CONCRETE STORMWATER PIPELINES – IMPROVING SUSTAINABILITY

Husham I. Al-Saleem
Freelance Civil Consultant

Americo dos Santos
Hynds Pipe Systems Ltd

HYNDS PIPE SYSTEMS

CONCRETE STORMWATER PIPELINES – IMPROVING SUSTAINABILITY

Husham I. Al-Saleem (Freelance Civil Consultant) &
Americo dos Santos (Hynds Pipe Systems Ltd)

ABSTRACT

Sustainable pipeline projects do not rely on using sustainable pipe materials alone. Sustainable pipeline installations require Performance-based specifications that allow Designers and Contractors to optimize the design, installation method and materials to achieve the required performance.

Performance-based specifications must provide Asset Owners with the assurance that new pipelines will meet the following performance requirements with a reasonable margin of safety:

1. Structural stability under service conditions
2. Water and silt tightness as appropriate for the installation
3. 100 year service life
4. Hydraulic capacity for the service life

This paper reviews current TA specifications and shows how these are often varied to overcome construction and testing constraints, usually leading to less economical and less sustainable outcomes.

A Performance-based approach is proposed for design, installation and verification of construction compliance that will assist the Concrete Drainage Industry in meeting the sustainability requirements of Asset Owners.

This is illustrated by a design example of a Performance-based Sustainable Design approach suitable for most installations. This uses the inherent strength of the concrete pipe, whilst minimising the quantity of imported select fill material, to provide sustainable pipeline/culvert installations.

Absolute watertightness in stormwater pipelines is only necessary in installations where ground water infiltration/exfiltration may affect soil stability, safety of adjacent structures or hydraulic capacity. In many installations, only excessive water infiltration/exfiltration should be of concern. Examples of appropriate requirements are discussed.

The proven high durability of the NZ manufactured concrete stormwater pipes can be fully utilised by better specifying the required performance for pipes in aggressive environments. Various aggressive ground conditions are reviewed and Designers are made aware of the inaccuracy of some of the testing methods employed which may result in incorrect assessment of the actual conditions.

KEYWORDS

Concrete Pipes, Stormwater Pipelines, Sustainability, Specifications, Installation examples and Performance-based Specifications.

PRESENTER PROFILE

Americo dos Santos BSc Eng. (Civil), MICE, MIStructE, FEngNZ, CPEng

Dos is a Chartered Civil and Structural Engineer. He joined Hynds Pipe Systems Ltd in 2000 and has been the Technical Services Manager since 2001.

Dos has more than 20 years' experience in the design, manufacture and installation of reinforced concrete pipe for both open trenched and trenchless applications.

He has been a member of Standards New Zealand/Standards Australia Committee WS-006 – Concrete Pipes since 2001, and was actively engaged in the development of AS/NZS 4058:2007 Precast Concrete Pipes - pressure and non-pressure and AS/NZS 3725:2007 - Design for installation of buried concrete pipes, and currently in AS 4198 – Precast Concrete access chambers for sewerage applications.

He is also a member of the Management Committee of the Concrete Pipe Association of Australasia (CPAA) since the early 2000's. He has been a speaker and presenter at many of the CPAA Roadshows and training sessions.

Dos has been recognized as a Fellow of Engineering New Zealand in 2020 for his significant contribution to engineering in New Zealand.

1 INTRODUCTION

Reinforced concrete pipe has a long and successful record in New Zealand, Australia and worldwide.

Steel reinforced concrete pipe was first developed in France by Monier in 1896 and subsequently introduced into North America in 1905 and Australia in 1910.

Since the introduction of steel reinforced concrete pipe to Australasia in the early 1900's, many hundreds of thousands of kilometers of concrete pipe have been installed in Australia and New Zealand. Many of these pipelines are still in operation and are a testament to the durability and the long service life of steel reinforced concrete pipe.

Steel reinforced concrete pipe have been designed to comply with AS/NZS 4058: 2007 and various predecessors such as AS 4058:1992 and NZS 3107-1977 These Standards were developed as performance based Standards, which have allowed manufacturers to use efficient structural designs alongside increasingly sophisticated and effective manufacturing processes to produce durable concrete pipe. Efficient design, minimizing the use of concrete and steel, combined with the use of mostly locally sourced raw materials, produce robust sustainable concrete pipe available nationwide at economical prices.

Long lasting performance of pipelines does not rely on pipe materials alone. Steel reinforced concrete pipeline installation design is based on AS/NZS 3725:2007. This Standard sets out the design process, material selection and installation options required to meet the intended 100-year service life, when used in combination with concrete pipes manufactured to AS/NZS 4058: 2007.

Whilst AS/NZS 3725:2007 provides a wide basis for pipeline installation design, this is often used by designers, specifiers and Asset Owners in a prescriptive manner, not considering a Performance-based approach that can lead to more sustainable solutions.

Sustainable pipelines require a Performance-based approach to allow Designers and Contractors to optimize the design, installation methods and materials to achieve the required performance.

A Performance-based approach (or specification) must provide Asset Owners with assurance that new pipelines/culverts will meet the performance requirements with a reasonable margin of safety. These requirements include:

- Structural stability under service conditions
- Water and Silt Tightness as appropriate for the installation
- 100 year Service Life with no or minimum scheduled maintenance
- Maintaining Design Hydraulic capacity for the entire Service Life

This paper will discuss a Performance-based approach to design for installation of stormwater pipeline that complies with the overarching principles of AS/NZS 3725:2007, using the inherent strength of the concrete pipe, whilst minimizing the amount of imported fill material, to produce a more sustainable pipeline installation. Design examples will be provided to illustrate the difference between a generic TA approach and a Performance-based approach.

The proven high durability of the NZ manufactured concrete stormwater pipes can be fully utilised by better specifying the required performance for pipes in aggressive environments. Various aggressive ground conditions are reviewed and Designers are made aware of the inaccuracy of some of the testing methods employed, which may result in incorrect assessment of the actual conditions

Quality Control and Quality Assurance measures specified and commonly used on site are often ineffective in verifying the existing and future performance or targeting unnecessary performance criteria. This paper will suggest site pre-construction investigation, construction Quality Control and Quality Assurance measures, which the authors believe, are appropriate for a sustainable Performance-based approach. This will ensure suitable durable pipes and embedment material selection, bedding compaction for structural stability, and on completion watertightness/silt tightness.

2 DESIGN AND INSTALLATION FOR STRUCTURAL STABILITY

Steel reinforced concrete pipeline installation design is based on AS/NZS 3725:2007. This Standard sets out the design process, material selection and installation options required to meet the intended 100-year Service Life, when used in combination with concrete pipes manufactured to AS/NZS 4058: 2007.

