WATER CORPORATION

Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 91

Standard for the Selection and Design of Cathodic Protection (CP) Systems

VERSION 4
REVISION 1

SEPTEMBER 2024

FOREWORD

The intent of Design Standards is to specify requirements that assure effective design and delivery of fit for purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation service standards and safety. Design standards are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of the Western Australia's Work Health and Safety (General) Regulations 2022 to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

Overview of Western Australia’s Work Health and Safety (General) Regulations 2022 (dmirs.wa.gov.au)

Enquiries relating to the technical content of a Design Standard should be directed to the Principal - Cathodic Protection Section, Engineering. Future Design Standard changes, if any, will be issued to registered Design Standard users as and when published.

Head of Engineering

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REVISION STATUS

The revision status of this standard is shown section by section below:

REVISION STATUS						
SECT.	VER./ REV.	DATE	PAGES REVISED	REVISION DESCRIPTION (Section, Clause, Sub-Clause)	RVWD.	APRV.
All	3/0	29.09.17	All	Revise reference to MESB	RT	GP
All	3/0	29.09.17	All	Remove all relevant monitoring and maintenance pages and reference	RT	GP
5.2	3/0	29.09.17	17	Revise remote monitoring requirements in TRU	RT	GP
7	3/0	29.09.17	26	Revise extent of protection and where it applies	RT	GP
12	3/0	29.09.17	33	Revise insulating flange joint requirements and reference DS21	RT	GP
13.2	3/0	29.09.17	34	Change electrical continuity bond type in line with modular construction specifications	RT	GP
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15	3/0	29.09.17	36	Change section from monitoring to monitoring facilities	RT	GP
16.5	3/0	29.09.17	38	Change VM reference from DS20 to DS23	RT	GP
17	3/0	29.09.17	39	Change VM reference from DS20 to DS23	RT	GP
18	3/0	29.09.17	40	Incorporate Appendix F as part of Appendix A	RT	GP
20	3/0	29.09.17	49	Rename previous Appendix E to Appendix C and revise Appendix from CP Surveys to commissioning requirements	RT	GP
5.2	3/1	16.12.20	17	Include GPS built in current interrupter in TRU	RT	GP
All	4.0	05.07.24	All	Complete review, update and tidy up of entire document, further specific changes as per below	JMo	SS
5.1	4.0	05.07.24	18	Corrected resistivity values	JMo	SS
5.2	4.0	05.07.24	20	Added specific requirements for remote monitoring devices and removed all references to “Cyplex”	JMo	SS

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6.3.1	4.0	05.07.24	27	Removed paragraph 3	JMo	SS
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DESIGN STANDARD DS 91

Standard for the Selection and Design of Cathodic Protection (CP) Systems

CONTENTS

Section *Page*

1 ABBREVIATIONS

AC	Alternating Current
ASS	Acid Sulphate Soils
AW	Anode Wastage
CD	Current Density
CP	Cathodic Protection
CPP	Cathodic Protection Potential
CPU	Cathodic Protection Unit
DC	Direct Current
DCD	DC Decoupler
EBV	Electrical Butterfly Valve
ELV	Extra Low Voltage
EMF	Electro Motive Force
FS	Foreign Structure
GAB	General Aerobic Bacteria
ICCP	Impressed Current Cathodic Protection
IF	Insulated Flange
MFM	Magnetic Flow Meter
MMO	Mixed Metal Oxide
MSCL	Mild Steel Cement Lined
OSH	Occupational Safety and Health
PM	Potential Monitoring
PRE	Permanent Reference Electrode
RE	Reference Electrode
RRJ	Rubber Ring Joint
SA	Sacrificial Anode
SCP	Soil Corrosion Probe
SRB	Sulphate Reducing Bacteria
SC	Surge Current
TC	Telluric Current
TP	Test Point (Test Post)
TRU	Transformer Rectifier Unit
VM	Voltage Mitigation
WR	Weld Restraint
wrt	with respect to

2 DEFINITIONS

Definitions used in this guideline are similar to those contained in Australian Standard AS 2832.1 - 2015, Cathodic Protection of Metals Part 1: Pipes and Cables

Anaerobic

Lacking free oxygen.

Anode (in general)

An electrode, placed in the electrolyte, to apply cathodic protection to the structure.

Anode screen

A safety barrier surrounding a submerged anode for the prevention of electrical shock or shorting.

Anode shield

A protective covering of insulating material applied to a coated structure in the immediate vicinity of an anode to reduce local cathodic current density.

Back EMF

An instantaneous open-circuit opposing voltage, between an anode and cathode of an operating ICCP system.

NOTE: Back EMF may have other definitions in other technologies.

Bond (electrical)

A metallic connection between points on the same structure or on different structures.

Bond (coating)

Adhesion between the coating materials and the substrate.

Cathode

The structure that is to be protected by cathodic protection.

Cathodic Disbondment

Detachment of a coating due to the effects of excessive cathodic polarisation.

Cathodic Protection

The mitigation of corrosion of metal, by making the metal the cathode in a galvanic or electrolytic cell.

Cathodic Protection Unit

DC power supply for an ICCP system.

Copper/Copper Sulphate (Cu/CuSO4) Reference Electrode

A reference electrode consisting of copper in a saturated solution of copper sulphate.

Corrosion

The deterioration of metal caused by an electrochemical reaction with its environment.

Corrosion Cell - Anode

The electrode at which metal dissolution (corrosion) takes place.

Corrosion Current

The current flowing in a corrosion cell and which is electrochemically equivalent to the anodic and cathodic reactions.

Coupon

A section of metal of similar size to a coating defect, used to monitor the corrosion of a coated structure that is subjected to CP (see resistance probe).

Current Density (at anode)

Current output of an anode, divided by the anode surface area.

Current Density (at cathode)

Current flowing to the cathode, divided by the cathode surface area.

Drainage bond

An electrical means whereby stray current is removed from the structure via a conductor.

Earth (noun)

The conducting mass of the general body of the earth.

Earth (verb)

The act of connecting a conductor to earth.

Electrode

An electronic conductor that allows current to flow either to or from the electrolyte with which it is in contact.

Electrode potential

The measured potential of an electrode in an electrolyte, relative to the potential of a reference electrode.

Electrolyte

A liquid or the liquid component in a composite material such as soil, in which electric current flows by ionic charge transfer.

Extra low voltage (ELV)

Voltage not exceeding 50V AC. or 120V DC. (max 10% ripple see AS/NZS 3000).

Ferrous metal structure

A structure comprising of an iron-based alloy, containing more than 50% iron.

Foreign (secondary) Structure

A buried or submerged structure that may be subject to interference arising from the CP of a primary structure.

Galvanic action

A spontaneous electrochemical reaction where a metallic anode in a dissimilar metal couple corrodes.

Galvanic Anode

An electrode used to protect a structure using galvanic action. A galvanic anode is also known as a sacrificial anode.

Half-cell

(See 'reference electrode')

Impressed Current

DC current supplied by an external power source to cathodically protect a structure.

Impressed Current Anode

The electrode connected to the positive terminal of an impressed current power supply.

Instantaneous Off-Potential

A potential substantially free of voltage gradients and “IR drops” through the electrolyte.

Insulating Joint (isolating joint)

A joint that breaks the electrical continuity of a structure but does not affect the mechanical integrity.

Interference

A significant change in current density and structure potential on a foreign structure caused by a CP system; it may be detected by a resultant potential change on the structure.

Interrupter

A timing device that permits a cyclic off/on interruption to the flow of CP current.

IR Drop

(See ‘resistance potential’).

Loop Resistance

The total external circuit resistance at the output terminals of the CP impressed current DC power supply.

Overprotection

A state that occurs when the cathodic polarisation of a structure is at a level beyond that required for corrosion protection. Overprotection may cause effects which are detrimental to the structure.

Polarisation

A change in the potential of a corroding metal from its natural steady state value (the corrosion potential), as a result of current flow.

Polarisation cell

A device which, at potential levels typical of cathodically protected structures, has low impedance to alternating current but high impedance to direct current.

Polarised Potential

The potential of a structure at the structure-to-soil interface. (This potential is thus free of voltage gradients that may accompany current flow through the electrolyte and is the “true” structure potential.)

Primary Structure

The structure that is subject to intentional CP.

Protective Potential

The potential to which a metallic structure is lowered to achieve corrosion protection.

Protective Current

The current that flows into a metallic structure from its electrolytic environment, and which cathodically protects the structure.

Reference cell/electrode

An electrode that has a stable potential in one or more electrolytes at a given temperature, thus enabling it to be used for the measurement of other electrode potentials.

Resistance Potential

That part of a measured electrode potential attributable to the passage of current through the resistance between the cathodic surface and reference electrode.

Resistance Probe

A corrosion monitoring device, which functions by exposing an element of metal the structure is manufactured from to the environment in which the structure is exposed. As the element corrodes, its cross-sectional area is reduced, thus increasing its longitudinal resistance. The change in resistance is measured with a very sensitive resistance measuring circuit.

NOTE: When monitoring a cathodically protected structure the element is connected to the structure to simulate a coating defect on the structure.

Silver/Silver Chloride reference electrode (Ag/AgCl)

An electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions.

Stray Current

Current flowing through paths other than the intended circuit.

Structure

A metal which has a surface in contact with an electrolyte.

Structure Potential

The potential of a structure relative to that of a specified reference electrode situated in the electrolyte immediately adjacent to the structure.

Structure Potential Shift

A change in the measured voltage of a metallic structure caused by the application of current from an external source.

Sulphate-Reducing Bacteria

A type of bacteria, which is capable of reducing sulphate to sulphide in anaerobic, near-neutral soils and natural waters.

Telluric Current (Geomagnetic Current)

The current induced by the variations in the earth's magnetic field that intersects the structure.

Test Point

A nominated point on a structure for electrical contact.

Transformer/Rectifier Unit

A form of CP DC power supply.

Voltage Mitigation

A system to reduce AC induced voltages to an acceptable level for personnel safety and to reduce AC corrosion effects.

