CRC Construction Innovation
BUILDING OUR FUTURE

Report
Holistic Model Modifications for Selected Building Elements

Research Project No: 2005-003-B-06

The research described in this report was carried out by:

Project Leader	Penny Corrigan
Researchers	Angela Bradbury Ivan Cole Robin Drogemuller Stephen Egan Wayne Ganther Tim Muster David Paterson Gerry Trinidad Natalie Sherman Andrew Martin Wan Yee Chan Richi Nayak Esther Ge
Project Affiliates	Peter Hope Michael Ball Frank Turvey Lee Wade Wayne Muller Lex Vanderstaay

Research Program: B
Sustainable Built Assets

Project: 2005-2003-B
Learning System for Life Prediction of Infrastructure

Date: August 2007

Distribution List

Cooperative Research Centre for Construction Innovation
Authors

Disclaimer

The Client makes use of this Report or any information provided by the Cooperative Research Centre for Construction Innovation in relation to the Consultancy Services at its own risk. Construction Innovation will not be responsible for the results of any actions taken by the Client or third parties on the basis of the information in this Report or other information provided by Construction Innovation nor for any errors or omissions that may be contained in this Report. Construction Innovation expressly disclaims any liability or responsibility to any person in respect of any thing done or omitted to be done by any person in reliance on this Report or any information provided.

Please direct all enquiries to:

Chief Executive Officer
Cooperative Research Centre for Construction Innovation
9th Floor, L Block, QUT, 2 George St
Brisbane   Qld   4000
AUSTRALIA
T: 61 7 3138 9291
F: 61 7 3138 9151
E: enquiries@construction-innovation.info
W: www.construction-innovation.info

Table of Contents

Page

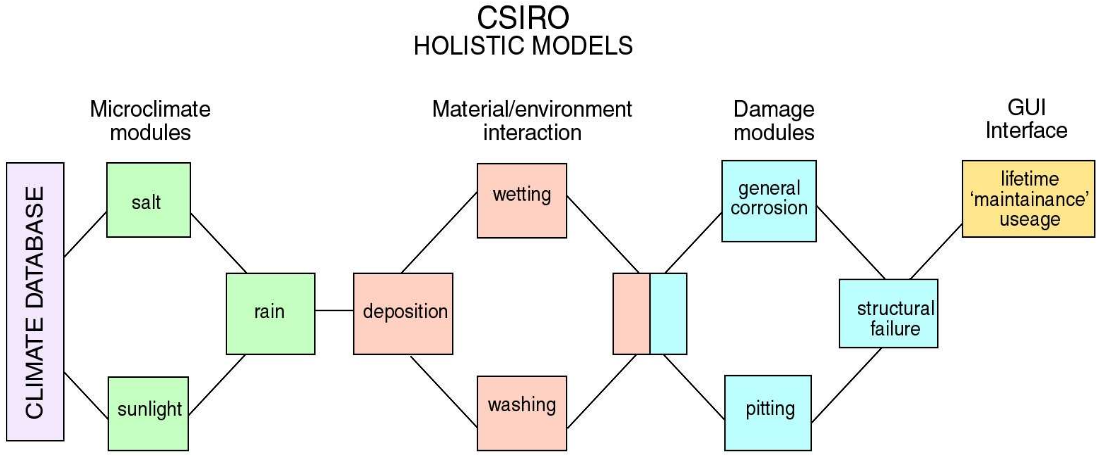
1. INTRODUCTION

This project is an extension of a previous CRC project (220-059-B) which developed a program for life prediction of gutters in Queensland schools. A number of sources of information on service life of metallic building components were formed into databases linked to a Case-Based Reasoning Engine which extracted relevant cases from each source.

1.1 Holistic Model

One of the databases was created using the CSIRO-developed holistic model of metallic corrosion which is based on an understanding of the basic corrosion processes ranging in scale from atomic electrochemical reactions to the macro scale of continental environmental factors. Figure 1 illustrates the modules of the holistic model which are divided into three broad groups: microclimate, material-environment interactions and damage modules.

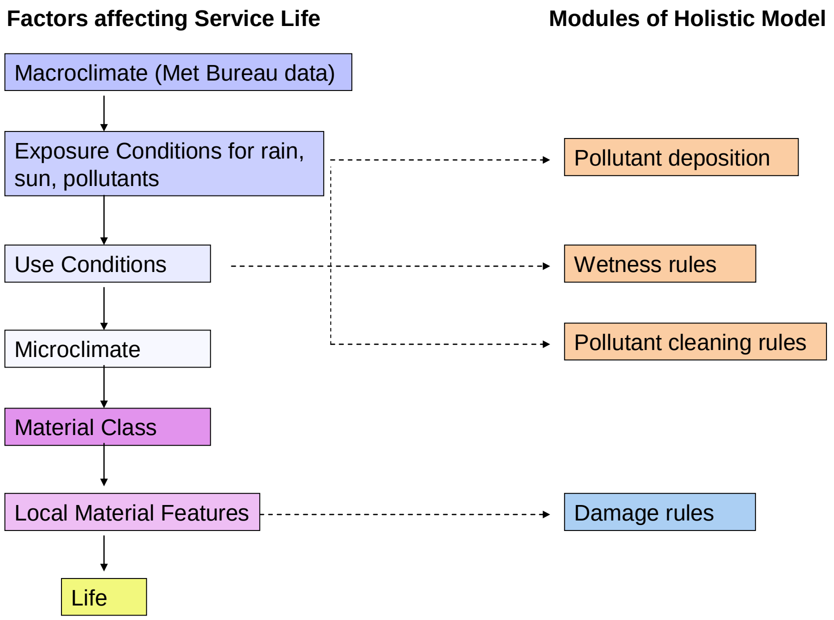
Figure 1: Structure of the modules of the holistic model for predicting corrosion



In the previous work based on gutters, modifications were made to several of the modules to tailor the calculations for the specific environments of gutters.

Figure 2 illustrates the different factors affecting the service life of a building component. These are shown on the right hand side of the diagram. The different modules of the holistic model that may need modification for factors specific to different building components are shown on the left side of the diagram with arrows indicating which factors are likely to affect which modules.

Figure 2. Factors affecting service life of metallic components and how they relate to modules of the holistic model.



A building component will be situated on a building experiencing climate depending on its geographic location. This can be referenced from the Bureau of Meteorology. The climatic conditions experienced by the building component eg, rain, sunlight and pollutant depositions may be altered by its positioning on the building and whether it is in an open, exposed position or sheltered in some way – either from the rain, sun, or pollutant bearing winds or combinations of these. These parameters will impact on the modules in the holistic model dealing with pollutant (salt) deposition and removal (natural cleaning or washing).

The microclimate conditions experienced by a component can also be influenced by maintenance and cleaning (use conditions) especially if the component is in a dirt accumulation zone. The accumulation of dirt and leaf litter can dramatically increase the time it takes for a component to dry after rainfall. This was experimentally determined for gutters in the previous project phase (CRC Report 2002-059-B No 16) and the time-of-wetness is a significant parameter in the wetting module of the holistic model. All these factors (exposure and use conditions) determine the microclimate experienced by the building component.

How the microclimate affects the building component will depend on the material of the component eg galvanised steel, Colorbond, zincalume, aluminium, etc. and any local material features eg edge effects, material incompatibilities where components are joined etc. These factors are considered in the damage modules of the holistic model. The ultimate outcome of how the microclimate affects the material and local features is the corrosion rate which determines the service life of the component.

In the previous phase of the project the modifications made to the holistic model to adapt it for use with gutters were detailed in the final report. These were incorporated into a stand alone program, mainly for development purposes, but useful for modelling the mass loss of gutters at any point in Australia. The program was used to generate the database for the Queensland schools used in the project software.

This report looks at the modifications to this modelling program required for the new building components.

2. HOLISTIC MODEL MODULES

The holistic model as shown in Figure 1 contains a number of modules that:

a) predict the salinity at a location,
b) predict the climate at a location,
c) predict salinity retention on a component on a building,
d) predict the state of a surface on a component on a building,
e) predict the damage of the component on the building.

For all components, a) and b) remain unchanged as these relate to the macroenvironment at a particular location.

2.1 Salinity Retention

In calculating whether salt will be retained on a surface in the event of rain it is assumed that salt cleans off a surface according to the following relationships:

$$D_i \text{ after wash} = \Phi + \psi * D_{i-1} \qquad \text{..Eqn (1)}$$

Where D_i is the retained salt after a rain event and D_{i-1} is the deposited salt prior to a rain event. Φ is taken as 1 and the values of ψ are given in **Error! Reference source not found.**. Here LMI, SMI and HMI refer to low, medium and high moisture index which is a parameter which describes the rate of evaporation and O refers to open exposure and S to sheltered.

Table 1 Values of ψ defined for various parameter combinations

Moisture Index	**Open/Sheltered**	**ψ**
LMI	O	0.1
	S	0.6
SMI	O	0.5
	S	0.6
HMI	O	0.5
	S	0.6

2.2 State of surface of building component

Three states of a surface are defined

a) S1 – dry
b) S2 –wet from wetting of hygroscopic salts
c) S3 - wet from rain

The holistic model calculates state on a three hour interval. The standard model assumes that a surface is in state 3 whenever rain is occurring but once the rain has ceased, it is dry before the next 3 hour period .If the rain ceased in the middle of the last time period this implies drying takes no more than 1.5 hours. Studies have indicated that this is a reasonable assumption for all cases, except where dirt and debris can accumulate. In these cases State 3 is extended and determined from experimental measurements.

2.3 Damage to Components

The damage to components is also calculated each three hours from a knowledge of the state of the component, the retained salinity and climatic parameters. Two different approaches are used for a) uncoated metals (steel, galvanised steel and zincalume) and b) coated steel eg. Colorbond.

