines and best practice, underground cables are configured and constructed with specific clearances to minimise exposure.

5.2 Safety Hazards from the Use of Lead

Whilst preparing a lead sheathed cable for jointing or terminating, the process of cutting or filing may produce lead dust that may be inhaled and absorbed into the body through the lungs or through contact with the skin. Blood lead levels (BLL's) in the body may be raised above safe levels if there is insufficient attention paid to means of reducing exposure and absorption. In its resting state in the cable itself, the lead is an inert and stable material and presents no health hazard.

Lead sheath cables on the EQL network are required to be worked on to maintain the existing underground system and are also modified as required to meet network requirements. EQL has dedicated work practices including Ergon's SP0403 and Energex's WP1204 for the preparation of lead sheath cables for jointing or terminating. These work practices along with training and education of EQL employees are designed to ensure the correct techniques are employed to mitigate the risk of producing lead dust to SFAIRP.

It has been the policy in Energex to install new cables that do not contain lead sheath cables and where economically feasible to remove cable lengths when existing underground network modification is conducted. In 2007, the Senior Technical Standards Engineer issued the TSD-07-41, *'Report on the Use of PLY in Energex'* memo, which provides broader context of the challenges that exist when maintaining legacy PLY networks.

Additional information on the broader use of lead can be located in two publications of the National Occupational Health and Safety Commission; *National Standard for the Control of Inorganic Lead at Work* [NOHSC: 1012 (1994); *National Code of Practice for the Control and Safe Use of Inorganic Lead at Work* [NOHSC: 2015 (1994)].

5.3 Cable Fluid

Fluid filled cables use a combination of paper insulation and oil under pressure to provide electrical insulation between conductors and/or to metallic sheathed earth. An oil reservoir, at the injection end of the cable, is regularly monitored to detect gradual loss of oil due to slow leaks. A low-pressure alarm is usually fitted to detect rapid loss of pressure arising from significant leaks. Identifying the leak source can be problematic without major civil works. Dealing with oil spills is documented in Standards 3062825 and 2857411.

Legacy transmission and sub transmission pressure assisted oil filled cables exist on the EQL network, although these are gradually being replaced due to poor condition.

5.4 Cypermethrin – Termite Repellent

In 2007, Energex decided to include cypermethrin in the outer jacket of all underground cables, as a termite repellent. Cypermethrin had gone through extensive testing by the United States Environmental Protection Agency (US EPA) and was considered a non-toxic substance. However, field staff reported adverse health effects when dealing with cypermethrin dosed cables and it is no longer included in specifications for cables.

Populations of installed cypermethrin dosed cable are present throughout the network and are currently managed through awareness and appropriate handling (HSEA Alert 201908-02). Whilst detailed records regarding these installations are poor, some 5,777kms of cable have been installed in Energex networks (28%) and 1,390kms of cable have been installed into Ergon Energy networks (15%) between 2007 and 2019 and these may contain cypermethrin in their insulation. Small populations that exist in the Ergon Energy region are due to alignment of cable specifications under joint workings.

EQL’s current termite protection approach for cables is to use a physical barrier. In the case of distribution cables this is a nylon jacket; for substation cables, double brass tape is used.

5.5 Asbestos Containing Material in the Underground Cable System

The health risks associated with exposure to asbestos are well documented. Energy Queensland has an aspirational intent to remove all asbestos from its networks by 2030. In the underground cable system, asbestos may be present in cable accessories including pits, pillars, and conduits, and in some cable insulation sheaths.

The overarching drivers, principles and objectives regarding EQL’s corporate approach to asbestos management are documented in EQL’s Asbestos Management Plan. EQL employs a Permit to Work System to control all risks when removing asbestos.

Published documents Asbestos Management Policy (690754) and Asbestos Management plan (690840) are in place to manage asbestos risk within EQL.

6 Current Issues

The following sections outline current issues that have been identified as having the potential to impact EQL's ability to meet corporate objectives.

6.1 Corrosion of Cast Iron Cable Potheads

Cast iron potheads are an obsolete legacy cable termination used to transition from the underground to overhead system. Each core of a multicore cable is terminated through porcelain bushings contained in a cast iron box. A dielectric material, such as hydrocarbon oil, pitch blend or asphalt, is used to fill the box, however, voids tend to exist within the dielectric material. Corrosion of the outer casing leads to water ingress into the voids. Partial discharge then causes pressurisation in the voids, and in some cases, leads to explosive release of pressure and catastrophic failure of the cast iron components.

EQL has implemented a replacement program to remove all known cast iron potheads from the network. Due to data quality issues, small populations of these terminations may still exist and will be replaced on discovery.

The AMP Action Plan Log advises this task was completed in FY2020. The LDCM was reformatted and reorganised since publishing of V1 of this AMP. Section 8.3 of the changed LDCM details that any cast iron pothead identified is to have a P2 defect recorded, initiating a planned replacement action. The AMP Action is therefore considered complete.