3 SCOPE

The scope of this standard is to provide Water Corporation personnel and Design Consultants with information to assist with the selection and design of CP systems for new and existing buried mild steel pipelines, metallic water storage tanks, and other infrastructure as stated in Sections 6.2.2 and 6.3.2 of this document.

The standard is intended to:

- Ensure consistency in the application of CP systems on all different relevant classes of assets.
- Ensure that designs meet Water Corporation requirements and comply with relevant Australian Standards
- Promote co-operation between all interested parties through a common understanding of the complex principles and practices associated with CP.

4 INTRODUCTION

4.1 Background

Corrosion is the destruction of a metal by a chemical or electrochemical reaction of the metal with its environment. In all electrolytes, such as soil, water and wastewater, metal atoms go into solution as electrically charged atoms (ions). This process results in rapid loss of metal commonly known as corrosion.

Cathodic Protection (CP) is defined as mitigating (reducing or eliminating) corrosion by making the metal a cathode by means of an impressed direct current (DC), or by connection to a suitable sacrificial anode (generally magnesium, aluminium, or zinc).

When CP is applied, there is an exponential decrease in the rate of corrosion with an increasing negative (cathodic) potential. When a certain level (protection potential) is reached, the rate of corrosion becomes negligible. Therefore, corrosion is prevented by effectively installed, operated and maintained CP on a buried or submerged structure. This is achieved by applying an appropriate DC current flow in opposition to the original corrosion current, thus driving the structure to a suitably more negative potential, and thus preventing the natural tendency of the metal to react with its environment. CP is a system utilised to mitigate corrosion of structures, such as buried pipes, submerged tank surfaces, and other structures.

To employ CP, a circuit is established by applying a suitable source of DC current to the structure to be protected. Current flows between the anode and the cathode due to the potential difference between them. For example, in soil with low resistivity, current would leave the pipeline at the anodic site, pass through the soil, and re-enter the pipeline at a cathodic site. The total system – anode, cathode, electrolyte, and metallic connection between anode and cathode is termed a corrosion cell.

NOTE: Design of any CP system using DS 91 should be read in conjunction with DS 20, Design Process for Electrical Works, DS 21, Major Pump Station – Electrical, to satisfy both Cathodic Protection and Voltage Mitigation requirements.

4.2 Corrosion

For corrosion to occur the following conditions must exist:

Electrodes:	An anode and cathode must be present
Conductive Path:	A metallic, conductive path electrically connecting the anode and cathode must exist. In the case of a metallic pipeline, the pipe itself is the conductive path.
Electrolyte:	The anode and cathode must be immersed in an electrically conductive media (electrolyte).
Electrical Potential Difference:	An electrical potential difference between the anode and cathode must be present.
Current:	When these conditions exist, an electric current will flow; it is where the current leaves a metallic object that corrosion occurs.

CP reverses this current flow and inhibits corrosion.

5 TYPES OF CP SYSTEMS

5.1 Sacrificial Anode CP (SACP) Systems

A SACP system utilises the varying galvanic potential of different metals, as per the galvanic series of metals. The more active metals (with a more negative potential) such as magnesium, zinc and aluminium, corrode preferentially to the structure intended for protection. When an electrical connection is made between a mild steel pipeline and magnesium material, the magnesium becomes the anode and the entire structure will become cathodic, thereby a level of protection will be afforded.

Magnesium or zinc anodes are generally used in buried type SACP systems dependent upon soil conditions. Zinc anodes are typically used in electrolytes with a resistivity value between 0.2 to 25Ω.m, and magnesium anodes are typically used in electrolytes between 10 and 100 Ω.m. Wherever practical, the site of lowest resistivity is preferred to be used for the anode installation, this minimises the anode-to electrolyte resistance.

Aluminium anodes are typically used in seawater environments only.

The datasheets for anode specifications should include the anode material and composition, weight, and dimensions, and where applicable package dimensions (for pre-packaged anodes, including anode plus backfill).

The materials composition used for magnesium, zinc and aluminium anodes shall comply with Australian Standard AS 2239.

An SACP system has limited capabilities, that are determined by the driving potential of the selected anode. An SACP system should only be installed once suitability is confirmed.

Factors affecting the design of SACP systems (once suitability of installation is confirmed) are summarised in Figure 1.

Factors To Be Considered for Selection Of Sacrificial (Galvanic) Anode System for buried structures

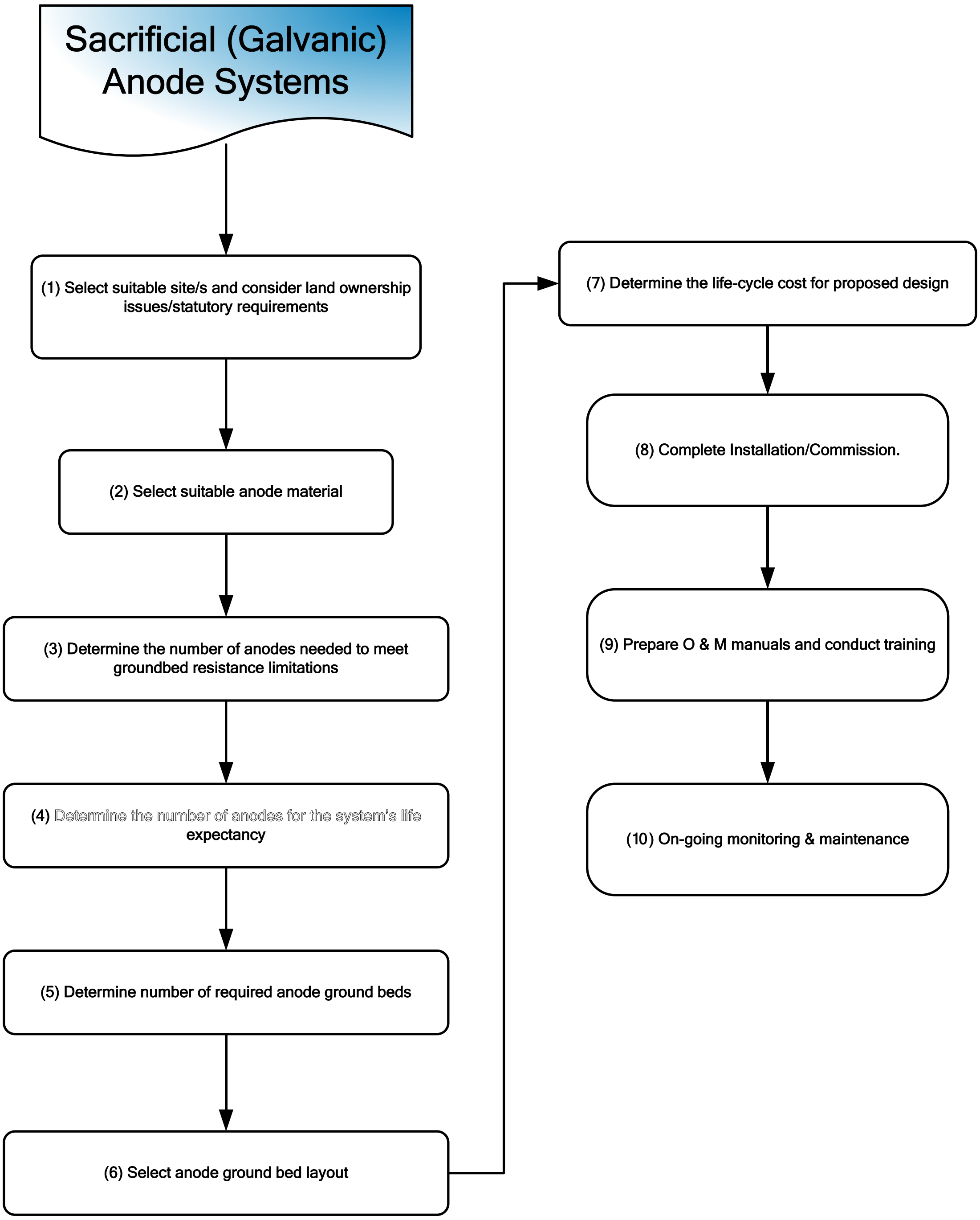


Figure 1 – Factors Affecting the Design of Sacrificial Anode CP Systems.

5.2 Impressed Current Cathodic Protection (ICCP) Systems

ICCP systems use a DC power supply to apply current to a metallic structure via an inert anode.

Current flows from the positive terminal of the power supply to the anode, the current then flows through the electrolyte (soil or water) and makes its way to defects in the coating of the structure intended for protection. A cable connection is installed between the structure and the negative terminal of the power supply; this completes the circuit.

The main difference between an SACP system and an ICCP system, is that the SACP system relies on the difference in potential between the galvanic anode and the structure, whereas the ICCP system uses an external DC power source to drive the current.

The primary advantage of ICCP systems over SACP systems is the increased capacity available, and the ability to vary and control the current output, and resultant structure potential. The ability to easily vary structure potentials, and make adjustments after system installation, gives the designer and operators of an ICCP system additional flexibility to compensate for changing environmental conditions throughout whole of asset lifecycle.

The external power source is typically either a transformer rectifier unit (TRU) that converts incoming AC power to the required DC output, or a solar powered system known as a Cathodic Protection Unit (CPU) that provides DC power without the requirement to use a transformer rectifier. The TRU/CPU can be adjusted, so that a suitable output can be maintained over the life of the CP system.

ICCP system anodes are typically constructed using Mixed Metal Oxide (MMO) coated titanium wire or tube.

TRU/CPU type, and panel layout shall be similar to that specified in Drawing No. LL33-054-011. Power supplies that are only serviceable by the vendor are not acceptable.

There shall be sufficient space within the TRU/CPU enclosure to physically locate a data logging device*[See Note Below] for remote monitoring of DC output voltage and current, and structure potential. These three sets of outputs shall be wired onto DIN mounted terminal blocks located on the same DIN rails for the DC outputs for ease of installation of the remote monitoring unit.

**Note – Data logging devices are currently under review to determine the specified product going forward to replace the currently installed and specified 3G Cyplex units.*

Once a suitable device is selected and approved, following an assessment of performance, durability, and data security by the CP Principal, both this document and the Strategic Product Register will be updated to reflect the chosen device for all existing and proposed CP systems.

