Structural resilience of core port infrastructure in a changing climate

Report series: Enhancing the resilience of seaports to a changing climate

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Work Package 2: Functional resilience of port environs in a changing climate – assets and operations

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Cover image

Port Botany © Flickr Creative Commons

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NOMENCLATURE

C_0	surface chloride concentration
C_{CO2}	time-dependent mass concentration of ambient CO_2
C_e	cement content
Cl	chloride deposition rate
C_r	chloride concentration threshold
d_{mean}	mean attack depth
d_{sap}	diameter of sapwood
D_1	diffusion coefficient after a year
D_{bar}	diameter of reinforcing bar
D_C	effective diffusion coefficient
D_{CO2}	CO_2 diffusion coefficient
D_{rain}	number of rain days per year
E	activation energy of the diffusion process
E_{ef}	elastic modulus of concrete
f'_c	concrete compressive strength
f_{sp}	concrete tensile strength
h	concrete cover
i_{corr}	corrosion rate of steel reinforcing bar
k_1	coarse aggregate correction factor
k_2	admixture correction factor
k_c	curing influence factor

k_{const}	construction parameter related to the construction configuration and protection of piles
k_e	environment exposure factor
k_{env}	environment parameter related to the effects of salinity and wave action at the port site
k_R	rate of loading correction factor
k_{sal}	salinity of seawater parameter
$k_{shelter}$	relates to the protection of pile to wave action
k_t	test method factor
k_{timber}	material parameter related to species of timber used, type of preservative and level of treatment used
k_{water}	climate parameter related to water
K	proportionality constant
L_{coast}	distance from the coast
m	corrosion type factor
M	corrosion loss per unit of exposed area
n	mass loss exponent
n_d	CO_2 age factor coefficient
n_m	age factor for microclimatic conditions (wetting and drying cycles)
r	marine borer attack rate
r_{crack}	rate of crack propagation
R	gas constant
RH	relative humidity
r_{heart}	rate of attack on heartwood
SO_2	sulphur dioxide concentration
t	exposure time
t_{cr}	time to severe cracking limit
t_{lag}	lag time
t_p	crack initiation time
t_{sap}	time for complete attack on sapwood
T	temperature
TOW	time of wetness
v	Poisson's ratio of concrete
w/c	concrete water-to-cement ratio
w_{lim}	crack width of severe cracking
x	depth of ingress
x_c	carbonation depth
Y	corrosion loss
α_{coast}	coast factor parameter
α_{exp}	site exposure factor
α_H	degree of cement hydration
α_{micro}	local shelter factor
α_{ocean}	ocean factor parameter
β_{coast}	coastal exposure condition factor
β_T	temperature factor
γ	unit weight
δ_0	thickness of porous zone
λ	conversion factor of corrosion rate
Ψ	factor dependent on diameter of steel reinforcing bar, concrete cover and thickness of porous zone

EXECUTIVE SUMMARY

The research presented here aimed to identify key port infrastructure elements affected by climate change, to understand the deterioration mechanisms relevant to these structural components, and forecast the rate of deterioration of structures over a period for which climate scientists could provide the necessary projections. The output is presented in the form of a software tool which provides the progression of a number of deterioration mechanisms affecting port structures according to six different climate futures. This will allow a port engineer to ascertain the changes needed in maintenance of port infrastructure over a 70 year time horizon. A methodology for calculating the changes to the life cycle cost of port structures is also presented with demonstration of the application of the method using three case study examples.

Three port corporations: Gladstone Ports Corporation, Sydney Ports Corporation (Port Botany) and Port Kembla Port Corporation provided a significant contribution to the project by meeting with the researchers, hosting researcher visits, attending workshops and providing the information necessary for validating the methodology developed.

Research commenced with visits to the ports and gathering of information to identify key port structures and the types of elements affected by climate change. After scoping the major structural elements and material types, researchers compiled the typical climate data required for modelling of impacts on these structural materials. The first major challenge for the research team was identifying reliable climate data for the three regions for a significant period into the future. The team worked with the CSIRO and Work Package 1 (WP1) to compile relevant data. It was decided to use two emissions scenarios and three climate future models. However, there were some extreme weather events for which reliable data could not be obtained. Therefore these events, such as extreme wind and storm events, were excluded from the analysis.

For the material deterioration mechanisms for which reliable input climate data were available and after a critical analysis of literature published to date, simulation models were compiled. An advanced probabilistic modelling approach was utilised to ensure that the variability of numerous input parameters were given due consideration. The methodology, initially developed as a proof of concept, was then converted in to a user friendly software tool to be used by ports engineers.

Outcomes indicate that the different climate scenarios do not significantly affect the deterioration progression between the base case (current climate) and the future climate scenario. However, the time taken by a structural element to reach a deterioration threshold: e.g. depth of carbonation of concrete reaching the concrete cover, is significantly reduced and in some occasions the threshold can be reached ten years earlier compared to the current climate. This indicates a significant increase in the frequency of maintenance activities required in future compared to the current practice to maintain structures to the levels currently adopted.

1. INTRODUCTION

Climate scientists are projecting change in the global climate with potentially profound impacts on infrastructure. Increases in annual globally averaged mean temperature, resulting in an increase in the number of warm days and nights and in temperature and precipitation extremes all are projected to occur with a high degree of confidence during the 21st century (IPCC, 2007). Climate models project that increasing atmospheric concentrations of greenhouse cases will lead not only to global warming but also changes in climatic variability – frequency, intensity and duration of extreme events such as hot days, heat waves and heavy storms.

The task of simulating potential future climatic conditions, and their impact on port infrastructure, is generally well beyond the resources available to a typical seaport structural engineer. Appropriate, fine-scale climate data is inherently difficult to collect. Large databases of historical climatic data can be obtained, but they are typically arranged in an ordered climate station format. This makes the task of identifying climate data for a particular port structure challenging. A more difficult problem is projecting future climate trends. The process involves selecting feasible greenhouse gas emissions scenarios, then choosing robust climate models to generate output variables which can be used to predict port asset performance.

The main aim of this project was to make the extraction of historical climate data and high quality climate change projections simple and applicable for a design or maintenance engineer. Research completed encompasses identifying types of port infrastructure vulnerable to climate change, establishing materials and exposure conditions, developing deterioration models based on current knowledge to simulate the effect of climate change on key seaport infrastructure and modelling the selected elements of infrastructure to derive outcomes which will aid in decision making. A considerable effort was concentrated on identifying input climate data most appropriate for the deterioration models developed.

A modelling approach is presented here for quantitative projections of damage probability on port infrastructure, taking into account the variability of material type, design considerations and environmental exposures with a changing climate. This deliverable reports on the research undertaken in the development of material deterioration models and their responses to a changing climate load. Using climate information drawn from historical weather records and future climate projections, existing deterioration models were refined to include climate data into modelling runs in order to analyse changes to deterioration rates of different materials when impacted by a change in climate variables. Outputs from this modelling process will assist port authorities in making informed decisions on maintenance and capital budget planning which allow for impacts of climate change.

This section covers the research methodology for the work scope of Work Package 3 (WP3). The broader, contextual framework of the research is illustrated in
Figure 1. The following 6 stages sit within this framework and were WP3's focus.

Stage 1: Seaport structural asset identification
Stage 1 involved the identification of components of port infrastructure vulnerable to the effects of climate change. The typical port assets were identified and broadly categorised by their operational environments.

Stage 2: Identification of climate data relevant for deterioration modelling

The climate data relevant for deterioration modelling was identified through close consultation with Work Package 1, Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology (BoM). This process required a thorough understanding of climate models, data projections available and their limitations.

Stage 3: Long term deterioration modelling

Stage 3 involved deterioration modelling of structural materials degradation due to climate change. Degradation mechanisms studied involved concrete, steel and timber structures.

Stage 4: Resilience matrices

This stage involved quantifying resilience using vulnerability and deterioration models.

Stage 5: Life cycle cost analysis

In the fifth stage, a methodology for life cycle costing was developed for a typical port asset and application of the methodology is demonstrated with case study examples. A cost optimisation tool was also developed to model cost effectiveness of deterioration treatment options.

Stage 6: Development of software tool for modelling deterioration

In the final stage, the models developed are captured in a user friendly software tool which can be used by port engineers in decision making on structural maintenance and refurbishment.

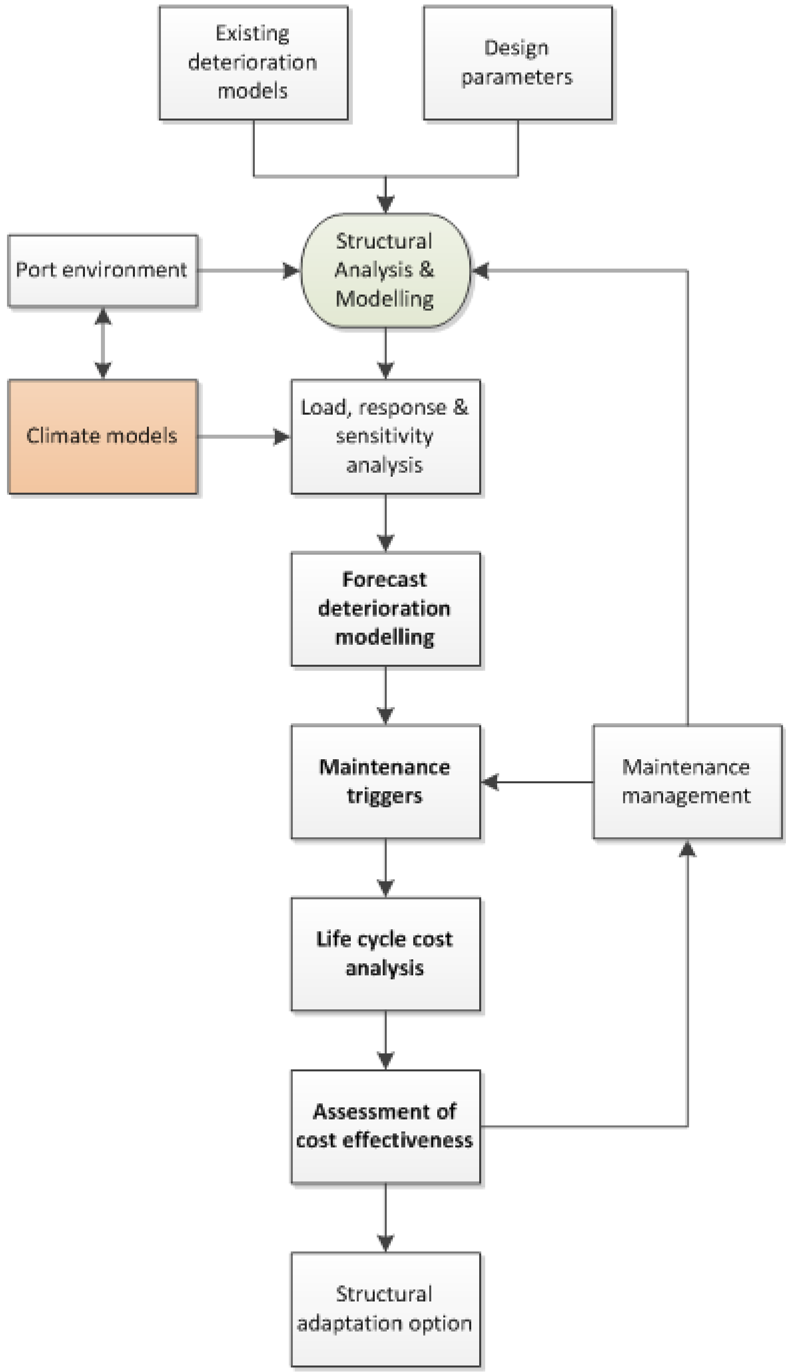


Figure 1: Climate change impacts assessment framework (Bolded areas denote the primary focus of this study)

2. UNDERSTANDING CLIMATE CHANGE: AN ENGINEER'S PERSPECTIVE OF VULNERABILITY ASSESSMENT

Historically, climate change was not deemed an important consideration in the design of port structures. However, today there is increasing awareness amongst engineers of the value of incorporating climate change factors into design and management of port infrastructures. Recognising the vulnerabilities associated with climate change is a valuable step towards better planning of new port infrastructure and reducing potential damage to existing infrastructure. Currently little information exists on climate risks and port infrastructure. To address this knowledge gap, research has been carried out in order to develop a methodology for assessing the vulnerability of different port assets to climate change in a systematic and comprehensive manner.

2.1 *Vulnerability assessment: climate change impacts relevant to port infrastructure*

Climate variability has little impact on infrastructure because the systems are built with large design safety factors in place to accommodate sudden impacts of loading (climate-related or not). These designs however consider relatively short term events. Long term changes in weather and increased climate extremes may have an impact, especially if environmental conditions are pushed outside the range for which the system was designed. These changes may have both negative and positive effects on the infrastructure system.

The overarching methodology for assessing the vulnerabilities of port structures was established based on a review of literature including international studies investigating the climate risks and adaptation efforts required by ports, climate analysis studies, and materials vulnerability studies. Current effects of climate variables on port structures were identified from information gathered from port authorities, published research work on material and structural degradation, and also by stakeholder interviews and consultation.

Three case studies along the eastern shore of Australia were selected: Port Kembla, Port of Gladstone and Port of Sydney (Port Botany site). These three ports represent various typologies (size of operation, type of freight handled and degree of specialisation), for example:

- Port Kembla and Port of Gladstone are bulk oriented (highly specialised) and export oriented
- Port of Sydney is container oriented (highly diversified) and import oriented
- The scale of operations in Port Kembla is relatively smaller than that of Port of Gladstone and Port of Sydney

A port's typology governs its structural make up and facilities. Therefore the typologies represented by these three ports allow for a broader scope of analysis, which in turn improves the understanding of the impacts of climate change on all types of port structures.

The general methodology that has been developed is summarised below:

- Identify port structures and categorise them according to the type of use and location as seaside, landside and transport infrastructure;
- Identify the type of material and structural form used in all the port structures (using port asset register and ground-truthing through on-site visits);
- Identify key climate variables;

- Identify the vulnerabilities of the port structures to different future climate variables;
- Identify the effect of climate variables on port structures considering the type of material in the structures and the type of structure, location, elevation, loading;
- Identify the most appropriate material deterioration models which can be used to assess the effect of climate variables on port structures.

An analysis based on materials has been determined as the most appropriate approach for this study because existing deterioration models are derived from behaviour of materials when subjected to various environmental conditions. To date climate change impacts have not been incorporated in these deterioration forecasting approaches.

2.2 *Identification of components of port infrastructure vulnerable to the effects of climate change*

When considering the potential impacts of climatic factors on ports, it is important to take into account local conditions of the area which can vary the type, range and magnitude of climate change impacts directly or indirectly affecting the port.

Port Kembla was selected as the major case study location for vulnerability assessment because it was accessible and has relatively well defined port operations encompassing a good mix of structural facilities. To provide a useful structure for the vulnerability assessment, the assets at Port Kembla were identified and broadly categorised by their operational environments into:

- Landside – berthing structures, protection barriers and port superstructures;
- Seaside – port channels and harbour basins; and
- Transport – road and rail infrastructure.

Categorising assets according to operational environment enabled them to be mapped in a clearer and more logical manner, providing a basis for systematic and comparative analysis.

2.2.1 Landside infrastructure

Berthing structures

The purpose of a berthing structure is mainly to provide a vertical front where ships can berth safely, for mooring of ships, loading and unloading goods. These include piers, wharves, jetties, bulkheads and docks. The berth fronts are constructed according to one of the following two principles - solid berth or open berth structures (Tsinker, 1995).

Solid berth structures are categorised when the fill is extended right out to the berth front where a vertical front wall is constructed to resist the horizontal load from the fill and a possible live load on the slab, as shown in Figure 2. The solid berth structures can be divided into three main groups, depending on the principle on which the front wall of the structure is constructed in order to obtain sufficient stability:

- *Gravity wall structure*: the front wall of the structure with its own deadweight and bottom friction will be able or self-sufficient to resist the loadings from backfill, useful load and other horizontal (e.g. cargo) and vertical (e.g. impact from vessels, wave and wind loading) loads acting on the berth wall structure itself.
- *Sheet pile structure*: the front wall is not adequate to resist any horizontal loads acting on the structure and must therefore be anchored to an anchoring plate, wall or rock behind the berth.

- *Structure with relieving platform*: this is a type of sheet pile wall with a relieving platform or a slab behind the sheet pile to reduce the horizontal forces against the sheet pile structure.

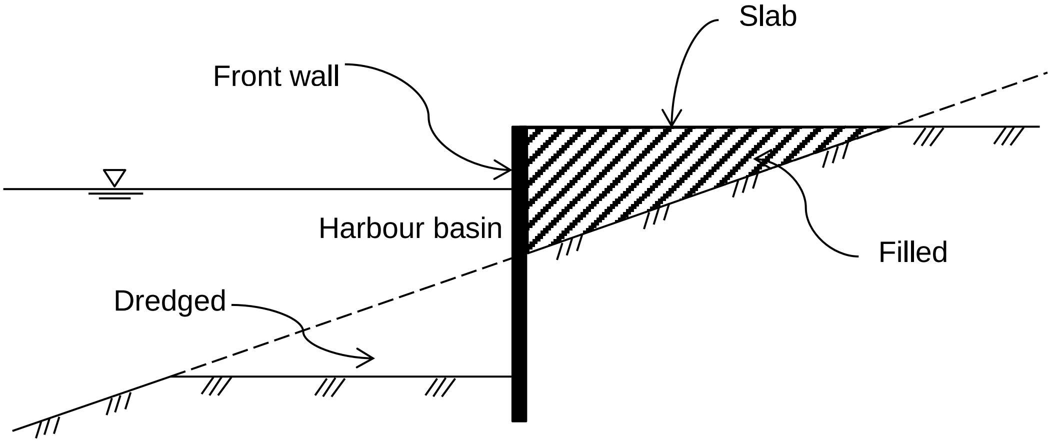


Figure 2: Solid berth

Open berth structures consist of a load-bearing slab constructed on columns (or piles) or lamella walls from the top of a dredged or filled slope and out to the berth front, as illustrated in Figure 3. The open berth structure can also be divided into the following main types, depending on how the front wall and platform are designed to resist loading and provide necessary stability:

- *Column or pile berths*: the berth platform and the berth front wall are founded on either columns or piles, or a combination of both, which do not have a satisfactory stability against external forces. Therefore, the berth structure is anchored, for instance by a friction plate in the filling. The structure is built simultaneously with the filling or after the fill has been established.
- *Lamella berths*: the berth platform and the berth front wall are founded on vertical lamellas, which provide the loaded berth structure with a satisfactory stability. The berth structures are stable enough in themselves to resist loads from ships, live loads, possible pressure from fill at the rear of the structure without the need for anchoring. In the same way as for gravity-wall structures, lamella berth is built by itself and then filled behind close up to the structure.

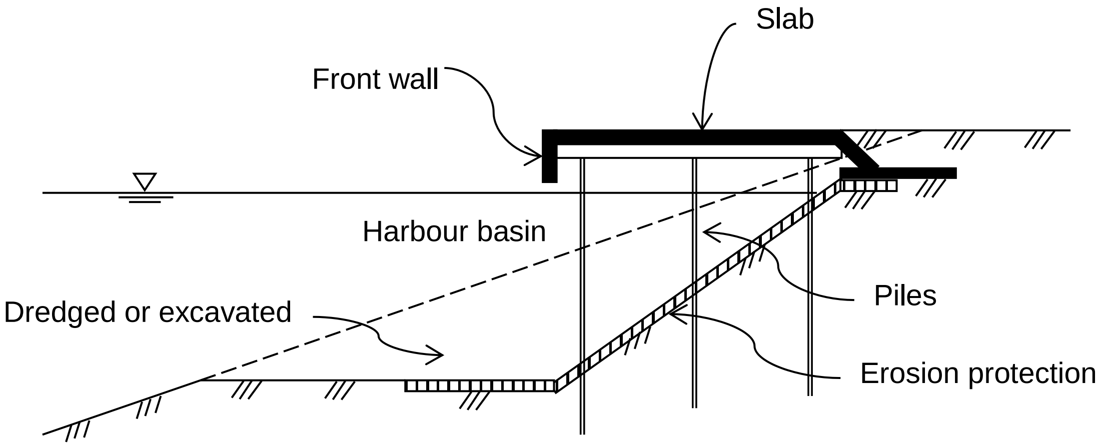


Figure 3: Open berth

Other typical physical subcomponents within the berthing structures and terminal are included in Table 1.

Table 1: Physical assets within berthing structures

Category	Berth subcomponents examples
Safety barriers	Bollards Handrails and guardrails
Equipment	Crane rails
Electrical services	Lighting Power supply (underground)
Hydraulics services	Potable and raw water supply Water drainage system Sewage disposal
Accessories and fitting	Access ladders Lifesaving equipment
Safety barriers	Bollards Handrails and guardrails
Port pavement	Kerbs Pavements

Table 2 below outlines the various climate change variables that impact berthing structures.

Table 2: Summary of climate change variables and impacts for berthing structures (IAPH, 2011)

Climate change variable	Direct impact on berthing structures	Indirect impact on berthing structures
• Increased severity of weather events (including rainfall, wind, cyclones and sea storms) • Sea level rise • Increased ocean swell • Ocean acidification	• Infrastructure damage and deterioration resulting from heavy storm activity • Inundation of infrastructure • Shifting tidal and splash zone level	• Increased maintenance and replacement costs • Increased risk of liability resulting from port damage

Protection barriers

Breakwaters are barriers constructed in the sea to provide protection for shipping against storms, and to create a safe area within which vessels may be moored, loaded or discharged. Breakwaters aim to protect the entrances to harbours and extend the shoreline out to sea. In comparison to seawalls, breakwaters can more efficiently dissipate energy generated by waves and storms. They may also be constructed offshore to reduce wave attacks on harbours. These structures may be made of concrete blocks, rock pikes or dolosse (double t-shaped concrete structures weighing around 20-40 tonnes). Breakwaters are most often used to reduce the effects of severe wave action inside harbours.

Seawalls are a common form of foreshore protection and are used in estuaries and on open ocean shores to protect against erosion or as retaining walls for reclaimed land. Loose armour seawalls are made of rubble or concrete in the form of loose blocks or dolosse.