Reinforced concrete stormwater pipes are generally specified to be installed as:

- Pipelines, which are designed and constructed to convey stormwater flow that has been collected or concentrated by buildings, roads and other impervious urban areas to an appropriate outfall.
- Alternatively, as Stormwater Culverts, which are designed and constructed to divert stormwater or stream flow from one side to the other side of a road or embankment.

2.1 AS/NZS 3725: DESIGN FOR INSTALLATION OF PIPELINES AND CULVERTS

AS/NZS 3725:2007 provides Designers with a wide variety of installation and superimposed load options for cost effective solutions that meet site-specific requirements.

AS/NZS 3725: 2007 solutions allow designers the freedom to:

2.1.1 REDUCE THE EARTH LOAD ON PIPES IN PIPELINE AND CULVERT INSTALLATIONS:

- By changing pipe projection from Positive to Negative Embankment including the use of the Induced Trench Installation.

- Reducing trench width in Trench, Negative Projection and Induced Trench Installations.

- Reducing pipe projection in a Positive Projection Installation.

2.1.2 SELECT AN APPROPRIATE BEDDING FACTOR:

- The Standard specifies bedding factors ranging from 1.5 to 4.0 depending on quality, quantity and degree of compaction of haunch and side zones. This allows Designers to select the most suitable solution for the site.

2.1.3 A LOWER BEDDING FACTOR MAY REQUIRE THE USE OF A HIGHER CLASS OF PIPES. THIS IS STILL USUALLY A MORE ECONOMICAL SOLUTION, SINCE HIGHER-CLASS PIPES MAY ONLY REQUIRE A MARGINAL INCREASE IN REINFORCEMENT IN MANY CASES, WHILST A HIGHER BEDDING FACTOR MIGHT INVOLVE IMPORTING HIGHER QUALITY MATERIALS AND HIGHER LEVEL OF COMPACTION. THE USE OF EXCAVATED OR LOCAL MATERIALS FOR PIPE INSTALLATIONS:

- AS/NZS 3725:2007 allows for the use of local or even excavated materials for bedding pipes. The Standard specifies that, if the grading of such materials is outside the specified grading limits of the Standard, their use is permitted with:

    - 15% reduction in Bedding Factor for materials outside the limits

    - Maximum bedding factor of 1.5 where the fraction passing the 0.6 mm sieve is outside the limits and is not cement stabilized.

- Clause 2.3 in AS/NZS 3725:2007 states, “This Standard shall not be interpreted to prevent the use of materials or methods of design or construction not specifically referred to herein, provided that such materials can be shown to meet the intent of this Standard”. This statement is often overlooked by Designers precluding the development of more appropriate solutions.

2.2 CPAA ENGINEERING GUIDELINES

Five years after the publication of AS/NZS 3725 in 2007, Designers more carefully considered specification requirements for the select fill in the bedding and haunch zones. It quickly became apparent to Industry, and Contractors in particular, that sourcing select fill materials required to meet the grading specification in Table 6 of the Standard was not simple, or in many instances, not available. As a result, many TA specifications default to AP20, which is a valuable road construction material produced from crushing hard rock with a grading that most closely matches the grading specified in AS/NZS 3725:2007.

To encourage the use of more readily available local bedding and haunch select fill material, the CPAA published ***Engineering Guideline – Selecting Materials for Bedding Steel Reinforced Concrete Pipe***. This document provides industry with some alternatives to consider when the select fill materials with grading limits outlined in AS/NZS 3725:2007 cannot be sourced locally, without compromising the bedding factor associated with the designed support type.

The CPAA Engineering Guideline provides guidance to Designers, Specifiers and Contractors, for the selection of fill material to be utilized when select fill in accordance with the Standard is difficult to source or work with.

2.2.1 GENERAL REQUIREMENTS FOR USE OF SELECT FILL MATERIALS

Select fill complying with the generic soil classes as defined in AS 1726 and shown in Table 1 of AS/NZS 3725 (refer to Table A of this document), but not complying with the particle size distribution of Tables 6 and 7 of AS/NZS 3725 may be used in the bed, haunch, and side zones, provided that:

- **a)** It shall be demonstrated through construction plans, quality control plans, and field trials that the degree of compaction shown in Table B of this guideline, corresponding to the selected bedding type and material, can be achieved, and,
- **b)** Methods to prevent migration of soil fines from, and into the bedding material, shall be provided when ground water movement or existing soil and bedding conditions are conducive to particle migration, and,
- **c)** Long thin particles are not used (despite complying with the grading standards), due to their angular shape which increases the risk of stress on the pipe due to inadequate or non-uniform bedding, and,
- **d)** Maximum particle size of select fill materials in bed, hunch, and side zones shall not be greater than the recommended limits given in Table C, or so selected to ensure uniform support around the pipes to prevent concentrated point loading.

Alternatively, if a) to d) inclusive cannot be achieved, the bedding material must be cement stabilized.

Table A

TABLE 1 FROM AS/NZS 3725: SOIL CLASSES AS DEFINED IN AS 1726

Abbreviation	Description
SC	Clayey sands with fines of low plasticity
SP	Poorly graded sands
SW	Well-graded sands
GC	Clayey gravels with fines of low plasticity
GW	Well-graded sand and gravel mixtures with little or no plastic fines
GP	Poorly graded sand and gravel mixtures with little or no plastic fines

Table B

MINIMUM COMPACTION REQUIREMENTS FOR VARIOUS BEDDING TYPES AND SELECT FILL SOIL CLASSES

Bedding Type	HS3		HS2		HS1		H2		H1	
Bedding Material	I_D	R_D	I_D	R_D	I_D	R_D	I_D	R_D	I_D	R_D
SW, SP, GW, GP	70	95	60	90	50	85	60	90	50	85
SC, GC	n/a	n/a	70	95	60	90	70	95	60	90

NOTES: 1. I_D refers to Density Index (%) and is for cohesionless materials (refer to Clause 8, AS/NZS 3725 for more information).
2. R_D refers to Dry Density Ratio (%) and is for cohesive materials (refer to Clause 8, AS/NZS 3725 for more information).

Table C

RECOMMENDED MAXIMUM PARTICLE SIZE (mm)

Pipe diameter	Bedding Zone	
DN	Bed and Haunch	Side
225- 1350	20	40
1500 - 2250	40	75
> 2250	65	75

NOTES: If the requirements for the above recommendations are met, the bedding factor reduction outlined in AS/NZS 3725 Clause 9.3.2will not apply. However, as in accordance with AS/NZS 3725 Clause 9.3.3, bedding factors will be reduced in line with the Standards recommendations if the conditions prescribed for the use of these materials cannot be demonstrated or achieved.