The TRU/CPU shall incorporate a built in GPS current interrupter for synchronised "CP On/Instant Off" potential testing. Factors affecting the design of ICCP system are summarised in Figure 2.

Factors To Be Considered for Selection Of Impressed Current System

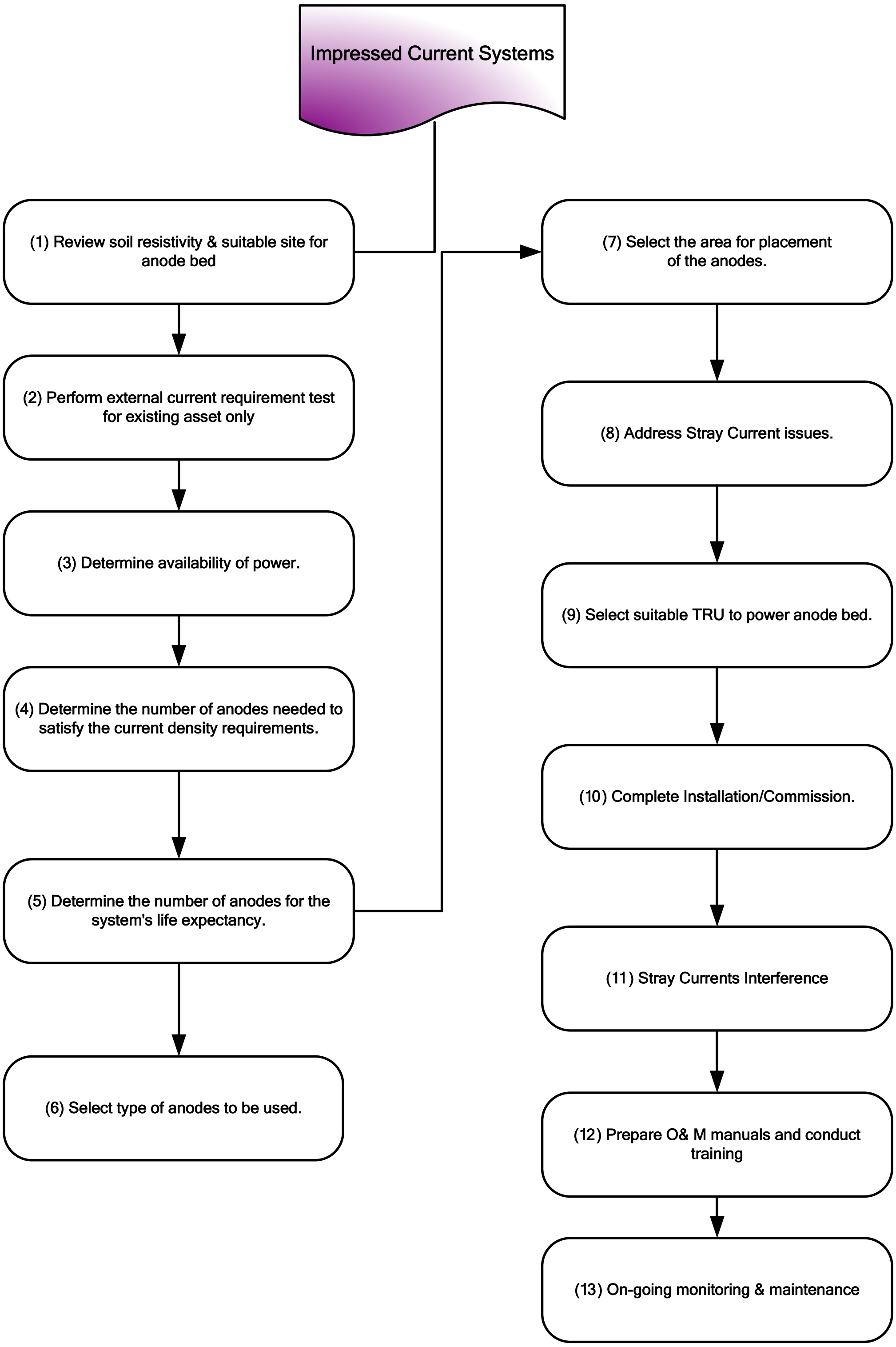


Figure 2 – Factors Affecting the Design of ICCP Systems.

Safety Issues:

Warning notices advising of the danger of electrical gradients near anodes, and the need to switch off the system prior to diving works shall be prominently displayed at all entry points to the water body. The system must be turned off and properly isolated and tagged, prior to the commencement of any underwater diving inspection or maintenance activities.

Signs shall be displayed indicating the presence of any immersed cables or anode supports which are not physically protected.

The contractor should be thoroughly familiar with the specifications for the works, and shall ensure that all works are completed in accordance with good engineering practice and the relevant specifications. Departures from design specifications shall be approved by the Durability Section only and shall be permanently recorded for future reference.

Installation of all electrical work is required to be carried out in accordance with AS 3000 and AS 3100 as applicable, local electrical regulations, and all other relevant Standards.

It is necessary that precautions be taken in combustible atmospheres to prevent sparking due to potential differences between protected and unprotected structures (Refer: AS 2430.1). The CP system shall be switched off (isolated and tagged) and insulated joints cross-bonded before being separated.

Effects of lightning, both on the protected structure and via the electricity distribution system (personnel protection aspects are specifically covered in AS 1768).

Effects of induced voltages and fault currents on the protected structure as defined in AS4853.

In addition, the following hazards shall be considered:

The effects of electric sparks on structures containing products which are flammable or capable of forming explosive air/gas mixtures (Refer: AS 1076.1 and AS 2430.1). It is also necessary, in such circumstances, to ensure control of static electricity; this may conflict with the insulating joint requirements of the CP system (Refer: AS 1020).

NOTES:

The extent of hazardous zones for various types of installation or for items of equipment which are used to handle flammable liquids or gases is defined in AS 2430.1. It is essential that there is no chance of a spark occurring within such a hazardous zone.

Conduit or ducting leading from a CP installation into hazardous areas, e.g. test boxes and TRU/CPU enclosures, shall be sealed to prevent the flow of flammable substances.

Where electrical continuity is required for any other purpose, DC electrical isolation of the CP system is to be achieved by the use of appropriately rated isolation or DC decoupling devices. These devices are subject to approval by local electrical supply authorities and may be used to link the electricity supply earthing system to cathodically protected plant without affecting CP potentials or the level of personnel safety.

Electrical gradients occur in water around fully and partially submerged anodes and in waterways adjacent to anodes, due to ICCP systems.

Paralysis and respiratory failure may result if a person's body extremities come into contact with electric field strengths greater than 3V/m in water (Refer AS 3859).

Should the design result in the electric field strength exceeding this value in areas of saline and non-saline waters frequently located close to ICCP anodes, warnings shall be given and access to such areas prevented by shielding or by other means.

FACTORS TO BE CONSIDERED FOR SELECTION OF IMPRESSED CURRENT SYSTEM

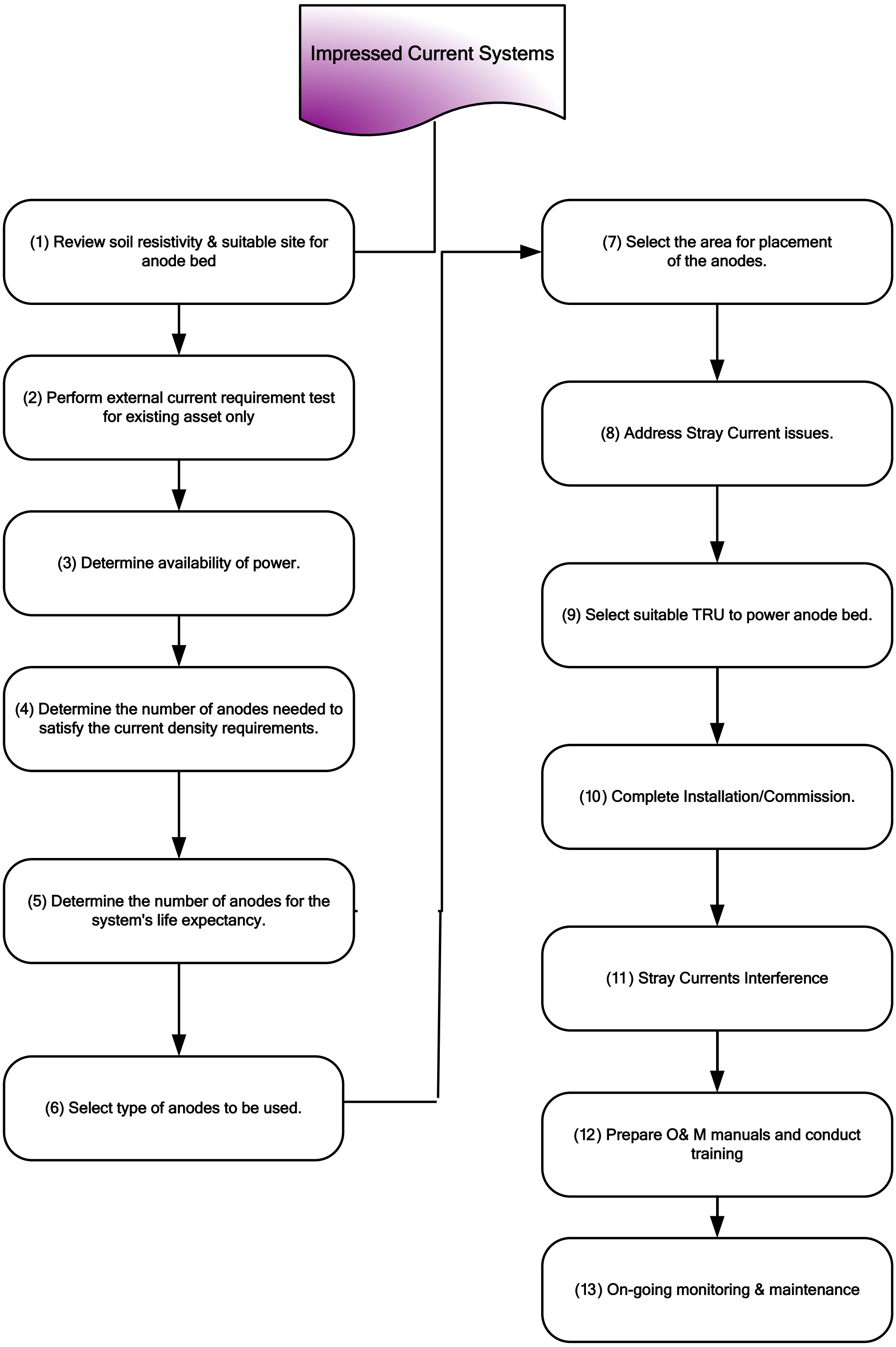


Figure 2 – Factors Affecting the Design of Impressed Current Systems.