Revetments are sloping structures used to armour shorelines against erosion. They are commonly used in rivers and estuaries and may consist of natural rock or concrete arranged in steps.

Sea-level rise combined with increased storm surges may lead to greater flood risk and sea incursion to port facilities. Port protection barriers such as those mentioned above are effective in most cases. However, sea level rise raises both the mean normal water and the height of waves during extreme weather events, which current breakwaters or seawalls may be unable to cope with. The severity and frequency of extreme events, such as cyclones, are extremely difficult to predict – making it challenging to build structures which take them into account. In many cases, port authorities are likely to employ a 'wait and see' strategy.

Wave action on a rubble-mound breakwater can produce rocking or removal of the armour units and their breakage or deterioration. Other direct and indirect impacts on protection barriers are outlined in Table 3.

Table 3: Summary of climate change variables and impacts for protection barriers (Esteban et al., 2011, IAPH, 2011)

Climate change variable	Direct impact on protection barriers	Indirect impact on protection barriers
• Increased severity of weather events (including rainfall, wind, cyclones and sea storms) • Sea level rise • Increased ocean swell	• Increased wave overtopping of protection barriers • Barrier material displacement or fracture • Erosion of barriers	• Exposure of harbour to ocean swells • Increased maintenance and replacement costs • Shipping delays • Damage to cargo and goods • Increased costs of sea trade and shipped goods • Increased risk of liability resulting from port damage

Breakwaters at Port Kembla

Port Kembla was the only case study port utilising protection barriers. Their protection barrier assets consist of two breakwaters (eastern and northern) and one seawall along the coal terminal. The location of these assets is indicated in the Figure 4.

Figure 4: Breakwaters at Port Kembla

The project team worked closely with the CSIRO to obtain climate projections for the Port Kembla area. Findings of note include sea level rise projected for NSW of 0.4 m in 2050 and 0.9 m in 2100. This would allow larger (breaking) waves to reach the breakwaters, resulting in larger forces on the seaward armour units and greater overtopping and forces on the leeward armour. There is no consistent modelling yet of wind although projections appear to indicate little change. There is however a possibility that the path of cyclones will shift south, thus exposing Port Kembla to significantly greater precipitation falling within a radius of 300 km of the eye of a cyclone by 2100.

The eastern breakwater at Port Kembla is 1186m in length. By current breakwater design practice, the eastern breakwater would be considered significantly under designed. The original rock armour was between the sizes of 10 to 40 tonnes on the seaward face (Spooner, 1938). Some of these rocks were replaced by 40 tonnes concrete armour units and hanbars over time since 1944 to maintain the structural integrity of the breakwater as the original rock source was limited (Carley and Cox, 2007).

The northern breakwater is 1013m in length. The eastern breakwater provides protection to the northern breakwater; this is evident as the repair quantities on the northern breakwater have been significantly reduced after the completion of the eastern breakwater. Furthermore, there are no reports of major damage since 1945 (Carley and Cox, 2007). The current breakwaters, in particular the eastern breakwater, have evolved to represent the minimum structure for which port operations are not frequently disrupted. Average repairs include 4000 tonnes replacement of armour units per year for each breakwater as the rock armour is constantly degrading. Other failure modes identified include: • Armour slumping • Armour dislodgement • Wave overtopping • Crest dislodgement • Armour degradation The coal loader seawall is approximately 1200m long and was constructed in 1980. The seawall has provided an embankment containing a roadway and rail mounted stackers servicing half of the total stockpile area. Since completion of the seawall, there has been accretion of sand in the front of the wall but the wall has yet to experience any waves approaching the design wave height.

Port superstructures

Port superstructure includes administration buildings, offices, warehouses, storage sheds and other terminal facilities. Increased frequency and intensity of extreme rainfall and wind could possibly cause damage to buildings. Accelerated degradation of materials, structures and foundations of buildings may occur through increased ground movement and changes in groundwater. Increased temperature and solar radiation could reduce the life of building and facility elements due to temperature expansion and materials breakdown of concrete joints, steel, asphalt, protective cladding, coatings, sealants, timber and masonry. This accelerated degradation of materials may reduce the life expectancy of buildings, structures and facilities, increasing the maintenance costs and leading to potential structural failure. Table 4 outlines potential direct and indirect impacts on port superstructure.

Table 4: Summary of climate change variables and impacts for port superstructure (Gallivan et al., 2009, IAPH, 2011)

Climate change variable	Direct impact on buildings	Indirect impact on buildings
• Increased variation in wet/dry spells • Increased temperature and heatwaves • Increase in extreme rainfall • Increased intensity of extreme wind • Sea level rise	• Failure of foundations • Degradation of superstructure materials • Increased storm and flood damage • Failure of roof and cladding	• Damage to cargo and goods • Increased costs of sea trade and shipped goods • Increased maintenance and replacement costs • Increased risk of liability resulting from port damage

2.2.2 Seaside infrastructure

Port channels and harbour basins

Generally, channels or waterways can be classified into the following groups:

- Group I: main traffic arteries which have satisfactory day and night navigational aids and where given depths are guaranteed
- Group II: similar to Group I, but with navigational aids for day navigation only
- Group III: important routes, which may have navigational aids and where depths are checked by regular surveys
- Group IV: local routes which have no navigational aids and where only estimates of depths are given

Channels and waterways can be further divided into unrestricted, semi-restricted and fully restricted channels:

- *Unrestricted channels* are channels or waterways in shallow water with widths of less than 10 to 15 times the beam of the largest ship using the channel, but without any dredging
- *Semi-restricted channels* are dredged channels in shallow water (Figure 5)
- *Fully restricted channels* are channels where the entire channel area is dredged, as shown in Figure 5

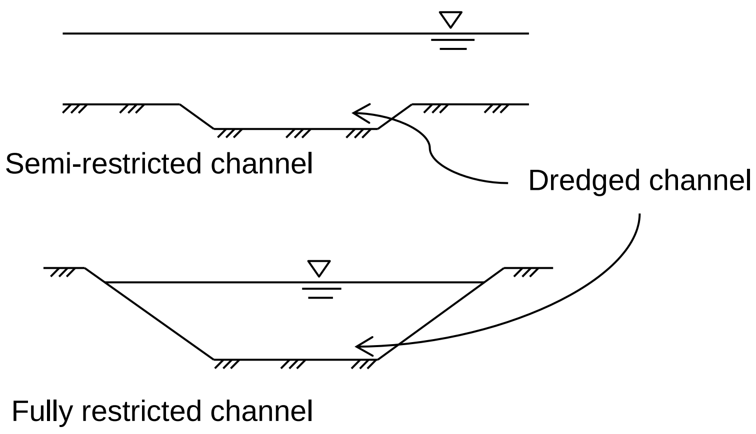


Figure 5: Semi-restricted and fully restricted channels

Port channels can potentially be impacted by sea level rise, affecting channel depth and therefore the navigability of the channels. Changes in precipitation and wave conditions can lead to altered sediment loads for channels, affecting navigability and dredging regimes.

The harbour basin can be defined as the protected water area which should provide safe and suitable accommodation for ships. They can be classified as natural, semi-natural and artificial. Climate change variables and impacts for channels and harbour basins are summarised in Table 5.

Table 5: Summary of climate change variables and impacts for channels and harbour basins (Gallivan et al., 2009)

Climate change variable	Direct impact on channels and harbour basins	Indirect impact on channels and harbour basins
• Wave action • Precipitation (increase/decrease) • Changes in seasonal precipitation • Sea level rise • Storms • Storm surge	• Change in water depth • Change in water flow • Increased/decreased sedimentation • Change in timing of seasonal high water and seasonal low water	• Bank failure • Increased load on structures • Changes to ships manoeuvrability • Reduced regularity of port traffic

Seaside infrastructure in case study ports

Port Kembla is a man-made port (which consists of Group 1 fully restricted channels mentioned earlier) and does not require annual maintenance dredging like some other river ports because of its geographic location. The depth at entrance between breakwaters is 16.75m and the depth of inner harbour entrance channel is 15.25m. While these assets are owned by NSW Maritime, Port Kembla Port Corporation is responsible for maintenance. Maintenance of these assets is condition-based with annual hydrographic surveys conducted on channels and basins in order to maintain its declared depths in its shipping channels and basins. Dredging is conducted on a 3 to 5 year cyclic basis.

A detailed analysis of the vulnerability of harbour basins and channels was not conducted as this project focussed on landside infrastructure.

2.2.3 Transport infrastructure

Road infrastructure

The road network within a port precinct is an important physical asset. Road infrastructure is a long-lived investment and consists of roads and bridges. Roads typically have design lives of 20 to 40 years and bridges of 100 years. Therefore, an understanding of the expected impacts of future climate change by asset managers could engender considerable cost savings in the long term. When considering the impact of climate change, it is necessary to consider the type, usage, age, pavement type, ownership and management structure for the components of road infrastructure that make up this network.

Table 6: Summary of climate change variables and impacts for road infrastructure (CSIRO et al., 2007)

Climate change variable	Direct impact on road infrastructure	Indirect impact on road infrastructure
• Increased temperatures and solar radiation • Increased temperature and heatwaves • Increased rainfall • Increased variation in wet/dry spells • Sea levels rise • Flooding	• Embrittlement and cracking of bitumen • Loss of water seal causing potholing • Low lying roads may be submerged • Damage to road foundations as a result of prolonged drought and low rainfall	• Increased maintenance costs to increase resilience • Temporary blocked road access. Re-routing to avoid affected roads • Interruption to commercial activities that depend on road transport

The location of road infrastructure will also be relevant in assessing the exposure to possible impacts of climate change. Roads in low lying areas are generally more susceptible to the effects of sea level rise and flooding, whereas roads located in hot climate zones tend to be vulnerable to the effects of increased temperature and solar radiation.

Road transportation in Port Kembla

Transport of commodities to or from Port Kembla is generally by road. There is road access to all port areas to both inner and outer harbours. Port Kembla Port Corporation currently owns and maintains approximately 5 km of road infrastructure.

Rail infrastructure

Rail infrastructure includes tracks, rolling stock, over and under-track structures, signalling and communication systems and related buildings, plants and equipment. As in the case of road infrastructure, the location of rail infrastructure will be critical in whether it is exposed to some climate-related hazards. The relevant parts of rail networks that service ports and port infrastructure by connecting ports to the hinterland are possibly susceptible to the effects of sea level rise, flooding and storm surges. Similarly, rail networks located in hot climate zones are most likely to suffer from train delays resulting from heat-affected swollen rail tracks (Nguyen et al., 2011).

Rail transportation in Port of Gladstone

Port of Gladstone relies heavily on the railway infrastructure to move their commodities, with rail accounting for approximately 80% of their total transportation modes.

During the 2011 floods in Queensland, coal supplies to the Gladstone port were restricted due mainly to rail lines between the mines and the port being adversely affected by severe rain events and flood waters. This led to operations stopping at the port, and it was noted that it was several months before the port was back to pre-flood capacity (Jobling, personal communication, August 2012).

Table 7: Summary of climate change variables and impacts for rail infrastructure (CSIRO et al., 2007, Nguyen et al., 2011)

Climate change variable	Direct impact on rail infrastructure	Indirect impact on rail infrastructure
• Increased temperatures and heatwaves • Increased intensity and frequency of storms • Sea level rise • Flooding	• Buckling of tracks • Submerging of low lying rail tracks which service ports • Signal and other electrical damage • Damage to rail foundations as a result of prolonged drought and low rainfall	• Delays, derailments and re-routing • Interruption to commercial activities that are dependent on rail transport • Increased maintenance and replacement costs • Increased risk of liability resulting from rail damage

The intense heat experienced in Melbourne during the 2009 summer illustrates a possible scenario of future climate change that would be applicable to the rail infrastructure within ports. Soaring temperatures can cause railway networks to buckle which, in turn, result in significant disruptions to services for extended periods of time (McEvoy et al., 2012, Nguyen et al., 2011).

2.3 *Physical port assets grouped according to construction material type*

The material used to construct each asset type is an important factor in determining the sensitivity of the asset to climate change. The construction materials which make up the assets previously identified can be listed as per

Table 8. Port Kembla was used to establish a baseline where their assets were categorised in material groups. This influenced the selection of deterioration models for the assets.

Table 8: Port Kembla assets and their construction materials

Asset type	Description	C	S	T
Protection barrier	Eastern breakwater	x		
	Northern breakwater	x		
	Revetment (The Cut)	x		
	West drain revetment	x		
	Coal loader seawalls	x		
Berths (jetties & wharves)	Berths 101 and 102	x		
	Berth 103	x		
	Berth 104	x		
	Berth 105-107	x	x	
	Jetty No 3 (Tug berths)			x
	Berth 201	x	x	x
	Berth 202-205	x		x
	Jetty No 4 (Berth 206)	x	x	x
	Old Cut tug berth	x		
Buildings	Administration building	x		
	Port operations building	x		
	Training and conference building	x		
	Port operations warehouse	x		
	Signal station	x		
	Survey boat building	x		
	Coal terminal	x	x	
	Multipurpose berth amenities		x	
	Multipurpose berth ship repairers amenities		x	
	Multipurpose berth cargo shed 1		x	
	Multipurpose berth cargo shed 2		x	
	Grain berth amenities	x		
	Grain berth substation	x		
Rail	Inner harbour - tracks 14.8 km, 30 turnouts, 5 bridges, 2 weighbridges, 1 level crossing, signalling, communications, electrical	x	x	x
	Outer harbour - tracks 15.1km, 74 turnouts, 2 bridges, 4 level crossing, signalling, communications, electrical, culverts and drainage systems	x	x	x

* C denotes concrete, S denotes steel, T denotes timber

Table 9 lists the deterioration mechanisms for each construction material and its sensitivity to corresponding climate variables. At this point, the interaction matrix was constructed to isolate the material elements that are likely to be affected by climate change. By doing so, the crucial deterioration mechanisms, such as corrosion of steel, and their related climate variables can be ascertained. A further explanation of climate variables which are most pertinent to the deterioration of port assets – sea level rise, precipitation, changes in wave conditions and higher temperatures – are explained in the next section.

Table 9: Material deterioration mechanisms matrix

Material	Deterioration mechanism	Climate variables							
		sea level rise	water table	temperature	rainfall/runoff	wave	wind	salinity	humidity
Steel	corrosion	tidal range, decade	n/a	air & ocean temp, avg & ext	n/a	mean, decade	mean, decade	mean, decade	mean & ext
	fatigue	n/a	n/a	n/a	n/a	mean, decade	mean, return period	n/a	n/a
	fracture	n/a	n/a	n/a	n/a	n/a	ext	n/a	n/a
Concrete	efflorescence	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	erosion (salt scaling)	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	mean, decade	mean, decade
	acid attack	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	sulphate attack	mean, decade	mean, decade	n/a	n/a	n/a	n/a	n/a	n/a
	alkali-silica attack	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	corrosion of steel reinforcing bar (chloride)	mean, decade tidal range	n/a	mean	3-day wet/dry period	mean, decade	mean, decade	mean, decade	n/a
	corrosion of steel reinforcing bar (CO_2)	n/a	n/a	n/a	no of wet days in 1 year	n/a	n/a	n/a	n/a
Timber	weather deterioration	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	n/a	mean, decade
	separation of cracks	mean, decade	mean, decade	mean air temp	no of dry days/yr, distribution	mean, decade	mean, decade	n/a	mean, decade
	decay fungi	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	insects & termites	n/a	n/a	mean air temp	n/a	n/a	n/a	n/a	mean

2.4 *Relevant climate variables*

While the type, range and the magnitude of climate change impacts will vary depending on local conditions, ports are expected to be directly and indirectly affected by climatic changes. Direct impacts may be caused by the change in climate variable itself, for example, increased temperatures may cause cracking or melting of bitumen, while indirect impacts may flow on from these direct impacts, such as restricted road access due to poor condition of the road.

Changes in sea level, precipitation, wave conditions and temperatures have been identified as the four primary climate variables that affect port structures. The generalised impact of these parameter changes are discussed below.

Changes in sea level

Sea level rise and the increased potential for storm surge is expected to increase extreme water levels and wave heights – thereby increasing the potential for wave overtopping and flooding which may affect physical infrastructure.

Port infrastructure assets are particularly prone to damage due to increased tidal and salt gradients, ground water pressure, corrosion of materials and greater splash zones due to heightened exposure. Sea level with respect to dock level is an important consideration for clearance of dock cranes and other structures. As such, any sea level rise changes could require some retrofitting of port infrastructure.

The navigability of shipping channels is also possibly affected by a change in sea level. While this may cause some channels to be more accessible to shipping farther inland, others could be adversely affected by changes in sedimentation rates and the location of shoals etc.

Rising sea levels, floods and inundation will have consequences for port transport infrastructure (rail and roads) and may involve damage to terminals, intermodal facilities, freight villages, storage and warehousing areas, containers and cargo. Extreme weather events (e.g. extreme storm surges) may also damage port hinterland connections, disrupting the intermodal supply chain and undermining transport connectivity. This would be of particular concern to port operators whose trade depends on well-functioning transportation networks in transit.

Changes in precipitation

Decreased precipitation can potentially result in increased ground movement, changes in the water table and associated increases in the salinity of soils. The combination of these changes could eventually accelerate the degradation of materials, structures, reinforcement and foundations; reduce the life expectancy of physical infrastructure; increase maintenance costs and, in the long term, contribute to structural failure.

Significant flood damage (magnitude and frequency) to road, rail and container marshalling yards may result from the increased frequency and intensity of extreme rainfall events.

The short term impacts of precipitation changes relate to pavement and drainage design, foundation conditions, the approach used to estimate the design flood and the development of targeted maintenance regimes. Longer term impacts may require changes in culvert design and the design and materials specification of road subgrade. It is important to note that transit storage sheds are not designed with proper guttering and drainage to cope with intense rainfall.

Changes in wave conditions

The effects of changing wave conditions on port structures are directly influenced by the extreme value of wave-induced load under long term distribution (which is necessary for a large deflection and a limit state strength analysis of these structures), and the long-term time history model of the wave-induced load. These two factors are needed to perform fatigue strength analysis. Breakwaters are typically designed based on historical wave data of the area, and are thus often not able to withstand the change in wave conditions brought about by climate change occurring in more recent years.

Overtopping of waves may cause damage to armour units in breakwaters, thereby allowing seawater to overflow onto port facilities and disrupting port activities. Constant overtopping of waves may lead to erosion or displacement of the units. A solution employed by most ports to manage this issue is to place new armour units on top of existing ones – an exercise which is both short-term and costly. This practice may need to be revisited as changes become more evident.

Changing temperatures

The majority of port infrastructure is affected by changing temperatures. For example, through the deterioration of paved areas, expansion stress and movement on steel bridges and rail tracks and the softening of asphalt which may lead to traffic-related rutting. Changing temperatures may also particularly affect structures and equipment made of metal such as warehouses and operating cranes.

3. DETERIORATION MODELLING

There is a lack of reliable models to predict deterioration as a function of time under a changing climate. To address this deficiency, numerical models involving simultaneous transient diffusion and long term deterioration reactions for various construction materials have been developed. These were derived from existing models and include the effect of variations in ‘climate properties’ as a function of time.

Moisture and temperature are major influences on port infrastructure deterioration. Other factors such as structural utilisation, material type, history of structure (previous maintenance), rehabilitation and construction works and other variables (such as geometry, material characteristics, orientation and environmental exposures) also influence degradation.

It has not been possible to examine the impacts of extreme weather events such as extreme rainfall, extreme temperature or flood frequencies which may also impact structural condition and operation. This research focussed on longer term, slow deterioration instead of sudden events which are not easy to project.

Four deterioration models were developed to assess structural elements performance: carbonation and chloride ingress models for concrete, marine borer attack for timber and corrosion of steel. These models were written in Microsoft Excel and Visual Basic for Application and later integrated into a software tool which will be further discussed in Section 5.

3.1 *Climate data for deterioration models*

The purpose of this section is to outline the data processing undertaken on the climate change data provided by CSIRO in preparation for input into the deterioration models described in greater detail later in this report. Looking into the future particularly to year 2070 is extremely difficult. Therefore, care should be taken in the use of the results presented in this report as these are based on a particular set of scenario assumptions used in the analysis and limited by a number of methodological uncertainties inherent in the approach taken. For example, the uncertainties in the levels of future emission scenarios, uncertainties in climatic responses to these scenarios and differences between the ranges of climate change models available (IPCC, 2000).

3.1.1 Climate modelling data

The CSIRO Division of Marine and Atmospheric Research was engaged to extract global and regional climate models for the period 1990 to 2070, producing results for a variety of climate variables relevant to the deterioration modelling (temperature, precipitation, salinity, etc) over 9 grid cells. Each grid cell (approximately 25 x 25km) is centred on the coast of the seaports in this study.

Two emission scenarios were selected for this research as they represent a high (A1FI) and moderate (A1B) greenhouse gas emission scenario respectively. Multiple atmospheric-ocean global climate models (AOGCMs) were used to project the climate variables and three possible climate futures were selected: a ‘most likely’ climate, a ‘hotter drier’ climate and a ‘cooler wetter’ climate. Details of the climate modelling work are separately reported (refer to WORK PACKAGE 1: Understanding Future Risks). The baseline is derived from the AOGCMs used in OzClim. Additional current and historical data were sourced online from the Bureau of Meteorology (BoM) and Integrated Marine Observing System databases.

3.1.2 Climate change data processing

Figure 6 outlines the data processing paths used to translate the CSIRO data sets into data inputs for deterioration modelling. The key elements of this processing included:

- Extraction of base climate, 2030 climate change, 2050 climate change and 2070 climate change data sets.
- Data interpolation was required to determine annual climate change over the period investigated.