2.3.1 Uncoated Metals

The standard holistic methods is used in which the corrosion rate is calculated each three hours according to the following equations:

$$Ms_1 = 0 \qquad \text{…Eqn (2)}$$

$$Ms_2 = \zeta * M_2 \qquad \text{…Eqn (3)}$$

Where M_2 depends on RH

For $35<RH<75$

$$M_2 = 3 + \Phi * D^{\Phi} \qquad \text{…Eqn (4)}$$

Where D is the retained salt and the values of the constants are given in the **Error! Reference source not found.**

For $RH>75$

$$M_2 = \Theta + \Omega * D^{\Psi} \qquad \text{…Eqn (5)}$$

For State 3

$$Ms_3 = \zeta * M_3 \qquad \text{…Eqn (6)}$$

In the case of M_3, the rate of mass loss varies on the basis of the component case as this depend on the state of the component.

Table 2 Constants for galvanised steel mass loss in State 2

Θ	0.02
Ω	0.027
Ψ	0.5
3	0.02
θ	0.027
Φ	0.5
ζ	1

Table 3 Constants for galvanised steel mass loss in State 3

	ζ
open	1
sheltered	2
Partial sheltered	1.5

Table 4 Constants for Zincalume mass loss in State 2.

Θ	0.027
Ω	0.004
Ψ	0.5
3	0.0
θ	0.002
Φ	0.5
ζ	1

Table 5 Constants for Zincalume mass loss in State 3

	ζ
open	1
sheltered	2
Partial sheltered	1.5

2.3.2 Coated Materials

The application of paint to galvanised steel and zincalume is not modelled because the paint application is carried out after the component installation and quality control on such paint films is poor. Colorbond® is a product of Bluescope steel and has been proven to have exceptional performance in most locations across Australia. It is now commonly used in roofs, gutters and downpipes. A common illustrative grade of Colorbond® is steel sheet (low carbon steel) with a coating of zincalume AZ 150 (150 g m^{-2}), which is overcoated on both sides with a 5 µm chromate-containing epoxy primer. The one-sided product has a 20 µm thick UV-resistant topcoat and a 5 µm grey backing coat covering the primer (Bluescope Steel, 2005). Colorbond® was introduced as a material into the holistic model for the previous phase of the project based on gutters. A model for the degradation of Colorbond® was proposed. In this phase of the project this model has been refined and validated with a range of measurements. This work is reported on in detail in report No 11.

3. MODEL MODIFICATIONS FOR SPECIFIC BUILDING COMPONENTS

The different parameters affecting the likely corrosion rates for the set of building components considered in this project were analysed and reported on in Report No. 3. These are summarised in Table 6. For each component there will be a database entry for each parameter type x each case x each material type, where relevant.

The previous phase of the project produced a stand alone program, mainly for development purposes that incorporated the parameter changes for gutters into the holistic model. The software implementation of the additional procedures required for the new components are detailed in the following sections.

Table 6

COMPONENT	PARAMETERS	CASES	MATERIALS
Gutters	Gutter segment	•Internal sides •Internal Bottom •External Bottom	Galvanised steel Zincalume Colorbond
	Rain exposure	•open •sheltered	
	Maintenance	•Cleaned •Not cleaned	
Downpipes	Downpipe region	Interior Exterior	Galvanised steel Zincalume Colorbond
	Edges	•Edge •Not edge	
	Blocked	•blocked above blockage at blockage below blockage •Not blocked	
	Rain exposure	•exposed •sheltered	
roof sheeting	Roof angle	•normal (drained) •very low (not drained)	Galvanised steel Zincalume Colorbond
	Maintenance	•Cleaned •Not cleaned	
fasteners	Roof fastener	•Well drained •flat roof	Stainless steel Hot-dip coated zinc-coated
	Fastener part	•head above sheet •exposed shank •shank in beam	
	Beam type	•Timber •Steel	
ridge capping	Edges	•Edge •Not edge	Galvanised steel Zincalume Colorbond Aluminium
	Material compatibility	•Material compatibility effect (4x4 matrix)	
flashing	Edges	•Edge •Not edge	Galvanised steel Zincalume Colorbond Aluminium
	Material compatibility	•Material compatibility effect (4x4 matrix)	
window frames	Building face	•Front •Side •Back	Aluminium (anodised) Coated aluminium Galvanised steel
	Rain exposure	•exposed •sheltered	
	Drainage	•Not drained •drained	
	Edge	•Edge •Not edge	
steel supports	Rain exposure	• exposed •sheltered	Galvanised steel zincalume
	Drainage	•drained •not drained	
sub-floor members	Ventilation rate	•high •medium •low	Galvanised steel Zincalume bare steel
	Drainage	•drained •not drained	
gang nail plates and strapping	Rain exposure	•exposed •sheltered	Galvanised steel Zincalume
	Timber/metal interaction		

3.1 Downpipes

3.1.1 Parameters

The important parameters for downpipes are similar to those for gutters, they are also are a component where dirt can accumulate so maintenance (or lack of it) can strongly influence the service life. Blockages in the downpipe may occur which will affect the drying time of the internal faces of the downpipe above the blockage. Blockage locations considered are *above*, *at* or *below* blockage. The interior and the exterior of the downpipe are considered separately.

Exposure: The exposure for downpipes will be in the *open* and *sheltered*. For sheltered exposure only the interior of the downpipes will be considered.

Materials: There are 3 types of material that can be considered namely *galvanised*, *zincalume* and *Colorbond*.

For each material considered, there are 5 different possible scenarios that would be considered and are as listed in Table 7.

Table 7 Possible cases for downpipes

Case	Exposure	Location	Blockage	Blocked Location
1	In the open (exposed)	Exterior	No	N/A
2		Interior	Yes	Above blockage
3				At blockage
4				Below blockage
5	Sheltered	Exterior	No	N/A

Note: if the downpipes is clean then the assumption is there is no blockage.

3.1.2 Deposition of salt

The deposition of salt is on the *front* of the building around the *edges*.

The rate of salt deposition (δ) is defined as follows:

$$\delta = \beta * \chi * \alpha \qquad \text{……Eqn(7)}$$

where β is a factor defining the effect of the face of a building,
χ is a factor defining the position on the face, and
α is the salt deposition in mg/m^2 for exterior exposure.

For downpipes β = 0.6 and χ = 3.

3.1.3 State of Surface

For downpipes, the rule for state 3 (wet from rain) classification is similar to the previous implementation for gutters. The surface is considered to be in state 3 if the surface is not sheltered and it is raining. It is assumed to be raining if in a 3-hours period the rainfall > 0. If the amount of rain in a 3-hours period is more than X mm then the surface remains wet for an additional N hours. The counting of N hours starts from the first occurrence of rain > X mm. The counting is not reset even if there are intermittent rain > X mm within the N hours period. This is the case when there is no blockage in the downpipes. However if there is blockage in the downpipes and rain > X mm then the surface stays in state 3 a further additional time depending on the type of blockage. This is summarised in Table 8.

Table 8 Calculations for extended drying times depending on state of downpipe.

Blockage	Rain > X mm	Extended hours in state 3
Yes/No	No	zero (0)
No	Yes	N
Yes – *below* blockage	Yes	$N + m_1$
Yes – *at* blockage	Yes	$N + m_2$
Yes – *above* blockage	Yes	$N + m_3$

The surface being considered wet for additional hours when rain > X mm is only applicable to the interior of the downpipes and not the exterior.

As with the gutters, a downpipe was instrumented with sensors to determine the length of time the surface remains wet after rain when there is a blockage in the drainpipe. This is discussed in Appendix A.

3.1.4 Mass loss calculations

The state 3 mass loss calculations have been modified to account for the possibility of blockages increasing the rate of corrosion:

Two rules are postulated:

- R1 - $Ms3a = (\xi * Ms3)$ …..Eqn(8)
- R2 - $Ms3a = (\xi * Ms3) + \beta * D^{\sigma}$ …..Eqn(9)

Rule R1 is applied in the situation where there is no blockage in the downpipes that is case 1 and case 4. For cases 2, 3 and 4 where the downpipes is blocked the second rule R2 is applied. (Case definition is in Table 7). The application of the rule to the state 3 mass loss calculation is given in table 9.

Table 9 Application of mass loss rules depending on case

Case	State 3 mass loss calculation (Ms3a)
1	R1
2	R2
3	R2
4	R2
5	R1

If there is an edge, then the calculated mass loss $Ms2a$ for state 2 and $Ms3a$ for state 3 is multiplied by the edge mass loss accelerator factor Λ_i as follows:

- State 2 - $Ms2a' = \Lambda_2 * Ms2a$ ….Eqn(10)
- State 3 - $Ms3a' = \Lambda_3 * Ms3a$ ….Eqn(11)

Downpipes are by definition at the edge of a dwelling so the edge mass loss accelerator factor Λ_i does apply in both the state 2 and state 3 mass loss calculations.

3.2 Roof Sheeting

3.2.1 Parameters

Roof type; The type of the roof considered is *normal* or *very flat* roof. The roof type determines whether the surface remains in state 3 for additional hours when there is rain.

Exposure: Roofs are assumed to be fully exposed and not sheltered and hence roof sheeting is only considered for open exposure.

Condition of the roof: The condition of the roof sheeting is either *cleaned* or *not cleaned* which controls whether rule R1 or R2 (see downpipes) will be applied in the state 3 mass loss calculation. Rule R1 is applied when the roof sheeting is cleaned while R2 is applied when dirty.

Material type: There are 3 types of material that are considered namely *galvanised*, *zincalume* and *Colorbond*.

For each material considered, there are 8 different possible scenarios that would be considered and are as listed in Table 10.

Table 10 Cases for roof sheeting

Case	Exposure	Salt deposition	Roof	Condition
1	In the open (exposed)	edge	Normal	Cleaned
2				Not cleaned
3			Very flat	Cleaned
4				Not cleaned
5		other positions	Normal	Cleaned
6				Not cleaned
7			Very flat	Cleaned
8				Not cleaned

3.2.2 Deposition of salt

The deposition of salt is on the *roof* of the building around the *edges* and other *positions* of the roof surface.

Equation 7 still applies and for downpipes $\beta = 0.4$ and $\chi = 3$.