6.2 Concentric Neutral Solid Aluminium Conductor (CONSAC) Cable

CONSAC (Concentric Neutral Solid Aluminium Conductor) is a legacy aluminium sheathed, paper-insulated LV cable that was installed in the network during the 1970s. The aluminium sheath also serves as the neutral conductor in this cable construction; however, it is susceptible to corrosion. This can lead to an open circuit of the neutral and pose a significant safety risk. EQL has undertaken proactive replacement programs to remove CONSAC to mitigate the risks associated with cable failures. 37km have been replaced in the Energex region to date. September 2023 records indicate 45km of CONSAC cables remaining in service within Energex networks, with regular faults continually reported. There are no records of CONSAC use in Ergon Energy networks.

Mobile application (PowerApp) has been implemented to capture this type of cable data and some CONSAC cable locations have already been identified.

The AMP Action Plan Log advises this task was completed in FY2020. The Action Plan register details completion comments as:

- Raising awareness - Completed
- SE program - in progress
- N/S regions program - reactively
- No change to LDCM required.

Universal data quality issues, and failure modes that lead to significant public safety risks (e.g., shocks, tingles, or potential fatality) call for a requirement to identify in-service CONSAC cables and subsequent removal from service. EQL currently identifies and/or replaces CONSAC cables in the event of failures. Identification is also achieved via local knowledge, among other methods. However, current approaches will be reviewed and determined in relation to the risks.

6.3 Cable Pit Safety

Distribution joints are typically installed in cable pits in the footpath services corridor with access through a solid, removable cover. Distribution cable pits are not typically backfilled to allow for new cables, or to perform cable repair on existing cables.

After the 2018 publication of this AMP (V1), a HV cable fault resulted in a destructive failure in a footpath cable pit, leading to the pit cover being explosively ejected. Although the pit was in a highly frequented area, there were no injuries resulting from the incident.

Investigation into the incident identified design issues around safe explosion venting, sparse pit construction and maintenance information, inadequate pit inspection procedures, and inadequate defect benchmarks. These issues were found to be applicable to both Ergon Energy and Energex assets. Additionally, the installation standard for many similar pits included use of non-vented lids.

The investigation resulted in the implementation of an updated pit design to accommodate fault-related over-pressure venting. Commencing in FY22, explosive mitigation covers (EMCs) have progressively been installed across the EQL underground network mitigating the risk of covers lifting in the event of an explosive failure of a cable joint. It is anticipated that replacement of non-venting covers will progress at the rate of 130 pits per year, with particular emphasis on highly frequented areas.

Additionally, a five-year pit inspection cycle has been implemented for HV distribution cable pits. Targeted cable pit data collection work is in progress and upgraded routine inspection and maintenance tasks have been deployed. Transmission and sub-transmission sheath link boxes are inspected on a three-year cycle in conjunction with sheath tests.

Formal documented Actions arising from the investigation address the above-mentioned elements, so additional strategic Action in this AMP version is considered redundant.

6.4 Cable Fluid leaks

Due to the ongoing number of leaks on transmission and sub-transmission fluid filled cables, a cost benefit analysis is required to assess the options of retaining the leaking cables as opposed to replacing them. Considered factors will include:

- Current and future on-going repair costs
- Environmental impacts and costs (e.g., environmental clean-up, disposal of contaminated materials, environmental violations penalties)
- Expected life
- Replacement cost
- Outage costs
- Other impacts.

6.5 Cable Sheath faults

Due to the ongoing number of cable sheath faults on transmission and sub-transmission cables, a cost benefit analysis is required to assess the options of retaining the cables as opposed to replacing them. Considered factors will include:

- Current and future on-going repair costs
- Expected life
- Replacement cost
- Outage costs
- Other impacts.

7 Emerging Issues

The following sections outline emerging issues which have been identified as having the potential to impact on EQL's ability to meet corporate objectives in the future.

7.1 Water Treeing in XLPE

Water trees form when moisture enters the insulation and forms discrete, micro voids in the polymer structure. These voids reduce the dielectric strength of the insulation, leaving the area more susceptible to partial discharge under high electrical stress than the surrounding insulation. Water trees may provide a location to initiate partial discharge and electrical tree growth. The formation of water trees may not lead to failure even if the water tree bridges the insulation. It is the ongoing growth of electrical trees formed at the site of water trees that cause the ultimate failure of the insulation.

EQL has experienced increasing numbers of premature XLPE insulated distribution cable failures (particularly in Far North Queensland) attributed to the presence of water trees in the cable dielectric. Many of the reported failures of XLPE at distribution voltages are anecdotal as post-failure laboratory analysis is required to confirm if trees are present, and this is not typically done at lower voltage designations. Current contract XLPE cables have an improved tree retardant TR-XLPE formulation which has better resistance against this failure mode. Water blocking tape and yarn has also been introduced to stem the longitudinal movement of water through the cable.