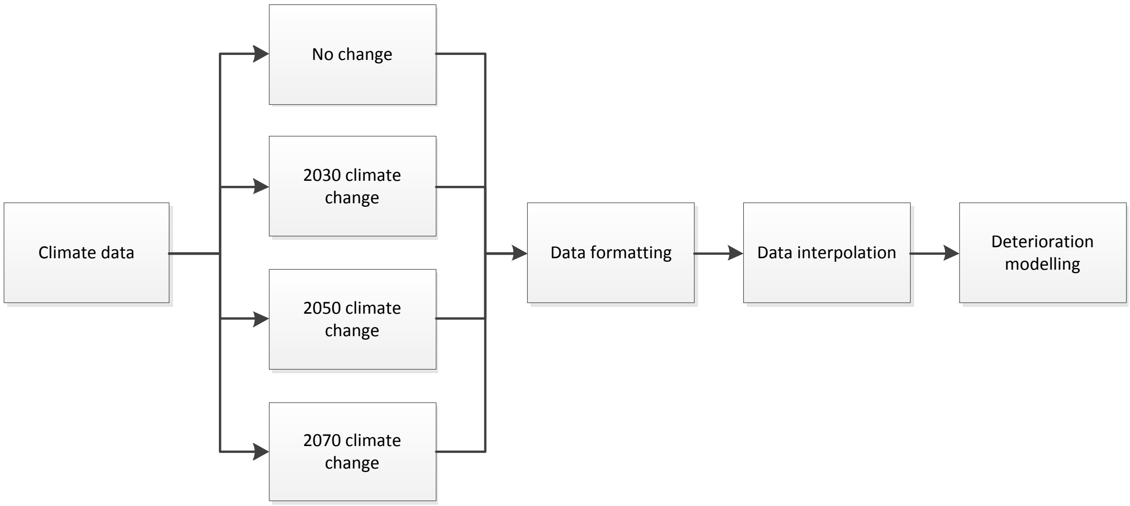


Figure 6: Data processing pathway

CSIRO data sets include in-built climate sensitivities. For example, changes in temperatures for all climate projections are expressed as a degree Celsius change per degree of global warming and changes in rainfall are expressed as a percentage change per degree in global warming. Hence, future climate data was determined using the following steps:

- Determine the mean annual value over a 30-year statistical data for a given site. The statistical data between 1975 to 2004 is taken as the base climate data as this correlates well with the baseline used in IPCC emission projections.
- Interpolate changes between climate periods.
- Apply changes to base climate.

Appendix 1 provides further details on the baseline data, climate periods interpolation and projected climate data used in the deterioration models. The next section summarises the climate results which were then written as climate inputs for the material deterioration models.

3.1.3 Climate data input for deterioration models

Carbon dioxide concentrations

The aggregated CO_2 concentrations provided in Figure 7 were applied to the deterioration models. This projection is applicable to all three locations studied. Concentrations in parts per million (ppm) can be converted into molar concentrations considering ambient temperatures and assuming ideal gas behaviour.

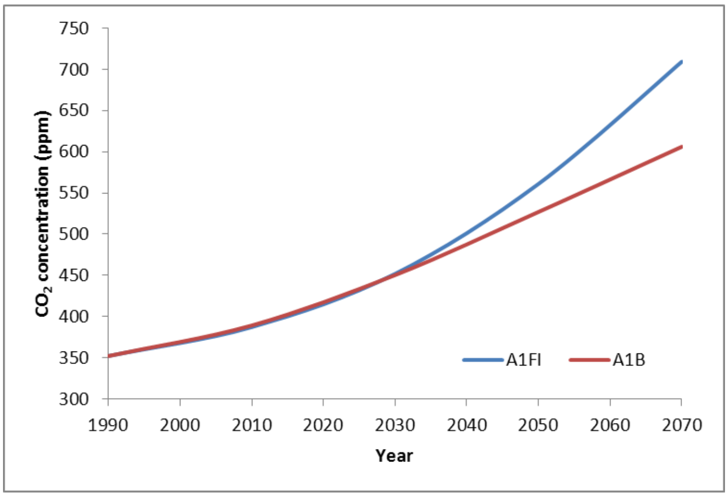
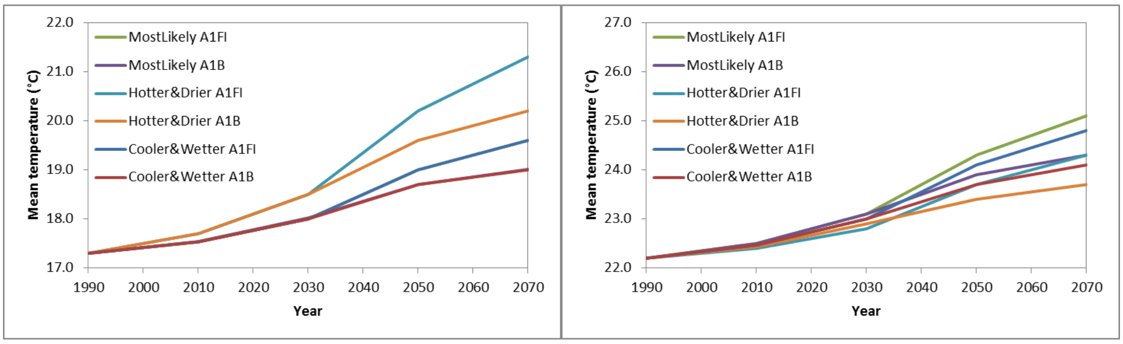


Figure 7: Projected annual mean atmospheric CO_2 concentration

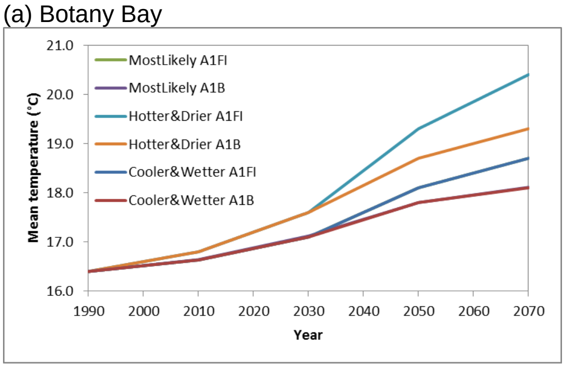
Surface temperatures

Figure 8 shows the projected mean temperature for Botany Bay, Gladstone and Port Kembla region using the corresponding baseline data provided. A rise in mean surface temperatures is projected for the three areas specified over the next fifty years, thus continuing the trend of warming in Australia.



(a) Botany Bay

(b) Gladstone

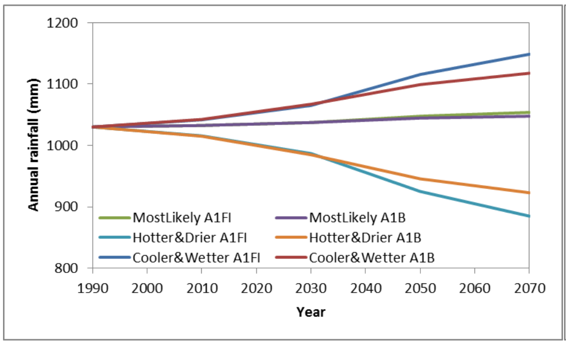


(c) Port Kembla

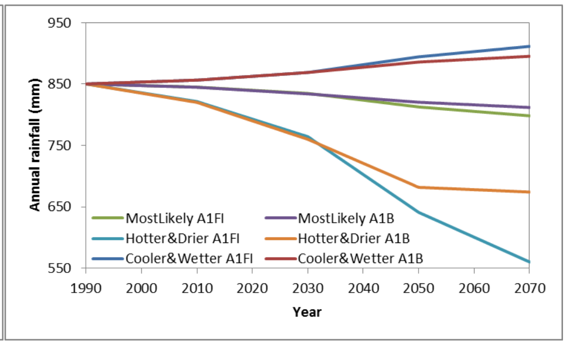
Figure 8: Mean surface temperature projections

Annual rainfall

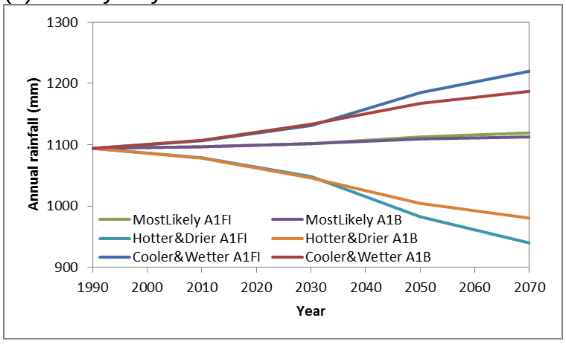
Figure 9 shows the projected annual rainfall for Botany Bay, Gladstone and Port Kembla until 2070.



(a) Botany Bay



(b) Gladstone

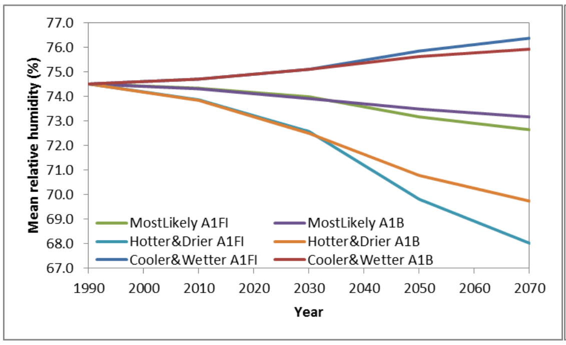


(c) Port Kembla

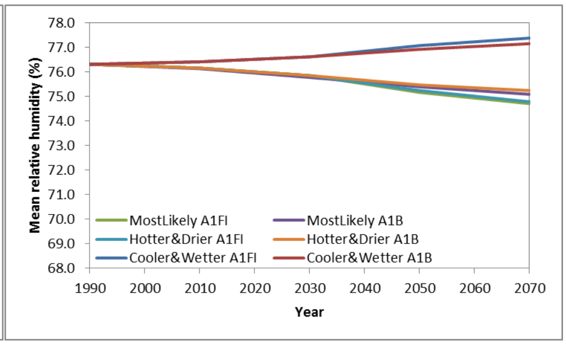
Figure 9: Annual rainfall projections

Relative humidity

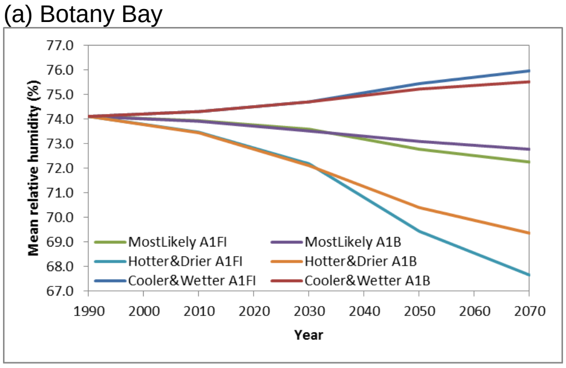
Figure 10 depicts the projected annual mean humidity for regions investigated. These were then applied to the baseline relative humidity. The relative humidity in Botany Bay and Port Kembla at 2070 is projected to range between 67% to 77% higher compared to relative humidity in 1990, while for Gladstone, this is projected to have a smaller range of between 74% and 78%.



(a) Botany Bay



(b) Gladstone

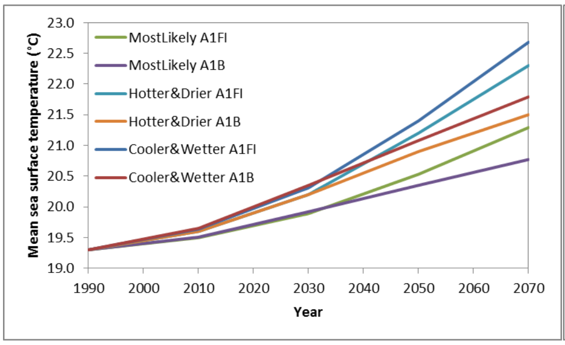


(c) Port Kembla

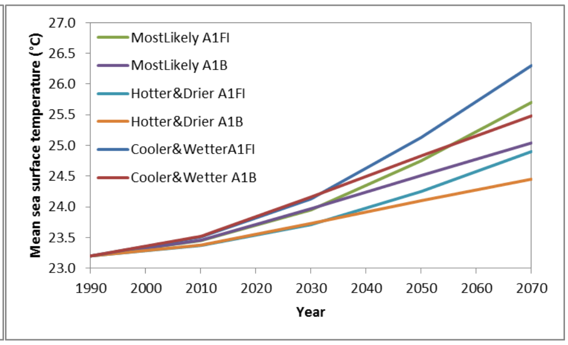
Figure 10: Mean relative humidity projections

Sea surface temperatures

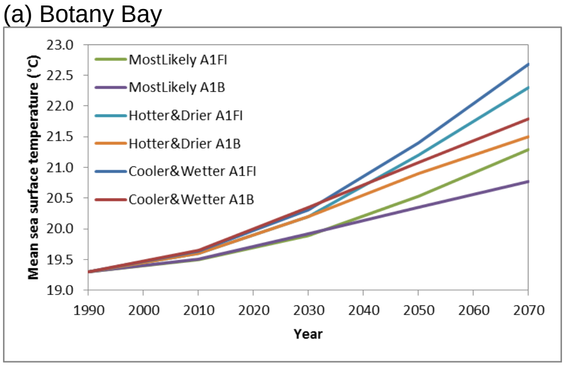
Figure 11 provide a summary of mean sea surface temperatures for the respective AOGCMs when applied to the baseline climate. Mean summer temperatures were used instead of mean annual temperatures as they were viewed to be more suitable for the timber deterioration models. A rise in mean sea surface temperatures is projected for the three areas specified until 2070, thus continuing the trend of warming of the oceans surrounding Australia.



(a) Botany Bay



(b) Gladstone

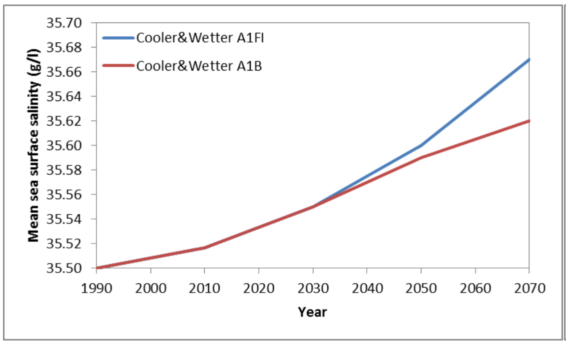


(c) Port Kembla

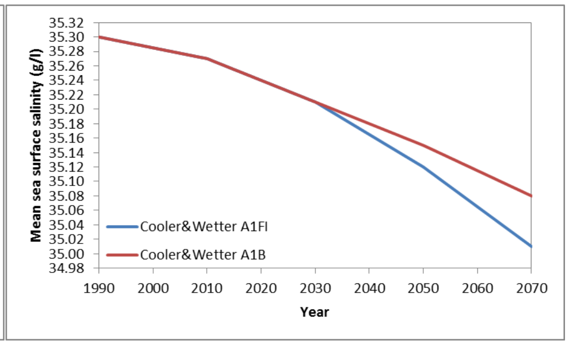
Figure 11: Sea surface temperatures projections

Sea surface salinity

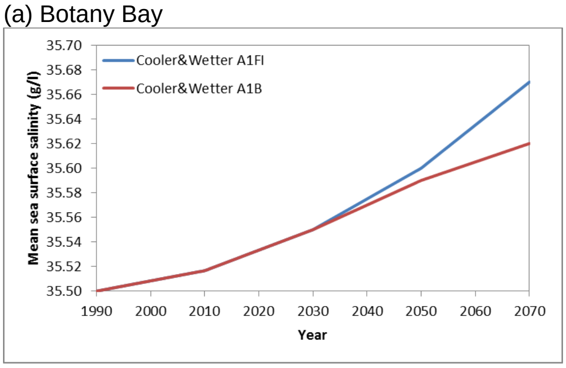
The sea surface salinity change for all investigated ports is reported in Figure 12. It is important to note that data projection is only available for the MIROC(hires) model. The sea surface salinity in Botany Bay and Port Kembla in 2070 is projected to increase by between 35.50g/l to 35.68g/l from the sea surface salinity recorded in 1990. In Gladstone, the sea surface salinity is projected to decrease to between 35.00g/l and 35.08g/l in 2070 compared to 35.30g/l recorded in 1990.



(a) Botany Bay



(b) Gladstone



(c) Port Kembla

Figure 12: Sea surface salinity projections [MIROC(hires) only]

3.2 *Deterioration of structural materials and models*

Seaport structures are subjected to various deteriorating agents throughout their service lives. The degree of deterioration depends on the properties of the exposed environment, which varies in accordance with the climatic conditions. Some of these climatic conditions were modelled as discussed in the previous section.

There are five distinct zones that affect structures in water (see Figure 13). These zones are atmospheric zone, splash zone, tidal zone, zone of continuous immersion and seabed zone. The atmospheric zone tends to contain some amount of salt, which increases the rate of atmospheric corrosion of marine structure with metal and deterioration of concrete over that of land structure materials. In timber structural components above the splash zone, fresh water may collect and stagnate, initiating rot. The splash zone constitutes an area from the high water level to the upper levels attained by spray. This zone is subjected to intermittent wetting and drying as waves run up or break on the structure. The tidal zone is the usual range between high and low levels which is periodically immersed. Below low tide level to the seabed the structure is continuously immersed and this is typically a zone of moderate to light attack on steel and concrete but not timber. Below the seabed, the structure's elements are buried and are relatively well protected as the lack of oxygen prohibits oxidation and the existence of most organisms.

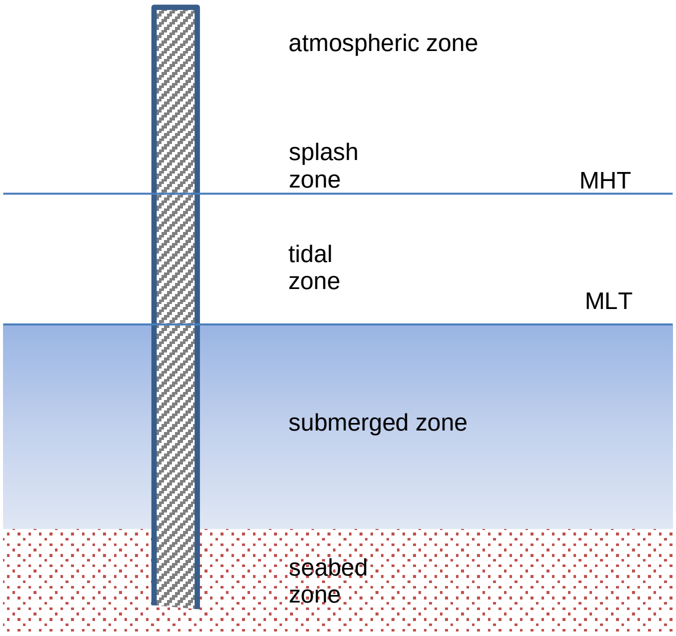


Figure 13: Zones of structure deterioration in the marine environment

After the initial analysis and vulnerability assessment, it was decided that physical structure subgroups will be aggregated to 3 large categories by type (materials and structure) and in deterioration behaviour. The three aggregated groups were concrete, steel and timber structures.

3.2.1 Concrete deterioration

Concrete deterioration is largely affected by the cracking of the concrete itself, resulting in corrosion of the embedded reinforcing steel. Concrete structures deteriorate mostly on account of a combination of stresses generated by cycles of heating and cooling, wetting and drying and corrosion of the reinforcing steel. With reinforced concrete structures, the electrochemical phenomenon of corrosion of embedded steel is always associated with the cracking and spalling of the concrete cover. Mechanisms for corrosion that are driven by factors such as temperature, humidity, carbon dioxide and chloride concentration will be exacerbated by a changing climate. Changes attributable in the initiation probability for corrosion will depend on the climate change scenario, local environmental exposure (i.e. arid, temperate or tropical climatic conditions, together with the proximity to sea etc.) and the standard that is applied to the structure.

The degradation of concrete is commonly modelled as occurring in three stages – corrosion initiation, crack initiation and crack propagation as shown in Figure 14. During initiation, changes begin to take place within the concrete as a result of interaction with the exposure environment, until a limit is reached where damage occurs. During propagation, a certain defined event occurs, e.g. cracks appear, until a specified threshold is reached.

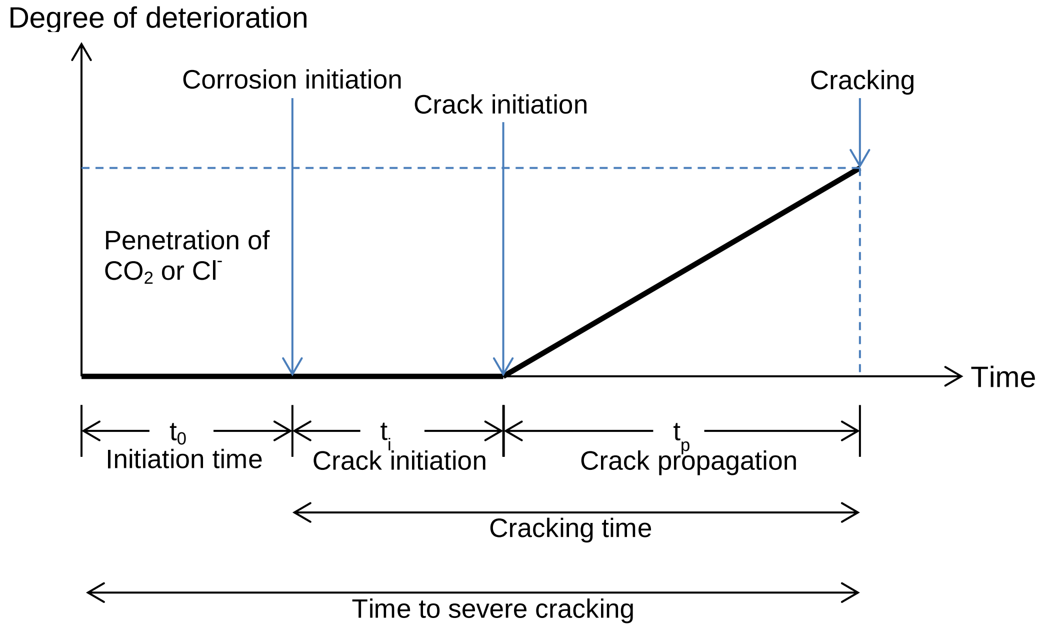


Figure 14: Degradation of reinforced concrete

Determination of corrosion rate, i_{corr}

The temperature effect on the corrosion rate as described by Duracrete (Stipanovic Oslakovic et al., 2010) is given as:

$$i_{corr}(\mathrm{t}) = i_{corr-20}[1 + K(T(t) - 20)] \qquad \textbf{\textit{Eq. 1}}$$

where T(t) is the temperature at time t and K is 0.025 if T < 20°C, otherwise K is 0.075 (if T > 20°C)

Determination of crack initiation time, t_i

Liu and Weyers (1998) proposed the following model to predict the time of crack initiation, which agrees reasonably well with crack initiation model as described in the literature (El Maaddawy and Soudki, 2007). This model is represented by the following equation:

$$t_i = \frac{1}{365}\left[\frac{7117.5(D_{bar} + 2\delta_0)(1 + \upsilon + \psi)}{i_{corr}E_{ef}}\right]\left[\frac{2hf_{sp}}{D} + \frac{2\delta_0 E_{ef}}{(1 + \upsilon + \psi)(D_{bar} + 2\delta_0)}\right] \qquad \textbf{\textit{Eq. 2}}$$

where D_{bar} is the diameter of the reinforcing bar (mm), δ_0 is the thickness of the porous zone, typically 10-20 μm (Palle, 2000), v is the Poisson's ratio of concrete, h is the cover (mm), f_{sp} is the concrete tensile strength (MPa), E_{ef} is the elastic modules of concrete (MPa) and i_{corr} is the corrosion rate in current density (μA/cm^2).