5.3 Advantages and Disadvantages

Table 1 – Advantages and Disadvantages of Various Types of CP System

	Impressed Current CP System	Sacrificial Anode CP System
Advantages	Longer anode life, current can be controlled.	Inherently simple in design.
	Significantly larger structures can be protected. Suitable for high resistivity electrolytes.	External power not required.
	Delivery of anode current is independent of surrounding environment.	Minimum interference to foreign structures.
Disadvantages	External power is required. Possible interference to foreign structures.	Only shorter pipe sections and smaller areas can be protected. Shorter anode life. Anode current delivery is dependent on anode chemistry and surrounding environment.
	OSH issues in submerged environments.	Not suitable for high resistivity areas. Not suitable for high current demand. High recurring anode replacement cost in remote areas or in areas where safety and environmental access may be an issue.

6 SELECTING THE APPROPRIATE SYSTEM

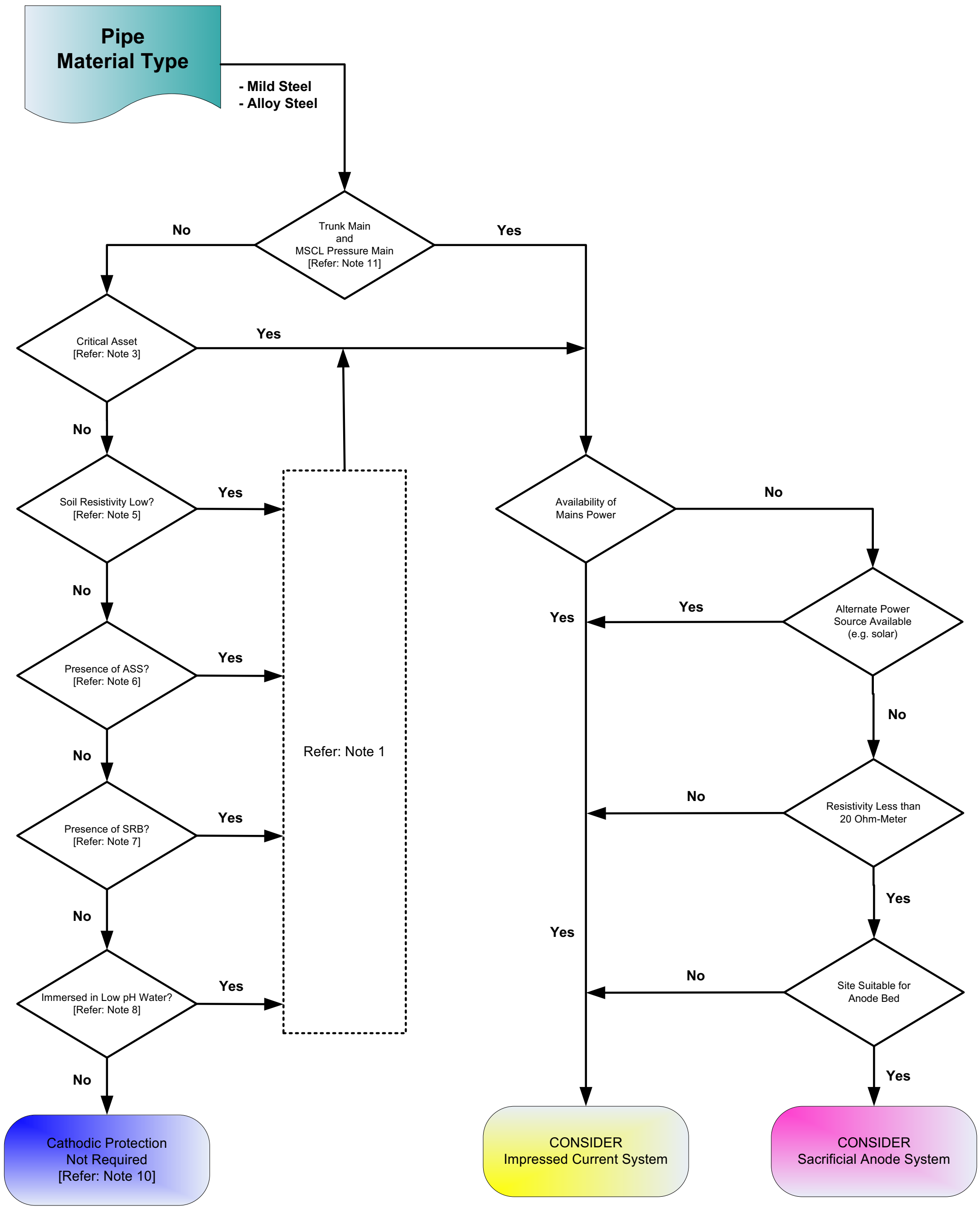
6.1 Guidelines for Selection of CP

The selection of CP system depends on a number of factors including a site investigation to provide information on the location of all structures (above and below ground), and geographical features in the vicinity of the structure to be protected, and land ownership (for statutory requirements). A summary of the key CP selection criterion for buried pipework is shown in Figure 3.

The following additional factors shall be considered prior to installing a CP system:

a) Structure age
b) Structure Construction Type, e.g. RRJ; Welded Joint, Weld Restraint
c) As constructed drawings and information (for identifying adjacent structures)
d) Materials of construction, e.g. MSCL etc.
e) Dimensions of intended protection scope
f) Any external electric influences, e.g. stray currents, and geomagnetic currents
g) Effectiveness of the protective system
h) Composition and level of the groundwater
i) Type and thickness of protective coatings
j) Type of backfill
k) Soil electrolyte conditions, e,g. pH, resistivity, ASS, SRB
l) History, frequency and location of bursts/failures on existing structures
m) Protective current requirements
n) Availability of power, e.g. Mains, Solar, etc.
o) Electrical continuity of the pipeline
p) Interaction with other installation, e.g. foreign structures, high voltage powerlines etc.
q) Installation and maintenance costs
r) Anode bed locations, which will have significant effects on the decision process
s) Decoupling of earthing and isolation from earthing systems
t) Electrical isolation of all offtakes and copper services
u) Encumbrances, e.g. heritage, aboriginal sites, Swan River Trust etc.
v) Proximity to High Voltage AC Power lines (induced fault currents)
w) Voltage mitigation requirements

CATHODIC PROTECTION SELECTION CRITERIA FOR BURIED PIPEWORK



Notes:

1) Where criteria for CP requirement is not uniform throughout the entire length of the pipe, consideration should be made to only protect sections of pipe meeting the CP installation requirements if the required section(s) can be effectively and economically isolated electrically.
2) For Sintakote, MSCL Rubber Ring Jointed pipe, a decision to use CP will require joints to be electrically bonded for sections with common attributes.
3) Refer to asset owner for asset criticality.
4) Refer to list of additional factors in Section 3, that may have to be taken into consideration.
5) If the soil resistivity is < 50 ohm-m, then CP should be considered.
6) If the ASS level is > 150 ppm, then CP should be considered. ASS tests should be carried out in accordance with Water Corporation Environmental Branch, Acid Sulphate Soil Management Plan document No. TBA.
7) Based on the testing carried by SaniCheck SRB test kits. Refer to Appendix F for testing procedure.
8) If the pH < 5.5 i.e. acidic then CP should be considered.
9) Stainless Steel or copper pipes and fittings must be insulated from MSCL, Ductile or Cast Iron pipework. Cathodic Protection are generally only applied to Mild Steel pipes.
10) Consider possible effects of stray current interference from other CP systems (e.g. gas mains)
11) CP system to be applied to MSCL pressure mains in “sensitive and highly sensitive areas’. Examples of ‘Sensitive areas” are permanent creeks, rivers and lakes. Example of “Highly sensitive areas” are Dry season pools in seasonal (intermittent) creeks, rivers and wetlands.

Figure 3 – CP Selection Criteria for Buried Pipework

6.2 Buried Structures

6.2.1 Pipelines

For pipelines, it is generally more economical to install SACP systems in the following circumstances:

- Short buried sections
- Protective coating in good condition
- No access to external power
- Suitably low soil resistivity soil for the installation of anodes

For longer, and larger diameter pipelines it is generally more economical to install an ICCP system. Existing pipelines with poor or deteriorated coatings require a substantial amount of CP current to ensure adequate protection; wherever possible known substantial coating defects should be excavated and repaired to minimise current demand and reduce the possibility of third-party interference. An ICCP system is very efficient, provided it is installed in a suitable environment; good soil conductivity locations are to be sought for anode groundbed locations, to keep the anode groundbed loop resistances to a minimum, Even though an ICCP system can be installed with a DC driving voltage of up to 50V, it is desirable to keep the CP system outputs to as low as reasonably practicable. Anode groundbed locations and the proximity to foreign structures are necessary considerations when designing an ICCP system.

Where approvals for regular excavations could be problematic, or the works impact the public unnecessarily due to being in a residential location, or recurring replacement of sacrificial anodes is prohibitive due to labour costs, consideration should be given to the use of small dedicated solar powered ICCP systems, even for short, buried pipeline sections.

6.2.2 Other Structures

- Road crossing casings and steel reinforcement
- Ocean Outfall Pipelines
- Buried /bypass valves
- Tank floor plates (external)
- Pipe supports and trestle legs

6.3 Immersed Structures

6.3.1 Water Storage Tanks

The internal submerged surfaces of steel water storage tanks that are welded and painted, shall be protected with suitably sized ICCP systems only for the following reasons:

- The taste of potable water in storage tanks can be affected by the excessive use of sacrificial anodes, additionally contamination can occur from the anode waste products.
- The anodes used in an ICCP system have no detrimental effect on the water quality, and may even provide an additional benefit to the water supply from the chlorine formed at the anode surface.