Transmission and sub-transmission cables are less at risk as these cables typically have a solid metallic sheath which is impervious to radial moisture ingress. However, moisture ingress can occur at damaged or faulted locations or via cable accessories. Cable sheath damage, a common cause of moisture ingress, can occur during installation, or because of excavation / construction works. Cable accessories, historically a point of vulnerability in cable systems, can allow moisture ingress, most often because of workmanship / material issues, but also due to mechanical damage. Once ingress occurs, moisture will propagate great distances throughout cables systems, including through accessories (joints/terminations) due to capillary action. Early steam cured versions of XLPE cable insulation are susceptible to the formation of water trees, as confirmed by laboratory analysis, increasing the likelihood of premature failure in these cable systems where sources of moisture ingress exist.

Use of Laminated Aluminium Tape (LAT) in lieu of lead sheathing was developed around 1990 in lieu of a lead or solid copper sheath moisture barrier. In the Ergon Energy network, there is around 255kms of cable employing LAT (mostly 22kV cable energised at 6.6kV, 11kV and 22kV and small quantities of 33kV insulated cable energised at 33kV) with the earliest recorded installation date of 2000. There is approximately 67kms of 33kV cable employing LAT in the Energex network with earliest recorded installation date of 1999. Overseas reports suggest performance is not as good as expected, with several failures mostly attributed to contacts between the LAT and copper wire screens; usually close to cable joints, terminations, and cable straps. The common attributes of these failures include lack of bonding and earthing connections.

The longevity of this construction is yet to be proven in Queensland, although it is commonly employed in Europe. The performance of this cable will continue to be monitored over time.

Currently, there isn't any reliable non-destructive diagnostic techniques and tools to assist in the identification and condition assessment of water tree propagation in cross-linked polyethylene (XLPE) insulated cables. Future studies will be required to find reliable and economical ways of assessing water tree/electrical tree problems in XLPE cables.

7.2 Spares

EQL maintains an inventory of strategic spares where deemed appropriate by subject matter experts (SMEs). Spares holdings are periodically reviewed to ensure the minimum holding quantity is appropriate for the installed population. As with all assets, spare components require periodic inspection and maintenance to ensure serviceability when called into service, as per *Standard for Network Assets Held as Strategic Spares* (Doc ID: 3055316). For example, consumable items such as resin compounds are reviewed and replaced from jointing kits as required to ensure they remain fit for purpose.

It is impractical to carry spares for all cable types and accessories. Critical or obsolete cable types require special attention to ensure adequate coverage for emergency situations.

Approximately 26% of all cables (Ergon Energy 29%, Energex 25%) are considered legacy cables (for the purposes of this AMP, these are all cables that are not XLPE insulated cables) and are potentially subject to obsolescence issues.

The most likely mode of failure for paper insulated, lead alloy sheathed, and oil pressure assisted cables is thermal or chemical degradation within the insulating papers. This results in electric trees and leads to dielectric failure.

Repair of legacy cable is, in most cases, achievable through transition joints to modern XLPE cable types, although this can introduce reliability issues, particularly at the joint itself. Transitioning from legacy fluid filled cables to solid insulation requires redesign of the hydraulic circuit to ensure the appropriate pressure is maintained. SMEs have advised that range taking, oil-XLPE transition joints are available which provide effective spares coverage for this population at minimal cost.

At distribution voltages, physical constraints such as duct or conduit dimensions promote like-for-like replacement as the only feasible option. Where feeder capacity is a driver for replacement this leads to increased civil works as new, larger conduits are required to accommodate the replacement cable.

Sourcing replacement cable and accessories such as joints and terminations for obsolescent cable technologies can prove difficult particularly if required in an emergency. As such, sufficient spares holdings for obsolescent cable types are critical.

A review of standards, solutions, and spares holdings is required to enable the prompt repair of legacy cable types such as paper insulated, lead alloy sheathed and pressure assisted, oil filled cables.

7.3 Cable Jointing Skill and Capability

Underground cable jointing is a low frequency task that, when required, demands specialised technical skill. In general, the required jointer skill and ability increase with operating voltage. The reliability of the joint is highly dependent on the training and experience of the cable jointer.

Transmission, submarine, and legacy cable types all require specialist skills that can only be developed through training, experience, and exposure over time. Due to the relatively low populations of transmission and submarine cable, and the diminishing populations of lead sheathed, or pressure assisted cables, maintaining the appropriate in-house skill level to repair and maintain these assets may prove challenging in the future.

There are quite number of distribution cable failures resultant from poor workmanship. The reduced number of available skilled jointers may lead to increased repair and restoration time on these assets during crisis events, particularly if contract labour is required.

7.4 Metallic Bonding of Transmission Cables

The use of roll springs and mechanical connectors as part of the installation of modern cable joints and terminations has been identified as a potential point of failure when bonding metallic sheaths. The types of connection methods include but are not limited to roll springs, jubilee clamps, bandit straps and hose clamps. Each of these methods introduces an increased risk of failure compared to a traditional wiped bond. The mechanical ferrule, or shear off, is an exception to the above as it is used for connecting screens, wires, and earth braids. It is not used for metallic sheaths, and as such, does not introduce an increased risk of failure.