The elastic modulus of the concrete can be estimated using equation (Noguchi et al., 2009) below:

$$E_{ef} = k_1 k_2 \times 3.35 \times 10^4 \left(\frac{\gamma}{2400}\right)^2 \left(\frac{f'_c}{60}\right)^{\frac{1}{3}} \qquad \textbf{\textit{Eq. 3}}$$

where k_1 and k_2 represents the correction factors for coarse aggregates and admixture type respectively.

Table 10: Coarse aggregate correction factor

Type of coarse aggregate	k_1
Crushed limestone, calcined bauxite	1.2
Crushed quartzitic aggregate, crushed andesite, crushed basalt, crushed clayslate, crushed cobblestone	0.95
Other coarse aggregate	1

Table 11: Admixture correction factor

Type of coarse aggregate	k_1
Silica fume	1.2
Crushed quartzitic aggregate, crushed andesite, crushed basalt, crushed claylate, crushed cobblestone	0.95
Other coarse aggregate	1

The splitting tensile strength, f_{sp}, is determined using Eq. 4 given by ACI-318 which is deemed suitable for a wide range of compressive strength.

$$f_{sp} = 0.556\sqrt{f'_c} \qquad \textbf{Eq. 4}$$

Determination of crack initiation time, t_p

The cracking time, t_p is defined using the equation below

$$t_p = k_R \left(\frac{w_{lim} - 0.05}{k_c r_{crack}}\right) \frac{0.0114}{i_{corr}} \qquad \textbf{Eq. 5}$$

where r_{crack} is the rate of crack propagation in mm/hr as determined by using $r_{crack} = 0.0008e^{-1.7\varphi_{cp}}$ and w_{lim} is the crack width that represents severe cracking (1 mm)

Correction factor for rate of loading, k_R, is defined in the equation below (Vu et al., 2005):

$$k_R = 0.95\left[exp\left(-\frac{0.3i_{corr(exp)}}{i_{corr(real)}}\right) - \frac{i_{corr(exp)}}{2500i_{corr(real)}} + 0.3\right] \qquad \textbf{Eq. 6}$$

The time after corrosion initiation for cracking of concrete surface to a severe limit can be generally expressed as a time-invariant equation:

$$\mathrm{t}_{cr} = t_i + t_p \qquad \textbf{Eq. 7}$$

And hence, time to severe cracking limit could be rewritten as:

$$\mathrm{t}_{cr} = \frac{1}{365}\left[\frac{7117.5(D_{bar} + 2\delta_0)(1 + \upsilon + \psi)}{i_{corr}E_{ef}}\right]\left[\frac{2hf_{sp}}{D} + \frac{2\delta_0 E_{ef}}{(1 + \upsilon + \psi)(D_{bar} + 2\delta_0)}\right] + k_R\left(\frac{w_{lim} - 0.05}{k_c r_{crack}}\right)\frac{0.0114}{i_{corr}} \qquad \textbf{Eq. 8}$$

Determination of time for section area loss of reinforcing bar

After corrosion initiation, the reinforcing bar loss at time t can be generalised as:

$$\Delta D_{bar} = m\lambda i_{corr} t \qquad \textbf{Eq. 9}$$

where λ is 0.0115 which represents the factor to convert corrosion rate from μA/cm^2 to mm/year, m is dependent on the type of corrosion (m=2 for uniform corrosion) and t is the time after corrosion initiation.

An explanation of two concrete deterioration mechanism models (i.e. deterioration due to chloride and carbonation intrusion) is provided in this section. These models are necessary to predict the deterioration of reinforced concrete structures due to climate change, although chloride ingress is more predominant in a marine environment. Both models focus on reinforcement corrosion.

Corrosion mechanism 1: Chloride ingress

Corrosion of reinforcing steel in concrete due to long term chloride ingress is one of the main causes of deterioration of reinforced concrete structures, particularly in marine environments. Chloride ions destroy the passive layer when the chloride content in the pore solution exceeds a critical value (chloride threshold). One model to describe the chloride ingress process in concrete was presented by Mejlbro (1996). The model, rewritten in a convenient form for design purposes, can be mathematically represented as follows:

$$C(x,t) = C_o\left[1 - erf\,\frac{x}{2\sqrt{D_c k_e k_t k_c \left(\frac{t_0}{t}\right)^n t}}\right] \qquad \textbf{Eq. 10}$$

where C_O is the chloride concentration at the surface (kg/m^3) provided in Table 12 and erf denotes the standard error function. D_C is the effective diffusion coefficient at a defined execution and environmental condition measure at time t, n is a factor which considers the influence from the material and environment on time-evolution of D_C, k_c is a factor that considers the curing influence, k_e considers the differences between different exposure environments (given in Table 13), k_t is a factor that considers the test-method and x is the depth.

Table 12: Surface chloride concentration in relation to various types of environment exposures (Val and Stewart, 2003)

Environment	Type	Mean (kg/m^3)	SD (kg/m^3)
tidal/splash	E1	7.35	0.7
atmospheric (coast)	E2	2.95	0.7
atmospheric (>1km fr coast)	E3	1.15	0.5

Table 13: Environmental exposure factor

Environment	n		k_e	
	mean	SD	mean	SD
atmospheric	0.65	0.07	0.676	0.114
tidal	0.37	0.07	0.924	0.155
splash	0.37	0.07	0.265	0.045
submerged	0.30	0.05	1.325	0.223

Eq. 10 was modified to include a surface temperature variable and therefore can be expressed as:

$$C(h,t) = C_o\left[1 - erf\frac{x}{2\sqrt{D_c k_e k_t k_c \beta_T \left(\frac{t_0}{t}\right)^n t}}\right] \qquad \textit{Eq. 11}$$

where h is the depth at cover and β_T is given as the temperature factor that can be obtained using the Arrhenius-type equation given as:

$$\beta_T(t) = e^{\left(\frac{E}{R}\left(\frac{1}{293} - \frac{1}{T_{av}(t)+273}\right)\right)} \qquad \textit{Eq. 12}$$

where E is the activation energy of the diffusion process (kJ/mol) given in Table 14 and R is the gas constant (kJ/mol K). And the average temperature over a period is given as:

$$T_{av}(t) = \sum_{t_0}^{t} T(t) \times \frac{1}{t - t_0} \qquad \textit{Eq. 13}$$

where T(t) is the temperature at time t.

Table 14: Activation energy for typical water-to-cement (w/c) ratio (Saetta et al., 1993)

w/c	E (kJ/mol)
0.3	50.0
0.4	41.8
0.5	44.6
0.6	32.0
0.7	32.0

The effect on ingress due to drying-wetting cyclic exposures will be considered in the next phase of chloride ingress modelling. The chloride boundary condition at the exposed side was such that the free chloride concentration during wetting phases will be 30.3 kg/m^3 and a chloride conductivity of 5.79x10^{-12} m^2/s as suggested by Meijers et al. (2005).

Corrosion is initiated when the chloride concentration exceeds a threshold level, C_r

$$C_r = Co\left[1 - erf\left(\frac{c}{2\sqrt{Dto}}\right)\right] \quad \textbf{Eq. 14}$$

However, it has proved challenging to establish a threshold chloride concentration due to numerous factors including (Bertolini et al., 2005):

- pH of concrete or the concentration of hydroxyl ions in the pore solution. Corrosion can take place only above a critical ratio of chloride and hydroxyl ions. This critical ratio can vary depending on type of cement and additives used.
- Presence of voids at the concrete and steel interface which depends on the workability of fresh concrete and compacting procedure. Voids may weaken the layer of cement hydration products deposited at the concrete and steel interface and thus favour local acidification which is required for corrosion to continue.

Manera et al (2008) has reported that the chloride threshold is increased significantly in submerged zone concrete due to high levels of moisture content. This leads to low oxygen content and to low values of steel electrochemical potential. The chloride concentration threshold adopted for this model follows a normal distribution of 3.35 kg/m^3 and COV of 0.375 kg/m^3.

Concrete case study 1: Pile C80 (Port Kembla)

Based on the results presented in Figure 15, it has been identified that the tidal zone is most affected by the change in climate. The magnitude of change for the other two zones analysed are marginal comparatively. For example, the probability of chloride corrosion damage initiation is recorded to change by 2.57% between the highest probability and the baseline for the tidal zone, whereas the difference in probability was recorded as 0.20% and 0.06% for atmospheric and splash zones respectively.

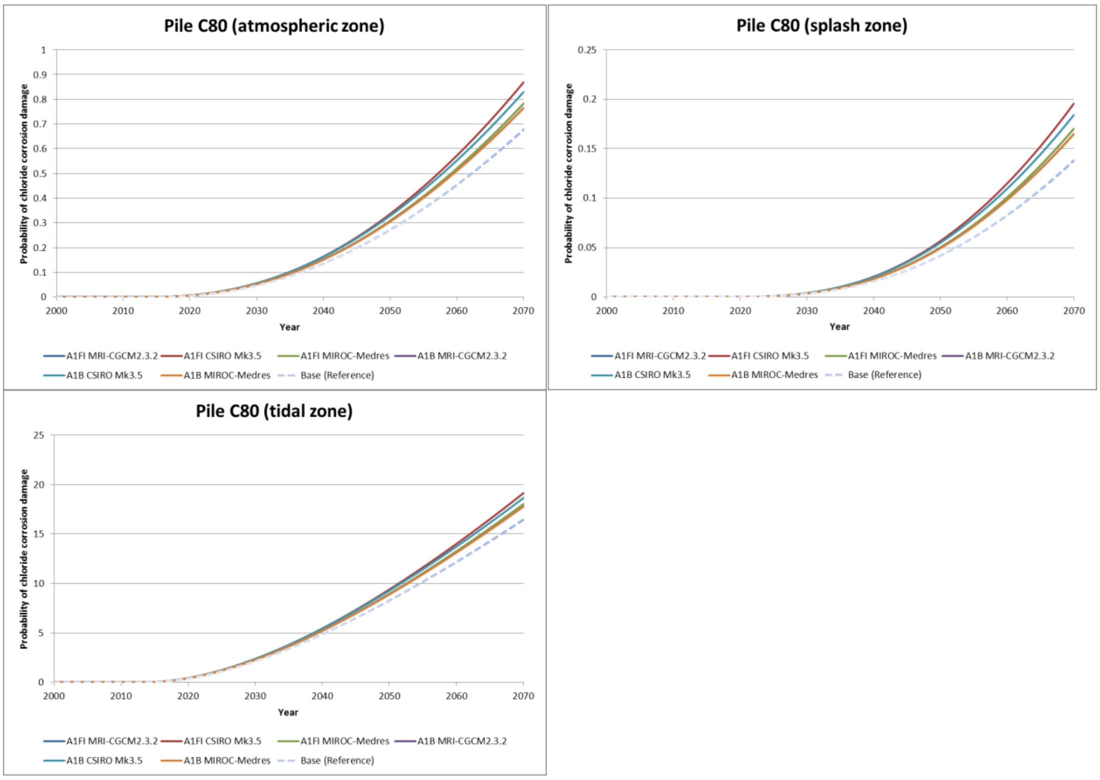


Figure 15: Probability of corrosion damage due to chloride ingress at atmospheric, splash and tidal zones (Pile C80)

Figure 16 shows the projected loss of area in the steel reinforcement due to chloride ingress. Although the magnitude of reinforcing bar loss is significantly higher in the tidal zone compared to the rest of the zones, our attention should be drawn to the effects of a changing climate (i.e. the difference). Hence, the change in reinforcing bar loss ranked in order is tidal zone (6 µm), atmospheric (3 µm) and splash (0.4 µm).

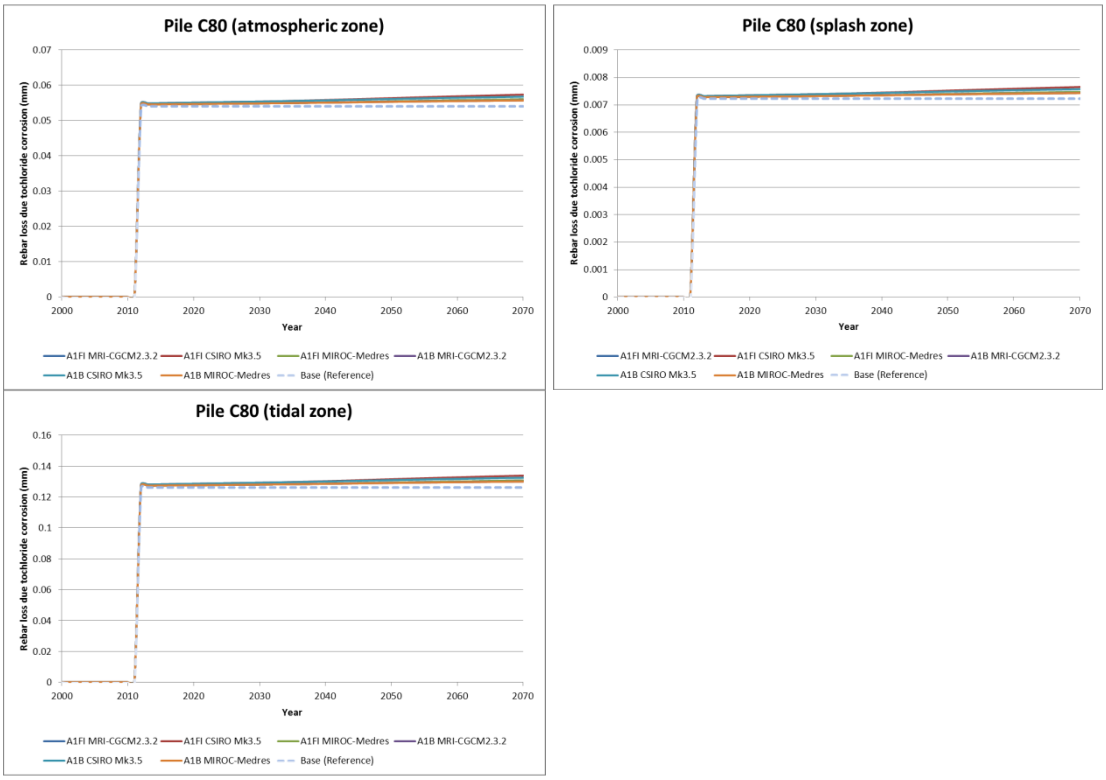


Figure 16: Loss of steel due to chloride-ingress related corrosion at atmospheric, splash and tidal zones (Pile C80)

Please see Appendix 2 for the other results in relation to the deterioration of concrete due to chloride ingress.

Corrosion mechanism 2: Carbonation ingress

The impact of carbonation has been the subject of many previous studies (Yoon et al., 2007, Dias, 2000, Li et al., 2011). The high pH level within the concrete pore solution is reduced by calcium carbonate ($CaCO_3$) formed as a consequence of the ingress of carbon dioxide gases into the pore solution. This leads to depassivation of the concrete layer protecting the reinforcement steel and initiates corrosion. Carbonation depth depends on many parameters: concrete quality, concrete cover, relative humidity, ambient carbon dioxide concentration (Houst and Wittmann, 2002).

The carbonation depth model by Yoon et al. (2007) considers a wide range of influencing parameters, namely aging of diffusion process, reduction in diffusion due to the increase of cement and calcium oxide content, reduction in diffusion due to increase of water-to-cement ratio and non-linear factor of diffusion processes under different environments in relation to time. The carbonation depth is predicted as a diffusion process based on Fick's 1st law and defined as follows:

$$x_c(t) = \sqrt{\frac{2D_{CO_2}(t)}{a} C_{CO_2}(t) \left(\frac{t_0}{t}\right)^{n_m}}$$ ***Eq. 15***

where x_c is the carbonation depth (cm) of concrete at time, t (years), D_{CO2} is the CO_2 diffusion coefficient (cm^2/yr), $C_{CO2}(t)$ is the time-dependent mass concentration of ambient CO_2 (kg/m^3) and n_m is the age factor for microclimatic conditions associated with the frequency of wetting and drying cycles (n_m = 0 for sheltered outdoor and n_m = 0.12 for unsheltered outdoor). The D_{CO2} is calculated using the Eq. 16.

$$D_{CO_2}(t) = D_1 \cdot t^{-n_d}$$ ***Eq. 16***

where D_1 is the diffusion coefficient after a year, n_d is the age factor of CO_2 coefficient. Table 15 provides mean values used to compute the CO_2 diffusion coefficient.

The amount of CO_2 for making completely carbonated concrete, a, has a function of CO_2 binding capacity. This can be calculated from the relationship between CaO in the cement and the degree of hydration in atmospheric condition as defined in Eq. 17.

$$a = 0.75 \cdot C_e \cdot CaO \cdot \alpha_H \frac{M_{CO_2}}{M_{CaO}}$$ ***Eq. 17***

where C_e is the cement content (kg/m^3), CaO is the calcium oxide (0.65), α_H represents the degree of hydration and M represents the molar masses of CO_2 and CaO respectively. The degree of hydration (de Larrard, 1999) is estimated as:

$$\alpha_H = 1 - e^{-3.38 w/c}$$ ***Eq. 18***

where w/c is the water-to-cement ratio.

Table 15: CO_2 diffusion coefficients for typical w/c ratio (Yoon et al., 2007)

w/c	$D_1 \times 10^{-4}$ (cm^2/s)	n_d
0.30	0.1034	0.1910
0.35	0.1914	0.2002
0.40	0.3543	0.2099
0.45	0.6496	0.2180
0.50	1.2358	0.2348
0.55	2.2248	0.2395
0.60	4.1553	0.2533
0.65	7.6901	0.2655

Eq. 15 is a point-in-time predictive model and assumes that $CO_2(t)$ is constant for all times up to time t. This will overestimate carbonation depth as the CO_2 concentration will gradually increase over time to the peak $CO_2(t)$. Therefore the carbonation depths are recalculated to factor in atmospheric CO_2 concentration conditions using the average CO_2 concentration over the time period as suggested by Stewart (Stewart et al., 2011). As such, Eq. 15 can be rewritten as:

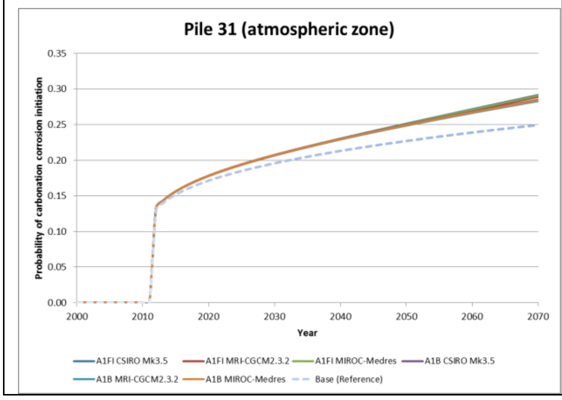
$$x_c(t) = \sqrt{\frac{2\beta_T(t)D_{CO_2}(t)}{a} k_{urban} \int_{t_0}^{t} C_{CO_2}(t)dt} \times \left(\frac{1}{t - t_0}\right)^{n_m} \qquad \textbf{\textit{Eq. 19}}$$

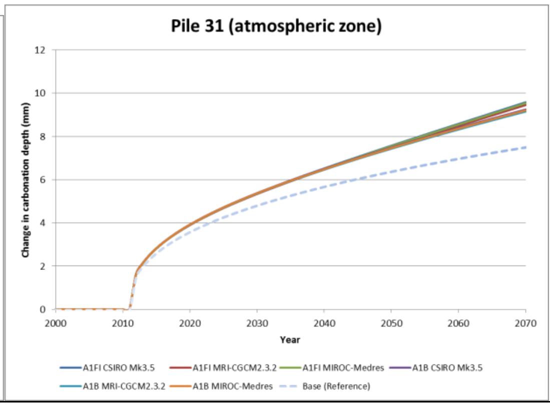
where β_T is given as the temperature factor as previously established (Eq. 12).

The change in carbonation depth, Δx_c (t') is used to measure the effects of climatic change at t' relative to t_0.

Concrete case study 2: Pile 31 (Gladstone)

Figures 17, 18 and 19 below show the results for Pile 31 at atmospheric, splash and tidal zones respectively after the carbonation modelling were completed with pile's input parameters. The results displayed are for all emissions scenarios and all possible future climate models as well as the baseline model which represents no change in climatic variables. It appears that the A1FI CSIRO Mk3.5 scenario, which is Gladstone's most likely scenario, is the most critical case in terms of corrosion rate, change in carbonation depth and probability of carbonation ingress. The results for the tidal zone here appear to have the most change from the baseline model and are therefore considered the most critical. The probability of carbonation induced corrosion initiation under this scenario in 2070 is roughly 29% which is an increase of approximately 10% from the baseline probability. Similarly, there is an increase of about 5 mm in carbonation depth in 2070 under the most likely and A1FI model and an increase of about 0.05 µA/cm^2 in corrosion rate. All scenario combinations appear to give very similar results and are all in a very similar range, which would indicate that it is highly probable that these results will be close to the actual results observed in 2070. The most drastic result seems to be the depth of carbonation in 2070 when compared to the baseline model. This is most adequately expressed in terms of intervention time. For example, if action is needed to be taken when the change in carbonation depth reached 4 mm, under the baseline model, action would occur somewhere in the vicinity of 2045, whereas under the most likely scenario, intervention would need to take place in approximately 2020, which is 25 years earlier. This shows the extent that climate change will affect the need to remedy the risk of carbonation.