6.3.2 Other Structures

- Piles or caissons
- Pressure vessels
- Structural steel and pipework within concrete tanks and clarifiers
- Vacuum tanks

7 EXTENT OF PROTECTION

7.1 Overview

For pipeline CP systems on newly installed pipelines, or renewed sections, the extent of protection shall typically be the two extremities of the constructed pipeline scope of work. Both ends are to be electrically isolated from existing pipelines at either end, via isolating joints or by self-isolating into non-conductive pipeline construction material. All metallic offtakes are to be electrically isolated from the pipeline.

Electrically operated equipment within the pipeline scope of work (EBVs, MFMs etc.) are to be isolated either side with an electrical continuity bond cable installed across the equipment.

The pipeline section intended for protection shall be electrically continuous, including the installation of electrical continuity bond cables across well coated valves.

Where the pipeline terminates at an installation where there is an extensive earthing system, such as pump stations, storage complexes, etc., the extent of protection shall be up to the last length of pipe at the farthest isolation valve away from the extensive earthing system. This is to ensure improved reliability of the CP system from future accidental bonding to earth which will compromise the CP system.

For CP systems installed for the dedicated protection of storage tank underground pipework, effective isolating joints must be installed, and isolation verified, at all pipeline connection points. All pipework shall be electrically bonded and protected with the one CP system.

Where the extent of protection is exclusively at road and river crossings, the pipeline shall be completely electrically isolated at both ends of each crossing prior to CP being installed.

For storage tanks, only steel tanks larger than 200m3 shall be protected. Steel tanks with waterproof liners shall not be protected as the steel is not in contact with the electrolyte. Steel pipework in concrete tanks shall only be protected after proper assessment to determine its benefits.

8 GROUND BED SELECTION

8.1 Overview

The following are some factors affecting the selection of ground beds, for further details refer to **Appendix A**.

In selecting the ground bed sites, the most important consideration from a design standpoint is determination of effective soil resistivity. The soil resistivity measurement techniques and interpretation of results are discussed in Appendix A 14.2.1. However, other points must be considered when selecting a site. Occasionally these considerations will exclude locations where soil resistivity measurements otherwise indicate a highly desirable construction site.

The following points shall be considered in the design of a ground bed:

1. Are there any other underground third-party metallic structures within the area of anodic influence surrounding the groundbed? If so, current from the anode groundbed may create a stray current interference problem that will require corrective measures if the site is used. Calculations of minimum separation distances shall be performed.
2. Is there adequate anode to protected pipeline separation distance.
3. Are there any significant anodic or cathodic field effects.
4. Power availability in the area if 240V is required, or enough real estate to install solar panels if needed.
5. Is the site reasonably accessible for construction and maintenance purposes?
6. Are there any known plans for building construction (new pipelines, highway development or other similar work) that will make the site untenable in the future?
7. Are there any environmental issues that make the site unattractive?
8. Are there any Aboriginal heritage or native title issues that may hinder/delay installation?

8.2 Sacrificial Ground Beds

In most cases, locations for sacrificial anode ground beds are easier to select than those for ICCP systems, because they do not require external power and are generally relatively free of interference with foreign underground structures.

8.3 Impressed Current Ground Beds

Deep well anode groundbeds can be described as one in which the anodes are located reasonably adjacent to the protected pipeline at a significant depth, dependent upon the most suitable soil resistivity layers. They are installed using a drill rig and can be drilled to depths of 50m and beyond.

Deep well anode groundbeds are effective in areas where soil resistivity is high, or where obtaining suitable separation distances, or when the size of available easements may be an issue. Deep well anode groundbeds generally reduce the risk of anodic affects to adjacent structures. Refer to Appendix A for typical ICCP anode groundbed design details.

8.3.1 Anode Groundbed Drilling

8.3.1.1 General

The following requirements shall be adhered to during anode groundbed drilling activities:

- The anode borehole shall be drilled using reverse circulation (RC) techniques to the minimum required depth.
- A surface casing shall be grouted in to facilitate drilling of the main hole.
- The hole shall be logged at 2m intervals, or at major changes in strata type.
- Logging shall include completion of the 'Geological Survey of Western Australia Particulars of Completed Borehole' form.
- The Contractor shall be responsible for the supply of all water and consumables necessary to complete the drilling works.
- The Contractor shall have available, or access to, equipment and materials to grout subsurface strata as necessary, to prevent contamination of different water strata.
- The Contractor shall be responsible for provision of access security around the borehole during non-working hours to prevent vandalism and debris from entering the hole.
- The Contractor shall provide suitable capacity open top tank(s) for containment and separation of drilling mud and cuttings. The use of temporary on-site pits is not permitted.

8.3.1.2 Aquifer Sealing

- The Contractor shall be responsible for ensuring aquifers intersected during drilling are sealed to minimise flow to the surface, or between aquifers.
- The Contractor shall verify with Water Corporation the approximate depth intervals of aquifers and obtain approval for the proposed aquifer sealing technique before proceeding.
- The Contractor shall advise the drilling sub-contractor of the agreed aquifer sealing technique prior to commencement of the works.
- Sealing shall be affected using a conventional drilling bentonite slurry (wall cake) in the following two (2) zones:
  - **Zone 1** - Natural ground surface to bottom of PVC surface casing.

    The annulus space between the PVC surface casing and borehole shall be left filled with a bentonite slurry either from the drilling process or pumped in separately.
  - **Zone 2** - Active Anode Interval (conductive carbon column)

    The installation methodology shall ensure that a bentonite slurry is displaced by the carbon backfill from the bottom to the top of the column interval.

    The bentonite slurry density shall meet the following specification:

    30 – 40kg Bentonite/1000L water + additives depending on actual site drilling conditions.

8.3.1.3 Anode/Backfill

The Contractor shall liaise with the calcined coke backfill supplier on the recommended procedure for the anode/backfill installation.

Key issues to be considered include:

- Fluidisation ratios
- Intake/delivery pump rate(s) and pressure(s)
- Wetting agents
- Backfill volume and loss determinations

The vent and backfill delivery pipe/s shall be installed the full depth of the borehole.

These pipe/s can be used to facilitate the installation of the anode assemblies.

Under no circumstances shall the anode cable be used to support the vent or fill pipe; the cable shall remain un-tensioned during the entire installation process and the 24-hour settling period.

24 hours after completion of backfilling, the Contractor shall check the borehole and top up as necessary to ensure the backfill level stabilises at the specified RL.

Extreme care must be taken at all times to ensure anode cable insulation material and electrodes are not damaged during the handling or installation process.

Construction plastic sheeting shall be laid out and used during anode assembly, to facilitate installation and prevent abrasion.

9 CP PROTECTION CRITERIA (SIZING THE SYSTEM)

9.1 General CP Protection Criteria

In general, all structures generate a natural static potential (i.e. with no CP applied). This potential is used to establish the required protection potential depending on soil type, any galvanic couples or interference caused by others.

The primary objective of the CP process is to ensure that the correct level of current flows onto the structure to be protected. Determination of the current required dictates the number and design of TRUs/CPUs needed, and the design and layout of the anode groundbeds.

The total current required is dependent upon the environment of the installation, the total area of exposed metal/quality of coating, the relative position of various metals in the Galvanic Series of Metals table, and structure geometry.

The best way to accurately determine the CP current requirement for an existing structure is to measure it in the field. An indication of the current required can be obtained by undertaking a current drain test in accordance with AS 2832.1 Appendix G2.3.d.

The criteria for the protection of a buried ferrous structure is to maintain an "Instant Off" potential on all parts of the structure equal to, or more negative than -850 mV wrt a $Cu/CuSO_4$ reference electrode. More negative potentials will be required to counteract the effects of Sulphur Reducing Bacteria (SRB).

A 100mV negative shift from a pipeline depolarised potential can also be used as a criterion for protection where it is assured there are no galvanic couples present.

In some areas where the above criteria may not be feasible because of adjacent structures, a level of protection can be achieved using a soil corrosion probe as a measure of the level of corrosion mitigation being achieved.

Consideration must also be given to the additional CP current requirements where electrical isolation from offtakes, and other equipment is not feasible.

Isolation of the pipeline from electrical earth must be achieved for the CP system to be able to provide effective protection levels.

9.2 Effects of Overprotection

Overprotection may cause accelerated disbondment of pipeline coatings and have other negative effects including hydrogen embrittlement.

For ferrous, lead, copper and copper-alloy structures, the overprotection potential threshold is equal to or more negative than -1.2 V "Instant Off" wrt a $Cu/CuSO_4$ reference electrode.

10 SELECTION OF ANODES – REFER APPENDIX A

10.1 Overview

There are significant differences between the types and expected life of anodes used in sacrificial anode and ICCP systems.

Refer to **Appendix A** for further information on the different types of anodes.

11 REFERENCE CELL

11.1 Overview

A reference cell can be defined as an electrode immersed in a stable electrolyte, designed for measurement of structure potentials. A pure metal in contact with a solution of known concentration of its own ion, at a specific temperature develops a potential which is characteristic and reproducible. When coupled with another half-cell, an overall potential develops which is the sum of both half-cells.

Reference cells are a vital part of corrosion monitoring systems. Reference cell testing estimates the electrical half-cell potential of the structure for the purpose of determining the potential of corrosion activity at the time of testing.

Depending upon the environment, two main types of reference cells are used for corrosion measurements including:

- Copper/Copper Sulphate [$Cu/CuSO_4$]
- Silver-Silver Chloride [Ag/AgCl]

A Cu/CuSO4 reference electrode is most commonly used for the measurement of pipeline potentials in soil and in freshwater environments, Ag/AgCl is only accurate when used in a saline environment. Zinc reference electrodes were previously used and are still occasionally found in Water Corporation CP installations however they are no longer installed in new systems and are less commonly seen as time progresses.