3.2.3 State of Surface

Table 11 summarises the application of the state 3 extension rule, the edge mass loss acceleration factor and the state 3 mass loss calculation rule.

Table 11 Effect of case on various parameters

Case	State 3 (additional hours)	Edge factor	$Ms3a$ rule
1		Λ_i	R1
2		Λ_i	R2
3	Yes	Λ_i	R1
4	Yes	Λ_i	R2
5			R1
6			R2
7	Yes		R1
8	Yes		R2

For roof sheeting, the rule for state 3 classification is similar to downpipes except in this case the extension of state 3 by an additional N hours only applies when the roof is *a very flat roof* and the rain $> X$ mm.

3.2.4 Mass loss calculations

It was considered that leaf litter build up on roofing may affect the pH of rain water and hence the corrosivity of the water. Tests were carried out to determine if this was the case and whether extra factors would need to be included in the mass loss calculations. The tests are detailed in Appendix B. The results suggest that pH changes need not be considered in the mass loss calculations.

Similar to downpipes, if there is an edge, then the calculated mass loss $Ms2a$ for state 2 and $Ms3a$ for state 3 is multiplied by the *edge mass loss accelerator factor* Λ_i (see downpipes).

3.3 Roof Fasteners

3.3.1 Parameters

Beam type: The type of the beam considered is *timber (T)* or *steel (S)* as illustrated in Figure 3.

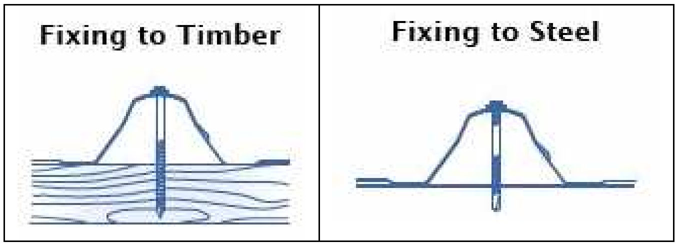


Figure 3 Roof fastener cases being considered: fixed to timber or fixed to steel.

Roof fastener sections: Figure 4 shows the 3 sections of the roof fastener that are considered. The first section (indicated as I in the figure) is the fastener head above the roof sheeting. The middle section (II) is the shank below the roof sheeting but has not been embedded in the beam. The last section (III) is the shank that has been embedded in the beam.

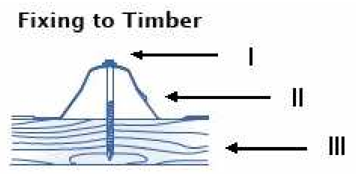


Figure 4. The various sections of a roof fastener

Roof type: The type of the roof considered is *normal* or *very flat* roof. The roof type determines whether the surface remains in state 3 for additional hours when there is rain.

Roof fastener/roof sheeting compatibility: There are 2 cases to be considered in terms of the compatibility between the roof fastener and roof sheeting, that is, either *compatible* or *not compatible*. If the roof fastener and roof sheeting are not compatibility then an acceleration factor is applied in the state 2 and state 3 mass loss calculations (see downpipes).

Material type: There are 3 types of material that are considered namely *stainless steel, hot-dipped coated* and *zinc coated*.

For each material considered, there are 16 different possible scenarios that would be considered and are listed in Table 12.

Table 12 Possible cases for roof fasteners

Case	Face Position	Roof Type	Fastener/Roof sheet interaction	Fastener Section
1	edges	normal	compatible	I
2				II
3			not compatible	I
4				II
5		very flat	compatible	I
6				II
7			not compatible	I
8				II
9	other positions	normal	compatible	I
10				II
11			not compatible	I
12				II
13		very flat	compatible	I
14				II
15			not compatible	I
16				II

NOTE: The last section (III) where the shank is embedded in the beam has been programmed previously and that will be used to generate the information for the database.

3.3.2 Deposition of salt

The deposition of salt is on the *roof* of the building around the *edges* and *other positions* on the roof surface.

In calculating the salt deposition for the middle section of the roof fastener (II) an additional building envelope factor is required.

The rate of salt deposition (δ) is defined as follows:

$$\delta = \beta * \chi * \gamma * \alpha \qquad \text{…Eqn(12)}$$

where β is a factor defining the effect of the face of a building,
χ is a factor defining the position on the face,
γ is the building envelope factor, and
α is the salt deposition in mg/m^2 for exterior exposure.

For fasteners β = 0.4, χ = , and γ = 10..

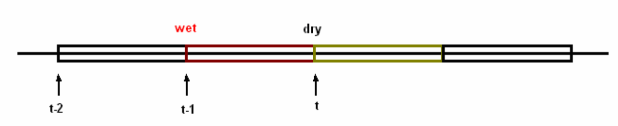
If the first section (I) of the roof fastener, ie. the head above the roof sheeting is considered then the salt deposition is that deposited in the open.

$$\delta = \alpha \qquad \text{…Eqn(13)}$$

3.3.3 State of Surface

For roof fastener, the state law requires a 3 hour period of daylight to dry. Daylight is considered to be between 6 am and 6 pm. This means if the rain event happens before 6 am and after 6 pm, that is, night time, then the surface continues to remain in state 3 until after the first 3 hour period without rain from 6 am to 6 pm. If the rain event is during daytime between 6 am and 6 pm then roof will only dry in the next 3 hour period without rain.

Scenario #1

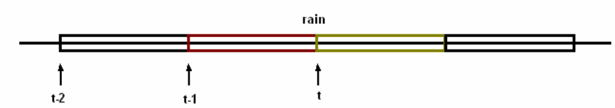


If it is *dry* at time interval t then

1. check to see at time interval $(t-1)$ the surface has stays wet for N hours
    a. if *yes* then check if it is
        - *dry* then state at time interval t is *dry*
        - *wet* then
            a. check to see if
                i. t > 6 am & t < 6 pm (i.e. *day-time*) then state at time interval t is *dry*
                ii. t <= 6 am & t >= 6 pm (i.e. *night-time*) then state at time interval t is *wet*

    b. if *no* then do nothing but accumulate wet hours

Scenario #2



If it is *rain* at time interval t then state at time interval t is *wet* & time interval $(t+1)$ will be scenario #1 again

3.3.3.1 Climate conditions in building envelopes

The *temperature* and *relative humidity* in the roof space are only applicable when the middle section of the roof fastener (II) is considered.

The temperature in the roof space T_{rs} is calculated as follows:

$$T_{rs} = T_{ad} + \beta(T_{ext} - T_{ad}) + \delta \qquad \text{Eqn(14)}$$

where T_{ad} - average daily temperature and calculated as follows

$$T_{ad} = \sum_{hr=1}^{8} T_{3hr} \Big/ 8 \qquad \text{Eqn(15)}$$

T_{ext} - external temperature for that 3-hour period

δ - a constant dependent on time of day and season (values given in Table 12)

β - solar radiation zone

Table 13: Values for δ, a constant dependent on the time of day and season

Time	**00:00**	**03:00**	**06:00**	**09:00**	**12:00**	**15:00**	**18:00**	**21:00**
Summer	-3	-3	0	15	30	15	5	-3
autumn	-3	-3	0	10	20	10	3	-3
winter	-3	-3	0	5	10	5	2	-3
spring	-3	-3	-3	10	20	15	5	-3

The solar radiation zone is determined by the latitude of the location of interest and is as given in Table 14.

Table 14. Solar radiation zones

Latitude	**Solar radiation zone**	**Index**
$> -25^\circ$	High	0.4
$\geq -35^\circ \quad \Lambda \quad \leq -25^\circ$	Medium	0.5
$< -35^\circ$	Low	0.6

The relative humidity in the roof space RH_{rs} is calculated in a similar way as temperature as follows:

$$RH_{rs} = RH_{ad} + \beta * (RH_{ext} - RH_{ad}) + \delta + \varsigma \qquad \text{Eqn(16)}$$

where RH_{ad} - average daily relative humidity and calculated as follows

$$RH_{ad} = \sum_{hr=1}^{8} RH_{3hr} \Big/ 8 \qquad \text{Eqn(17)}$$

RH_{ext} - external relative humidity for that 3-hour period

δ - a constant dependent on time of day and season

β - solar radiation zone

ς - a factor to promote condensation

The factor to promote condensation is to be introduced at a given frequency at dawn for example 8 times per month. Dawn is taken to be at 6 am in the morning. The eight days on which this factor is applied is implemented using a random generator.

3.4 Ridge Capping and Flashing

Ridge capping and flashing are considered together as the model modifications are identical.

3.4.1 Parameters

Exposure: Roofs are assumed to be fully exposed and not sheltered and hence ridge capping and flashing are only considered for open exposure.

Material type: There are 3 types of ridge capping material that are considered namely *galvanized, zincalume* and *aluminium*.

Roof material type: There are 4 types of roof material possible with each material type for the ridge capping, namely galvanized, zincalume, colorbond and aluminium.

For each material considered, there are 8 different possible scenarios that would be considered and are listed in Table 15:

Table 15 Possible cases for ridge capping and flashing

Case	Drainage	Exposure	Building Face	Face Position	Roof Material
1	drained	open	roof	edges	galvanized
2					zincalume
3					colorbond
4					aluminum
5				other positions	galvanized
6					zincalume
7					colorbond
8					aluminum

3.4.2 Deposition of salt

Similar to roof sheeting, the deposition of salt is on the *roof* of the building around the *edges* and other *positions* of the roof surface.

3.4.3 State of Surface

The drainage condition in ridge capping and flashing is always drained and hence there are no extended wet hours to state 3 when it rains. Thus the state 3 classification rule used is based on the original implementation.

3.4.4 Mass loss calculations

Similar to downpipes, if there is an edge, then the calculated mass loss $Ms2a$ for state 2 and $Ms3a$ for state 3 is multiplied by the *edge mass loss accelerator factor* Λ_i (see downpipes).

Material compatibility factor: Similar to the roof fastener, ridge capping and flashing has a compatibility factor. The compatibility factor is between the material of the ridge capping and flashing and the roof.