In 2005, a directive was issued by Southeast Principle and Senior Engineers, to cease installations of mechanical connection bonds on transmission level underground cables (Figure 17). The decision was driven by the reduction in critical network cable reliability, and the extreme expenses associated with carrying out repairs to transmission underground cables where these bonding methods were utilised. In 2021, the directive to ban mechanical bonding methods was re-endorsed by the current underground transmission standard's Principal Engineer.

Development of an EQL program is progressing to proactively inspect and repair critical feeders that have known mechanical connected metallic sheaths to prevent further catastrophic failures and reduced asset life. Details of mechanical connection failures, including their causes, can be read in cable failure reports including the most recent *Asset Maintenance Briefing Note* (S-86).

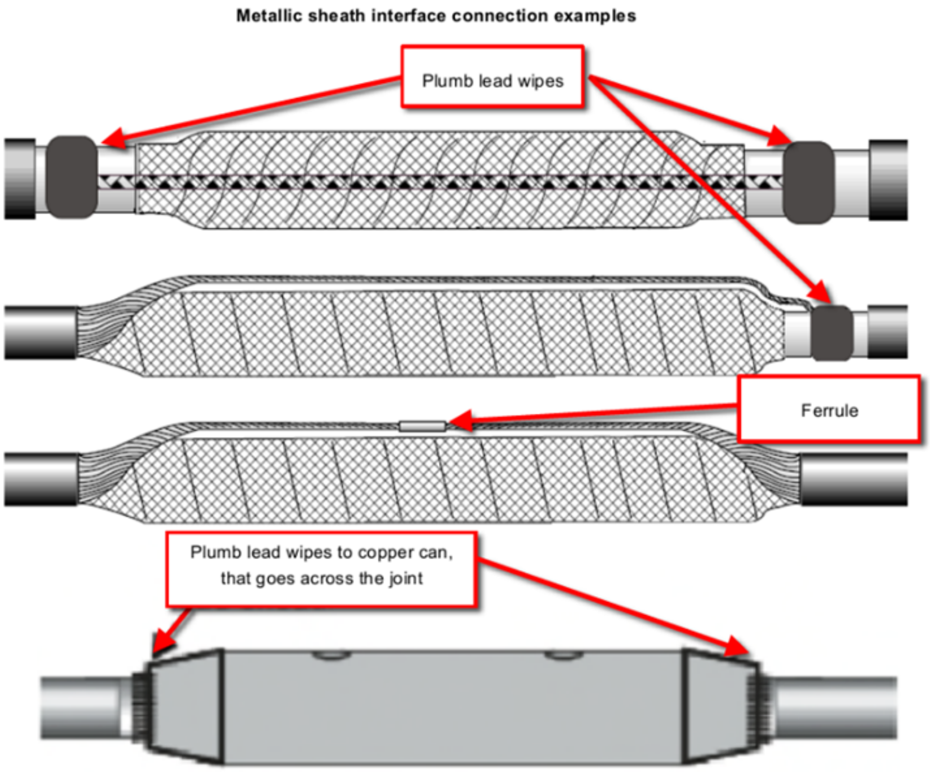

Figure 17: Metallic sheath bonding and mechanical ferrule connection

7.5 Low clearance terminations

Section 27 of the EQL SDCM has recently been updated to include information around low clearance within substations after safety concerns were raised. When encountering a suspected low HV clearance conductor, cable termination or bushing is identified, it is advised to measure the height during a substation routine inspection. Any low clearances are managed as per *Standard for Managing*

Substation Asset Defects (Doc ID 2945521). Several low credence terminations have been reported as defects and are being actioned progressively.

7.6 Submarine Cables

EQL operates submarine cable installations that provide supply to several island communities (Table 6).

Domain	Location	Type	Age	Length (km)	Construction	Status
Ergon Energy	Magnetic Island 3 (Feeder TM-03, Townsville Marina No. 03)	150 mm^2 Cu 11KV PLY	1983	12	Buried under Sea bed close to Marina and Nelly Bay, rest sitting on Sea bed.	Operational
Ergon Energy	Magnetic Island 4 (Feeder TM-10, Townsville Marina No. 10)	150 mm^2 Cu 22KV PLY	1991	12	Buried under Sea bed close to Marina and Nelly Bay, rest sitting on Sea bed.	Operational
Ergon Energy	Magnetic Island 5	150 mm^2 Cu 22KV	-	-	-	Applied Permit
Ergon Energy	Dunk Island	35 mm^2 Cu 22KV PLY	1982	5.1	Buried under Sea bed	Operational
Ergon Energy	Hayman Island	150 mm^2 Cu 22KV XLPE	1999	30	Buried under Sea bed	Operational
Energex	Russel Island (RIS2)	185 mm^2 Cu 11kV PLYSW	1999	2.1	Buried under Sea bed	Operational
Energex	Bribie Island (BISTPT3)	0.4 in^2 Cu 11kV PLYSW	2001	0.9	Buried under Sea bed	Operational

Table 6: EQL Submarine Cables

These assets are subjected to risks not normally associated with a buried cable, including tidal movements and storm surges associated with extreme weather, vessel anchor damage, and environmental factors such as sea worms and corrosion. Due to the location and relatively long route lengths, locating and repairing faults in submarine cables is a difficult task, requiring divers and specialised labour and equipment.