Refer **Appendix B** for further information on Reference Cells.

12 INSULATED FLANGE JOINTS

12.1 Overview

Insulated flange (IF) joints, where required for dissimilar metal interfaces, electrical isolation of CP systems and isolation of electrical equipment such as EBVs and instrumentation (MFMs) shall comply with the requirements of Design Standard DS38-2. All IF joints installed shall be provided with surge protection devices to prevent damage to the flange during lightning activity or fault conditions, and for personnel safety as per DS21 Section 11.6.2, unless it is across a bypass pipeline (where the surge protection device has already been provided across the IF joint on the main pipeline). Surge protection devices used are to comply with DS21 Section 11.8; additionally, IF joints shall be provided with test facilities in accordance with drawing LL33-054-004 to facilitate for IF joint integrity testing.

IF joints shall be adequately wrapped in accordance with drawing JZ39-91-10 to ensure no water ingress which may compromise the IF integrity.

13 ELECTRICAL CONTINUITY

13.1 Overview

For a CP system to operate, the asset within the scope of protection must be electrically continuous. This can be achieved by welding, or tack welding or via electrical bonding straps for rubber ring jointed pipes.

13.2 Methods

For all metallic non welded pipes, electrical continuity shall be via CP continuity cables in accordance with Water Corporation Standard Drawings LL33-054-041 or preferably LL33-054-042 following installation procedure IP-CBC5128001.

Quality control documentation shall be kept during installation of all continuity bonds, including bond cable serial number data corresponding with the pipeline chainage of the bond location, and the person installing the bond. The quality control documentation is to be forwarded to the Superintendent weekly for review and an electronic copy of this document shall form part of the commissioning documentation. The Superintendent will forward a copy of the continuity bonds quality control documentation to the Durability Team periodically during construction.

14 SLEEVED/CASED CROSSINGS

14.1 Overview

Where metallic sleeves or stainless-steel overwrap is used to protect the carrier pipe, care should be taken to ensure that they are not in direct electrical contact with the carrier pipe. Non-metallic spacers **ONLY** should be used to separate the metallic sleeve from the carrier pipe. A CP TP should be installed for every metallic sleeve installed to provide the ability to check that the metallic sleeve is electrically isolated from the carrier pipe as per drawing LL33-054-006.

NOTE: Design of any CP system using DS 91 should be read in conjunction with DS 60 - Water Supply Distribution Standard Pipelines Other Than Reticulation, to satisfy both CP and sleeved crossing requirements.

15 CP MONITORING FACILITIES

15.1 Overview

All CP system designs shall incorporate monitoring facilities to provide a continual assessment of the condition of the asset. Adequate monitoring and testing to ensure that the required level of protection is provided forms an integral part of the CP system process. TPs shall be constructed as per Water Corporation Standard Drawings LL33-054-001 and LL33-054-002.

Monitoring methods, testing programs and CP adjustment procedures will be provided to the Asset Manager as part of Operations and Maintenance Manual (O&M) when the CP system is commissioned.

In accordance with Australian Standards and good engineering practice, the following summarises the testing regime that should be followed:

- ICCP systems – 52W detailed technical CP system survey
- SACP systems – 2Y detailed technical CP system survey

Additionally, ICCP system power supplies should be checked for operability a minimum of four weekly; in circumstances where remote monitoring is reliably installed, the requirement for manual checks is eliminated.

15.2 Potential Monitoring Test Points

Potential monitoring (PM) TPs are required for measurement of structure potentials and determining the level of protection being achieved as per drawing LL33-054-003. The spacing of PM TPs shall be based on AS 2832.1 Section 4.5.2, typically every 500m for suburban and built-up areas and every 2000m for semi-rural areas. Future land zoning and development should be considered when selecting appropriate TP spacing.

15.3 Insulating Flange Test Points

Insulating flange (IF) TPs as per drawing LL33-054-004 are required to be installed across every IF to enable testing of the integrity of the electrical isolation. In addition, all IFs require a solid state DC decoupler installed across the flange for protection of the IF, and electrical safety of personnel, unless the IF is across a by-pass line and a solid state DC decoupler has already been installed within the main pipeline.

15.4 Foreign Structure Test Points

Foreign structure (FS) TPs as per drawing LL33-054-005 are required across every foreign pipeline crossing, including in some cases, different Water Corporation metallic pipelines. These TPs are required for interference testing and possible interference bonding to negate any interference affects identified. Where foreign pipelines run parallel and in close proximity to Water Corporation metallic pipelines and may cause interference, IF TPs installed at 500m spacings are required.

15.5 Cased Crossing Test Points

Cased crossing TPs are needed for metallic pipes installed in metallic casings, They are required to facilitate testing to confirm that the metallic casing remains electrically isolated from the metallic pipes., Cased crossing TPs as per drawing LL33-054-006 are required at one end of each cased crossing; where the cased crossing is over 100m in length, a cased crossing TP at each end of the cased crossing is recommended.

16 STRAY CURRENT INTERFERENCE & AC VOLTAGE MITIGATION

16.1 Overview

Stray current corrosion (interference corrosion) is corrosion caused by current from an external source that travels through paths other than the intended circuit. Accelerated corrosion will result where the current leaves a pipe surface; this may result in catastrophic failure of either the foreign structure, or the Water Corporation pipeline at the point where the stray current exits into the soil. Stray currents can be caused in two ways, either by direct connection or through a soil gradient.

The corrosion resulting from stray currents (external sources) is similar to that from galvanic cells (which generate their own current) but different remedial measures may be required. Soil and water characteristics affect the corrosion rate in the same manner as galvanic corrosion.

16.2 Detection of Interference Levels

A quantitative assessment of the probable damage caused by interference currents is complicated because the extent of current discharge from a foreign structure, and the surface area from which it emits are often not known.

Interference is normally evaluated by measuring the change of potential of the foreign structure, while the offending CP system TRU/CPU has the output interrupted.

Interference level limits are generally 20mV in the positive direction and 200mV in the negative; this is covered in more detail in Section 8.3.3.3 of AS 2832.1.

16.3 Stray Current - Mitigation

16.3.1 Control by Sacrificial Anodes

Interference may be controlled by installing sacrificial anodes on the foreign structure, to return the potential to at least as electronegative as that which existed prior to the interference.

16.3.2 Control by Bonding

Interference may be controlled by bonding the foreign structure to the primary structure, or by connecting the foreign structure directly into the ICCP system.

Further details on minimisation of stray current effects on underground structures are described in Section 8.3.2, AS 2832.1, Cathodic Protection of Metals, Part 1: Pipes and Cables.

16.4 Alternating Current Effects from High Voltage Electrical Powerlines - Overview

Modern pipelines are usually coated with high quality anti-corrosion coatings, that have highly effective electrically insulating properties. Pipelines are often laid in roadway easements that also have high voltage electricity distribution lines installed in parallel either alongside underground or overhead.

The overall result is that pipelines are now much more prone to being subjected to electrical effects resulting from the presence of powerlines. Significant voltage may be induced under normal steady-state powerline operating conditions, and more substantial effects may occur during fault conditions, when surges of very high currents could flow.

Electrical fault conditions may occur at frequencies ranging from less than once, up to several times per year, depending on factors such as location and powerline construction. They may cause electric shock to personnel working on pipelines adjacent to the powerlines and may present a number of possible hazards to the pipelines, as follows:

- Damage to electrical insulation in devices such as monolithic isolation joints, isolating flanges, and isolating couplings and unions.
- Damage to or puncture of protective coatings.
- Damage to electrical and electronic equipment.
- Electrical arcing which can fuse the pipeline steel.

16.5 AC Voltage Currents - Mitigation

Mitigative measures employed to control or minimise the effects of powerlines include:

(a) Earthing decoupling devices such as DC surge diverters, coupled with:

- Electrical earthing in the form of discrete electrodes, earthing beds or lengths of earthing cable or ribbon.
- Earth safety mats or grids to limit step touch potentials adjacent to accessible points on the structure.

(b) Measures that restrict access to direct contact with the structure or its appurtenances.

The protective measures employed need to be appropriate to the specific circumstances and the level of exposure. Although most electrical hazards arise under powerline fault conditions, effects that can cause risk to integrity of structures or safety of personnel may also occur during normal powerline operation. Further information on requirements for electrical safety on pipelines subject to power system influences may be found in AS 4853, Electrical Hazards on Metallic Pipelines, and Water Corporation Design Standard DS 23, Pipeline AC Interference & Substation Earthing.

NOTE: Design of any CP system using DS 91 should be read in conjunction with DS 23, Pipeline AC Interference & Substation Earthing and DS 21, Major Pump Station – Electrical, to satisfy both CP and VM requirements.

16.5.1 Surge Protection

Many buried pipelines are protected from corrosion by CP systems. To maintain the insulation integrity of the pipe at metering and telemetry stations, insulating joints are inserted into the pipe, and those sections between insulating joints are grounded at the station.

With long lengths of pipelines, induced voltages in the pipe caused by local lightning or power line faults activities can be in the order of tens of kilovolts. The result is that IF failure is almost inevitable, with flange type insulated joints particularly susceptible.

To protect against insulated joint break-down, surge diverters are normally connected directly across joints. The type of surge diverters must be approved by the Water Corporation, Electrical Section of Engineering.

When the insulated joint voltage starts to rise due to transients, the DC surge diverters will conduct and safely pass the transient current to ground; this limits the voltage stress across the joint. After conduction the surge diverter automatically resets to its inactive (DC open circuit) state.

17 REFERENCES

Principles and Prevention of Corrosion, D.A. Jones, MacMillan Publication, USA.

Cathodic Protection, PLE Corrosion Protection Pty Limited, Victoria, Australia.

Cathodic Protection, Part 1. Code of practice for land and marine applications, BS 7361.

AS 2239, Sacrificial (Galvanic) anodes for Cathodic Protection.

AS 2832.1, Cathodic protection of metals, Part 1: Pipes and Cables.

Control of Pipeline Corrosion, A.W. Peabody, NACE Corrosion Association, Houston, Texas, USA.

Marshall E. Parker & Edward G. Peattie, Pipeline Corrosion and Cathodic Protection, NACE Publication.