2.3 NEW ZEALAND (TA) INSTALLATION STANDARDS (STORMWATER PIPELINES)

A previous review of pipe installation standards of most main cities in New Zealand indicates that most reference AS/NZS 3725:2007 as the basic Standard for concrete pipe installation design and installation construction (Al Saleem & Langdon 2015). Further review of the current TA Standards indicates that this is still valid for most updated versions.

However, in many instances the generic installation design detailed ignores the intent of AS/NZS 3725:2007, which deliberately specifies a variety of installation designs, to facilitate the selection of an appropriate site-specific design, simply by balancing design between bedding factors and pipe classes.

Figure 1 below illustrates a typical generic TA installation detail.

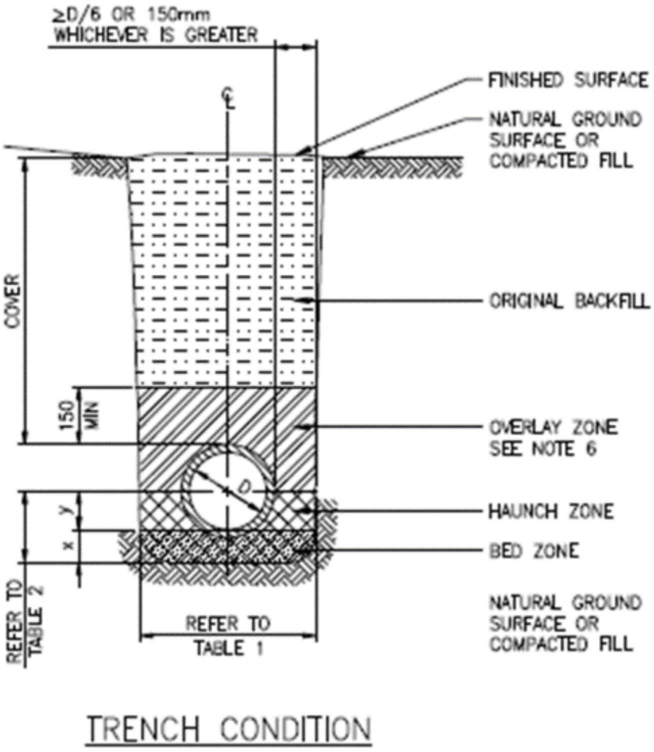


Figure 1: Typical New Zealand (TA) Installation "Drawing"(Not to Scale)

However, it should be noted that although the TA specifications and generic details typically require narrow trenches, the requirement for a high degree of compaction of embedment material on the side of the pipe, and subsequent testing, often results in wider trenches. These requirements often lead to a minimum side cover of 400 mm as illustrated in Figure 2 below:

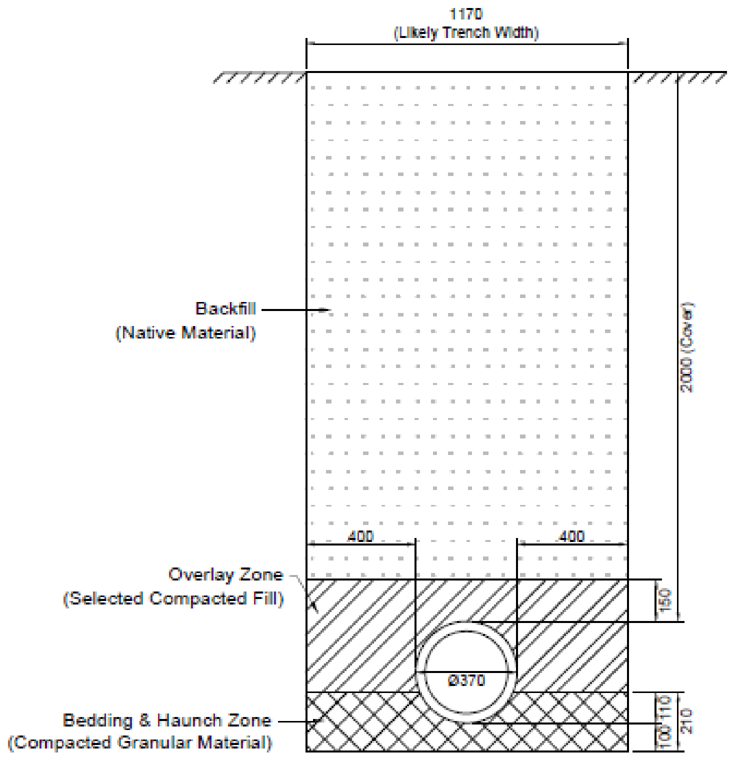


Figure 2: Typical Installation to Fully Meet (TA) Specification's Requirements (Not to Scale

Features of this resultant installation include:

- Wider trench - to allow for haunch and side zone compaction. Typically, minimum width = OD + 800mm (= 1170mm for a 300 mm diameter concrete pipe)
- Requirement for high quality crushed aggregates (mostly AP20 or equivalent) for bed, haunch, and side zones.
- Typically, Contractors use the same bedding material, such as AP20, for the overlay zone to avoid complicated logistics of having to source different types of imported materials to complete the pipe installation.
- Compaction of embedment materials in 150mm layers and compaction testing.
- 150mm overlay zone on top of the pipe.

Whist reinforced concrete stormwater pipes generally specified to be installed as either pipelines or culverts, most New Zealand TA specifications and codes of practice stop short of specifying methods of design and construction. Engineers in many cases implement the default TA specifications rather than designing the installations from first principles.

3 SUSTAINABLE DESIGN AND INSTALLATION FOR STRUCTURAL STABILITY

The following sections will discuss a sustainable design and installation approach for structural stability of both pipelines and culverts, complying with National Standards and following basic principles in use since the early 20th Century.

This approach is based on utilizing a lower, but more easily achievable installation support type, and matching this with commonly available economical Class of concrete pipe.

3.1 SUSTAINABLE PIPELINE INSTALLATION - DESIGN EXAMPLE

To illustrate how AS/NZS 3725:2007 allows designers to develop a sustainable solution utilizing the flexibility of the Standard and its Supplement, the following installation was designed to illustrate the difference between a sustainable Performance-based approach and a generic design based on a typical TA specification.