An outage can take several days to repair in good weather, or longer if weather conditions are poor. Due to the specialised nature of these assets, sourcing skilled labour and materials to repair these assets can result in extended outages and reduced reliability.

Section 3.2 details the additional legislative and regulatory obligations applicable to the operation of these cables.

Tests and activities designed to confirm ongoing condition assessment for these cables are carried out as per *Standard for Distribution and Sub-Transmission Cable Systems* (Doc ID 2970703). Contingency plans focus upon mobile generation for the impacted island. This is substantially impacted by the total load demand, and is seasonal in nature. Contingency plans are therefore developed on a case-by-case basis. This Action is considered complete.

Previous experience suggests that extensive interaction with GBRMPA prior to submarine cable replacement should take place, mostly around environmental management of the impacts upon underwater national park flora and fauna. Given the notably high cost of replacement and the extensive environmental obligations involved in work planning for replacement, dedicated and specific replacement strategies should be developed, especially for the older (pre-1985) cables.

7.7 Cable Joint Failures

Workmanship and moisture ingress are considered the primary root causes of joint failure, however, due to the catastrophic nature of many joint failure events, determining the cause of failure can be difficult. Water can enter cables at fault locations or at cable joints which are historically known to be the weakest point in a cable system. It is difficult to achieve a watertight joint, particularly with 'shrink' based accessories due to the expansion and contraction of cables under load. Three core cables are particularly difficult to seal due to the interstices between cores. Transitioning between different cable types can also prove challenging.

Joint and termination kits contain all required materials including bi-metallic, range taking, and sheer bolt connectors (where available) to reduce workmanship issues. Cable specifications have also been modified to include water blocking tapes and yarns to stem the longitudinal flow of water through the cable.

The shelf life of joint components, particularly the resin compound used in filled joints, has also been identified as an emerging issue. It appears that the environmental conditions in Queensland may contribute to the premature expiry of the material and affect the ability of the resin to cure. This can allow moisture to ingress leading to failure of resin filled joints.

7.8 Recovery of Redundant Cable

Underground cable was historically directly buried in the ground due to the increased initial cost of ducted or conducted installation.

At end of life, direct buried cables are typically cut, capped, and left in place due to the prohibitive cost of digging up the cable and reinstating the finished surface. Increasingly, councils and road authorities are requesting recovery of these assets at the time of decommissioning. If enforced by third parties, this has the potential to add significant costs to underground feeder projects.

Development or modification of existing Memorandum of Understanding (MOU) agreements is required with third-party stakeholders to ensure a consistent, agreed approach to the recovery of abandoned underground cable assets.

7.9 LV Underground Pillar Failures

A considerable number of defects and in-service failures are attributed to LV pillars. (Refer Section 3.4). Pillars are typically installed above ground, adjacent to the footpath services corridor, and as such, are exposed to third-party vehicular damage and vandalism. Several failures have been attributed to high impedance connections or failure of the combined fuse-switch (CFS) units housed within the pillar. Exceedingly high numbers of pillar defects are reported due to third party damages.

Routine thermoscanning of underground pillars was trialled and subsequently introduced on a five-year cycle within EQL. Thermoscanning can detect increases in temperature which occur inside the pillar because of high resistance joints and connections. This can lead to failure and pillar fires.

Exploration of high impact resistant pillar materials or modifications to design standards are suggested. This would accommodate additional mechanical protection, such as protective bollards at high-risk locations, to reduce the likelihood of third-party damage to underground pillars.

8 Improvements and Innovation

The following sections outline any improvements or innovations to asset management strategies relevant to this asset class, being investigated by EQL.

8.1 Health Index and Risk Monetisation

To support / justify the increased replacement volumes and resolve the economic limitation of Ergon Energy, EQL has:

- Developed a condition-based risk quantification modelling tool to establish optimum replacement volumes.
- Committed to adopt an economic, customer value-based approach when it comes to ensuring the safety and reliability of the network. To substantiate the advantages of this approach for the community and businesses over the modelling period, we have employed Net Present Value (NPV) modelling. This commitment is in line with efforts to minimise the impact on customer prices.
    - A cost benefit analysis has been conducted to confirm that the underground cable asset replacements are prudent capital investments.

8.2 Asset Management Approach

EQL uses several CBRM models to forecast the retirement of Energex underground cables >/= 33kV. The use of disparate models for different cable subclasses results in loss of relative importance parity information across the asset class.