Cathodic Protection – An Introduction, NACE Publication, 1987.

MC Miller - How to use and maintain $Cu/CuSO_4$ Reference Electrodes datasheet.

AS/NZS 3000 Wiring Rules - Electrical Installations (Australian/New Zealand).

AS 3008, Electrical Installations – Selection of Cables.

AS/NZS 1768 Lightning Protection

AS/NZS 3859 Effects of current passing through the human body

Guide for Measurement of Interference Caused by Cathodic Protection and Railway Drainage Systems, NSW Electrolysis Committee, NSW Department of Energy, PO Box 536 St Leonards, 2065, October 1998.

CP Handbook for Technicians, Adelaide Electrolysis Investigating Committee.

AS 4853, Electrical Hazards on Metallic Pipelines.

DS 21, Water Corporation Design Standard, Major Pump Station – Electrical.

DS 23, Water Corporation Design Standard, Pipeline AC Interference & Substation Earthing.

DS 38-2, Water Corporation Design Standard, Flange Connections.

DS 38-3, Water Corporation Design Standard, Flange Bolting.

DS 60, Water Corporation Design Standard, Water Supply Distribution Standard Pipelines Other Than Reticulation.

18 APPENDIX–A: DESIGN OF CP SYSTEMS

18.1 Qualification of Designers

CP systems must be designed by a suitably qualified professional. The "corrosion expert" responsible for design of the system must have a minimum of five years' experience in the design of CP systems and the design experience must be type specific. For instance, a CP engineer who only has experience designing water tank CP systems shall not design a CP system for pipelines.

18.2 Factors Affecting Design

18.2.1 Soil and/or Water Resistivity

Resistivity is used to determine the aggressiveness of the medium in which the structure will be installed; this helps to determine the CP system type, either ICCP or SACP. Resistivity is one of the most important factors in selecting anode groundbed locations. The number of anodes required, the length and diameter of the backfill column, the voltage rating of the rectifier and power costs are all influenced by soil resistivity. In general, the lowest and most uniform soil resistivity location with respect to depth should be utilised for a deep well anode groundbed site. Consideration should be given to perched water tables that affect corrosivity assessments due to varying seasonal cycles. Numerous methods are available for determining resistivity, depending on the type of instrument used these include:

- Wenner four pin method
- Soil box method
- Soil conductivity method

Reference shall be made to instrument supplier instruction booklets for calibration and operation of the instruments used. Table 3 provides guidelines for the soil resistivity which is classified as follows:

Table 3 – Interpretation of Soil Resistivity and Corrosion Classification Assessment [Ref: BS 7361 - 1:1991]

Resistivity (Ohm-m)	Classification
0-10	Severely corrosive
10-50	Corrosive
50-100	Moderately corrosive
100 and above	Slightly corrosive

18.2.2 pH, Chlorides and Sulphates

The major constituents that accelerate soil corrosion are the presence of chlorides and sulphates, and the pH (acidity) of the soil. The degree of corrosivity due to chlorides, sulphates and pH is shown in Table 4. As a general rule, if the concentration of chlorides are > 500 ppm, sulphates > 150 ppm, or a pH of <5.5, then CP should be considered.

Table 4 - Effect of Chlorides, Sulphates, and pH on the Corrosion of Buried Steel Pipelines

Component/Concentration (ppm)	Corrosivity Assessment	Comments
Chloride		
>5,000	Severe	Chloride concentration is automatically considered when taking the resistivity measurements
1,500–5,000	Considerable	
500–1,500	Corrosive	
<500	Threshold	
Sulphate		
>10,000	Severe	
1,500–10,000	Considerable	
150–1,500	Positive	
0–150	Negligible	
pH		
<5.5	Severe	Considered critical in determining CP installation requirements.
5.5–6.5	Moderate	
6.5–7.5	Neutral	
>7.5	None (alkaline)	

Note:

- Bicarbonates are not typically detrimental to buried metallic structures. However, high concentrations of bicarbonates found in soils/groundwater tend to lower the resistivity without the resulting increase in corrosion activity. Soil samples should be taken at the depth of the pipeline in areas where soil resistivity data may indicate corrosive conditions.
- If soil samples are not measured "on location" but are collected for later measurement, they shall be kept in air-tight containers to preserve the normal moisture content. In some instances, abnormally dry surface soils may be moistened with distilled water to measure their resistivity under wet conditions.

18.2.3 Sulphate Reducing Bacteria - SRB

If the measured SRB level is $\geq 10^3$, then SRB is viewed as a significantly increased risk to the probability of corrosion, and CP should be considered for mitigation.

Table 5 – The Probability of Corrosion due to SRB

Sulphate Reducers/ml	Interpretation
10^5 (100,000) or more/ml	Heavy
10^3-10^4 (1,000 - 10,000)/ml	Moderate
10^2-10^3 (100 - 1,000)/ml	Low
10^1-10^2 (10 - 100)/ml	Very Low
10^1(10) or less/ml	Generally Insignificant

18.2.4 Current Requirement

If field testing is not practical, then current requirements can be estimated from the following Table 6:

Table 6 – Typical Current Density (CD) Requirements for the Protection of Bare Steel Immersed in Various Environments

Environment	Resistivity Ω.m	Initial CD mA/m^2	Mean CD mA/m^2	Final CD mA/m^2
Fresh water (potable)	>20	≥50 ≤80	≥50 ≤80	≥50 ≤80
Brackish water	≥0.3 ≤20	≥80 ≤120	≥80 ≤120	≥80 ≤120
Brackish water and sewage	0.5-20	50-100	20-100	20-100
Seawater	<0.3	120	90	90
Seabed mud	----	20	20	20

NOTE: These values may need to be increased for structures immersed in environments warmer than 25°C, and they should be reduced if the structure is coated.

Approximate CP current requirements can also be determined according to the formula:

$$I = \left[\frac{10^4}{\rho}\right]^{0.3} \times 10.76$$

where

I = current density in mA/m^2

ρ = soil or water resistivity in ohm-cm

The major difference between SACP and ICCP systems is the driving voltage attainable and therefore the current output. A SACP system has a driving voltage which is limited by the Electro Motive Force (EMF) of the galvanic cell (e.g. -1.7V for magnesium anodes connected to a steel structure); whereas an impressed current system can achieve any driving voltage required (up to 50 Volts). The effective EMF of the galvanic cell is proportional to several factors in the operating environment including resistivity, pH and temperature. Current requirements for coated structures will increase over time due to coating deterioration and other factors. For safety reasons, the driving voltage shall not exceed 50 V DC.

18.3 Anode Selection – Typical Properties and Uses of Anodes for Cathodic Protection Systems

TYPICAL PROPERTIES AND USES OF ANODES FOR CATHODIC PROTECTION

Description of anode	Typical application	Typical environment resistivity* Ω.m	Typical current density A/m^2	Approximate measured consumption rate kg/a	Relevant Australian Standard
GALVANIC ANODES					
Zinc	All waters and soils	0.2 to 25	Controlled by total circuit resistance	12	AS 2239
Magnesium	All waters and soils	10 to 100†		7	AS 2239
Aluminium	Seawater	0.2 to 1		3.5 to 5	AS 2239
IMPRESSED CURRENT ANODES‡					
Platinized titanium/niobium§	Seawater, sea bed or soils, with calcined petroleum coke when used in soils	0.2 to 2	100 to 1000	10^{-5}	—
Mixed metal oxide§	All waters, sea bed or soils, with calcined petroleum coke when used in soils	0.2 to 10	100 to 600	10^{-6}	
Silicon iron¶	All waters, sea bed or soils, with carbonaceous backfill when used in soils	0.2 to 10	5 to 20	From 0.1 in calcined petroleum coke in soils to 0.5 directly installed in seawater	—
Scrap steel	All waters, sea bed or soils, with or without carbonaceous backfill	10 to 200	0.1 to 1	10	—
Lead/silver alloy	Seawater	0.2 to 0.5	10 to 50	<0.1	—
Graphite with backfill	With carbonaceous backfill	0.5 to 100	10 to 50	—	—
BACKFILL FOR IMPRESSED CURRENT ANODES					
Calcined petroleum coke	Soils	>1			

* Typical environment resistivity is that of the material immediately surrounding the anode. Usage of many materials can be extended into higher resistivity environments by the use of an appropriate backfill. The need for backfill is determined by taking into account the combination of soil resistivity, anode material and current output requirement. Backfill is desirable for high current buried anodes.

† Magnesium alloy anodes are normally buried in gypsum-bentonite backfill.

‡ With the exception of steel, the impressed current anodes listed do not obey Faraday's Law, the dissolution rate being less. However, the consumption rate increases if the stated current densities are exceeded or if the environmental conditions are unsuitable.

§ Platinized titanium and niobium anodes should only be operated at low current densities if installed directly in the sea bed without backfill. Voltages across any bare titanium/electrolyte interface should not exceed 8 V in chloride environments.

¶ The composition of silicon iron typically includes chromium and molybdenum to resist high chloride environments.

Note: The above Table is an extract from AS 2832.1:2015 Cathodic protection of metals, Part 1: Pipes and cables.

18.4 Other Factors to be Considered

18.4.1 Sacrificial Anode Systems

Sacrificial Anodes are normally produced by casting the anode alloy material around a steel core or insert, which is then attached directly or indirectly to the structure requiring protection. Some anodes are produced by extrusion method, with or without a steel core. Cores are prepared prior to casting to ensure maximum electrical contact with the sacrificial anode alloy. The inserts protrude beyond the body of the anode to provide a means of attaching the anode to the structure via welding or bolting.

Sacrificial anodes are often connected to the structure via a TP, this allows for temporary disconnection of the anode which facilitates detailed CP system testing, with the ability to undertake CP “Instant Off” potentials, and to check the health of the anode. The ability to measure and record the anode output current, and anode open circuit potential can then be used to trend the expected anode life.