The compatibility factor between the two components is given in Table 16.

Table 16 Compatibility factors for possible material combinations

Roof material	Galvanized	Zincalume	Aluminium
Galvanized	1	1	1
Zincalume	1.5	1	1
Colorbond	1	1	1
Aluminium	1.5	1.5	1

The damage rules for state 2 and state 3 are as given below:

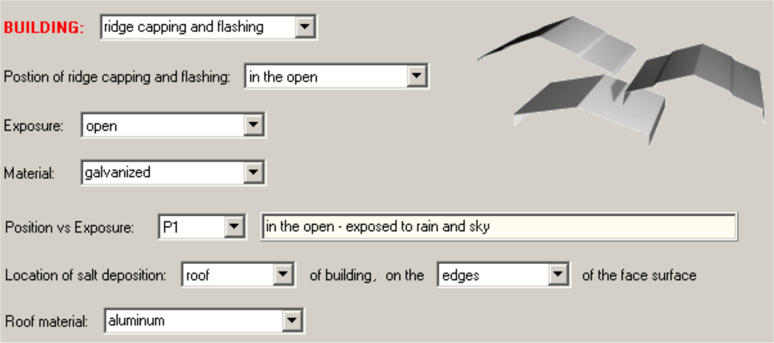
$$Ms2a' = A * B * Ms2a \qquad \text{Eqn(18)}$$

$$Ms3a' = A * B * Ms3a \qquad \text{Eqn(19)}$$

where A – *edge factor*

B – *material compatibility effect*

Figure 5 shows the data entry screen in the program where the user can select the different combination of attributes in which ridge capping and flashing is analyzed.



BUILDING: ridge capping and flashing

Postion of ridge capping and flashing: in the open

Exposure: open

Material: galvanized

Position vs Exposure: P1 in the open - exposed to rain and sky

Location of salt deposition: roof of building, on the edges of the face surface

Roof material: aluminum

Figure 5 Data entry screen showing parameters for ridge capping and flashing

3.5 Window Frames

3.5.1 Parameters

Drainage condition: Two cases are considered, that is, drained or not drained. Not drained will affect the classification of state 3 by extending the hours the surface is considered to still be wet.

Exposure: Similar to downpipes, the exposure for window frames will be in the *open* and *sheltered*. For *sheltered* exposure the drainage condition possible is '*drained*'. The case of '*not drained*' is not considered. For *open* exposure the deposition of salt is only considered at '*other positions'* of the building face.

Material type: There are 3 types of window frames material that are considered namely *aluminium*, *coated aluminium* and *galvanized steel*.

For each material considered, there are 12 different possible scenarios that would be considered and are listed in Table 17:

Table 17 Possible cases for windows

Case	Building Face	Exposure	Face Position	Drainage
1	front	open	other positions	drained
2				not drained
3	side			drained
4				not drained
5	back			drained
6				not drained
7	front	sheltered	edges	drained
8			other positions	
9	side		edges	
10			other positions	
11	back		edges	
12			other positions	

3.5.2 Deposition of salt

For window frames the deposition of salt is on the *front*, *side* and *back* of the building around the *edges* and other *positions* of the roof surface.

Using this approach eliminates the need to implement separately the orientation factor which was described in previous documentation.

Face factors are defined for the different faces.

3.5.3 State of Surface

For window frames, the rule for state 3 classification is similar to downpipes except in this case the extension of state 3 by an additional N hours only applies when the drainage condition is *not drained* and the rain > X mm.

3.6 Steel Supports

3.6.1 Parameters

Drainage condition: Two cases are considered, that is, drained or not well drained which is associated with cracks or joints in the concrete. Similar to window frames, not drained will affect the classification of state 3 by extending the hours the surface is considered still wet.

Exposure: Similar to window frames, the exposure for steel supports will be in the *open* and *sheltered*.

Material type: There are 2 types of steel supports material that are considered namely galvanized and zincalume.

For each material considered, there are 8 different possible scenarios that would be considered and are as listed in table 18.

Table 18 Possible cases for steel supports

Case	Position	Exposure	Building Face	Face Position	Drainage
1	others	open	front	edges	drained
2					not well drained
3				other positions	drained
4					not well drained
5		sheltered		edges	drained
6					not well drained
7				other positions	drained
8					not well drained

3.6.2 Deposition of salt

For steel supports the deposition of salt is assumed on the *front* of the building around the *edges* and other *positions* of the surface.

3.6.3 State of Surface

For steel supports, the rule for state 3 classification is similar to window frames. The extension of state 3 by an additional N hours only applies when the drainage condition is *not drained* and the rain > X mm.

3.7 Subfloor Members

3.7.1 Parameters

Drainage condition: Two cases are considered, that is, drained or not well drained. Similar to steel supports frames, not drained affects the classification of state 2 by extending the hours the surface is considered still wet.

***Ventilation factor*:** For subfloor member there is a ventilation factor which is dependent on the ventilation rates. There are 3 levels of ventilation and is classified as *high*, *medium* and *low*. The ventilation condition in turn affects the time a surface remains wet after wetness from a salt wetting period that is a state 2 condition.

A ventilation factor is a constant which is associated with each level of ventilation as shown in Table 19.

Table 19 The ventilation factors for subfloor members

Ventilation level	Factor
High	1
Medium	0.5
Low	0.2

Exposure: The subfloor being located inside the building, it is assumed to be fully sheltered and not exposed and hence the subfloor members are only considered for sheltered exposure.

Material type: There are 3 types of subfloor members material that are considered namely *galvanized*, *zincalume* and *bare steel*.

For each material considered, there are 6 different possible scenarios that would be considered and are as listed in Table 20.

Table 20 Possible cases for subfloor members

Case	Position	Exposure	Building Face	Drainage	Ventilation
1	others	sheltered	front	drained	high
2					medium
3					low
4				not well drained	high
5					medium
6					low

3.7.2 Deposition of salt

For subfloor members the deposition of salt is the *front* of the building with no face position considered.

The figure below shows the data entry screen for entering the face factor, the factors for the different level of ventilations and also the formula for calculating the rate of salt deposition for subfloor members.

The rate of salt deposition is defined as:

$$\delta = \beta * \nu * \alpha \qquad \text{…Eqn(20)}$$

where β is a factor defining the effect of the face of a building,
ν is the ventilation factor, and
α is the salt deposition in mg/m^2 for exterior exposure.

β is defined as 0.6 for sub-floor members and ν takes the values defined in Table 18.

3.7.3 State of Surface

The implementation of the state 2 classification rule for subfloor members is similar to that of state 3 classification in other components.

The extension of the surface in state 2 by N additional hours only applies if both the surface is classified as in state 2 using the condition $RH_s > \varepsilon$ and the drainage condition is *not drained*. The number of additional hours that a surface remains as wet will depend on the ventilation level. The value of ε depends on the salt deposition D according to the list below:

$0 < D < 6$	$\varepsilon = 100$,
$6 =< D < 21$	$\varepsilon = 75$
$21 =< D$	$\varepsilon = 35$

where D is in mg/m^2.

The extended wet hours for the different ventilation rates are: 0 (high), 24 (medium) and 48 (low).

3.8 Testing of Models

The models for the different building elements are tested using data in the vicinity of Cairns where the salinity is 4.0 and 40 mg/m^2.day respectively for Benign and Marine conditions, average humidity is 74% and rainfall 1764 mils.

3.8.1 Failure conditions

The model generates a mass loss per year so that in order to calculate a predicted life then equation 21 is used to calculate the mass loss over a number of years.

$$ML = Al^* T^n \qquad \text{….. Eqn(21)}$$

where ML is mass loss over n years and Al is the mass loss in one year.

The end point or failure varies for the material under consideration and is defined as:

ML= 165 for galvanized
ML= 90 for zincalume
ML= 15 for aluminium

3.8.2 Results

The results for the different building elements in the different cases are listed for the two environments (Benign and Marine) using the salinity, average humidity and rainfall for near Cairns. These are shown in Table 21.

The results generated using the different component models are of the same order as experimental results and those found in the Delphi survey, but all have been derived independently.

Table 21

Component	**Material**	**Environment**	**Parameters**	**Case**	**Annual loss**	**life**	**n**
Roof	galvanised	Benign	Open-Edges-normal	Clean	6.4	>50	0.5
Roof	galvanised	Benign	Open-edges-normal	Not clean	22	29	0.6
Roof	Galvanized	Marine	Open-edges-normal	clean	35	13	0.6
Roof	Galvanized	Marine	Open-edges -normal	Not clean	118	2	0.6
Gutters	Galvanised	Marine	Open-front face-edge-edge		39	11	0.6
Gutters	Galvanised	Benign	Open-front –face edge-edge		11	>50	0.5
Gutters	Galvanised	Marine	Sheltered-front face-edge		99	3	0.6
Gutters	Galvanised	Benign	Sheltered-front face-edge		22	29	0.6
Gutters	Galvanised	Marine	Open-front face –bottom -edge	Cleaned	59	6	0.6
Gutters	Galvanised	Benign	Open-front face –bottom -edge	cleaned	11	>50	0.5
Downpipes	Galvanised	Marine	Open-exterior-edge		49	8	0.6
	Galvanised	Benign	Open-exterior-edge		7	>50	0.5
	Galvanised	Marine	Sheltered-exterior-edge		123	2	0.6
	Galvanised	Benign	Sheltered-exterior-edge		24	25	0.5
		Marine	Open-interior -edge		51	7	0.6
		Benign	Open-interior-edge		11	>50	0.5
		Marine	Open-interior-edge	Blocked	137	1	0.6
		benign	Open-interior-edge	blocked	33	15	0.5
Ridge Cap	Galvanised	Marine	Open-edge	galvanised	36	13	0.6
		Benign	Open-edge	galvanised	12	>50	0.5
Ridge Cap	Galvanised	Marine	Open-edge	zincalume	52	7	0.6
		Benign	Open-edge	zincalume	17	43	0.6
Steel Support	Galvanised	Marine	Open-other positions	drained	44	9	0.6
		Benign	Open-other positions	drained	8.4	>50	0.5
Steel Support	Galvanised	Marine	Sheltered-edge	drained	122	2	0.7
		Benign	Sheltered-edge	drained	23	27	0.6
Steel Support	Galvanised	Marine	Open-other positions	Not well drained			
		Benign	Open-other positions	Not well drained	36	13	0.6
fasteners	Hot dip-head	marine	Open-edge head above roof sheet	compatible	53	32	0.7
		benign	Open-edge head above roof sheet	compatible	16	>50	0.7
fasteners	Hot dip -head	marine	Open-edge head above roof sheet	Non -compatible	136	8	0.7
		benign	Open-edge head above roof sheet	Non-compatible	37	38	0.7
fasteners	Zinc plated - head	marine	Open-edge head above roof sheet	compatible	53	5	0.7
		benign	Open-edge head above roof sheet	compatible	16	28	0.7