EQL has a preliminary model covering Ergon Energy high voltage cables. The 2010 model was never commissioned due to insufficient resources and information. As a result, most Ergon Energy cables are effectively operated with a run-to-failure strategy or identified visual defect (also refer Section 8.3). The data improvements made since 2010 offer potential for development of a working model.

Distribution and low voltage cables are replaced upon identified defect or ultimate failure. There is an opportunity to apply the concepts of the CBRM approach used at higher voltages to the lower voltage cable. This would assist in gaining a better understanding of the forecast life of these assets, and ensure sustainable programs are in place to manage network risk. This asset class is the third most critical in terms of achieving corporate objectives.

8.3 Cable Diagnostics and Condition Trending of Critical Cables

In general, routine tests of sub-transmission and transmission cable types to prove cable condition are limited to sheath tests and visual inspection only. These tests can only provide pass/fail results against pre-defined criteria.

Advanced, non-routine test methods (such as partial discharge, core insulation resistance, and dielectric dissipation factor (tan δ)) are available to provide trending on the deterioration of the cable insulation; in some cases, location of degradation sites. These tests have historically been performed by EQL where deemed necessary, by request only.

During the assessment of the 2032 Olympic venue feeding cables, EQL has developed a risk score and risk ranking method. This method is based on known condition data, cable size, cable insulation type, age, number of joints, number of terminations, etc. The risk score is then utilised to generate the CBRM health index. However, further development of this methodology and inspection techniques is needed for CBRM health index application to any type of cable.

9 Lifecycle Strategies

The following sections outline the approach of EQL to the lifecycle asset management of this asset class.

9.1 Philosophy of Approach

EQL currently employs a diverse range of philosophies and asset management strategies, principally developed by the legacy organisations of Ergon Energy and Energex, that are implemented under the EQL common asset management umbrella.

CBRM predictive methodology is used to determine end of serviceable life of underground cables at voltage designations of 33kV and above in the Energex network.

EQL distribution is effectively operated utilising a run-to-near-failure strategy, relying on identified visual defects (Section 8.3). The data improvements made since 2010 offer potential for development of a working CBRM model, at least for all high voltage cables. This would support EQL's asset management intent to progress toward proactive asset management for this asset class.

EQL does not currently have aged or condition-based strategies in place to manage the lifecycle of LV and distribution underground cables. Cables at this voltage are replaced upon identified defect or ultimate failure. Replacement programs are generally driven by repeat failures from within a population that are of safety or reliability concern to the business.

In some circumstances, underground cable replacement is coordinated with network augmentation works, otherwise cable is repaired or replaced as required on observed condition.

9.2 Supporting Data Requirements

There is a disparity between asset records being kept in the Ergon Energy and Energex regions. Historical data capture practices restrict the ability to analyse the large volumes of data associated with this asset class without substantial manual effort and offers significant potential for improved asset management.

Legacy organisation Ergon Energy developed and implemented a recording system for all failures, incorporating a requirement to record the failed asset component (object), the damage found, and the cause of the failure using the Maintenance Strategy Support System (MSSS) in Ellipse; the current Enterprise Asset Management System (EAMS). Energex maintained detailed records of failures in a separate outage related database external to the corporate asset management system. EQL has adopted the MSSS approach and is building this system for asset records over time, providing the information necessary to support improvements in inspection and maintenance practices. There is an expectation that this will also support and influence standard design and procurement decisions. Alignment of failure and defect data capture across regions is required to take full advantage of the larger data set available across the state.

To support the forecasting of replacement volume for business planning purposes, specific information such as the insulation type, conductor type, age, location, and environment in which assets fail, is being developed. This is the source of much of the information detailed in this AMP. Over time, this will support the application of probabilistic reliability engineering techniques such as Weibull Analysis.

Defect benchmarks and definitions have now been aligned across Ergon Energy and Energex and implemented in the field. Essential data capture methodologies have yet to be aligned and are not expected to do so until common technology systems are distributed across Ergon Energy and Energex.

9.3 Acquisition and Procurement

EQL's procurement policy and practices are detailed in *Sustainable Procurement Policy* P011. Underground cable assets are specified in line with relevant Australian Standards, industry best practice and in consultation with stakeholders and SMEs. Underground cable assets are procured on period contracts awarded through technical and commercial evaluation in line with the Queensland Government's QTenders process.

Underground cable networks associated with connection assets, such as large customer or subdivision connections, may also be designed, procured, and constructed by approved service providers to EQL standards under the contestable works process. The connection assets are "gifted" to EQL following final product audit and acceptance of the installation. EQL own, operate, maintain, and replace these assets from the date of acceptance.

9.4 Operation and Maintenance

Operation and maintenance includes planned and corrective maintenance. Operation and maintenance procedures are supported by a suite of documentation. They describe in detail the levels of maintenance applicable, the activities to be undertaken, the frequency of each activity, and the defect and assessment criteria. This criterion is used to compare condition and testing which determines the required actions. The relevant documents are included in Appendix 1 for reference.