Sacrificial anodes are infrequently used where the electrolyte resistivity is in excess of 20 Ω.m. Sacrificial anodes have a relatively low driving voltage wrt the protected metallic structure. In high resistivity soils, such low anode driving voltages generally are not able to produce sufficient current output to achieve full protection. Therefore, in high resistivity soils, an ICCP system is more appropriate. For guidance on the installation of sacrificial anodes, refer to AS 2239: 2003 Galvanic (sacrificial) anodes for cathodic protection – Appendix B.

18.4.1.1 Sacrificial Anode Selection

Alloys used for sacrificial anodes are based on magnesium, zinc or aluminium. Certain alloys may produce toxic bi-products and it shall be ascertained whether the particular alloy proposed is permitted under the intended conditions of use. The selection of anodes for a particular application can be a complex process, requiring a thorough knowledge of:

- The environment of the installation
- Anode alloy composition
- Anticipated anode consumption rate
- Anode mass and shape

Table 7 - Typical Properties of Sacrificial Anode Alloys

Anode alloy type	O/C Potential, wrt $Cu/CuSO_4$	Typical anode consumption rate in soil (kg/A. year)
Aluminium	-1.05 to -1.1 V	Not used
Magnesium		
• High potential	-1.7 V	7
• Low potential	-1.5V	7
Zinc	-1.1 V	12

NOTES:

- Magnesium alloys are not suitable for long term protection in saline environments, as they will self-corrode rapidly. The indicated consumption rate for magnesium can be significantly higher for lower soil resistivities.
- Copper sulphate reference electrodes are not recommended for prolonged use in seawater.

18.4.1.2 Typical Masses, Dimensions and Shapes of Sacrificial Anodes

Anodes are normally cast or extruded.

Cast anodes are generally formed in a rectangular prism shape.

Extruded anodes are usually in the form of rod up to 3 meters long containing a mild steel core of 3 to 5mm in diameter. Extruded ribbon style anodes are also produced and are usually a diamond shape.

Typical anode masses and dimensions are shown in AS 2239 2003 Galvanic (sacrificial) anodes for cathodic protection – Appendix B. The selection of anode type and mass depends on various factors. It is highly recommended that designers refer to the manufacturer's data sheet for further details including composition, dimensions, efficiencies, mass etc. of the various types of anodes, to ensure that the system provides the required level of protection without the negative consequences of over protection.

18.4.2 Impressed Current CP Systems

Design of ICCP deep well anode groundbeds should include consideration of the following factors:

- The continuous rating of the DC voltage output
- Maximum anode current density
- Anode design service life
- Backfill material requirements, preferred backfill material is Calcined Petroleum Coke Breeze (Loresco SC,3 or equivalent) for the full length of the active anode column)
- Typical electrolyte resistivity
- Impact and mitigation of expected down hole anodic reaction products, including chlorine, hypochlorous acid and carbon oxides
- Possible development of highly acidic conditions

18.4.2.1 Anode Fabrication

Several anode types can be used as per Table G1, AS 2832.1:2015. Within Water Corporation, Mixed Metal Oxide (MMO) anodes are generally used, where specified they shall comply with the following:

- The anodes shall be MMO coated titanium tubes or wires.
- The tubes are to be manufactured from Grade 1 Titanium per ASTM B338 (or approved equivalent).
- The wires are to be manufactured from Grade 1 Titanium per ASTM B348 (or approved equivalent).
- The coating composition shall be iridium based with a final thickness to suit the manufacturer's proprietary information on consumption rates wrt the rated output.

- The anode assembly shall be constructed in a continuous string configuration; the final number of individual anodes, tube diameter and overall length shall be determined on the basis of the manufacturer's proprietary design information.

18.4.2.2 Anode Cable

Cables shall consist of the following:

- Core shall consist of flexible copper strands.
- The primary insulation of the cable shall be fabricated from proprietary Halar/Kynar (or approved chlorine resistant material).
- The sheath shall be high molecular weight polyethylene (HMWPE) (or approve equivalent)
- The minimum cable cross section shall be 16 mm^2.

18.4.2.3 Anode Backfill

Loresco SC3 calcined carbon backfill (or approved equivalent) shall be used for anode backfill in compliance with the following:

- Resistivity: Max. 10Ω.cm
- Fixed carbon content: Minimum 99%
- Max. Particle size: 1 mm
- Bulk density: Nominal 1185 kg/m^3

The material shall be dust free.

18.4.2.4 Anode Vent Pipe

A vent pipe shall be installed the full length of an anode deep well to facilitate the release of chlorine and other gases produced by the anodes.

- The vent pipe shall be constructed from slotted DN 20 UPVC Class 12 (minimum) pressure pipe.
- The slot shall be 1.2 mm wide nominally, with coverage not exceeding 50% of the pipe circumference. The spacing between slots shall be 10mm nominal.
- The pipe shall be wrapped in geofabric.

18.4.2.5 Anode Casing

The upper borehole casing shall be constructed using 150NB Class 9 (minimum) UPVC pipe (or approved equivalent).

The active anode zone casing, where required, shall be slotted 150NB Class 9 (minimum) UPVC pipe (or approved equivalent).

18.4.2.6 Anode Well Head Arrangement

Refer to Water Corporation standard drawing no. LL33-054-021, Impressed Current Deepwell Anode Groundbed Typical Detail for details of the anode wellhead arrangement.

19 APPENDIX–B: REFERENCE ELECTRODES

19.1 General

Copper/Copper Sulphate ($Cu/CuSO_4$) permanent reference electrodes shall be installed at TRU/CPUs and TPs used for the measurement of structure potentials, for all soil and freshwater installations. Silver/Silver Chloride (Ag/AgCl) reference electrodes shall be used in saline environments.

Permanent reference electrodes installed at TRU/CPU sites shall be checked during the regular annual surveys wrt a calibrated portable reference electrode to ensure their potential has not drifted beyond an acceptable calibration range (+/- 100mV). Prompt replacement of inaccurate reference electrodes is mandatory.

Accurate structure potential measurements can be undertaken with a portable reference electrode placed as close as possible above the protected structure.

19.1.1 Maintenance of $Cu/CuSO_4$ Reference Electrodes

Copper in saturated copper sulphate solution will maintain stable potentials within reasonable limits, under practical field conditions. However, with regular use in different soil conditions, $Cu/CuSO_4$ reference electrodes can become contaminated causing inaccurate potential measurements.

To maintain a stable potential the reference electrode should be regularly serviced and kept in good condition. This is achieved by replacing the saturated copper sulphate solution, cleaning the copper rod with fine grade emery paper, and washing of all components in distilled water. Distilled water shall be used for making the saturated copper sulphate solution, for consistent results, laboratory grade $CuSO_4$ crystals/powder shall be used.

The reference electrode shall be checked for calibration in accordance with AS2832:2015 Appendix K, Figure K1 and Table K1.

19.1.2 Measurement of Structure Potentials

To obtain reliable results when monitoring CP potentials, there must be a conductive path between the reference electrode and the structure. The reference electrode must be placed in intimate contact with the soil above the structure (as close as possible).

Good results in different environments are achieved as follows:

1. Moist sand/soil (electrolyte)- ensures intimate contact between the reference electrode and the electrolyte medium.
2. Dry soil - digging a small depression and filling with water containing a small amount of wetting agent is beneficial.
3. Dry sand - pour water around the reference cell and saturate the electrode placement location.
4. Concrete – a water saturated sponge (or water with wetting agent) placed between the concrete and reference cell can assist with obtaining accurate readings.
5. Bitumen - use a $Cu/CuSO_4$ reference electrode with a saturated sponge over cracks to facilitate contact with the underlying soil.
6. Salt and Brackish Water - use Silver/Silver Chloride (Ag/AgC1) reference electrodes.

19.1.3 Reference Cells – Common Sources of Error

Voltmeters used in conjunction with reference electrodes to monitor CP potentials shall be of sufficiently high impedance (10 MΩ or greater), so that any contact resistance that may occur between the electrode and the electrolyte does not affect the readings.

When taking readings, the porous tip of the reference cell must be in intimate contact with the soil - grass or other vegetation or deleterious materials will add resistance and result in inaccurate readings. Prolonged use of reference cells can result in the porous plug assembly becoming contaminated with foreign materials or becoming worn or cracked; if this occurs the porous plug must be replaced.

If the $CuSO_4$ solution within the cell becomes cloudy, reverse osmosis has occurred and the solution must be replaced.

20 APPENDIX-C: COMMISSIONING

20.1 CP System Commissioning

The commissioning survey should include, but not be limited to the following tests and measurements to ensure that the structure is protected in accordance with the design criteria, and that all equipment is installed and functioning correctly:

- Pre-commissioning - measurement of structure potentials at all TPs before energisation of the CP system.
- A check for correct polarity of electrical circuits, i.e. positive to anode and negative to structure.
- For ICCP systems, measure and record the anode loop resistance.
- Set the TRU/CPU DC initial outputs (current and voltage) to provide optimal protection potentials
- Allow suitable time for polarisation of the protected structure – see NOTE below
- Set the TRU/CPU to interrupt mode to enable CP "On" and "Instant Off" potentials to be monitored.
- Measure CP parameters at all TPs and ensure all TPs are functioning as intended and confirm correct installation/operation.
- Measure and record coupon CP "On", "Instant Off" and "Off/Off" potentials and currents, where installed
- Measure and record electrical resistance probe information, where applicable
- Verify the calibration of permanent $Cu/CuSO_4$ reference electrodes
- Analyse and assess TP CP "On" and "Instant Off" potentials to confirm electrical continuity of pipelines.
- Test any relevant IFs and associated DCDs for adequate isolation and correct operation
- Undertake interference testing as required of foreign structures and third-party assets

NOTE: Following the application of CP, the potential level of the structure generally becomes more negative over time due to the effects of polarisation. To ensure that the structure potential is in the optimal protection range, it may be necessary to conduct several sets of potential measurements at spaced timings at the power source and select TPs.

20.2 Documentation

Records shall include the following items:

- Design documentation:
  - As constructed drawings complete with GPS co-ordinates of all significant CP facilities (TRU/CPU, TPs)
  - Operation & Maintenance Manual
  - System installation ITPs
- Commissioning survey report including but not limited to:
  - Results of any FS interference mitigation if required
  - Results of soil corrosion probes, where installed
  - Results of equipment checks.

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