Example details:

300 mm Ø pipeline Length: 100m

Soil cover to top of pipe: 2m Side cover: 150 mm

Live Load: HN-HO-72

Trench width: Pipe OD + 300 mm = 670mm (for Sustainable example) – Fig 3 refers

Pipe OD + 800 mm = 670mm (for Generic TA example) – Fig 2 refers

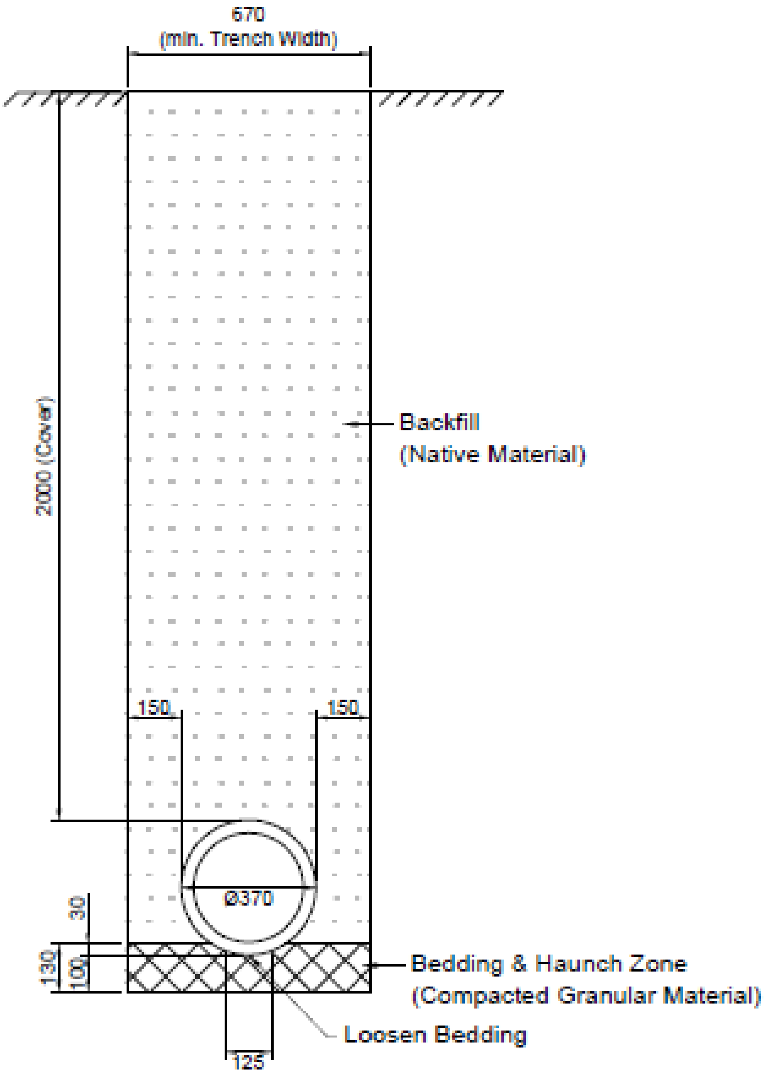


Figure 3: Proposed Sustainable Installation Detail

The Sustainable installation is based on H1 bedding, which has a bedding factor of 1.5. However, in this case, bedding factor is reduced to 1.3 to allow the use of bedding and haunch material that is locally available, but not necessarily meeting the Standard grading requirements. The bedding factor reduction of 15 % is detailed in Cl 9.3.2 (b) of AS/NZS3725: 2007.

The design calculations were carried out for both installations using the CPAA PipeClass software. Appendix 1 details the PipeClass output for this Sustainable Design example.

The results indicate that it is possible to achieve a substantial reduction in material and construction plant requirements, without compromising the structural stability or durability of the pipeline. This approach therefore provides a more sustainable option that should be considered by Asset Owners and Territorial Authorities (TA's).

Table 1: Comparison of Activities for Construction of 100 m of 300 mm Concrete Pipeline Using Typical and Sustainable Design Approaches

Activity for 100m Pipeline		TA Typical Installation	AS/NZS 3725 Sustainable Installation	% Saving
Excavation	Quantity	290m3	166m3	42%
	Spoil out of site (use bulking factor 1.5)	110m3	25m3	77%
Embedment (Including overlay zone)	Materials	Imported High Quality Crashed Aggregates	Any locally available material suitable for compaction & free from sensitive clay	
	Quantity (Use compaction factor 1.3)	107.6m3	13.4m3	87.50%
	Compaction	4 layers @ 150mm with testing	1 layer, No testing required	75%
Backfill	Materials and Compaction	To meet subgrade standards	To meet subgrade standards	

3.2 SUSTAINABLE PIPELINE DESIGN APPLICATION

To illustrate the potential application of a Sustainable Design approach, the installation illustrated in Fig 3 was considered across a range of small diameter pipes installed at various depths and subjected to either no traffic load, or HN-HO-72.

The installation is based on H1 bedding, which has a bedding factor of 1.5. However, in this case, bedding factor is reduced to 1.3 to allow the use of bedding and haunch material that is locally available, but not necessarily meeting the Standard grading requirements. The bedding factor reduction of 15 % is detailed in Cl 9.3.2 (b) of AS/NZS3725: 2007.

It should be noted that this bedding factor reduction is a conservative assumption, since it could be ignored if the conditions of CPAA Guidelines are met. Nevertheless, it is used here to illustrate that a sustainable solution is still possible, whilst using material that does not strictly meet the requirements of the Standard.

The Installation detail (based on Figure 3):

- Width of trench = Pipe OD + 300 mm
- The use of any low-grade select fill meeting Soil Classes detailed of Table 1 of AS/NZS 3725: 2007 and which are available on site or locally.
- Compaction of the bedding layer slightly higher than the required pipe soffit level to allow for bedding materials to form a 10% OD haunch zone. Compaction is controlled by a site supervisor, and no testing is required. It should be noted that this practice is particularly important for small diameter pipes that are susceptible to circumferential cracking if installed without adequate longitudinal support.

- Loosened middle 1/3 pipe OD to allow the pipe to settle into the bedding for improved structural support.
- Use any available material that achieves the subgrade quality required for the rest of pipe backfill (ordinary fill).
- HN-HO-72 Loading

The design calculations were carried out using the CPAA PipeClass software which is available free of charge from the CPAA Website, https://www.cpaa.asn.au/.

Appendix 1 details a sample of PipeClass output for this type of installation.

Table 2 below illustrates the pipe Classes required to meet the structural stability requirements for this type of installation.