Component	**Material**	**Environment**	**Parameters**	**Case**	**Annual loss**	**life**	**n**
fasteners	zincplated -head	marine	Open-edge head above roof sheet	Non -compatible	136	6	0.7
		benign	Open-edge head above roof sheet	Non-compatible	37	1	0.7
fasteners	Hot dip-head	marine	Open-edge , shank below roof but not embedded in beam	Compatible	159	6	0.7
fasteners	Hot dip-head	benign	Open-edge shank below roof but not embedded in beam	Compatible	39.8	48	0.7
Roof	Zincalume	Benign	Open –edges-normal	Clean	4.8	>50	0.5
Roof	Zincalume	Benign	Open –edges-normal	Not clean	8.2	>50	0.5
Roof	zincalume	Marine	Open –edges-normal	clean	10	39	0.6
Roof	Zincalume	Marine	Open –edges-normal	Not clean	24	9	0.6
Gutters	Zincalume	Marine	Open –edge -edge		11	33	0.6
Gutters	Zincalume	Benign	Open-edge-edsge		6.8	50	0.5
Gutters	Zincalume	Marine	Sheltered-front face-edge		11	33	0.6
Gutters	Zincalume	Benign	Sheltered-front face -edge		2.2	50	0.5
Gutters	Zincalume	Marine	Open-front face –bottom -edge	clean	11	33	0.6
Gutters	Zincalume	Benign	Open-front face –bottom -edge	clean	6.8	50	0.5
Downpipes	Zincalume	Marine	Open-exterior-edge		14	22	0.6
Downpipes	Zincalume	Benign	Open-exterior-edge		6.6	>50	0.5
Downpipes	Zincalume	Marine	Sheltered-exterior-edge		25	8	0.6
Downpipes	Zincalume	Benign	Sheltered-exterior-edge		6.9	>50	0.5
Downpipes	Zincalume	Marine	Open-interior-edge	cleaned	14	22	0.6
Downpipes	Zincalume	Benign	Open-interior -edge	cleaned	6.6	>50	0.5
Downpipes	Zincalume	Marine	Open –interior-edge	Blocked	31	6	0.6
Downpipes	Zincalume	benign	Open-interior-edge	blocked	11	33	0.6
Ridge Cap	Zincalume	Marine	Open-edge	Zincalume	13.5	24	0.6
		Benign	Open-edge	zincalume	9.5	>50	0.5
Steel Support		Marine	Open-other positions	drained	9	>50	0.5
		Benign	Open-other positions	drained	5	>50	0.5
Steel Support		Marine	Sheltered-edge	drained	22.4	10	0.6
		Benign	Sheltered-edge	drained	6.5	>50	0.5
Steel Support		Marine	Open-other positions	Not well drained	22	10	0.6
		Benign	Open-other positions	Not well drained	8.7	>50	0.5
Window	Aluminium	Marine	Open-front face -other position	drained	0.89	35	0.8
Window	Aluminium	Benign	Open-front face –other position	drained	0.27	>50	0.8
Window	Aluminium	Marine	Open-front face -other position	Not drained	0.39	>50	0.8
Window	Aluminium	Benign	Open-front face –other position	Not drained	0.27	>50	0.8

Component	**Material**	**Environment**	**Parameters**	**Case**	**Annual loss**	**life**	**n**
Window	Aluminium	Marine	Sheltered-front face -edge	Drained	1.37	20	0.8
Window	Aluminium	Benign	Sheltered –front face edge	drained	0.30	>50	0.8

APPENDIX A INSTRUMENTATION OF A DOWNPIPE

A.1 Introduction

A number of downpipes were examined internally to see where corrosion occurs. The downpipes where cut in half to expose the insides. An example of a square section Zincalume downpipe and a round galvanised downpipe are shown. In order to understand why the corrosion occurs in the places it occurs some understanding of how the downpipes are made is needed. Reference 1 details how square section downpipes are often constructed.

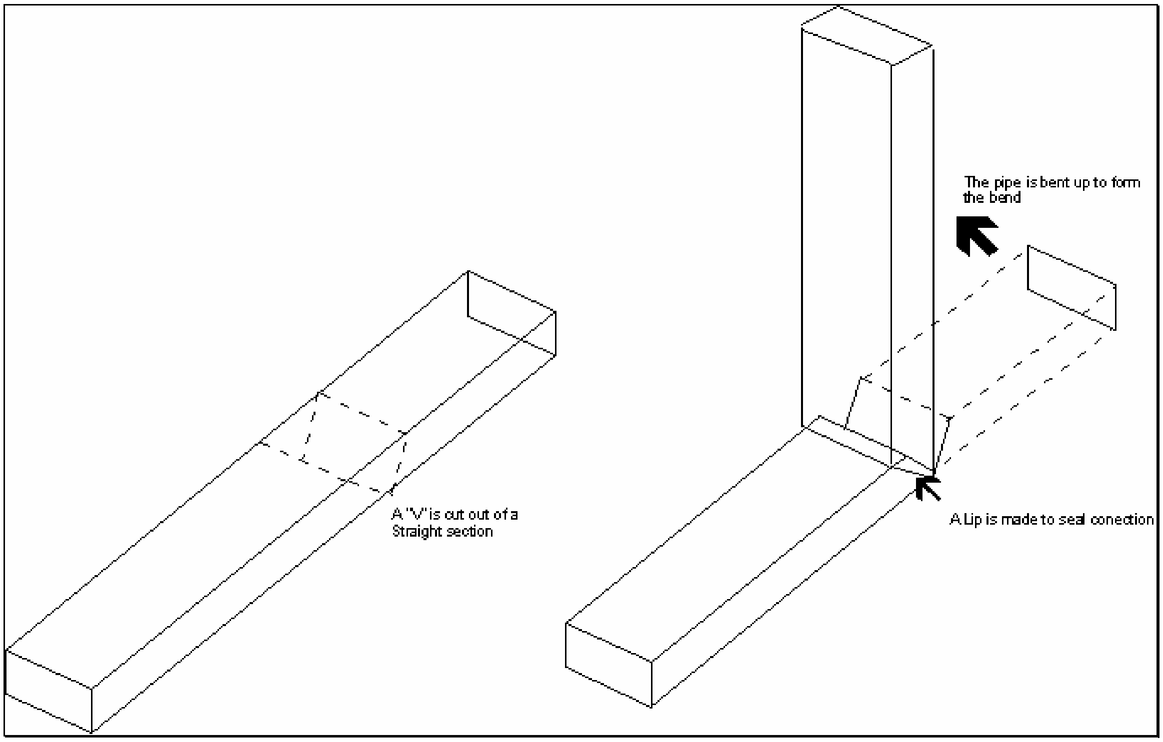


Figure A6, Construction of a bend in a square section downpipe

Figure A6, shows how a bend is constructed in square section downpipes. The bend is often pop riveted and sealed with silicone, in past years the join would have been soldered. The join creates a number of issues for the durability of the pipe. The cut edges will expose the metal to the environment unless it is well sealed by either additional paint or silicone. The lip created to assist joining the two halves can hold moisture and dirt, and thus increase time of wetness and therefore corrosion.

A.2 Inspected Downpipes

A.2.1 Square section downpipe

A number of downpipes were cut in half along the side and an example is shown in Figure A7. This is a square section down pipe with an insert used at the top of the downpipe to connect it to the gutter. This insert allows the downpipe to be adjusted to suit differing distances from the wall, where the main part of the downpipe is fixed and the gutter.