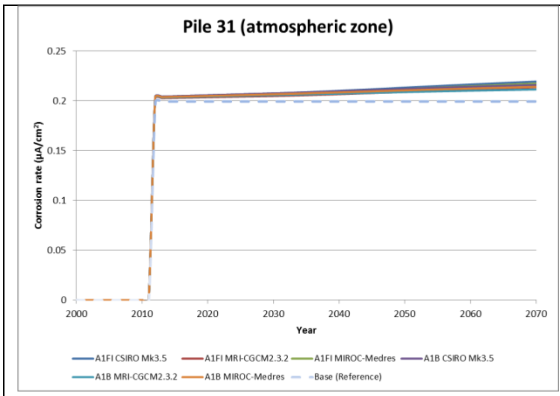


Figure 17: Pile 31 atmospheric zone carbonation results

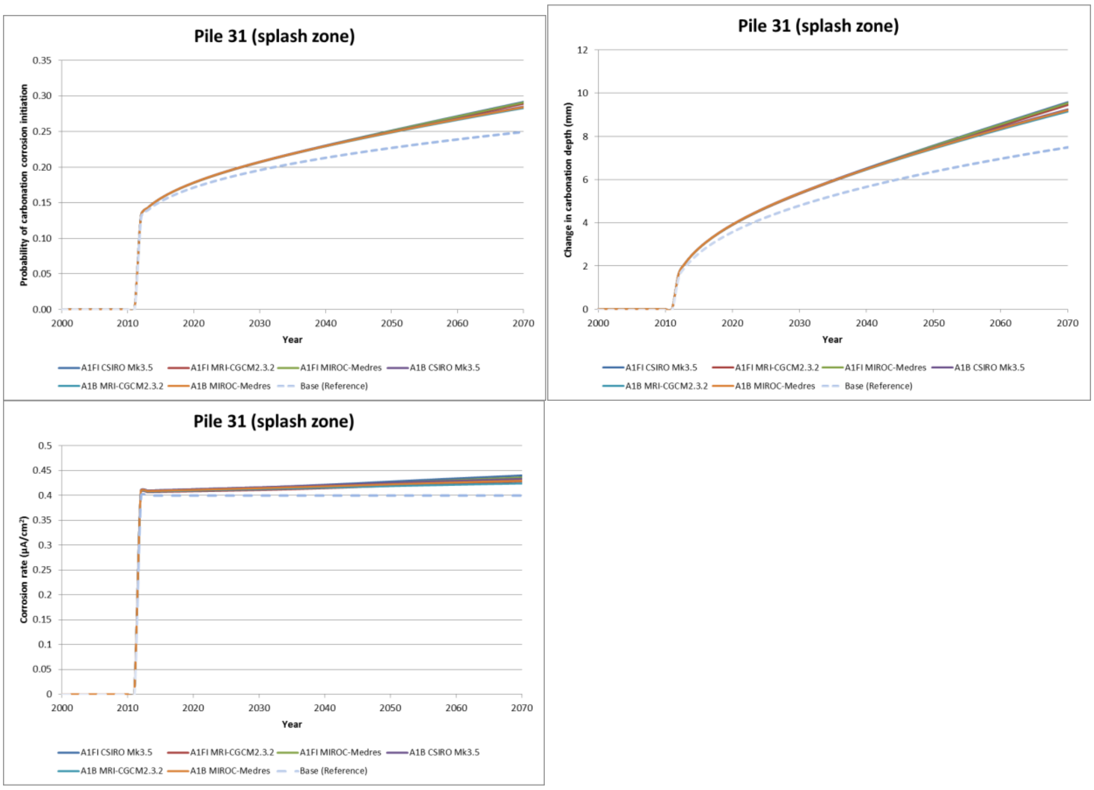
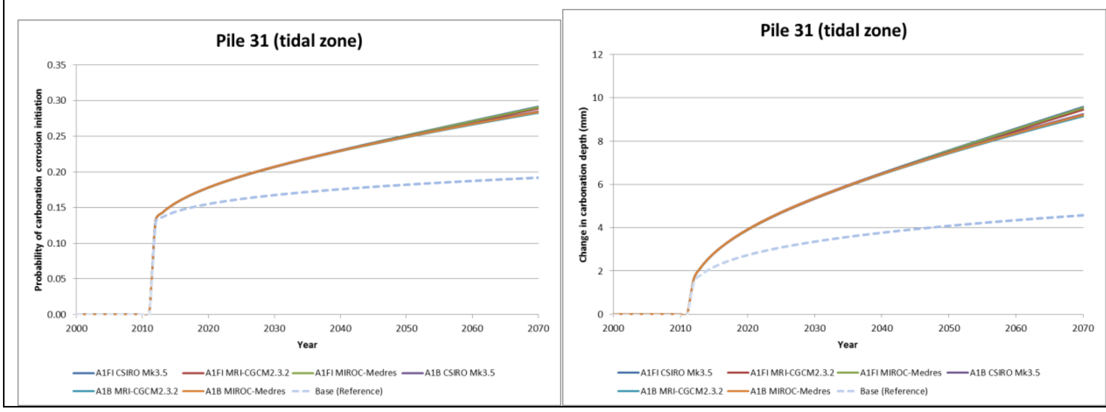


Figure 18: Pile 31 splash zone carbonation results



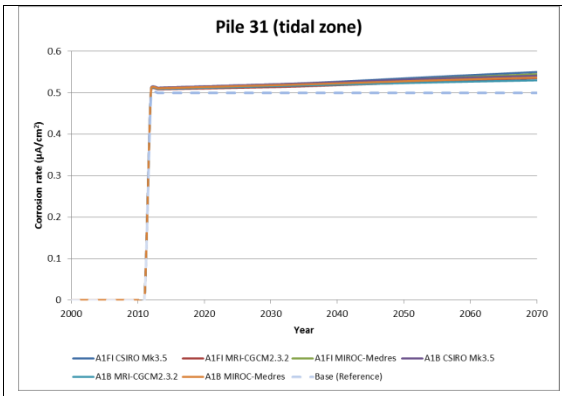


Figure 19: Pile 31 tidal zone carbonation results

3.2.2 Steel deterioration

Corrosion of steel occurs because of small physical and chemical differences present in metals such as minor impurities or local composition variations or environment effects. For example, a change in amounts of dissolved oxygen varying with depth of immersion in non-uniform salts due to pollution in a marine environment. A chemical reaction takes place on iron (the principal constituent of carbon steel) corroding the material (Revie, 2011). The electrons flow from the anode iron to the cathode through a metallic circuit which causes iron to convert to ferrous hydroxide. This corrosion can severely decrease the structural capacity of the steel member.

Existing methods of estimating long-term corrosion loss are based on time but do not account for variation in environmental conditions. Previous studies by Klinesmith et al. (2007) have expressed corrosion loss as a power model

$$M = Kt^n \qquad \textbf{\textit{Eq. 20}}$$

where M is the loss caused by corrosion per unit of exposed area, t is the exposure time and K is the proportionality constant and n is the mass loss exponent. The given model is limited to corrosion loss as a function of time and coefficients K and n represent all other factors including climatic factors.

Three large factors which influence corrosiveness

- Time of wetness
- Atmospheric chloride content
- Atmospheric sulphur dioxide content

Seawater typically contains about 3.5% sodium chloride, although the salinity may be stronger in some areas. The rate of corrosion is controlled by the chloride content, oxygen and seawater temperature. 3.5% salt content of seawater produces the most corrosive chloride salt solution (Roberge and Beaudoin, 1988). Dry steel does not corrode even in the presence of chloride and below a relative humidly of 60% chloride induced corrosion is negligible (Bentz, 2003).

The time of wetness, TOW, is approximated to the time which RH is greater than 80% and the temperature is greater than 0°C (Dean and Reiser, 2002). Rain, dew and water absorption contributes significantly to this as it changes the presence of water on the surface of the steel. It is also important to highlight that corrosion does not occur in the absence of water. Thus corrosion is zero when the TOW is zero.

Since time of wetness data is not easily projected, it can be estimated using the equation below:

$$TOW = 0.22 D_{rain} \quad \textbf{\textit{Eq. 21}}$$

where D_{rain} is the number of rain days per year for which a rain day is defined as a day on which there is at least 0.2 mm of rain. This assumed relationship was computed using data from the Bureau of Meteorology, see Figure 20.

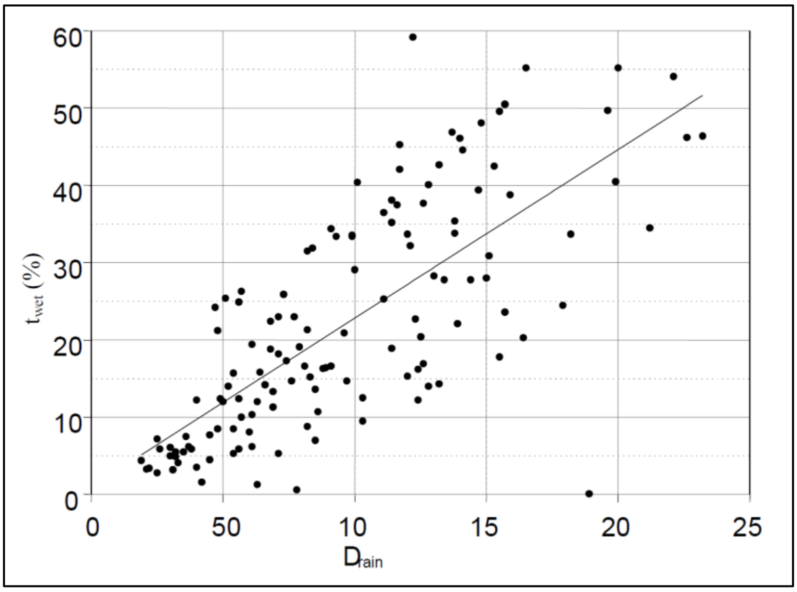


Figure 20: Relationship between rain days and time of wetness (Bureau of Meteorology sites)

If D_{rain} data is not readily available, D_{rain} data for sites near coasts in Table 16 were used in accordance to hazard and coastal zones defined in Figure 21 and Figure 22 respectively.

Table 16: Number of rain days according to hazard zones and corresponding coastal zones (Wang and Leicester, 2008)

Zone	Coastal zone	D_{rain}
A	C1	70
B	C2	40
C	C1	100
D	C2	130
E	C3	130

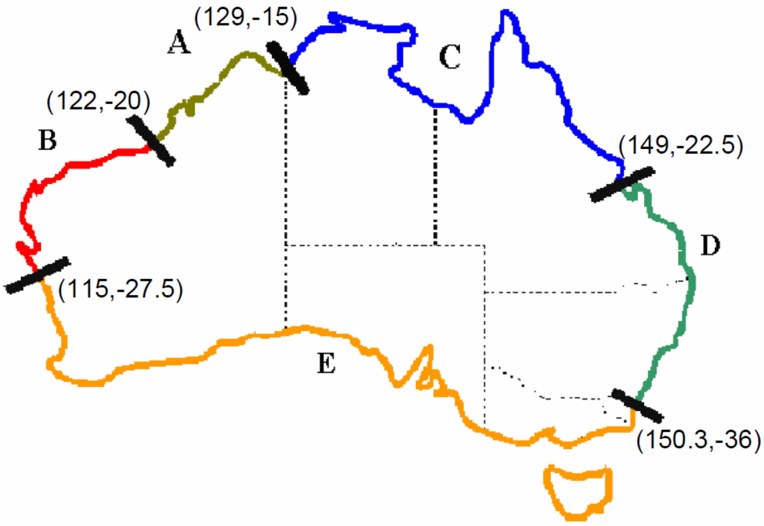


Figure 21: Hazard zones categorised according to corrosion due to airborne salt (Nguyen et al., 2008a)

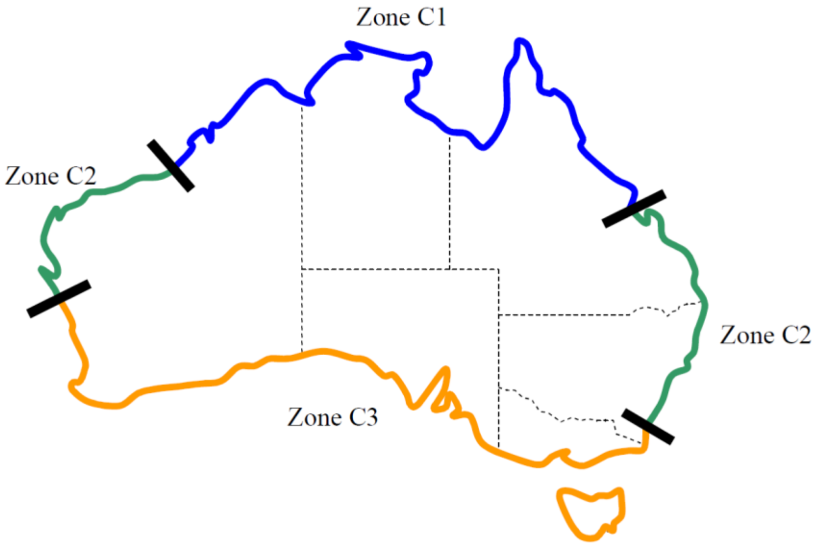


Figure 22: Coastal type zone (Nguyen et al., 2008a)

Air salinity is a measure of chlorides present in the atmosphere. In marine environments, the levels of corrosion are generally higher than normal because of the high levels of sea salts found in coastal zones. The air salinity and the rate of corrosion will therefore decrease as the distance from the coast increases. The chloride levels (mg/m^2) are estimated using the equation below:

$$Cl = max\begin{cases} \alpha_{exp}\alpha_{micro}[\alpha_{coast}\beta_{coast}(0.9e^{-10L_{coast}} + 0.1e^{-L_{coast}}) + \alpha_{ocean}e^{-0.02L_{coast}}] \\ 1.0 \end{cases} \quad \textbf{Eq. 22}$$

where L_{coast} is the distance from the coast in km, α_{coast} and α_{ocean} are parameters that take into account the effect of coastal zonation (Table 17), β_{coast} is the effect of coastal exposure (Table 18), α_{exp} is the effect of site exposure (Table 19) and α_{micro} is the effect of local shelter factors (α_{micro} = 1.0 for outside and unsheltered).

Table 17: Zone factors

Coastal zone	α_{coast}	α_{ocean}
C1	50	2
C2	150	6
C3	500	20

Table 18: Coastal exposure conditions

Class	Coastal exposure condition	β_{coast}
EXP1	Closed bay	0.05
EXP2	Partially closed bay	0.10
EXP3	Open bay	0.35
EXP4	Open surf	1.00

Table 19: Site classifications

Class	Site classification	α_{exo}
SITE1	Open to sea	2.00
SITE2	Urban (suburbs)	0.50
SITE3	Urban (city centre)	0.25
SITE4	Other sites	1.00

Corrosion loss (Klinesmith et al., 2007) can be generally estimated in a form of

$$Y = At^B \left(\frac{TOW}{C}\right)^D \left(1 + \frac{SO_2}{E}\right)^F \left(1 + \frac{Cl}{G}\right)^H e^{J(T+T_0)} \qquad \textbf{\textit{Eq. 23}}$$

where Y is the corrosion loss (µm), t is the exposure time (years), TOW is the time of wetness (h/year), SO_2 is the sulphur dioxide concentration, Cl is the chloride deposition rate (mg/m^2/day), T is the air temperature (°C) and A, B, C, D, E, F, G, H, J and T_0 are empirical coefficients.

This could be expressed to include temperature, relative humidity, TOW and dry gauze salinity using the following equation (Lien and San, 2002)

$$Y = 0.0157RH^{2.3} \left(\frac{TOW}{3800}\right)^{0.15} \left(1 + \frac{Cl}{50}\right)^{0.22} e^{-0.0019(T+20)} \qquad \textbf{\textit{Eq. 24}}$$

Steel case study: Pile B48 (Port Kembla)

Analysis was run on Pile B48 (Jetty 4) as an example of corrosion loss projection over time. Corrosion loss projection differed between scenarios, with A1FI MIROC-Medres and A1B MIROC-Medres projections showing a gradual increase over baseline data until 2070, and the other four scenarios showing a gradual decrease compared to baseline data for that same time period (Figure 23).

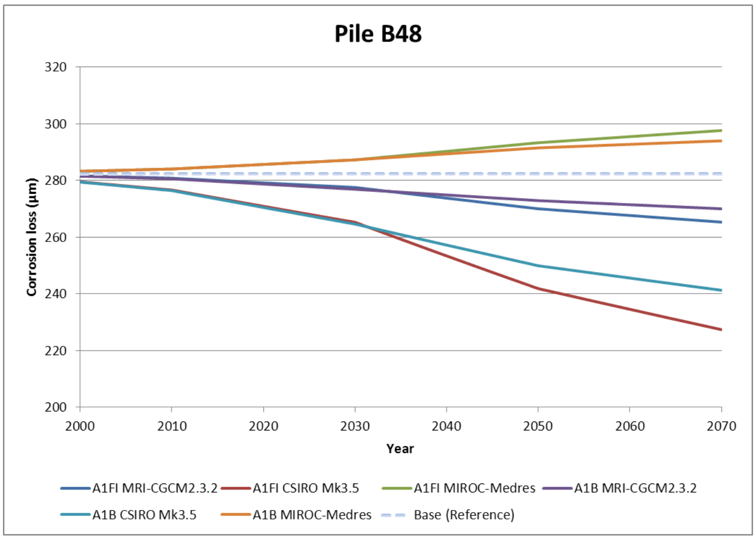


Figure 23: Steel corrosion loss of Pile B48 (Port Kembla)

3.2.3 Timber deterioration

Timber generally provides satisfactory performance in port environments. However, it is susceptible to degradation by a variety of marine organisms, such as bacteria, fungi and marine borers. The presence of marine borers is largely dependent on environmental factors, such as temperature and salinity of water.

The durability of timber structures is more highly dependent on the microstructure and composition of the materials used than any other port construction material. Timber elements can endure for long periods if they are kept in cool, dry and dark conditions. However, if wetted substantially, they are unable to resist degradation and cannot remain serviceable over long periods.

There are four main types of marine borers that attack timber in seawater, namely *Limnoria*, *Sphaeroma*, *Teredinids* and *Martesia* (Cookson, 1986). As timber piles are commonly used as supports in legacy wharves and jetties, the piles are susceptible to attacks by marine borers, usually within the tidal zone (especially near the lower tidal zone).

Figure 24: Marine borer hazard zones (MacKenzie, 2010)

The depth of borer attack after a certain period, t (years), can be modelled based on an estimate of the mean attack depth, d_{mean}. The model developed by Nguyen et al. (2008b) assumes all borer attacks, regardless of their borer species, occurs on a narrow front along the perimeter of the pile's cross-section in the tidal zone, with the 'unattacked' timber retaining 100% of its initial strength.

$$d_{mean}(\mathrm{t}) = \begin{cases} 0 & if\ t \leq t_{lag} \\ (t - t_{lag})r & if\ t > t_{lag} \end{cases} \qquad \textbf{\textit{Eq. 25}}$$

where t_{lag} (years) is the idealised lag time before a steady attack rate (Figure 25), denoted by r (mm/year).

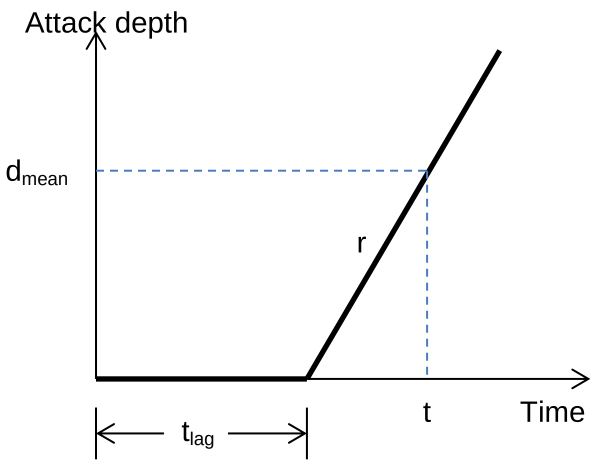


Figure 25: Basic model of timber attacked by marine borers (Nguyen et al., 2009)

The marine borer attack rate, r (mm/year) can be mathematically represented using:

$$r = k_{water} k_{timber} k_{env} k_{const}$$ ***Eq. 26***

where k_{water} is the climate parameter related to water; k_{timber} is the material parameter related to species of timber used, type of preservative and level of treatment used; k_{env} is the environment parameter related to the effects of salinity and wave action at the port site and k_{const} is the construction parameter related to the construction configuration and protection of piles.

The effect of water temperature, k_{water}, can be expressed using the following equation in accordance with Knox (1963):

$$k_{water} = 0.1e^{0.13T}$$ ***Eq. 27***

where T is the mean summer water temperatures of the coastal zones

The material parameter, k_{timber}, for various types and treatments of heartwood and sapwood is given in Table 20.

Table 20: Material parameter for various timber types, k_{timber}

Material			k_{timber}	
			Borer Hazard Zones A-C	Borer Hazard Zones D-G
Heartwood	Class 1	HW1	1.1	1.3
	Class 2	HW2	1.7	5.2
	Class 3	HW3	3.4	8.8
	Class 4	HW4	17.0	25.0
Sapwood of softwood	Untreated	SPSU	40.0	40.0
	Creosote-treated 24%kg/kg	SPSCR1	1.7	1.7
	Creosote-treated 40%kg/kg	SPSCR2	1.0	1.0
	CCA-treated 0.6%kg/kg	SPSCC1	4.7	4.7
	CCA-treated 1%kg/kg	SPSCC2	3.0	3.0
	CCA-treated 2%kg/kg	SPSCC3	1.8	1.8
	CCA-treated 5%kg/kg	SPSCC4	1.0	1.0
	Double-treated CC2+CR2	SPSDBT	0.9	0.9
Sapwood of hardwood	Untreated	SPHU	25.0	25.0
	Creosote-treated 13%kg/kg	SPHCR1	0.8	0.8
	Creosote-treated 22%kg/kg	SPHCR2	0.6	0.6
	CCA-treated 0.7%kg/kg	SPHCC1	3.2	3.2
	CCA-treated 1.2%kg/kg	SPHCC2	1.8	1.8
	CCA-treated 2.4%kg/kg	SPHCC3	1.1	1.1
	Double-treated CC2+CR2	SPHDBT	0.5	0.5

The environment parameter, k_{env} is determined using Eq. 28.

$$k_{env} = k_{sal} k_{shelter} \qquad \textbf{\textit{Eq. 28}}$$

where k_{sal} denotes the effect of salinity of seawater and $k_{shelter}$ relates to the protection of pile to wave action. Table 21 summarises the classifications and values for k_{sal} parameter while $k_{shelter}$ is given as 1.0 when sheltered from strong current or surf (e.g. behind breakwaters) and 0.6 if otherwise.