Table 2: Pipe Classes for AS/NZS 3725 Sustainable Design Example

ND	225			300			375			450		
LL	No	HN	HO	No	HN	HO	No	HN	HO	No	HN	HO
Depth												
1.00	2	2	2	2	2	4	2	2	4	2	2	4
1.25	2	2	2	2	2	4	2	2	4	2	2	4
1.50	2	2	2	2	2	4	2	4	4	2	4	4
1.75	2	2	4	2	4	4	2	4	4	2	4	4
2.00	2	4	4	2	4	4*	4	4	4	4	4	4
2.25	2	4	4	4	4	4	4	4	4	4	4	4
2.50	4	4	4	4	4	4	4	4	4	4	4	4
2.75	4	4	4	4	4	4	4	4	4	4	4	4
3.00	4	4	4	4	4	4	4	4	4	4	4	4
3.25	4	4	4	4	4	4	4	4	4	4	4	4
3.50	4	4	4	4	4	4	4	4	4	4	4	4
3.75	4	4	4	4	4	4	4	4	4	4	4	4
4.00	4	4	4	4	4	4	4	4	4	4	4	4
4.25	4	4	4	4	4	4	4	4	4	4	4	4
4.50	4	4	4	4	4	4	4	4	4	4	4	4
4.75	4	4	4	4	4	4	4	4	4	4	4	4
5.00	4	4	4	4	4	4	4	4	4	4	4	4
Note	1- Class 4 pipes are marked in this matrix in the yellow cells instead of Class 3 which normally not available in New Zealand unless specially ordered for large projects.											
	* Indicates the sample design used in Table 1 to compare resources with Standard (TA) Practice											

The results shown in Table 2 above illustrate how most of the common brownfield and greenfield stormwater pipeline installations can be constructed sustainably provided TA specifications are modified to encourage this approach.

3.3 VERIFICATION OF STRUCTURAL STABILITY

The AS/NZS 3725:2007 design and installation concept is based on relating actual service load on the pipeline to the test Proof Load of the selected Class of pipe. Proof load on pipes (as defined by AS/NZS 4058:2007), is the specified load applied to and sustained by a pipe, without the appearance of cracks greater than the appropriate test crack.

Based on this concept, if the pipeline or culvert pipe is subjected to the design service load and does not result in any longitudinal cracking or has longitudinal cracks of width equal to or less than the test proof crack as defined in Clause C5.3.2 of AS/NZS 4058:2007, it shall be reported as conforming.

Crack width, as defined by the Standard, should be measured directly for large diameter pipes that allow for man entry or by estimation by experienced professionals reviewing CCTV footages for small diameter pipes. Section E3 of the Fourth Edition of “New Zealand Gravity Pipe Inspection Manual” provides the basis and guidelines for evaluating cracks in concrete pipelines or culverts. (Water NZ 2019)

4 SUSTAINABLE DESIGN AND INSTALLATION FOR SILT AND WATERTIGHTNESS

4.1 SUSTAINABLE PIPELINE DESIGN FOR SILT AND WATERTIGHTNESS

The stability of structures constructed above pipelines requires that the pipes joints are silt tight, as movement of silt to the inside the pipe may result in the formation of sinkholes and subsequent failure of the installation.

Unlike silt tightness, watertightness of stormwater pipes is only required in certain construction cases where excessive water leaks from pipes may cause soil washout and failures, or for protection of the environment outside the pipe from contamination by the stormwater. Excessive infiltration should also be avoided to ensure the pipeline performs to the intended design capacity.

In designing for silt and watertightness, Designers should note that all concrete pipe produced in New Zealand by the major pipe manufacturers, is usually watertight as defined by AS/NZS 4058:2007. Both the pipe wall and the “Rubber Ring” joints are designed, and factory tested to withstand a factory watertightness pressure of 90 kPa without significant water losses.

Sustainable design for water and silt tightness can be achieved simply by specifying a rubber ring pipes and installation to AS/NZS 3725:2007.

In special cases where absolute watertightness is required for the safety of the installation or the environment, Designers should specify verification methods to test that the pipes were installed correctly to maintain the watertightness of the pipeline or culvert.

4.2 VERIFICATION OF SILT AND WATERTIGHTNESS

Verification of silt and watertightness could be established by:

4.2.1 CCTV OR VISUAL INSPECTION:

CCTV or visual inspection of the pipeline or culvert can easily identify any defect that may cause silt migration or excessive water leaks. Examples of defects that may cause leaks and/or silt migration which are detectable by visual inspection include:

- **a)** Rubber ring not in place or not properly installed.
- **b)** Wide circumferential or multiple cracks may result in silt migration or excessive water leaks.
- **c)** Holed or broken pipe wall

4.2.2 WATERTIGHTNESS OR AIR PRESSURE TESTING:

In some rare site-specific cases, when the safety of the installed pipeline, the public or the environment are at risk, specification of absolute watertightness may be required.

The CPAA Engineering Guideline "**Performance Testing of Installed Non-Pressure Rubber Ring Jointed Concrete Stormwater Pipelines**" details the tests to be considered, procedures for testing and evaluation. The tests include:

- **a)** Watertightness Testing of the pipeline
- **b)** Watertightness testing of Individual Joints
- **c)** Air Testing of the pipeline

Specifiers of the Air Test should be aware that watertight concrete is not necessarily airtight. Therefore, the air test is fine for acceptance but not rejection of the pipeline. In the case of a failed air test, the watertightness test should be carried out for acceptance/rejection.

5 SUSTAINABLE DESIGN AND INSTALLATION FOR 100 YEARS DURABILITY

5.1 AGGRESSIVE ENVIRONMENT

Reinforced concrete pipe produced in New Zealand by the major pipe suppliers is manufactured and tested to the requirements of AS/NZS 4058:2007. The Standard requires manufacturers to use very high quality/high strength concrete mix with very low water/cement ratio and high cement content. The manufacturing processes using this high-performance concrete produce pipe walls with a high-density and low water absorption.

AS/NZS 4058: 2007 states "*Based on past experience of concrete pipe installations, a service life of 100 years could be expected when pipes are manufactured in accordance with this Standard and installed in Accordance with AS/NZS 3725:2007 in a 'normal' environment and 'marine' environment as defined in this Standard*".

Appendix E in AS/NZS 4058:2007 provides guidance for the concentration limits of some soil/terrain constituents of the buried environments applicable to 'normal' and 'marine' environments.

Where one or more of the listed concentration limits are exceeded the environment is considered 'other'. In this instance specification of additional cover, supplementary cementitious materials (SCM's) or other protective treatments are required.

Stormwater is normally free from aggressive chemicals that might affect the durability of concrete pipelines and culverts. Consequently, sustainable design for installation of concrete stormwater pipes usually only requires specifying standard pipes and installation procedures. However, some stormwater pipelines or culverts are designed for installation in an aggressive environment where soil or ground water chemical properties are outside the limits detailed in the Standard.