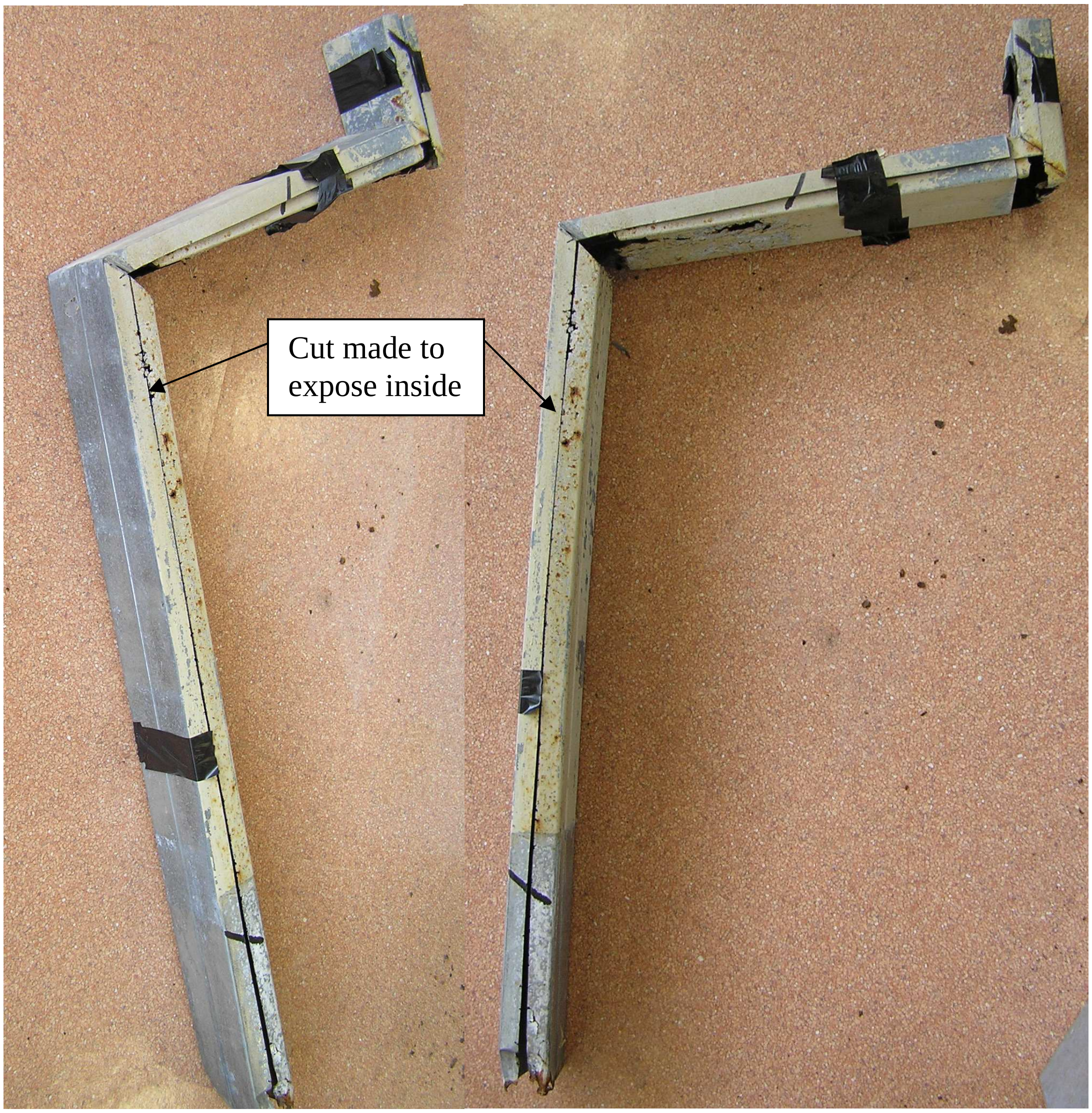


Figure A7, Painted Zincalume downpipe

The outside of the Square section Zincalume downpipe (Figure A7) shows that the only red rust (RR) present on the outside is where the downpipe has corroded from the inside to the outside. The downpipe is in good condition except where it would seem that the water from the gutter has flowed. The following figures illustrate the condition of the downpipe.

Figure A8, Top section of downpipe

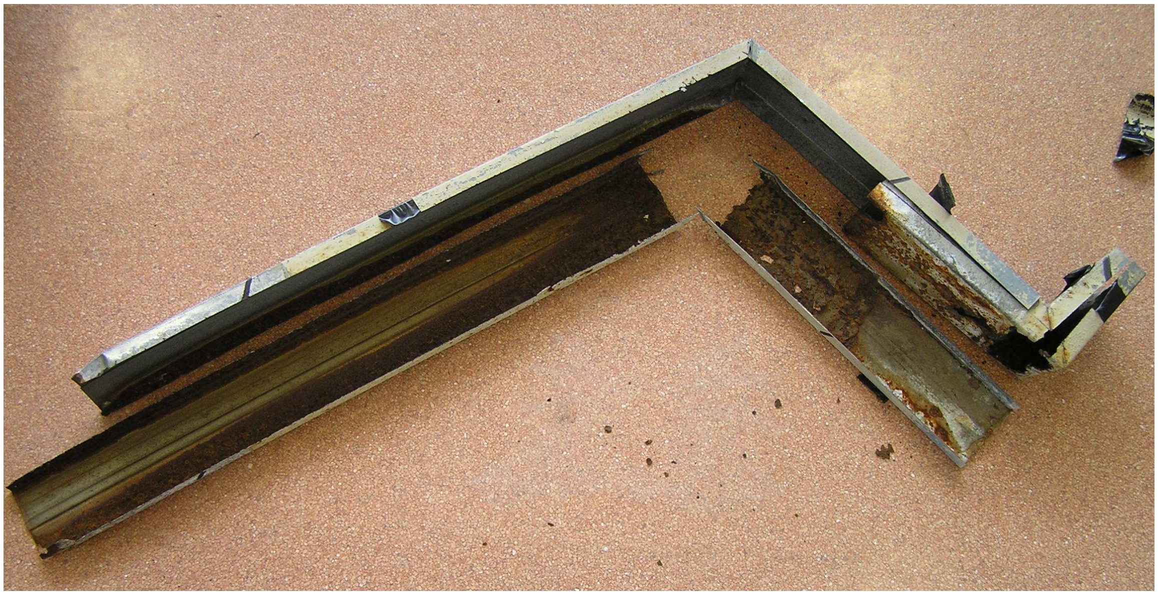


Figure A9, Inside of downpipe

Figure A5, Top section of downpipe showing insert section that connects to gutter

Figure A6, Inside insert which connects to gutter

Figure A7, very top section of downpipe

Figure A8, Top section insert showing no corrosion on the upper surfaces of the insert or the main part of the downpipe

Figure A9, Top section insert showing no corrosion on the upper surfaces of the insert or the main part of the downpipe

Figure A10, lower section of the downpipe

Figure A11, Insert used to connect the downpipe to the gutter, showing significant corrosion on lower surface.

A.2.2 Round section downpipe

The round galvanised pipe, Figure A12, shows that the most coating loss inside the pipe is on the areas that have water flowing over them and most coating loss on the outside of the down pipe is at a join and on what was a horizontal sheltered (unwashed) surface.

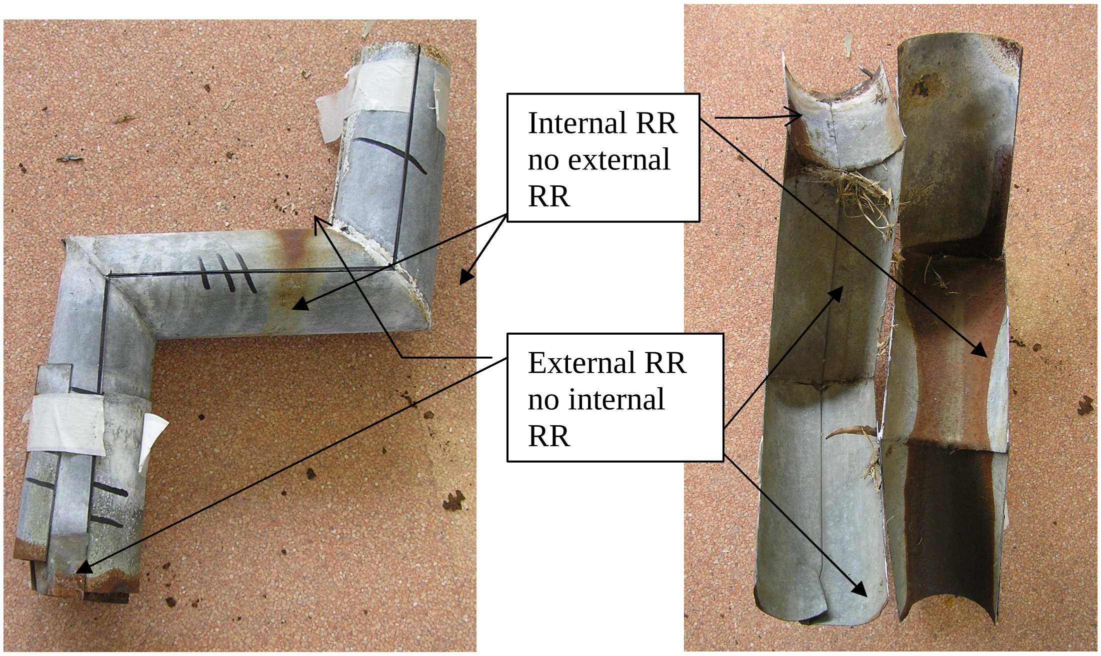


Figure A12, Round galvanised downpipe >30 Years

A.3 Monitoring a Downpipe

One downpipe was selected near some other monitoring to be used for instrumentation. A piece was removed from the non corroded side for access to install sensors.

Figure A13, Downpipe *insitu*

It can be seen inside the downpipe looking through the ends and in the access hole, that the water follows a certain path through the downpipe. This is shown by the rust patterns inside the downpipe. Figure A13 to Figure A18 show the rust patterns inside the downpipe.