Table 21: Salinity parameter for various salinity concentrations, k_{sal}

Class	Salinity (ppt)	k_{sal}	
		Borer Hazard Zones A-D	Borer Hazard Zones E-G
Class 1	1 - 10	0.7	1.0
Class 2	11 - 25	0.8	1.0
Class 3	> 26	1.0	1.0

Next, the construction parameter, k_{const} takes into account the construction detailing and protection provided. This parameter is determined using the equation below:

$$k_{const} = k_{protect} k_{contact} k_{knot} \qquad \textbf{\textit{Eq. 29}}$$

where $k_{protect}$ denotes the protection parameter that depends on the type of protection measure provided (Table 22), $k_{contact}$ is the contact parameter that depends on the contact surface with other timber members (Table 23) and k_{knot} is the knot parameter that is governed by the presence of knots (Table 24).

Table 22: Protection parameter, $k_{protect}$

Maintenance measure		$k_{protect}$
Floating collar	MTN1	0.5
None	MTN2	1.0

Table 23: Contact parameter, $k_{contact}$

Contact		$k_{contact}$
Contact with other timber member	CNT1	2.0
None	CNT2	1.0

Table 24: Knot parameter, k_{knot}

Knot presence		k_{knot}
Having knots without protective plate	KNT1	2.0
Having knots with protective plate	KNT2	1.0
None	KNT3	1.0

Marine borers attack two layers of a typical timber member, firstly the sapwood (outer layer) and then progresses through the heartwood (inner layer). Modifying the basic model as previously depicted in Figure 25, the mean attack depth at a specified design time can be depicted in Figure 26.

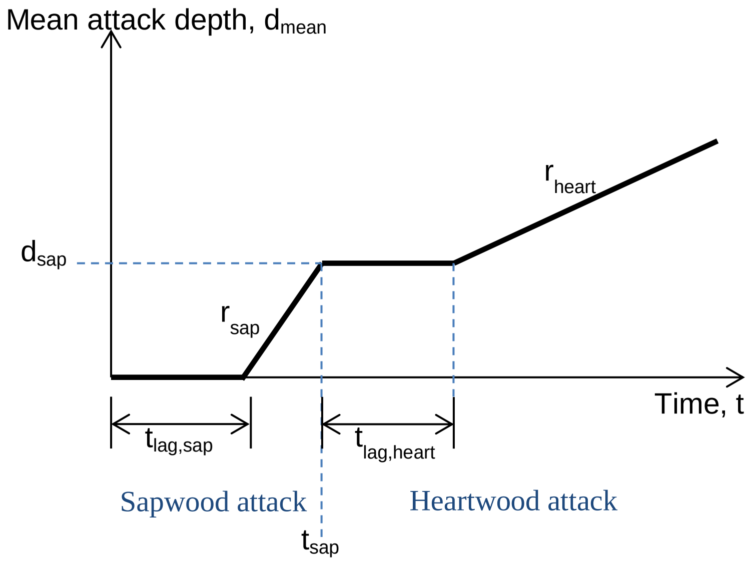


Figure 26: Attack progress of marine borers (Nguyen et al., 2009)

After the mean attack depth, d_{mean}, at a specified time, t, can be established using Eq. 30.

$$d_{mean}(\mathrm{t}) = \begin{cases} d_{sap} & if\ t \leq t_{sap} + t_{lag,heart} \\ d_{sap} + \left(t - t_{sap} - t_{lag,heart}\right) r_{heart} & if\ t > t_{sap} + t_{lag,heart} \end{cases} \quad \textbf{\textit{Eq. 30}}$$

where t_{sap} is the time taken for borers to completely attack the sapwood (denoted by d_{sap}), $t_{lag,heart}$ is the lag for heartwood and r_{heart} is the rate of attack on heartwood. The lag time is a function of the rate using the following equation:

$$t_{lag} = \begin{cases} 0 & if\ r \geq 20 \\ 2.0 - 0.1r & if\ r < 20 \end{cases} \quad \textbf{\textit{Eq. 31}}$$

Replacement of pile is recommended when the pile diameter is reduced to 200 mm according to AS1720.1: Timber structures code. Hence, this will be used as a threshold for the maximum allowable depth of borer attack on timber.

Timber case study: Pile 145 (Port Kembla)

A typical model predicting mean borer attack depths on timber for the six climate change scenarios are provided in Figure 27, and the estimate of when pile replacement will be required is depicted in Figure 28. A gradual increase above baseline is observed for all scenarios until 2070, with all models predicting a replacement of the pile between 2030 and 2040.

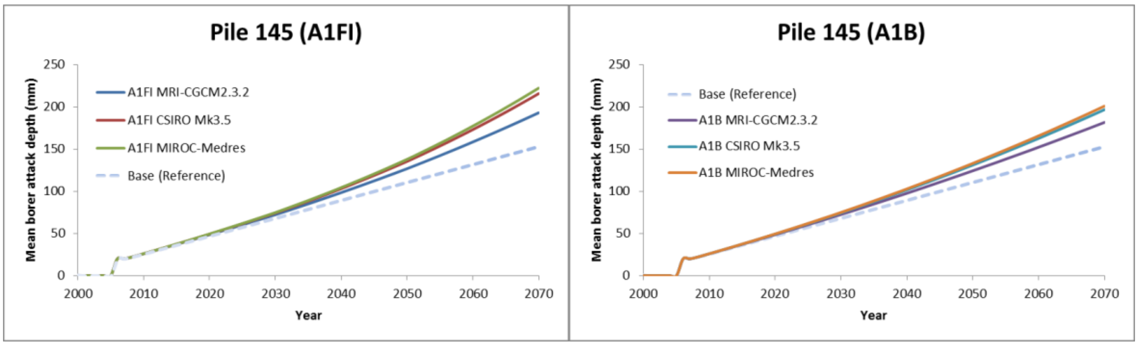


Figure 27: Mean marine borer attack depth on Pile 145

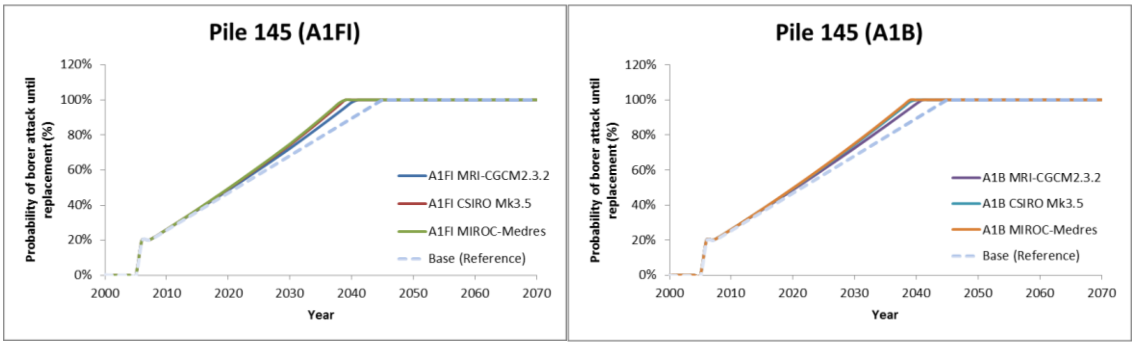


Figure 28: Probability of pile replacement requirement (D ≤ 200mm) on Pile 145

3.3 *Engineering resilience*

For the purposes of this project, the resilience of port structures was measured as the capacity of a given system to cope with a changing climate. Resilience has a direct relationship to the threat to the infrastructure posed by climate change, the consequences of the impact, and its ability to recover. Threat is therefore estimated using the probability of occurrence for an identified area. For example, the probability of corrosion initiation of reinforced concrete structures.

The deterioration models developed predict the values of various system performance indicators. Their outputs are based on the model structure, time-series inputs and a host of climate variables whose values describe the system being simulated. Sensitivity analysis conducted aims to describe how much model output values are affected by changes in the model input values. The importance of imprecision or uncertainty in model inputs in the model process can be quantified and provides a general assessment of model precision when used to assess system outputs for alternative scenarios, as well as detailed information addressing the relative significance of errors in various parameters.

3.3.1 Resilience capacity

Traditionally, as illustrated in Figure 29, robustness of infrastructure can be visualised by changes with time. For port infrastructure, this may be a percentage of capacity reduction which slowly increases over time (without influence from climate change). In other words, the potential for capacity reduction is increasing at a steady rate prior to a change in climate. Maintenance is required or 'triggered' when the capacity reduction reaches a threshold at t_b. With climate change, this maintenance may be triggered earlier in time at t_c. Robustness is restored when the system is returned to its original capacity with maintenance. Hence, the total area under the curve (Figure 29) represents the resilience of the system. If the system is fully resilient, it will follow the original baseline curve and this area will be minute.

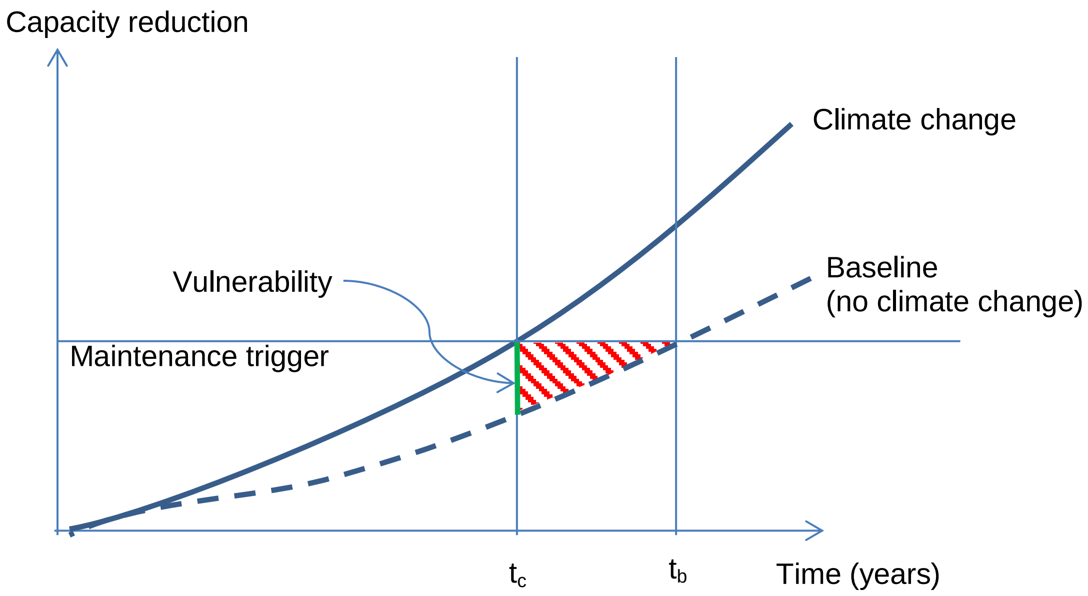


Figure 29: The total area under capacity reduction vs time curve represents resilience capacity

3.3.2 Uncertainty and Monte Carlo simulation

Uncertainty and risk characterise many of the input parameters in any evaluation process. This characterisation is even more apparent when the lifetime of the analysis stretches over long periods of time. A deterministic sensitivity analysis approach was employed to analyse the robustness of the models. It is based on the idea of varying a set of parameter values at a time. The output variable such as corrosion rate of steel in concrete was used as a performance measure. Monte Carlo simulation was conducted and the climate multivariate relationships to the model outputs were studied. In brief, Monte Carlo simulation randomly samples values from projections according to their pre-constructed probability distributions and records the responses from the models. Weibull distribution was assigned to these climate variables with the projected climate value used as the mean. This was conducted over three time slices, namely 2030, 2050 and 2070.

Figure 30 represents a sample tornado diagram showing the range of the output variables representing corrosion initiation probability for high and low values of each of the climate variable sets. Parameters are sorted so that the largest range is on top and the smallest on the bottom, so that the diagram looks like a tornado.

A sample spider plot (Figure 31) illustrates the relationships between model output describing corrosion initiation probability and variations in each of the parameter sets, expressed as a deviation from their projected figures.

These results represent the sensitivity of the output variable for a given time slice, 2070. It can be observed that temperature has a high influence on the corrosion initiation probability of concrete due to carbonation while the influence of carbon dioxide and concentration is marginal.

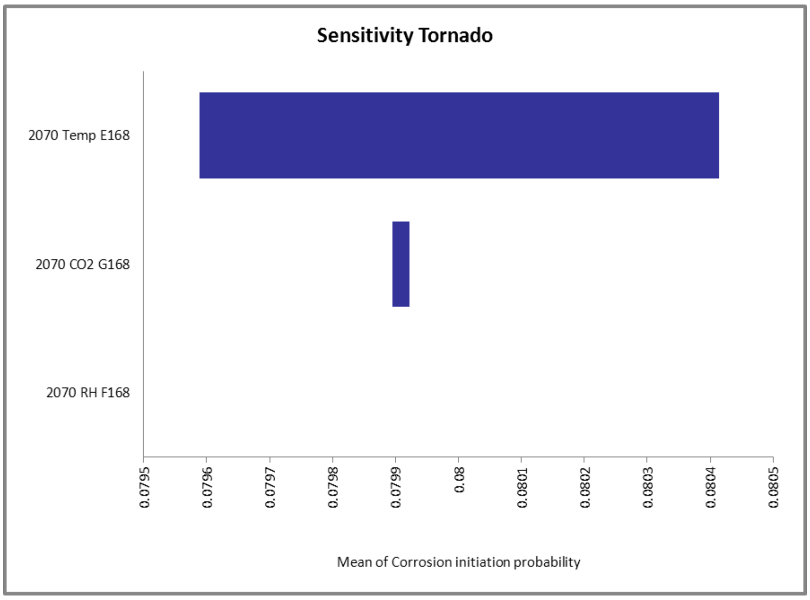


Figure 30: A tornado diagram showing the range of the output variables representing corrosion initiation probability due to carbonation

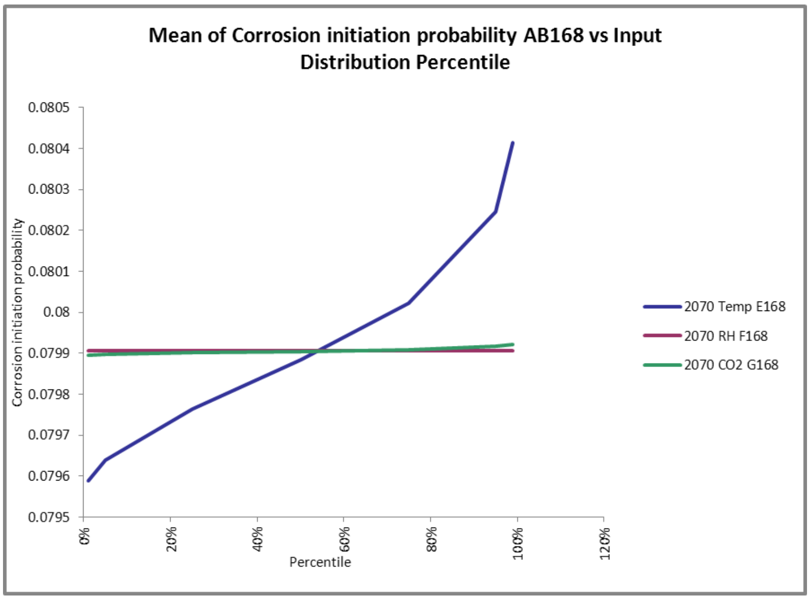


Figure 31: A spider plot illustrates the relationships between the model output describing corrosion initiation probability due to carbonation and variation in each of the parameter sets

Table 25 shows an example summary of the sensitivity analysis and relationship of various climate variables (e.g. temperature, relative humidity and carbon dioxide concentrations) for a given output (e.g. corrosion initiation probability). The sample data presented here was used to examine and rank the combined effects to output responses of a multivariate climate system. This data, together with the resilience capacity areas, discussed earlier, was used to quantify the overall resilience of a structural element subjected to climate change.

Table 25: Corrosion initiation probability range sensitivity to climate variable inputs

Climate future model	Climate variable	2030 A1FI	2030 A1B	2050 A1FI	2050 A1B	2070 A1FI	2070 A1B
MRI-CGCM2.3.2	Temperature	0.00146	0.00146	0.00099	0.00099	0.00082	0.00080
	Relative humidity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	CO_2 concentration	0.00006	0.00006	0.00004	0.00004	0.00003	0.00003
CSIRO Mk3.5	Temperature	0.00147	0.00147	0.00101	0.00099	0.00084	0.00081
	Relative humidity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	CO_2 concentration	0.00006	0.00006	0.00004	0.00004	0.00003	0.00003
MIROC-Medres	Temperature	0.00212	0.00146	0.00099	0.00099	0.00082	0.00080
	Relative humidity	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	CO_2 concentration	0.00000	0.00006	0.00004	0.00004	0.00003	0.00003

Case study: Concrete deterioration

The resilience matrix built here was for the section of Pile C80 (Port Kembla) in the splash zone where carbonation mechanism was studied. The resilience of the systems (see Tables 26 to 29) are generally projected to be high in 2030, becoming low in 2070 (with the exception of reinforcing bar loss due to carbonation, which is medium in 2070.) Both temperature and carbon dioxide rank significantly as parameter influences in the projections.

Table 26: Resilience of the system compared to baseline (carbonation depth)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
CSIRO Mk3.5	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
MIROC-Medres	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)

*brackets indicate ratings of ranked climate variable influence. CO_2 denotes carbon dioxide concentration levels

Table 27: Resilience of the system compared to baseline (corrosion initiation probability due to carbonation)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
CSIRO Mk3.5	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
MIROC-Medres	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)

*brackets indicate ratings of ranked climate variable influence. CO_2 denotes carbon dioxide concentration levels

Table 28: Resilience of the system compared to baseline (damage initiation probability due to carbonation)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
CSIRO Mk3.5	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)
MIROC-Medres	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	High (Temp, CO_2)	Low (Temp, CO_2)	Low (Temp, CO_2)

*brackets indicate ratings of ranked climate variable influence. CO_2 denotes carbon dioxide concentration levels

Table 29: Resilience of the system compared to baseline (reinforcing bar loss due to carbonation)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)
CSIRO Mk3.5	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)
MIROC-Medres	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)

*brackets indicate ratings of ranked climate variable influence

The same pile was analysed for resilience towards the chloride ingress deterioration mechanism. The resilience matrices for the given outputs are presented in Tables 30 to 33. Similarly to the carbonation deterioration mechanism, the matrices for chloride concentration mechanism are projected to decrease from high in 2030 to low in 2070; however the highest ranking parameter influence is temperature only, as opposed to both temperature and carbon dioxide.

Table 30: Resilience of the system compared to baseline (chloride concentration)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
CSIRO Mk3.5	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
MIROC-Medres	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)

*brackets indicate ratings of ranked climate variable influence

Table 31: Resilience of the system compared to baseline (corrosion initiation probability due to chloride ingress)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
CSIRO Mk3.5	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
MIROC-Medres	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)

*brackets indicate ratings of ranked climate variable influence

Table 32: Resilience of the system compared to baseline (damage initiation probability due to chloride ingress)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
CSIRO Mk3.5	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)
MIROC-Medres	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Low (Temp)	Low (Temp)

*brackets indicate ratings of ranked climate variable influence

Table 33: Resilience of the system compared to baseline (reinforcing bar loss due to chloride ingress)

Model	2030		2050		2070	
	A1FI	**A1B**	**A1FI**	**A1B**	**A1FI**	**A1B**
MRI-CGCM2.3.2	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)
CSIRO Mk3.5	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)
MIROC-Medres	High (Temp)	High (Temp)	High (Temp)	High (Temp)	Med (Temp)	Med (Temp)

*brackets indicate ratings of ranked climate variable influence

Case study: Timber deterioration

Pile 145 (Port Kembla) was analysed for resilience of timber against the probability of marine borer attacks and marine borer attack depth. Resilience against marine borer attacks are projected to be low in 2030 and high from 2050, with sea surface temperature ranking as the highest influencing climate variable in 2030 and A1F1 scenario in 2050. In the A1B scenario in 2030 and both scenarios in 2070, changes in climate variables are not projected to have any influence on the probability of marine borer attack – this is anticipated to be because of the high resilience of the system.

Resilience against marine borer attack depth changes from high in 2030 to low in 2070, and is affected primarily by changes in sea surface temperatures. Therefore it would appear that over time, sea surface temperature will be less conducive to borers.

Table 34: Resilience of the system compared to baseline (probability of marine borer attack)

Model	2030		2050		2070	
	A1FI	**A1B**	**A1FI**	**A1B**	**A1FI**	**A1B**
MRI-CGCM2.3.2	Low (SST)	Low (SST)	High (SST)	High (N/I)	High (N/I)	High (N/I)
CSIRO Mk3.5	Low (SST)	Low (SST)	High (SST)	High (N/I)	High (N/I)	High (N/I)
MIROC-Medres	Low (SST)	Low (SST)	High (SST)	High (N/I)	High (N/I)	High (N/I)

*brackets indicate ratings of ranked climate variable influence. SST denotes sea surface temperature. N/I indicates that no climate variable was ranked more significantly

Table 35: Resilience of the system compared to baseline (marine borer attack depth)

Model	2030		2050		2070	
	A1FI	**A1B**	**A1FI**	**A1B**	**A1FI**	**A1B**
MRI-CGCM2.3.2	High (SST)	High (SST)	High (SST)	High (SST)	Low (SST)	Low (SST)
CSIRO Mk3.5	High (SST)	High (SST)	High (SST)	High (SST)	Low (SST)	Low (SST)
MIROC-Medres	High (SST)	High (SST)	High (SST)	High (SST)	Low (SST)	Low (SST)

*brackets indicate ratings of ranked climate variable influence. SST denotes sea surface temperature

Case study: Steel deterioration

Pile B48 (Port Kembla) was analysed for the resilience of steel corrosion. Steel corrosion loss was projected to range from medium to high for the three models studied as depicted in Table 36, with relative humidity ranked as the highest influencing climate variable followed by temperature.