Table 3: Standard Pipes compliance limits of aggressive chemicals

Concentration limits in aggressive conditions - minimum 10 mm cover (From Table E1 of AS/NZS 4058:2007)

Constituent	Soil classification		
	Clay/stagnant	Medium	Sandy/flowing
Chloride (p.p.m Cl–) max.			
Unreinforced concrete	No limit	No limit	No limit
Reinforced concrete	20,000	20,000	20,000
Sulfate (p.p.m SO_4–) max.			
Type GP – general purpose type Portland cement	1 000	1 000	1 000
Type SR – sulfate resisting type Portland cement	10,000	10,000	10,000
Acidity			
Acid (pH) (min.)	4.5	5.0	5.5
Exchangeable soil acid (mL of 0.1 M NaOH consumed by 100 g air-dried soil, max.)	70	50	30
Aggressive CO_2 (p.p.m) max.	150	50	15

Chemical tests of aggressive soils or ground water should be conducted for comparison with the limits specified in Appendix E of the Standard. If test results indicate that, the soil or ground water has one or more aggressive element outside these limits, Designers and Specifiers should consult with the pipe manufacturers to agree a sustainable solution that suits their specific site conditions. The solutions may involve, but are not limited to the following:

a) The use of Marine grade pipes as specified by the Standard when pipes are in contact with tidal water.

b) Increased cover to reinforcement based on Humes Australia research work that correlates lifetime with thickness of cover, for both acidic and aggressive CO_2 environments, which was adopted by both CPAA and AS/NZS 4058. (Wix 1988)

c) The use of supplementary cementitious materials such as Blast Furnace Slag, Micro-silica or Fly ash in the concrete to improve sulfate resistance and overall durability.

d) The use of alkaline aggregates in concrete mix or bedding materials to buffer the acid attack from acidic soils and ground waters.

e) The use of carbonate rich aggregates for pipe bedding to buffer the effect of acid and extend the life of the pipes. If carbonate aggregates are not available from a sustainable source, the use of crushed recycled concrete is generally the sustainable solution of choice.

Designers and Planners have started requesting Chemical Analysis of soils and ground water in recent years, especially for areas where presence of aggressive chemicals are expected or observed through general inspection. However, analysis in many cases does not follow the procedures used for development of Table E1 of the Standard.

A typical example of tests conducted in one project in North Island is shown in ***Appendix 2.*** The tests were conducted by one of the most respected chemical testing laboratories In New Zealand, but without the client requesting a specific test method. The results were clearly different from the procedures used to develop Table E1 in the Standard. These procedures are described in Humes Australia R&D Report, RC.6095 - 24/11/1977 (Harrison 1977).

Table 4 provides a comparison between the test requirements for Table E1 assessment and the typical testing that is done. As illustrated, the results are often not comparable because of the different test methods employed. This disparity made interpretation of the results extremely difficult and/or not correct. It is therefore essential that Designers specify the correct tests and not accept standard laboratory tests typically carried out for other applications.

Table 4: Comparison between AS/NZS 4058 Requirements and Typical Testing

Test/ Procedure	**Procedure as per AS/NZS 4058 Table E1**	**Procedure Typically used in New Zealand**	**Effect on accuracy or interpretation of results**
Soil Sample Preparation	Water extracted from insitu soil sample by diluting sample at ratio 2 Water/1 Soil by mass	Insitu soil air dried, then sieved on 2mm sieve. Water extracted from the finer fraction by diluting the sample at ratio 2 Water/ 1 Soil by volume	Excluding part of the soil before water extraction may exclude some water soluble chemicals from the results. Ratio by mass requires more neutral water in the extract and increases the pH of acidic soils.
Aqueous Sample Preparation	Aggressive CO_2 in groundwater and stream water should be captured by collecting fresh water samples in a gas tight jar and using temperature as sampled during testing	Samples are collected by the clients without any precautions to keep dissolved CO_2 in the sample or record temperature	CO_2 is either leached from the organic deposits in the ground water or dissolved during precipitation of rain water. In both cases the gas is in a critical balance and should be kept in its insitu condition for correct evaluation of its aggressive effect
pH	Test on water extract prepared using W/S ratio by mass or test on fresh acquis sample with carbonic acid as present insitu	Test on water extract prepared by volume on some of the sample or test on preprepared aqueous sample with carbonic acid content changed during sampling process	Typical tests mostly give slightly higher values for soil extract samples and possibly lower for acquis samples.
Sulphates	Test on water extract prepared using W/S ratio by mass or test on fresh aqueous sample. Values in the Standard are **ppm of the aqueous extract**	Test on dry soil using Ion Chromatography determination of potassium phosphate extraction. The results presented in **mg/Kg of dry soil weight**	The Standard limits are for "**Water Soluble Sulphates**" that are aggressive to concrete by forming ettringites. While the typical test calculates "**Total Sulphate"** including the non soluble component that has no aggressive effect on concrete.
Chlorides	Test on water extract prepared using W/S ratio by mass or test on fresh aqueous sample. Values in the Standard are **ppm of the aqueous extract**	Test on dry soil using Ion Chromatography determination of es potassium phosphate extraction. The results presented in **mg/Kg of dry soil weight**	The Standard limits are for "**Water Soluble Chlorides**" that are aggressive to concrete by forming ettringites. While the typical test calculates "**Total Chlorides"** including the non soluble component that has no aggressive effect on concrete.
Aggressive Carbon Dioxide CO_2	Test on fresh aqueous sample for the Carbon Dioxide that aggressive to concrete using tests like "EN 13577 Chemical Attack on Concrete – Determination of Aggressive Carbon Dioxide in Water"	Calculation of "Free Carbon Dioxide" from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO2 D 22nd ed. 2012.	The typical test is expected to give very high results when low pH values is due to acids other than Carbonic Acid. Test of aggressive Carbon Dioxide is based on reaction of the Carbon Dioxide (Carbonic Acid) rich sample with Calcium Carbonate and determine from the result the real quantity of CO_2 that will actually dissolved concrete components in future.

5.2 ABRASION OF PIPES INVERT

Some culverts built at the end of steep streams may have durability issues due to the abrasion effect of water transporting streambed soils and boulders.

Durable design requires careful consideration of this case and full collaboration between the Designers and pipe manufacturers. Measures to increase the abrasion resistance of pipe inverts may be required, and can be included either during pipe manufacture or on site after installation.

6 SUSTAINABLE HYDRAULIC DESIGN

Most Engineering design firms in New Zealand use a state of art modeling techniques to design pipelines and culverts to meet the specific requirements of the asset owners. Design seldom involves optimization of pipe sizes to meet the low capacity requirement.

Sustainable hydraulic design should involve the use of the standard size pipes available in the country. Any deviation from the standard sizes might require pipe manufacturers to invest and use unnecessary resources that affect the sustainability of the final product.