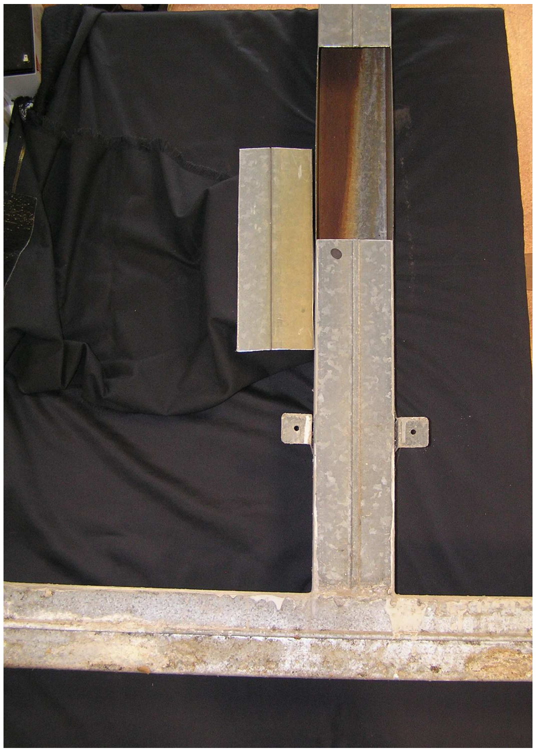


Figure A14, Bottom section of down pipe with piece removed for access

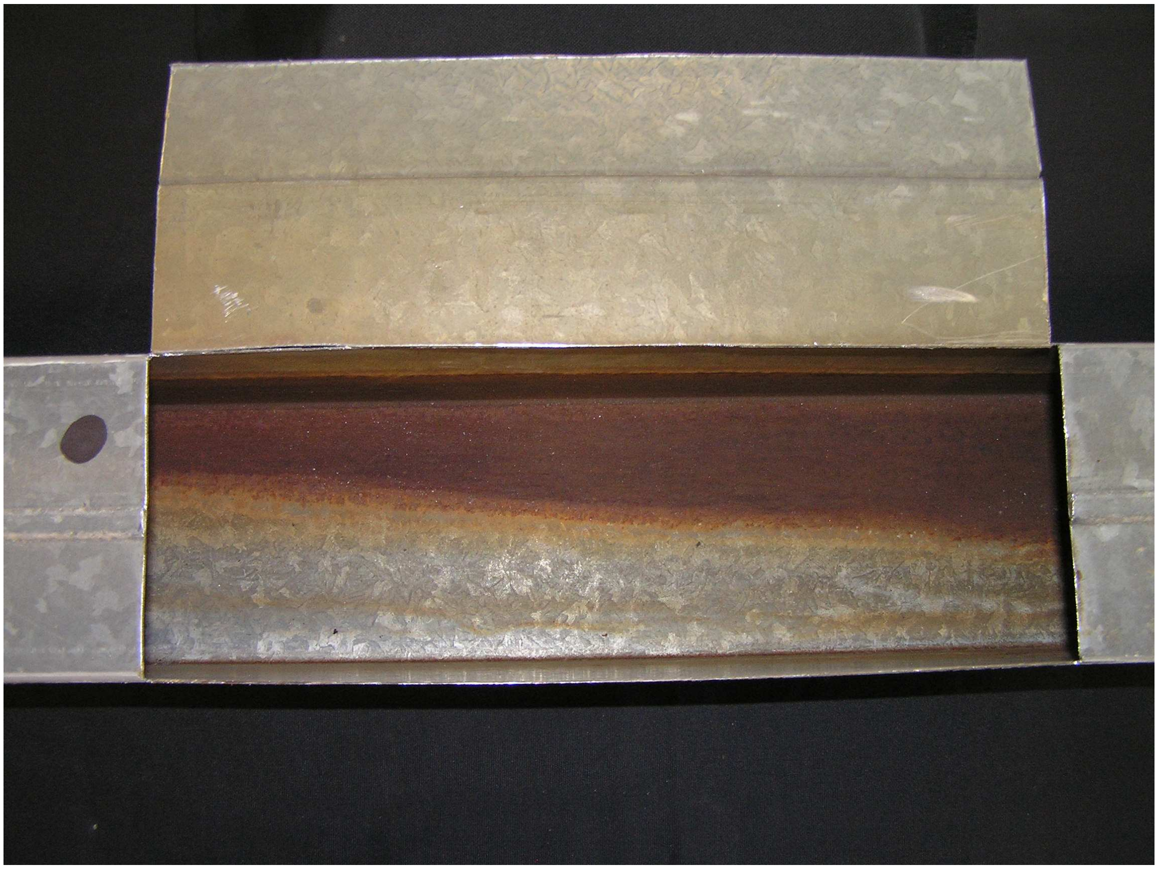


Figure A15, opening cut for access

Figure A16, from inspection opening looking up to bend before gutter connection

Figure A17, from inspection opening looking down

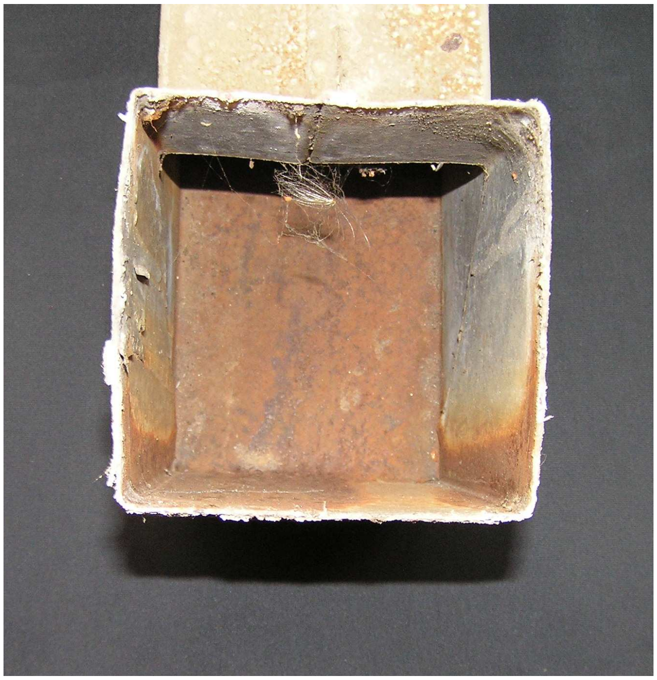


Figure A18, looking inside downpipe from gutter connection

Figure A19 shows the instrumentation installed in the downpipe. The instrumentation includes relative humidity, temperature, wetness and corrosion.

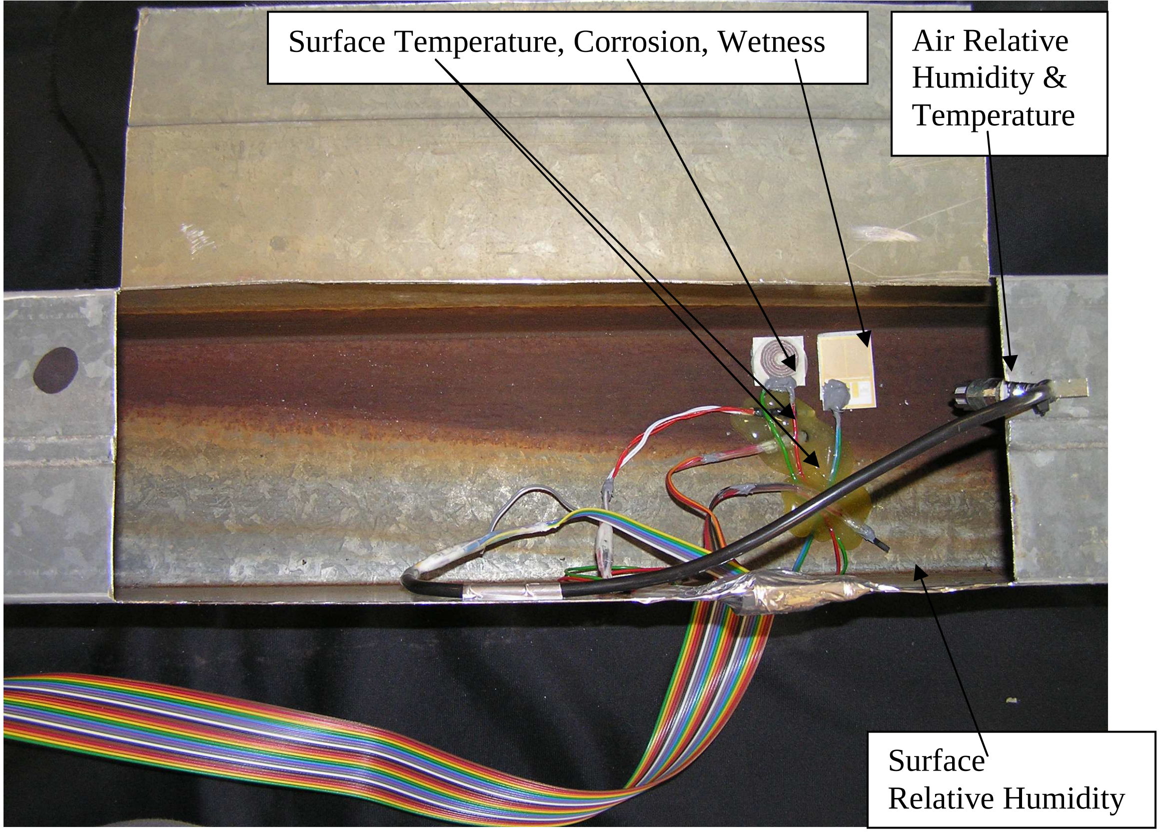


Figure A19, Instrumentation installed in the downpipe

Data has been collected from the downpipe over a number of months. Due to the extreme environment created in the downpipe the reliability of the sensors is not as good as would be liked. The relative humidity (RH) sensors are the least reliable as they do not work and are damaged when they get wet. The RH sensors can recover when they are dried but the reading becomes unreliable. Even with these problems the data collected does provide some interesting trends. A sample of the data collected is shown in Figure A20.