Table 36: Resilience of the system compared to baseline (steel corrosion loss)

Model	2030		2050		2070	
	A1FI	A1B	A1FI	A1B	A1FI	A1B
MRI-CGCM2.3.2	Med (RH, Temp)	Med (RH, Temp)	Med (RH, Temp)	Med (RH, Temp)	High (RH, Temp)	High (RH, Temp)
CSIRO Mk3.5	Med (RH, Temp)	Med (RH, Temp)	Med (RH, Temp)	Med (RH, Temp)	High (RH, Temp)	High (RH, Temp)
MIROC-Medres	High (RH, Temp)	High (RH, Temp)	High (RH, Temp)	High (RH, Temp)	High (RH, Temp)	High (RH, Temp)

*brackets indicate ratings of ranked climate variable influence. RH denotes relative humidity

4. LIFE CYCLE COST ANALYSIS

Seaport structures are subject to deterioration due to the severe nature of the marine environment. When impacted by climate change, the deterioration is expected to accelerate, which may necessitate more rehabilitation activities. This section aims to measure the difference between the life cycle cost of seaport structures when impacted by climate change, compared with the cost of seaport structures when climate change impact is not considered. A design and maintenance cost management tool was developed to optimise maintenance sequence and determine the effectiveness of maintenance options in the form of net present value return.

4.1 *Life cycle costing model*

A series of activities occur in the life cycle of concrete structures in seaports. These activities include design, construction, inspection, maintenance and rehabilitation and bring the following costs:

- Initial Cost (I_0): This includes the design and construction cost for the structure when the structure is built.
- Inspection Cost (C_I): Cost associated with the inspection of structures, occurring regularly such as every Δt_I years
- Maintenance Cost (C_M): Cost associated with the upkeep of the structure such as painting and treatment of minor cracks in the concrete, occurring regularly, such as every Δt_M years.
- Rehabilitation Cost (C_R): Cost associated with the major works to improve the service life of the structure, such as resurfacing the concrete pile and implementing cathodic protection if the crack width is larger than 1 mm. If rehabilitation work is not undertaken, spalling of concrete cover will develop quickly, leading to a serviceability failure. Rehabilitation may occur every Δt_R years.
- Salvage Cost (C_S): Cost difference between salvage value and the removal cost, occurring at the end of the life of the structure.

The life cycle cost of a concrete structure will be influenced by the following parameters:

- The values of the activity costs as listed above
- The frequency of activity occurrences
- The expected service life of the structure (*N* years)
- The discount rate adopted (*i*), in Australia 7% is normally chosen

When time value is not considered, the life cycle cost of a seaport structure in an expected service life may be conceptually represented as

$$LCC = I_0 + C_I + C_M + C_R + C_S \qquad \textbf{\textit{Eq. 32}}$$

4.1.1 Newly constructed structure

The present value of the life cycle cost can be given as:

$$PV_{Lcc} = I_0 + PVF\ (C_I + C_M + C_R + C_S) \qquad \textbf{\textit{Eq. 33}}$$

where PV_{Lcc} is the present value of life cycle cost and *PVF* is the cumulative present value factor.

If the following assumptions are made:

- failure cost such as damages, cost of life, injury, user delay etc. is not considered,
- the expected service life of the concrete structure is N years,
- inspection occurs every Δt_I year,
- maintenance occurs every Δt_M year and
- rehabilitation occurs every Δt_R year (the rehabilitation time can be derived from the deterioration curve due to the climate change impact)

Then, the life cycle cost model can be given as:

$$\begin{aligned} PV_{LCC} = I_0 + C_I[(P/F\,,i,\Delta t_I) + (P/F\,,i,2\Delta t_I) + \cdots + (P/F\,,i,N\,)] \\ + C_M[(P/F\,,i,\Delta t_M) + (P/F\,,i,2\Delta t_M) + \cdots + (P/F\,,i,N\,)] \\ + C_R[(P/F\,,i,\Delta t_R) + (P/F\,,i,2\Delta t_R) + \cdots + (P/F\,,i,N\,)] \\ + C_S(P/F\,,i,N\,) \end{aligned} \qquad \textbf{Eq. 34}$$

where $(P/F, i, \Delta t)$ is the present value factor, $(P/F, i, \Delta t) = {}^{1}\!/_{(1+i)^{\Delta t}}$

4.1.2 Existing structure

Many seaport structures were built by Australian port authorities and have been in use for many years. These existing structures might have already gone through maintenance and rehabilitation over the years. Therefore, when calculating the life cycle cost, both the maintenance and rehabilitation activities in the past and future should be taken into consideration.

In developing the life cycle costing model for the existing structure, the following assumptions are made:

- failure cost such as damages, cost of life, injury and user delay is not considered.
- the expected service life of the concrete structure is N years
- the concrete structure was designed and constructed t_p years ago
- the concrete structure is expected to serve for t_f years into the future, and $N = t_p + t_f$
- inspection occurs every Δt_I year
- maintenance occurs every Δt_M year
- rehabilitation occurs every Δt_R year (the rehabilitation time can be derived from the deterioration curve due to the climate change impact)

Firstly, at the time when the structure was built, the present value of the life cycle cost is calculated using the same methods as if it is a new built structure.

$$\begin{aligned} PV_{LCC_0} = I_0 + C_I[(P/F\,,i,\Delta t_I) + (P/F\,,i,2\Delta t_I) + \cdots + (P/F\,,i,N\,)] \\ + C_M[(P/F\,,i,\Delta t_M) + (P/F\,,i,2\Delta t_M) + \cdots + (P/F\,,i,N\,)] \\ + C_R[(P/F\,,i,\Delta t_R) + (P/F\,,i,2\Delta t_R) + \cdots + (P/F\,,i,N\,)] \\ + C_S(P/F\,,i,N\,) \end{aligned} \qquad \textbf{Eq. 35}$$

Secondly, at the current time, the present value of the life cycle cost can be given as:

$$PV_{LCC} = PV_{LCC_0}(F/P\,,i,t_p) \qquad \textbf{Eq. 36}$$

where PV_{LCC} is the present value of life cycle cost, PV_{LCC_0} is the present value of life cycle cost at the time when the structure was built and $(F/P, i, t_p)$ is the single payment compound amount factor, $\left(F/P, i, t_p\right) = (1 + i)^{t_p}$

4.2 Life cycle cost comparison with and without climate change

4.2.1 Newly built structure

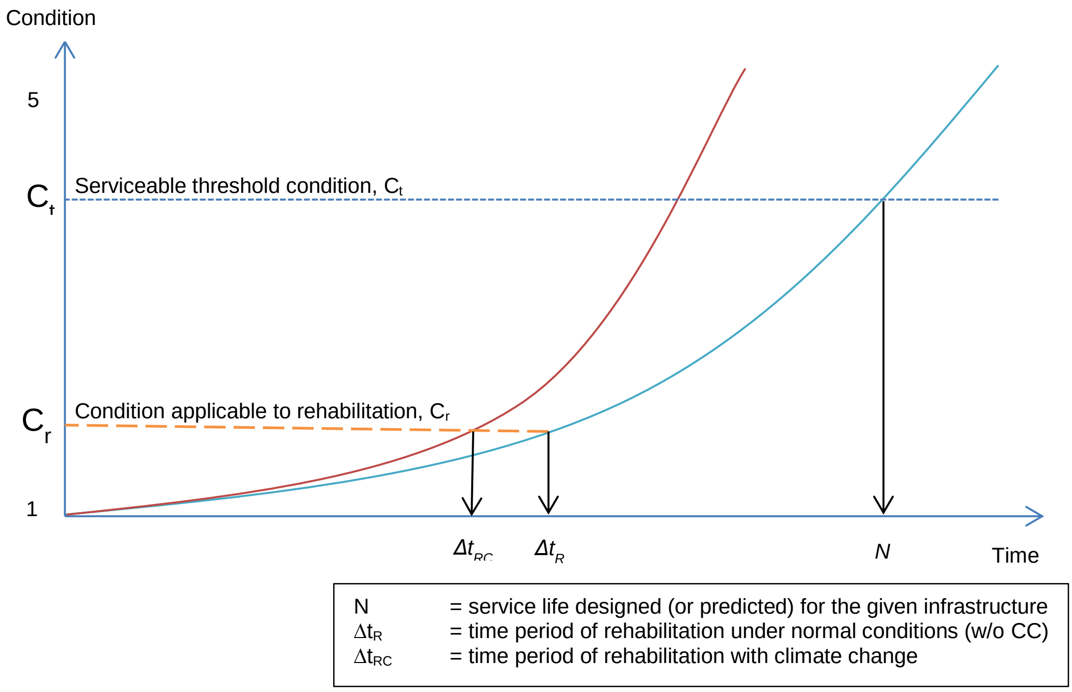


Figure 32: Deterioration curves with and without considering climate change impact

Figure 32 presents two deterioration curves for seaport structures. The blue curve represents a deterioration scenario without climate change while the red represents a scenario with climate change. C_t is the serviceable threshold condition beyond which the seaport structure is deemed to be unserviceable. C_r is condition which triggers rehabilitation activities. As climate change impact might accelerate the structural deterioration, the rehabilitation time period with climate change Δt_{RC} is shorter than the period without climate change Δt_R. Figure 33 presents the deterioration curves and reoccurrence of rehabilitation in a typical seaport structure's service life.

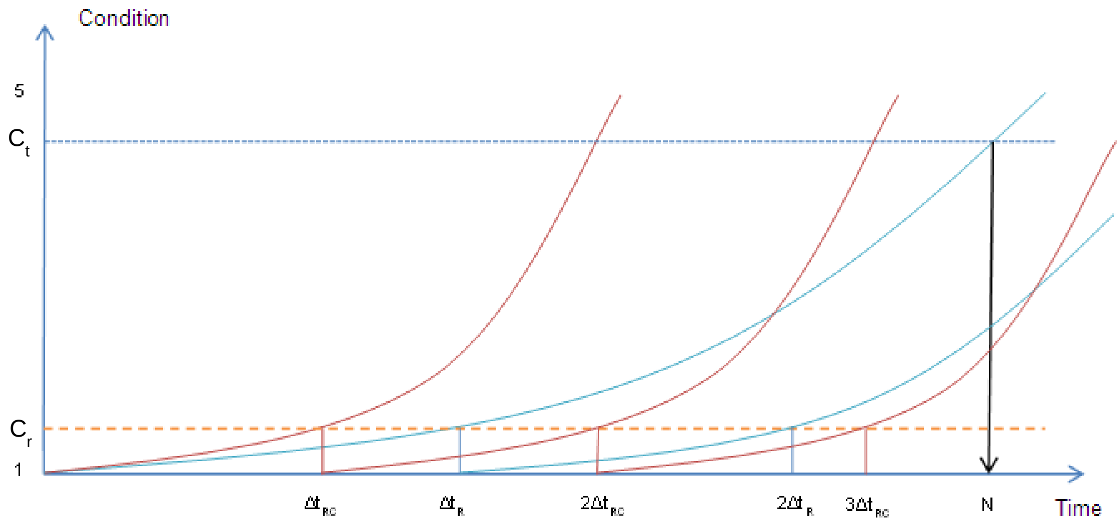


Figure 33: Deterioration curves and reoccurrence of rehabilitation in seaport structure service life

Figure 34 presents the maintenance and inspection frequency along the life cycle of seaport structures. As inspection and maintenance would not improve the service condition of structures, their frequency is shown in a static deterioration curve without considering rehabilitation activities.

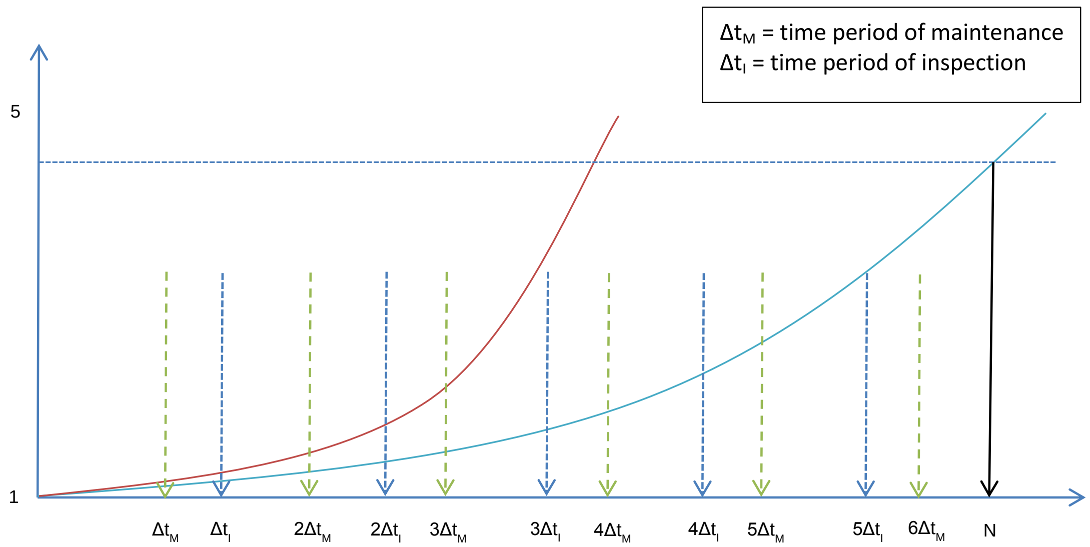


Figure 34: Reoccurrence frequency of inspection and maintenance undertaken

n_I = number of occurrences of inspection cost during N time = $N/\Delta t_I$
n_M = number of occurrences of maintenance cost during N time = $N/\Delta t_M$
n_R = number of occurrences of inspection cost during N time (without climate change) = $N/\Delta t_R$
n_{Rc} = number of occurrences of inspection cost during N time (with climate change) = $N/\Delta t_{Rc}$

Assume,
Inspect cost for one occurrence = C_I
Maintenance cost for one occurrence = C_M
Rehabilitation cost for one occurrence = C_R

Life cycle cost for the expected service life time N without climate change

As per Eq. 33 and Eq. 34, the life cycle cost can be given as:

$$\begin{aligned} PV_{LCC^{W/C}} = I_0 &+ C_I[(P/F, i, \Delta t_I) + (P/F, i, 2\Delta t_I) + \cdots + (P/F, i, N)] \\ &+ C_M[(P/F, i, \Delta t_M) + (P/F, i, 2\Delta t_M) + \cdots + (P/F, i, N)] \\ &+ C_R[(P/F, i, \Delta t_R) + (P/F, i, 2\Delta t_R) + \cdots + (P/F, i, N)] \\ &+ C_S(P/F, i, N) \end{aligned} \qquad \textbf{\textit{Eq. 37}}$$

where $PV_{LCC^{W/C}}$ indicates the net present value of life cycle cost without climate change

Expected service life $N = n_I \Delta t_I = n_M \Delta t_M = n_R \Delta t_R$

Present value of **initial cost** = I_0

Present value of **inspection cost**= $C_I\left[\frac{1}{(1+i)^{\Delta t_I}} + \frac{1}{(1+i)^{2\Delta t_I}} + \frac{1}{(1+i)^{3\Delta t_I}} + \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots + \frac{1}{(1+i)^{n_I \Delta t_I}}\right]$

$= \frac{C_I[(1+i)^{n_I \Delta t_I} - 1]}{(1+i)^{n_I \Delta t_I}[(1+i)^{\Delta t_I} - 1]}$

Present value of **maintenance cost=**

$= C_M\left[\frac{1}{(1+i)^{\Delta t_M}} + \frac{1}{(1+i)^{2\Delta t_M}} + \frac{1}{(1+i)^{3\Delta t_M}} + \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots + \frac{1}{(1+i)^{n_M \Delta t_M}}\right]$

$= \frac{C_M[(1+i)^{n_M \Delta t_M} - 1]}{(1+i)^{n_M \Delta t_M}[(1+i)^{\Delta t_M} - 1]}$

Present value of **rehabilitation cost=**

$= C_R\left[\frac{1}{(1+i)^{\Delta t_R}} + \frac{1}{(1+i)^{2\Delta t_R}} + \frac{1}{(1+i)^{3\Delta t_R}} + \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots + \frac{1}{(1+i)^{n_R \Delta t_R}}\right]$

$= \frac{C_R[(1+i)^{n_R \Delta t_R} - 1]}{(1+i)^{n_R \Delta t_R}[(1+i)^{\Delta t_R} - 1]}$

Present value of **salvage cost** = $\frac{C_S}{(1+i)^N}$

Thus

$$\begin{aligned} PV_{LCC^{W/C}} = I_0 + C_I \frac{[(1+i)^{n_I \Delta t_I} - 1]}{(1+i)^{n_I \Delta t_I}[(1+i)^{\Delta t_I} - 1]} + C_M \frac{[(1+i)^{n_M \Delta t_M} - 1]}{(1+i)^{n_M \Delta t_M}[(1+i)^{\Delta t_M} - 1]} \\ + C_R \frac{[(1+i)^{n_R \Delta t_R} - 1]}{(1+i)^{n_R \Delta t_R}[(1+i)^{\Delta t_R} - 1]} + C_S \frac{1}{(1+i)^N} \end{aligned} \qquad \textbf{\textit{Eq. 38}}$$

Life cycle cost for the expected service life time N with climate change

As per Eq. 33 and Eq. 34, the life cycle cost can be given as:

$$\begin{aligned} PV_{LCC^{W}} = I_0 &+ C_I[(P/F, i, \Delta t_I) + (P/F, i, 2\Delta t_I) + \cdots + (P/F, i, N)] \\ &+ C_M[(P/F, i, \Delta t_M) + (P/F, i, 2\Delta t_M) + \cdots + (P/F, i, N)] \\ &+ C_R[(P/F, i, \Delta t_{RC}) + (P/F, i, 2\Delta t_{RC}) + \cdots + (P/F, i, N)] \\ &+ C_S(P/F, i, N) \end{aligned} \qquad \textbf{\textit{Eq. 39}}$$

where $PV_{LCC^{W}}$ indicates the net present value of life cycle cost with climate change

Expected service life $N = n_I \Delta t_I = n_M \Delta t_M = n_{RC} \Delta t_{RC}$

Present value of **initial cost** = I_0

Present value of **inspection cost**= $C_I\left[\frac{1}{(1+i)^{\Delta t_I}}+\frac{1}{(1+i)^{2\Delta t_I}}+\frac{1}{(1+i)^{3\Delta t_I}}+\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots+\frac{1}{(1+i)^{n_I\Delta t_I}}\right]$

$=\frac{C_I\left[(1+i)^{n_I\Delta t_I}-1\right]}{(1+i)^{n_I\Delta t_I}\left[(1+i)^{\Delta t_I}-1\right]}$

Present value of **maintenance cost=**

$= C_M\left[\frac{1}{(1+i)^{\Delta t_M}}+\frac{1}{(1+i)^{2\Delta t_M}}+\frac{1}{(1+i)^{3\Delta t_M}}+\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots+\frac{1}{(1+i)^{n_M\Delta t_M}}\right]$

$=\frac{C_M\left[(1+i)^{n_M\Delta t_M}-1\right]}{(1+i)^{n_M\Delta t_M}\left[(1+i)^{\Delta t_M}-1\right]}$

Present value of **rehabilitation cost=**

$= C_R\left[\frac{1}{(1+i)^{\Delta t_{Rc}}}+\frac{1}{(1+i)^{2\Delta t_{Rc}}}+\frac{1}{(1+i)^{3\Delta t_{Rc}}}+\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots+\frac{1}{(1+i)^{n_{Rc}\Delta t_{Rc}}}\right]$

$=\frac{C_R\left[(1+i)^{n_{Rc}\Delta t_{Rc}}-1\right]}{(1+i)^{n_{Rc}\Delta t_{Rc}}\left[(1+i)^{\Delta t_{Rc}}-1\right]}$

Present value of **salvage cost** = $\frac{C_S}{(1+i)^N}$

Thus

$$PV_{LCC^W} = I_0 + C_I\frac{\left[(1+i)^{n_I\Delta t_I}-1\right]}{(1+i)^{n_I\Delta t_I}\left[(1+i)^{\Delta t_I}-1\right]} + C_M\frac{\left[(1+i)^{n_M\Delta t_M}-1\right]}{(1+i)^{n_M\Delta t_M}\left[(1+i)^{\Delta t_M}-1\right]} + C_R\frac{\left[(1+i)^{n_{Rc}\Delta t_{Rc}}-1\right]}{(1+i)^{n_{Rc}\Delta t_{Rc}}\left[(1+i)^{\Delta t_{Rc}}-1\right]} + C_S\frac{1}{(1+i)^N} \qquad \textbf{\textit{Eq. 40}}$$

Life cycle cost difference (ΔLCC) between two conditions with climate change and without climate change

Ideally, if a whole set of data is available for one concrete structure, its life cycle cost with and without considering climate change impact can be calculated based on Eq. 39 and Eq. 40. Then, the life cycle cost difference (ΔLCC) can be established.

However, for the following two reasons

- the difficulty in obtaining data for many parameters such as I_0, C_I and C_M,
- the purpose of the model aiming to capture the influence/difference resulting from climate change impact

an alternative way to measure the life cycle cost difference (ΔLCC) for the concrete structure in seaports between two conditions with and without climate change can be presented as below, as per Eq. 39 and Eq. 40.

$$\Delta LCC = PV_{LCC^W} - PV_{LCC^{W/C}} = C_R\left[\frac{\left[(1+i)^{n_{Rc}\Delta t_{Rc}}-1\right]}{(1+i)^{n_{Rc}\Delta t_{Rc}}\left[(1+i)^{\Delta t_{Rc}}-1\right]} - \frac{\left[(1+i)^{n_R\Delta t_R}-1\right]}{(1+i)^{n_R\Delta t_R}\left[(1+i)^{\Delta t_R}-1\right]}\right] \qquad \textbf{\textit{Eq. 41}}$$

As per the equation, the following variables have to be established,

i= The discount rate adopted (*i*), in Australia 7% is normally chosen

Δt_R = Frequency/time period of rehabilitation under normal conditions (without considering climate change impact)

Δt_{RC} = Frequency/time period of rehabilitation under the conditions (considering climate change impact)

C_R = Rehabilitation cost

N = expected service life of the structure

Then, $n_R = N/\Delta t_R$ $n_{Rc} = N/\Delta t_{Rc}$

Accordingly, under six climate change scenarios, the life cycle cost difference (ΔLCC) can be measured and presented in the following table.