7 PROPOSED PERFORMANCE-BASED SPECIFICATIONS

The New Zealand Construction Industry is familiar with the concept of Performance-based specifications. The New Zealand Building Code used by the Engineering and Building professionals provides a good example of how performance-based specifications can be used.

7.1 PERFORMANCE

Stormwater pipelines and culverts shall be designed, constructed and tested to meet the following performance requirements:

a) Structural integrity under design loads, meeting specified serviceability limits
b) No adverse Environmental impact through:
    - Causing flooding
    - Contaminating or damaging receiving water courses
    - Contaminating groundwater
    - Causing odors or producing corrosive gases.
c) Durability to achieve design life with minimum or no maintenance.
d) Silt tightness, by not allowing migration of outside soil to the inside of the pipes
e) Watertightness to specified level
f) Ability to be maintained as planned
g) No adverse effects surrounding soil, or adjacent structures and utility services
h) Maintaining design flow.

7.2 VERIFICATION

7.2.1 VERIFICATION OF STRUCTURAL INTEGRITY

a) Pipes complying with the appropriate Class and Type as per AS/NZS 4058:2007.

b) Design loads and installation requirements complying with the following in order of precedence:

- AS/NZS 3725:2007, or
- Any acceptable similar international standard, or
- Basic principles of soil structure interaction as developed by Masterton and Spangler (ACPA 2007), or
- Finite element analysis of the installation to compare actual bending moments on the pipe with its design and test bending moments

c) Verification of embedment material by testing of particle size distribution and other test requirements specified in AS/NZS 3725:2007 and/or CPAA Engineering Guidelines.

d) Verification of compatibility of natural soil and embedment material using filter criteria as discussed in a previous paper by the Author.(Al-Saleem & Cook 2018)

e) Verification of compliance of installation by compaction or strength testing of embedment and/or

f) CCTV or visual inspection or measurement/estimation of longitudinal cracks width.

7.2.2 VERIFICATION OF SILT AND WATERTIGHTNESS

a) Pipes complying with Watertightness requirements of AS/NZS 4058:2007, and

b) Joints are installed as per manufacturer's recommend procedure, and

c) CCTV or visual inspection to assure pipelines are free from defects that may cause water infiltration or exfiltration and silt migration, or

d) Alternatively, pipes pass the field air and/or watertightness testing as per CPAA procedures, **when absolute watertightness is specified** due to structural or geotechnical stability requirements or environmental protection.

7.2.3 VERIFICATION OF DURABILITY

a) Pipes complying with specified environment type of AS/NZS 4058:2007, and

b) Pipes installed to AS/NZS 3725:2007 or other approved Standard requirements, or

c) Alternatively, pipes are specially manufactured to meet specific aggressive environmental conditions when exposure environment conditions exceed Table E1 of AS/NZS 4058:2007 values.

7.2.4 VERIFICATION OF HYDRAULIC CAPACITY

a) Pipeline and culvert pipes diameter and grade selected to ensure capacity to handle stormwater calculated per New Zealand Building Code or TA specification, and

b) CCTV and/or visual inspection confirms that pipes have been installed to the design grades and are free from dips and obstructions that may reduce their design capacity.

7.3 ACCEPTABLE SOLUTIONS

New Zealand TA's are encouraged to allow Acceptable Solution installations based on a Performance-based Sustainable Design approach that meet the performance criteria for the project., This will encourage more Designers to consider a Sustainable Design option.

Verification of construction compliance to the specified Acceptable Solution may be through visual or CCTV inspection of the installed pipeline, and Producer/Quality Statements from the Contractors.

8 CONCLUSIONS

In conclusion, this paper proposes a Performance-based approach for the design and construction of sustainable concrete pipeline/culvert installations.

Typical TA specifications have been discussed and examples provided to illustrate how construction requirements on site often result in less sustainable options, particularly when the intent of AS/NZS 3725: 2007 is ignored and a rigid specification approach is adopted.

A Performance-based Sustainable Design approach was illustrated by way of an example, which shows that this can be applied across a wide range of pipe diameters and depths of installation whilst still meeting Standard and Code requirements.

Verification methods have been discussed for structural stability, Water and silt tightness, and durability in aggressive conditions.

A Performance-based Specification is proposed for an Acceptable Solution to be considered by TA's for the design and construction of sustainable concrete pipeline/culvert installations.

ACKNOWLEDGEMENTS

The Authors wish to acknowledge the support of the CPAA in reviewing the abstract of the paper and allowing the use, and/or reproduction and use of Articles and Tables from their publications. Readers can refer to the original publications whenever mentioned in this paper through the CPAA website on the following link: https://www.cpaa.asn.au/General/technical-resources.html

REFERENCES

ACPA (2007) ,"Concrete Pipe Design Manual", American Concrete Pipe Association - 2007, Ch.

Al-Saleem, H. I., Langdon, W. (2015) "Installation of Reinforced Concrete Pipes; Theory and Practice". Water New Zealand, Stormwater Conference 2015.

Al-Saleem, H. I., Cook, D. (2018) "Better Understanding of The Intent Of AS/NZS 3725:2007 – Case Study". Water New Zealand, Stormwater Conference 2018.

Harrison, N.L. (1977) "External Corrosion and Protection of Buried Concrete" Humes Australia Internal Report RC.6095 dated 24/11/1977 (Available by request from CPAA Member Companies).

Water New Zealand "New Zealand Gravity Pipe Inspection Manual" Section E3, 2019.

Wix, R. (1988) "Concrete Pipes Exposed To Acidic Ground Conditions or Aggressive Carbon Dioxide". Humes Concrete RC. 1525, 06/06/1988 Concrete R&D.