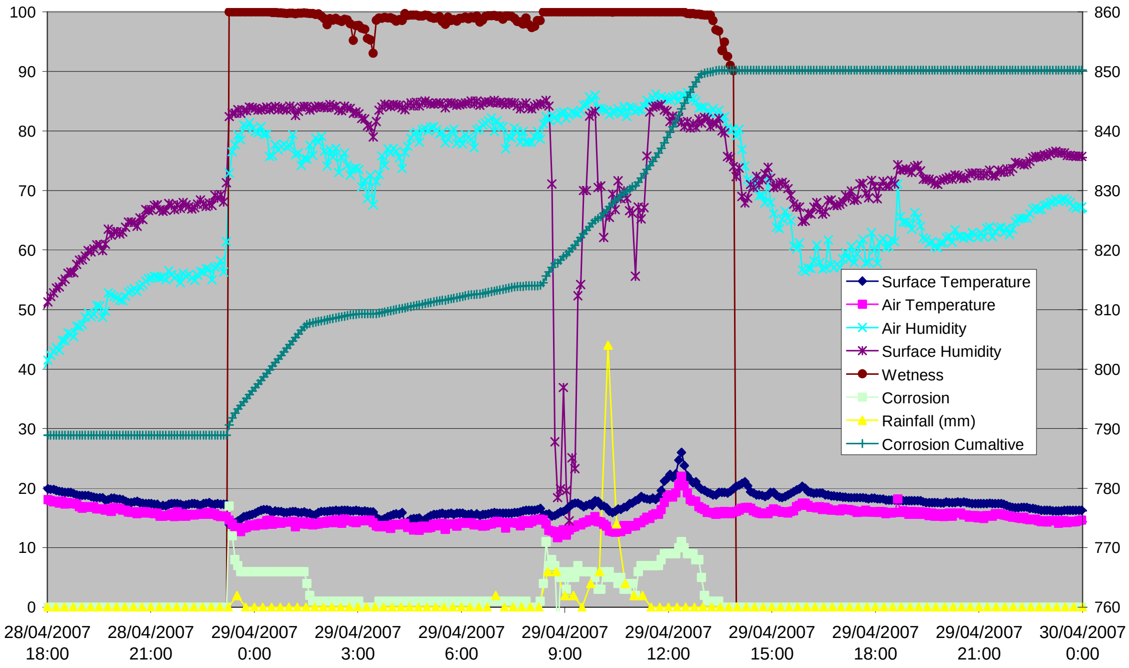


Figure A20, Sample of Data from the instrumented downpipe

The data shown in Figure A20 is complex but there are a few trends that are obvious. The yellow line is the rainfall readings from a weather station located within 250 metres of the downpipe, the readings have been multiplied by 10 so that there are clear on the graph, (a reading of 40 is actually 4mm). The rainfall readings are taken every 15 minutes and a rain depth of 0.2 mm is needed before the gauge reads, which means that light drizzle may not be recorded but could run of the roof and down the downpipe. Two main rain events occur in the graph. The first is before midnight on the 28/4 and the second is around 9am on the 29th. The rain event at 9am was a significant amount of rain and it can be seen that the surface humidity sensor has recorded incorrect readings probably due to being wet from the rain. It would have been expected that inside the enclosed area of the downpipe that the RH would have been closer to 100% than has been recorded. While the RH sensors are still recording trends in RH the sensors have probably been damage by water at some stage and the readings, while showing the correct trends are most likely inaccurate. Further work will be taken to install some protection for the RH sensors.

The wetness sensor, brown line, shows that the downpipe is wet from the first rain event right through until just before 3pm on the 29th. While the wetness is fairly consistent through the period the corrosion sensor, (light green line instantaneous corrosion, dark green line cumulative corrosion) shows that the sensor is corroding at different rates probably with the different amounts of water flowing through the downpipe.

A.4 References

1. http://www.stratco.com.au/pdfs/Stratco_DIY_Gutters_and_Downpipes.pdf

APPENDIX B INVESTIGATION OF pH OF LEAF LITTER

B1. Introduction

Leaf matter is often found in gutters and commonly it remains there for a significant amount of time. The conditions in the gutters are usually damp as the leaves provide a moisture barrier. This would contribute to the degradation of the metallic guttering. Different species of leaves have different effects on metallic gutters as it is found that they have varying pH values and the presence of dirt and other debris is also shown to affect the pH.

B2 Experimental Set-Up

1. A range of leaves were collected from gutters including the leaves directly from the tree which contributed to the leaf litter in the gutter. The aim was to collect from Australian tree species.
2. All specimens were photographed.
3. A 50 g dry mass of leaves/matter was measured and placed into 1 litre of distilled water. The leaf matter was pulverised/blended to make a suspension with some of the water. This was then tipped into a 'pre-weighed' plastic tray. The total mass was recorded and equalled 50 g (matter) + 1000 g (water) + empty tray mass.
4. The pH was measured on the first day and then after 1, 4, 12 and 22 days (Note: the water was readjusted to obtain the mass established in step 3 prior to each pH measurement).
5. After 21 days every sample was filtered to remove debris and leaf matter. The filtered solution was then analysed.
6. For each sample, a 10 mL aliquot of solution was pipetted into a measuring cylinder. Using a pipette 10 ml of 0.1 M KOH was added and then made up to 100 ml using MilliQ water. This solution was autotitrated against dilute hydrochloric acid (0.05 M) using an autotitrator.

It was interesting to note that it was difficult to pulverize/blend the Willow Myrtle (Agonis Flexvosa willd.) sample – it was very hardy and difficult to shred

B2.1 Details on the location of the leaf litter samples

The leaf litter was sourced from various locations as described below.

*Eucalyptus sample :*The leaf sample is a combination of the following species: Yellow Box E. Melliodora, Yellow Gum E. Leucoxylon and Red Box E. Polyanthemous.

*LAG 2 sample :*The house has a concrete tiled roof which (the tiles are about 6 years old). The gutters look like normal galvanised steel gutters, painted on the outside. The gutters in that area of the house are about 10 years old. The house is in Bentleigh.
LAG1 sample: A very large liquid amber tree hangs over the house and contributes nearly 99% of the litter. The gutters are from the 1950s – original gutters and are galvanised metal. The roof material is cement tile – probably low cement content as they are tile made just after the war.
WMG sample: Galvanised iron/steel gutters which are 40 yrs old, concrete tiled roof, house located in Cheltenham.
GA sample: Galvanized gutters which are 26 years old, glazed terracotta roof 26 years old, house is located in Glen Iris.
CG sample: Zincalume gutters which are 5.5 yrs old, tiled roof of the same age and the house is located in Clayton.

B3 Results

Some of the leaf litter samples developed mould over the duration of the experiment. Prior to measurements, samples were topped up with distilled water to the original mass.

Table B1 below shows the weights of the samples used for the analysis.

Table B1. Mass of leaf litter and solutions

Sample	Mass of empty container (g)	Mass leaf matter (g)	Total Mass with DI water (g)
LAG1	271.66	50	1321.66
GAT	281.53	13.83	571.96
EG	277.96	50	1327.96
LAG2	269.40	50	1319.40
LAT1	365.44	50	1415.44
GAG	262.76	50	1312.76
WMT	264.85	50	1314.85
LAT2	199.43	50	1249.43
WMG	265.38	50	1315.38
CT	278.31	50	1328.31
CG	368.76	50	1418.76
ET	241.97	33.10	937.07

After the experiment was set up, pH measurements were taken initially and again at 1, 4 and 22 days duration, as shown in Table B2.

Table B2. pH measurements of leaf litter solutions/suspensions

Sample	pH			
	Initially	1 day	4 days	22 days
LAG1	5.47	5.69	6.03	6.17
GAT	5.96	5.83	7.51	7.08
EG	5.26	5.26	6.20	6.16
LAG2	5.95	6.00	7.08	7.38
LAT1	4.14	4.28	4.00	4.38
GAG	6.72	6.45	7.15	7.36
WMT	5.18	5.12	5.19	5.56
LAT2	4.26	4.35	4.36	4.39

WMG	6.49	6.64	7.12	6.94
CT	4.46	4.37	4.18	4.04
CG	6.10	6.15	6.69	6.81
ET	5.73			

Abbreviations used for samples:
LAG1 = Liquid amber gutter sample 1
LAT1 = Liquid amber tree sample 1
LAG2 = Liquid amber gutter sample 2
LAT2 = Liquid amber tree sample 2
GAT = Golden ash tree sample
GAG = Golden ash gutter sample
EG = eucalyptus gutter sample
ET = Eucalyptus tree sample
CT = conifer tree sample
CG = conifer gutter sample
WMG = Willow myrtle gutter sample
WMT = Willow myrtle tree sample

Table B3 shows the elemental analysis of each of the leaf litter solutions. All the elements were analysed using the ICP (Inductively Coupled Plasma - Atomic Emission Spectrometer) and for chloride, concentrations were determined in duplicate by potentiometric titration with silver nitrate.

Most of the metallic content of the leaf litter solutions was in the very low range. The chromium content of all of the solutions was less than 0.01 ppm. Similarly for copper the values ranged from 0.03 to 0.12 ppm. The manganese values ranged from less than 0.002 to 5.7 ppm. Zinc had values ranging from less than 0.01 to 2.2 ppm. Aluminium ranged from 0.07 to 3.2 ppm and iron ranged from 0.05 to 4.8 ppm. It was noted that for the same tree species there was a difference in the values between the gutter sample and the tree sample.

Table B3. Elemental analysis of solutions

Sample Reference	Al	Ca	Cl	Cr	Cu	Fe	K	Mg	Mn	Na	P	S	Si	Zn
WMG	0.41	75	30	<0.01	0.04	4.8	25	9.0	<0.002	10	6.2	7.9	15	0.46
WMT	0.07	30	190	<0.01	0.10	0.55	131	20	<0.002	110	60	35	6.4	<0.01
LAT1	1.6	135	190	<0.01	0.12	0.18	165	105	2.3	60	30	15	30	2.2
LAT2	0.67	90	210	<0.01	0.05	0.15	192	120	5.7	80	55	20	45	0.79
LAG1	0.54	30	53	<0.01	0.06	0.41	41	8.0	0.19	20	15	3.2	35	<0.01
LAG2	0.24	44	85	<0.01	0.03	0.16	53	13	<0.002	40	20	3.7	25	<0.01
GAG	0.51	145	120	<0.01	0.06	3.7	107	45	<0.002	100	10	18	10	2.2
GAT	0.66	220	213	<0.01	0.08	0.96	156	70	<0.002	120	10	55	15	0.05
EG	0.63	70	120	<0.01	0.05	1.1	143	30	3.9	18	30	15	5.7	<0.01
CG	0.25	87	5	<0.01	0.03	0.05	20	10	<0.002	6.5	4.5	2.4	9.3	<0.01
ET	0.18	7.8	80	<0.01	0.02	0.12	61	9.5	0.75	90	15	10	0.2	1.0
CT	3.2	150	418	<0.01	0.05	2.8	226	40	<0.002	200	20	40	9.7	0.53

**Cooperative Research Centre
for Construction Innovation**
9th Floor, L Block
QUT Gardens Point
2 George Street
BRISBANE QLD 4001
AUSTRALIA

Tel: +61 7 3138 9291

Fax: +61 7 3138 9151

Email:
enquiries@construction-innovation.info

Web:
www.construction-innovation.info

Established and supported
under the Australian
Government's Cooperative
Research Centres Program