EQL maintenance policies and standards are aligned with obligations outlined in the Electricity Act and Regulations to maintain a safe and reliable electrical supply network.

9.4.1 Preventive Maintenance

Preventive maintenance comprises of scheduled inspection and maintenance activities required to ensure network assets remain serviceable and fit for purpose throughout their asset life cycle.

At transmission and sub-transmission voltages, routine preventative maintenance monitors the electrical condition of the cable over sheaths and sheath voltage limiters, the performance of pressure feeds, the accuracy and condition of pressure gauges and alarm systems, and the physical condition of the above ground structures and terminations. EQL utilises an established routine test methodology to enable condition monitoring of critical cables (refer Section 8.3).

At distribution voltages, periodic inspections check the external condition of distribution cable systems including ring main units, link pillars, link boxes and service pillars to ensure equipment remains in an acceptable condition.

Underground cable maintenance tasks and frequency rates are contained in *Network Schedule of Maintenance Activity Frequency 2024-25* (Doc ID 12357714).

Under the inspection process, underground cables are assessed according to a set of pass/fail benchmark criteria documented in the LDCM, SDCM, and MAC. Individual benchmark failure records are labelled "Defects". The benchmark criteria are reviewed periodically based upon overall population failure and refurbishment statistics, as well as reported situational circumstances that have been encountered. The inspection process mostly consists of ground-based personnel checking for visual clues of defects on the above ground portions of the cables and accessories. Defects are scheduled for repair according to a documented risk-based priority scheme (P1/P2/C3/no defect). Actual individual repair periods are recorded and monitored, with performance criteria established for the population repair period statistics.

9.4.2 Corrective Maintenance

Corrective maintenance is generated from preventive maintenance programs, ad-hoc inspections, public reports, and in-service failures. Urgent maintenance (i.e., immediately life threatening or loss of supply) is addressed immediately. Non-urgent maintenance is scheduled to allow appropriate planning and coordination to occur.

For corrective maintenance, underground cables are repaired to the current standard where cost effective and technically feasible. If it is not technically feasible, repairs are carried out to the standard in place at the time of original commissioning. Known augmentation plans are considered prior to carrying out corrective maintenance.

Emergency maintenance may be required at any time of the day or night due to failure of cable, joints or terminations, or damage arising from third parties, e.g., cable damage during excavation. This requires experienced and skilled staff, a range of tools and equipment, well maintained records and instructions, and adequate stocks of cable, joints, terminations, and insulating fluid (where applicable).

9.5 Refurbishment and Replacement

The following sections outline the practices used to either extend the life of the asset through refurbishment or to replace the asset at the end of its serviceable life.

9.5.1 Refurbishment

On identification of defects or improvements through regular inspection and testing, EQL undertakes refurbishment of underground cable assets to ensure they remain safe and fit for purpose. Inspection driven refurbishment is typically limited to items ancillary to the cable itself such as pillars or terminations. Where an underground cable fails in service, the faulted section is typically removed and replaced by a new cable section, jointed to the remaining system.

Refurbishment of the underground environment may also be undertaken where reduced cover, subsidence or vermin activity is present.

In past practices, Ergon Energy utilised a cable rejuvenation technique (injecting high-pressure silicon into the core of XLPE cable) to repel water and prevent the formation of water trees in the cable. This technique is not a viable option for extending the life of XLPE cables.

9.5.2 Replacement

Underground cable systems are designed and constructed to ensure that they are fit for purpose and will continue to perform and operate safely under system normal and contingency situations. When the asset can no longer safely perform its intended function, is not economically viable to refurbish, or presents an unacceptable risk to the business, it is considered end of life and planned replacement is proposed.

Annual data varies slightly each year, depending upon the need identified. Routine replacements are generally utilised for ad hoc replacement of problematic assets when they are identified. Replacement of critical and sub-transmission cables assets is usually subject to detailed and specific Business Case justifications leading to bespoke projects, or included as part of larger augmentation works.

9.6 Disposal

Section 7.8 details issues related to recovery (or not) of redundant underground cable assets. Pressure assisted oil filled cables are purged prior to abandonment or recovery to safely remove as much oil as possible to minimise the threat to the environment. Used high voltage cable fluid is not generally suitable for reclamation or reconditioning, and is disposed of via an approved, licensed contractor. Care is taken to safely dispose of impregnated, non-draining paper cable or other contaminated materials such as bitumen or oil filled potheads or terminations. Recovered underground cable, which may include the copper or aluminium conductor together with other materials, is disposed of via scrap merchants.

10 Program Requirements and Delivery

The programs of maintenance, refurbishment and replacement required to deliver the strategies of this AMP are documented in Network Program Documents and reflected in corporate management systems. Programs are typically coordinated to address the requirements of multiple asset classes at a higher level, such as a substation site or feeder, to provide delivery efficiency and reduce travel costs and overheads. The Network Program Documents provide a description of works included in the respective programs as well as the forecast units.

Program budgets are approved in accordance with Corporate Financial Policy. The physical and financial performance of programs is monitored and reported monthly to manage variations in delivery and resulting network risk.