Republished by CPAA,
www.cpaa.asn.au/images/publications/technical_papers/cpaa_concrete_pipe_exposed_to_acidic_ground_conditions.pdf

Appendix 1

CPAA
PipeClass
Pipe Load Summary Sheet

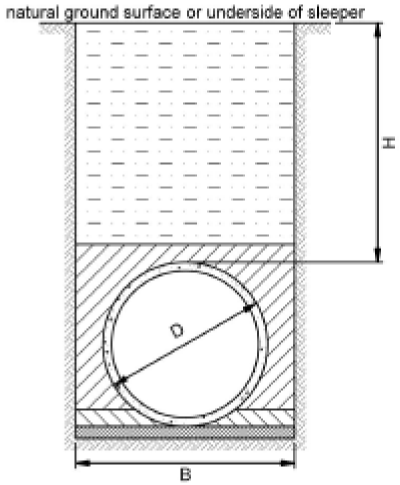
DESIGN OF 300 DIA. RRJ DRAINAGE PIPE

Client And Project Details Date: 05-Mar-2020

Job number:	Design: Design01
Client:	Designer:
Project: New Project	Company:
Description:	File: New Project

Design Parameters

Installation Condition:	trench
Pipe Nominal Diameter (mm):	300
Pipe External Diameter, D (mm):	362
Pipeline Orientation:	skew
Soil Type:	wet clay
Soil Density (kN/m³):	20
Soil Parameter Kμ:	0.1100
Trench Width, B (m):	0.662
Height Of Fill, H (m):	2.000
Support Type:	H1
Bedding Factor:	1.3



In Service Load Cases/Combinations Considered (controlling load case/combination highlighted)

Load Description*	Fill Height (m)	Wg/1.3	Wq/1.5	Tc	Pipe Class
earth	2.000	14.9		14.9	2
HN-85%	2.000	14.9	1.9	16.7	3
HN	2.000	14.9	2.1	16.9	3
HO	2.000	14.9	3.8	18.7	3

All loads in kN/m. *Includes earth load at fill height shown.

Controlling Loads: earth + HO standard vehicle
Minimum Test Load: Tc = 14.9 + 3.8 = 18.7 kN/m

Adopt 300 dia. Class 3 RRJ pipe (300/3 RRJ) in accordance with AS/NZS 4058:2007.

Design Notes:
1. A nominal pipe wall thickness of 29 mm has been assumed.

PipeClass v2.0.23

CPAA
PipeClass
Detailed Load Report

DESIGN OF 300 DIA. CLASS 3 RRJ DRAINAGE PIPE

Client And Project Details Date: 05-Mar-2020

Job number:	Design: Design01
Client:	Designer:
Project: New Project	Company:
Description:	File: New Project

In Service Load Cases/Combinations Considered (controlling load case/combination highlighted)

Load Description*	Fill Height (m)	Wg/1.3	Wq/1.5	Tc	Pipe Class
earth	2.000	14.9		14.9	2
HN-85%	2.000	14.9	1.9	16.7	3
HN	2.000	14.9	2.1	16.9	3
HO	2.000	14.9	3.8	18.7	3

All loads in kN/m. *Includes earth load at fill height shown

earth
Height of fill, H = 2.000 m
Pipeline orientation is skew

Trench Condition, vertical walls
Spangler coefficient, Ct = 2.207
Working load due to earth fill, Wg = 19.3 kN/m

Positive Projection Check
Settlement ratio, rs = 1.000
Projection ratio, p = 0.700
Plane of equal settlement height, He = 0.703
Modified Spangler coefficient, C'e = 1.432
Working load due to earth fill, Wg = 20.7 kN/m

Trench controls, adopt Wg = 19.3 kN/m

HN-85%
Axle Load Calculation
Footprint width at top of pipe, L1 = 5.200 m
Footprint length at top of pipe, L2 = 3.100 m
Footprint area, A = 16.120 m2
Load on footprint = 102.0 kN

Impact factor = 1.00
Live load pressure at top of pipe, q = 6.328 kPa

Minimum of L2 and D, S = 0.362 m
Effective supporting length of pipe, Le = 5.594 m

Working load due to axle loads, Wq (axle) = 2.1 kN/m

Lane Load Calculation
Lane load design pressure (at surface) = 3.500 kPa
Lane width = 3.000 m

Impact factor = 1.00
Lane load pressure at top of pipe = 1.780 kPa

Working load due to lane load, Wq (lane) = 0.6 kN/m

Total working load due to live load, Wq = 2.8 kN/m

Appendix 2

Sample Type: Soil						
	Sample Name:	P9 1m 10-Apr-2014 11:00 am	P10 2m 10-Apr-2014 9:30 am	P2 2m 10-Apr-2014 12:30 pm		
	Lab Number:	1262143.7	1262143.8	1262143.9		
Baumann-Gully Acidity	mL/kg dry wt	In Progress	In Progress	In Progress	-	-
Chloride	mg/kg dry wt	39	11	18	-	-
pH	pH Units	5.0	5.4	5.4	-	-
Sulphate	mg/kg dry wt	153	39	102	-	-

Sample Type: Aqueous						
	Sample Name:	P1 Field Temp=19.3°C 10-Apr-2014 10:35 am	P2 10-Apr-2014 12:05 pm	P3 Field Temp=19.1°C 10-Apr-2014 10:10 am	P4 10-Apr-2014 10:25 am	P9 Field Temp=19.3°C 10-Apr-2014 9:55 am
	Lab Number:	1262143.1	1262143.2	1262143.3	1262143.4	1262143.5
pH	pH Units	5.2	6.5	5.3	5.3	5.9
Total Alkalinity	g/m³ as $CaCO_3$	76	1,010	118	126	114
Free Carbon Dioxide	g/m³ at 25°C	1,030	580	1,270	1,180	290

	Sample Name:	P10 Field Temp=19.7°C 10-Apr-2014 9:40 am				
	Lab Number:	1262143.6				
pH	pH Units	5.7	-	-	-	-
Total Alkalinity	g/m³ as $CaCO_3$	122	-	-	-	-
Free Carbon Dioxide	g/m³ at 25°C	500	-	-	-	-

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Baumann-Gully Acidity	1 M Na Acetate extraction of < 2 mm fraction. Titration. Reported as mL of 0.1 M NaOH required per kg soil. DIN 4030 Part 2, 1991 (modified).	5 mL/kg dry wt	7-9
Environmental Solids Sample Preparation	Air dried at 35°C and sieved, <2mm fraction. Used for sample preparation. May contain a residual moisture content of 2-5%.	-	7-9
Soil Prep Dry & Sieve for Agriculture	Air dried at 35°C and sieved, <2mm fraction.	-	7-9
esICextn	(1:5) ratio of sample (g):0.02M potassium dihydrogen ortho-phosphate extractant (mL), analysis by Ion Chromatography. In House.	-	7-9
Chloride	Ion Chromatography determination of es potassium phosphate extraction.	3 mg/kg dry wt	7-9
pH	1:2 (v/v) soil : water slurry followed by potentiometric determination of pH.	0.1 pH Units	7-9

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sulphate	Ion Chromatography determination of es potassium phosphate extraction.	3 mg/kg dry wt	7-9

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
pH	pH meter. APHA 4500-H^+ B 22nd ed. 2012.	0.1 pH Units	1-6
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (Modified for alk <20) 22nd ed. 2012.	1.0 g/m³ as $CaCO_3$	1-6
Free Carbon Dioxide	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 22nd ed. 2012.	1.0 g/m³ at 25°C	1-6

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.