Appendix 1. References

It takes several years to integrate all standards and documents after a merger between two large corporations. This table details key documents authorised/approved for use in either legacy organisation that supports this AMP.

Legacy Organisation	Document Number	Title	Type
EQL	Net Policy – 001 (P049)	Asset Management Policy	Policy
EQL	P043	Risk Management Policy	Policy
Ergon Energy Energex	2928929	Maintenance Acceptance Criteria	Standard
EQL	2877290	Network Risk Framework	Standard
Ergon Energy Energex	2023-Q3	Lines Defect Classification Manual	Manual
Ergon Energy Energex	Asset Maintenance site	Substation Defect Classification Manual	Manual
Ergon Energy Energex	2945521	Standard for Managing Substation Asset Defects	Standard
Ergon Energy Energex	2945509	Standard for Managing Line Asset Defects	Standard
Ergon Energy	3054145	Standard for Distribution Line Design Underground	Standard
Energex	STD00305	Underground Distribution Construction Manual	Standard
Energex Ergon	2970703	Maintenance Standard for Distribution Cable Systems	Standard

Appendix 2. Definitions

The following definitions may appear in this AMP.

Term	Definition
Condition Based Risk Management	A formal methodology used to define current condition of assets in terms of health indices and to model future condition of assets, network performance, and risk based on different maintenance, asset refurbishment, or asset replacement strategies.
Corrective Maintenance	This type of maintenance involves planned repair, replacement, or restoration work that is carried out to repair an identified asset defect or failure occurrence, to bring the network to at least its minimum acceptable and safe operating condition. An annual estimate is provided for the PoW against the appropriate category and resource type.
Distribution	LV and up to 22kV networks, all SWER networks.
Forced Maintenance	This type of maintenance involves urgent, unplanned repair, replacement, or restoration work that is carried out as quickly as possible after the occurrence of an unexpected event or failure; to bring the network to at least its minimum acceptable and safe operating condition. Although unplanned, an annual estimate is provided for the PoW against the appropriate category and resource type.
Preventative Maintenance	This type of maintenance involves routine planned/scheduled work, including systematic inspections, detection, and correction of incipient failures, testing of a condition and routine parts replacement designed to keep the asset in an ongoing continued serviceable condition, capable of delivering its intended service.
Sub-Transmission	33kV and 66kV networks
Transmission	Above 66kV networks

Appendix 3. Acronyms and Abbreviations

The following abbreviations and acronyms may appear in this AMP.

Abbreviation or Acronym	Definition
AER	Australian Energy Regulator
AIDM	Asset Inspection & Defect Management system
ALARP	As Low As Reasonably Practicable
AMP	Asset Management Plan
Augex	Augmentation Expenditure
BLL	Blood Lead Level
Capex	Capital expenditure
CBRM	Condition Based Risk Management
CONSAC	Concentric Neutral, Solid Aluminium Conductor
DEE	Dangerous Electrical Event
DGA	Dissolved Gas Analysis
DLA	Dielectric Loss Angle
DTS	Digital Temperature Sensing
EQL	Energy Queensland Limited
EMF	Electromagnetic Fields
ESCOP	Electricity Safety Code of Practice
ESR	Queensland Electrical Safety Regulation (2013)
IoT	Internet of Things
GBRMPA	Great Barrier Reef Marine Park Authority
HSL	Hochstadter Separately screened Lead sheathed
HV	High Voltage
ISCA	In-Service Condition Assessment
LAT	Laminated Aluminium Tape
LDCM	Lines Defect Classification Manual
LV	Low Voltage
LY	Lead Alloy
MAC	Maintenance Acceptance Criteria
MOU	Memorandum of Understanding
MSS	Minimum service standards
MSSS	Maintenance Strategy Support System
NOHSC	National Occupational Health and Safety Commission

Abbreviation or Acronym	Definition
OFPA	Oil Filled, Paper insulated, Aluminium sheathed.
Opex	Operating Expenditure
OTI	Oil Temperature Indicators
PCB	Polychlorinated Biphenyls
PILC	Paper Insulated Lead Covered
PLY	Paper Lead Alloy
PLYDBT	Paper Lead Alloy Double Brass Tape
POC	Point of Connection (between EQL assets and customer assets)
PVC	Polyvinyl Chloride
POEL	Privately owned Electric Line
PRD	Pressure Relief Device
QLD	Queensland
REPEX	Replacement capital expenditure
RIN	Regulatory Information Notice
RMU	Ring Main Unit
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
SDCM	Substation Defect Classification Manual
SHI	Security and Hazard Inspection
SFAIRP	So Far As Is Reasonably Practicable
STPIS	Service target performance incentive scheme
SVL	Sheath Voltage Limiter
TR-XLPE	Tree Retardant Cross-Linked Polyethylene
US EPA	United States Environmental Protection Agency
WCP	Water Content of Paper
XLPE	Cross-Linked Polyethylene