Table 37: Calculation of life cycle cost difference for newly built structure

Climate Change Scenario	Δt_{RC}	Δt_R	C_R	i	N	ΔLCC
1						
2						
3						
4						
5						
6						

4.2.2 Existing structure

For existing structure;

$$\mathrm{N} = \mathrm{t_p} + \mathrm{t_f} \quad \textbf{\textit{Eq. 42}}$$

where,
$\mathrm{t_p}$ = Time from the construction date to the current time
$\mathrm{t_f}$ = Time from the current time date to the time of expected service life

Life cycle cost for the expected service life time N without climate change

Firstly, as per Eq. 35, at the time when the structure was built, the present value of the life cycle cost $PV_{LCC_0^{W/C}}$is calculated using the same methods as if it is a new built structure.

$$\begin{aligned} PV_{LCC_0^{W/C}} = I_0 &+ C_I[(P/F\,,i,\Delta t_I) + (P/F\,,i,2\Delta t_I) + \cdots + (P/F\,,i,N\,)] \\ &+ C_M[(P/F\,,i,\Delta t_M) + (P/F\,,i,2\Delta t_M) + \cdots + (P/F\,,i,N\,)] \\ &+ C_R[(P/F\,,i,\Delta t_R) + (P/F\,,i,2\Delta t_R) + \cdots + (P/F\,,i,N\,)] \\ &+ C_S(P/F\,,i,N\,) \end{aligned} \quad \textbf{\textit{Eq. 43}}$$

Secondly, following the same method described in Section 4.2.1, at the time when the structure was built, the present value of the life cycle cost $PV_{LCC_0^{W/C}}$ can be given as

$$PV_{LCC_0^{W/C}} = I_0 + C_I \frac{\left[(1+i)^{n_I \Delta t_I} - 1\right]}{(1+i)^{n_I \Delta t_I}\left[(1+i)^{\Delta t_I} - 1\right]} + C_M \frac{\left[(1+i)^{n_M \Delta t_M} - 1\right]}{(1+i)^{n_M \Delta t_M}\left[(1+i)^{\Delta t_M} - 1\right]} + C_R \frac{\left[(1+i)^{n_R \Delta t_R} - 1\right]}{(1+i)^{n_R \Delta t_R}\left[(1+i)^{\Delta t_R} - 1\right]} + C_S \frac{1}{(1+i)^N} \quad \textit{Eq. 44}$$

Thirdly, as per Eq. 36 at the current time, the present value of the life cycle cost can be given as

$$PV_{LCC^{W/C}} = PV_{LCC_0^{W/C}} (1+i)^{t_p} \quad \textit{Eq. 45}$$

Life cycle cost for the expected service life time N with climate change

As per Eq. 35 and following the same method described in Section 4.2.1, at the time when the structure was built, the Present Value of the life cycle cost $PV_{LCC_0^W}$ can be given as

$$PV_{LCC_0^{W}} = I_0 + C_I \frac{\left[(1+i)^{n_I \Delta t_I} - 1\right]}{(1+i)^{n_I \Delta t_I}\left[(1+i)^{\Delta t_I} - 1\right]} + C_M \frac{\left[(1+i)^{n_M \Delta t_M} - 1\right]}{(1+i)^{n_M \Delta t_M}\left[(1+i)^{\Delta t_M} - 1\right]} + C_R \frac{\left[(1+i)^{n_{Rc} \Delta t_{Rc}} - 1\right]}{(1+i)^{n_{Rc} \Delta t_{Rc}}\left[(1+i)^{\Delta t_{Rc}} - 1\right]} + C_S \frac{1}{(1+i)^N} \quad \textit{Eq. 46}$$

As per Eq. 36, at the current time, the present value of the life cycle cost can be given as

$$PV_{LCC^{W}} = PV_{LCC_0^{W}} (1+i)^{t_p} \quad \textit{Eq. 47}$$

Life cycle cost difference (ΔLCC) between two conditions with climate change and without climate change

Ideally, if a whole set of data is available for a concrete structure, its life cycle cost with and without considering climate change impact can be calculated based on Equations 45 and 47. Then, the life cycle cost difference (ΔLCC) can be established.

However, for the following two reasons

- The difficulty in obtaining data for many parameters such as I_0, $C_I$and C_M,
- The purpose of the model aiming to only capture the influence/difference resulting from climate change impact

an alternative way to measure the life cycle cost difference (ΔLCC) for concrete structure in seaports between two conditions with and without climate change can be presented as below, as per Equations 45 and 47.

$$\Delta LCC = PV_{LCC}{}^{w}\text{-}PV_{LCC}{}^{w/c}$$

$$= C_R\left[\frac{[(1+i)^{n_{Rc}\Delta t_{Rc}}-1]}{(1+i)^{n_{Rc}\Delta t_{Rc}}[(1+i)^{\Delta t_{Rc}}-1]}-\frac{[(1+i)^{n_R\Delta t_R}-1]}{(1+i)^{n_R\Delta t_R}[(1+i)^{\Delta t_R}-1]}\right](1+i)^{t_p} \quad \textbf{\textit{Eq. 48}}$$

As per the equation, the following variables have to be established,

i= The discount rate adopted (*i*), in Australia 7% is normally chosen

Δt_R = Frequency/time period of rehabilitation under normal conditions (without considering climate change impact)

Δt_{RC} = Frequency/time period of rehabilitation under the conditions (considering climate change impact)

C_R = Rehabilitation cost

N = expected service life of the structure

t_p = Time from the construction date to the current time

Then, $n_R = N/\Delta t_R$ $n_{Rc} = N/\Delta t_{Rc}$

Accordingly, under different climate change scenarios, the life cycle cost difference (ΔLCC) can be measured and presented in the following table.

Table 38: Calculation of life cycle cost difference for existing structure

Climate Change Scenario	Δt_{RC}	Δt_R	C_R	i	t_p	N	ΔLCC
1							
2							
3							
4							
5							
6							

4.2.3 Case study based on a concrete pile (Pile 31, Gladstone)

The life cycle cost difference for Pile 31 with and without considering climate change impact is measured in this section. Due to limited data availability, it is difficult to calculate the life cycle cost of the pile directly. Therefore, we choose only to measure the cost difference brought by rehabilitation activities.

A set of data on the pile rehabilitation was obtained from one of the partner port authorities. It is worth noting that the pile is treated as a new pile as rehabilitation data is not available for the past years since it was built.

The following assumptions were made.

- Interest rate (i) was given as 7% over the expected life (N) of 100 years.
- Rehabilitation cost C_R *was* calculated for the pile within the tidal impact zone. Given that the pile's diameter is 550mm, pile section needs rehabilitation with cathodic protection per metre, and rehabilitation cost per unit (sqm) is given \$1300. Therefore, for each pile, the rehabilitation cost C_R= \$309.

- The model currently developed uses crack widths of 1mm to quantify damage due to carbonation, and this information was used to find Δt_R and Δt_{RC}.
- Due to uncertainty in the climate change data, carbonation corrosion damage at 20% probability was chosen to trigger the rehabilitation, as a proactive and conservative approach. In this case study, the life cycle cost difference for six climate change scenarios were calculated.

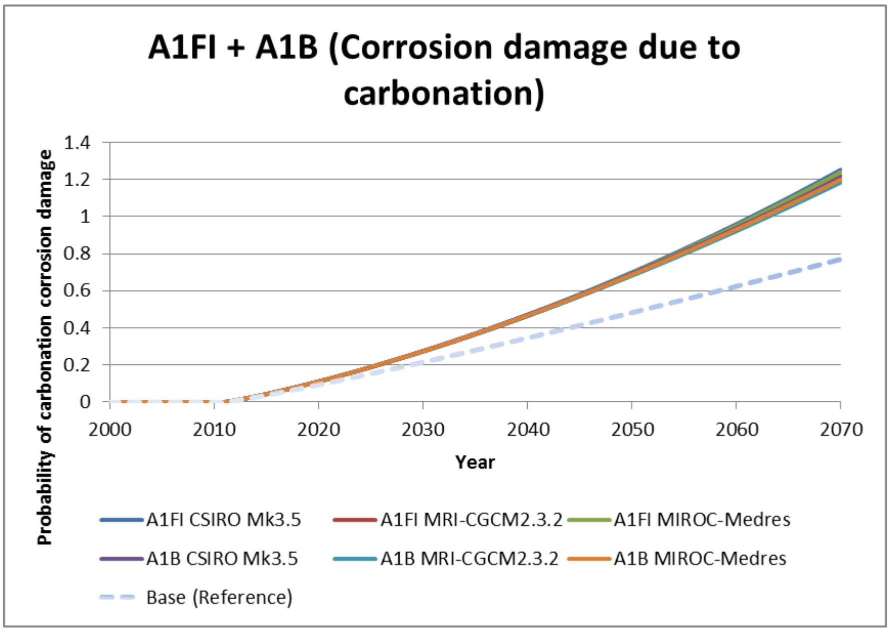


Figure 35: Deterioration due to carbonation corrosion damage under different climate change scenarios for Pile 31 (tidal zone)

With reference to the deterioration curves due to carbonation corrosion damage for Pile 31 in the tidal zone (Figure 35), it is observed that the six climate change scenarios (A1FI most likely, A1FI hotter & drier, A1FI cooler & wetter, A1B most likely, A1B hotter & drier and A1B cooler & wetter) do not present much difference on rehabilitation time/frequency under 20% probability of carbonation corrosion damage. It can be judged that Δt_R =19 years and Δt_{RC} =16 years.

As per Eq. 41, the life cycle cost difference (ΔLCC) for Pile 31 is worked out.

Table 39: Life cycle cost difference calculation with 7% discount rate on Pile 31

Climate change scenario	Δt_{RC} (Years)	Δt_R (Years)	C_R ($)	i	N (Years)	ΔLCC ($)
1	16	19	309	0.07	100	40.14
2	16					40.14
3	16					40.14
4	16					40.14
5	16					40.14
6	16					40.14

The results indicate the life cycle cost for a concrete pile considering climate change is higher than the life cycle cost without considering climate change.

While 7% discount rate is a commonly used value in engineering life cycle cost analysis, it is generally used for short term planning (e.g. 10 year horizon). As such, a smaller discount rate may be more suitable for longer term studies. For climate change considerations where effects and impacts are within the range of the time horizon, 3% discount rate was adopted in addition to the earlier 7% study. This life cycle cost difference is then worked out in Table 40.

Table 40: Life cycle cost difference calculation with 3% discount rate on Pile 31

Climate change scenario	Δt_{RC} (Years)	Δt_R (Years)	C_R ($)	i	N (Years)	ΔLCC ($)
1	16	19	309	0.03	100	95.72
2	16					95.72
3	16					95.72
4	16					95.72
5	16					95.72
6	16					95.72

The results show with 3% discount rate, the life cycle cost for a concrete pile undergoing climate change is again higher than the life cycle cost without climate change. It is worth noting that the life cycle cost difference for one single pile is enlarged from $40.41 to $95.72 per metre, which indicates that a lower discount rate can better reveal the cost impact brought by climate change on seaport structures.

Discussion

The calculation of the life cycle cost of a concrete structure in seaport requires a complete set of design, construction and maintenance data. Due to the limited data available, it is difficult to directly measure the life cycle cost of the concrete structure, and hence it is difficult to measure the life cycle cost difference of the structure with and without considering climate change impact.

With assumptions, the alternative life cycle cost comparison model proposed only aims to capture the differences in rehabilitation frequency of the concrete structure due to climate change compared to without considering climate change. This method significantly reduces the amount of data required.

Under six different climate change scenarios, deterioration due to carbonation corrosion damage is similar at a given level of probability. In the given case study using Pile 31, it is clear that under the six climate change scenarios, the life cycle cost of the pile is slightly higher than that without considering climate change. However, the difference is not significant given that the additional cost is $95.72 per metre (with 3% discount rate) over an expected service life of 100 years.

4.3 *Design and treatment cost optimisation tool*

Optimising design and maintenance-related treatment cost is regarded as a strategic approach for seaport structures. In this section, a cost optimisation model for evaluating treatment options is presented. The objective of this tool is to develop a life cycle strategy that can bring about an optimum gain in terms of maintenance and renewal options from a cost perspective. This tool has been developed using Microsoft Excel and Visual Basic for Applications.

The optimisation uses a Monte Carlo simulation process (similar to Section 3.3.2) to evaluate opportunities to suggest changes in design criteria, asset management policies, maintenance cycles and operating strategies. With this tool, the user would be able to determine the best time for intervention and also determine the effectiveness of the treatment in the form of a Net Present Value (NPV) return.

The user input required for this tool includes the following:

- Asset remaining life to intervention point (based on expert judgement)
- Analysis period (up to 100 years)
- Current maintenance and operational cost (per year)
- Current additional benefits (per year)
- Treatment costs
- Useful life of treatment
- Maintenance and operational cost (per year) of treatment
- Additional benefits (per year) of treatment

Figure 36 and Figure 37 show a typical user input form for the tool.

Asset remaining life to intervention point	Current Year	Analysis period
5	2012	50
Maintenance/Operational Cost per Year (Current)	$60	
Benefits per Year (Current)	$10	

Figure 36: Current design and maintenance input form

Treatment Option 1	Replacement	
Treatment Cost	Unit rate ($)	Measurement
$6,650	$700	9.5
Useful life as a result of the treatment	25	Years
Maintenance/Operational Cost per Year	$20	
Benefits per Year	$10	

Figure 37: New treatment input form

The tool is capable of providing optimisation of 3 treatment options. Currently, the tool generates up to 100 scenarios for combinations of treatment application, timing and sequence of treatments. It then ranks the 'optimised' scenario based on lowest NPV; Table 41 and Figure 38 show the NPV ranges of scenarios ranked from the lowest to the highest. A sample result is given in Figure 39 (refer to Appendix 3 for detailed results). This shows that for the fictitious information entered, scenario number 29 is the best case cost optimisation solution. It displays the periods where major interventions should be planned/expected, and the anticipated cost of the interventions.

The information provided by this tool may then be incorporated into the deterioration models, to allow for a more robust assessment of how a port structure deteriorates over time. Due to project constraints, this currently exists as a standalone module – in future it would be beneficial to integrate this tool with the deterioration models.

Table 41: Scenarios (top 20) ranked according to NPV

No.	NPV	Scenario
1	$4,246	Scenario 29 - Total
2	$4,248	Scenario 14 - Total
3	$4,252	Scenario 41 - Total
4	$4,253	Scenario 77 - Total
5	$4,254	Scenario 79 - Total
6	$4,282	Scenario 52 - Total
7	$4,288	Scenario 67 - Total
8	$4,293	Scenario 59 - Total
9	$4,294	Scenario 6 - Total
10	$4,314	Scenario 83 - Total
11	$4,318	Scenario 80 - Total
12	$4,323	Scenario 58 - Total
13	$4,402	Scenario 1 - Total
14	$4,413	Scenario 12 - Total
15	$4,413	Scenario 43 - Total
16	$4,418	Scenario 16 - Total
17	$4,419	Scenario 54 - Total
18	$4,420	Scenario 97 - Total
19	$4,444	Scenario 15 - Total
20	$4,456	Scenario 36 - Total

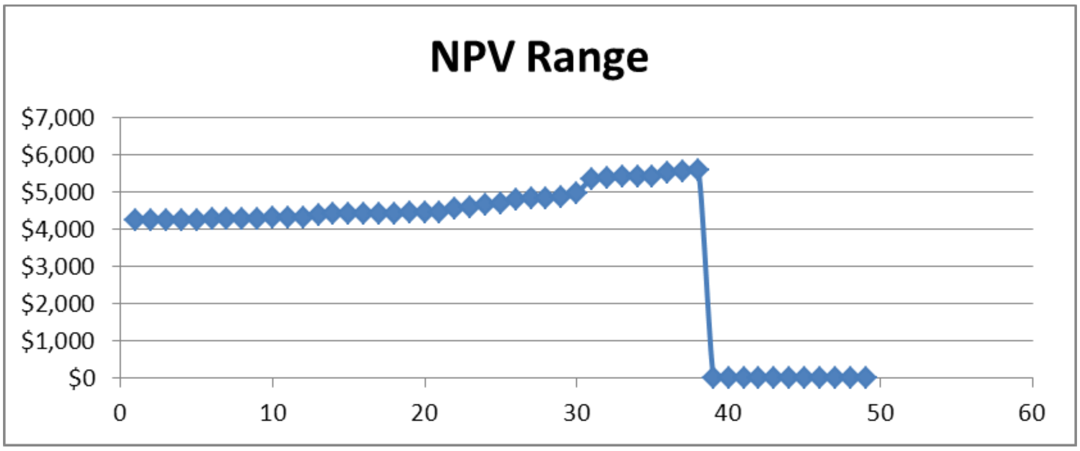


Figure 38: Example of lowest NPV range showing best case scenario

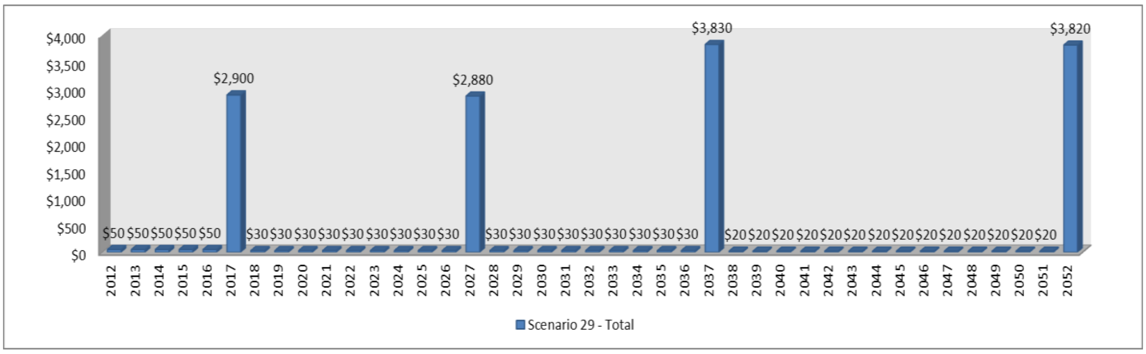


Figure 39: Example of best case scenario of cost optimisation

5. SOFTWARE TOOL

A software tool has been developed using the methodology and analytical process described in Section 3. The tool has the capability to carry out cascading classification so that a particular element type can be classified on the basis of numerous factors, e.g., design type, material type, exposure type, etc.

The online tool is a web application developed using the Microsoft ASP.NET 4.0 web development framework with SQL Server 2010 as the database. The current version of the system captures user input via a sequence of web forms and uses the Microsoft Excel based projection model developed by WP3 for executing the mathematical formulae. This approach of integrating the Microsoft Excel based model expedited the development process as the developers did not require the understanding of the complex mathematical formulae and only needed to work with the references to inputs and outputs. It also allows newer versions of the model to be easily integrated into the online tool by just replacing the relevant Excel files, without the need to make any programming changes (provided the input/output references remain the same).

5.1 *Graphical user interface*

Figures 40 - 43 show the main interface for the software program. The tool has the following four interfaces:

- Climate data selection view: In the climate data view, users can select the location, greenhouse emission scenario, climate futures model and start year of analysis (see Figure 40).
- Material properties view: Once the construction material (concrete, steel or timber) has been selected from the material classification form, the material properties for the given material will be available for view or edited (see Figure 41).
- Structural definitions view: The properties of the structural elements or components to be analysed would be recorded at this stage (see Figure 42)
- Results view: The deterioration model curves and their sensitivity for a given climate scenario will be displayed on this screen (see Figure 43). Users will have the option to download the output data in the form of a CSV file.

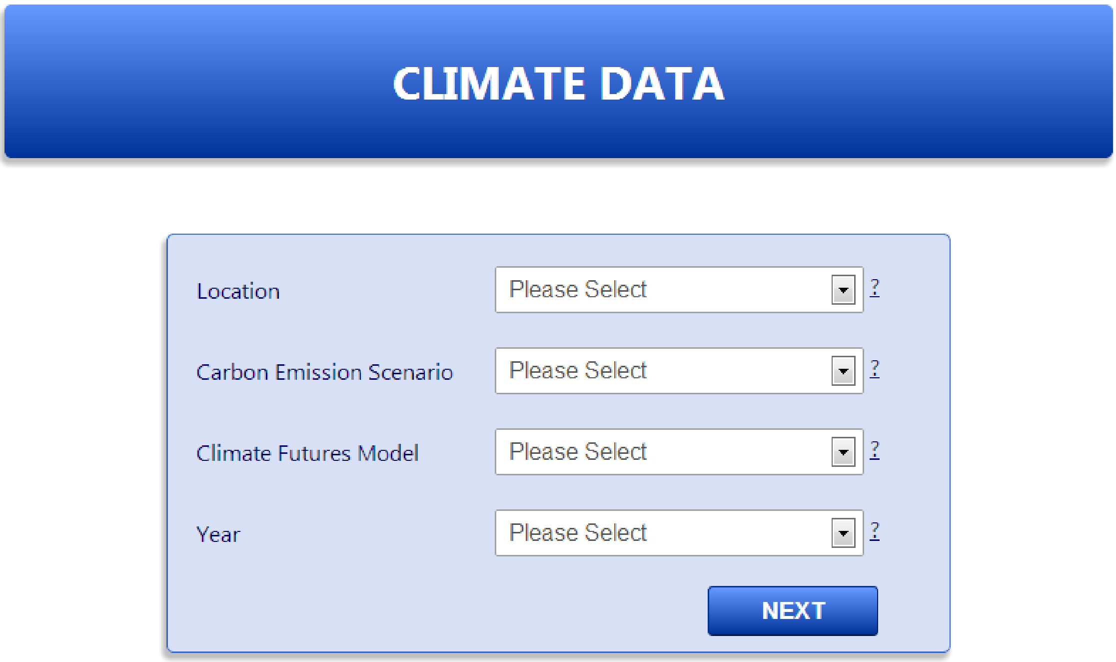


Figure 40: Screenshot of the software tool interface

MATERIAL PROPERTIES

Climate Data / Material Properties

Construction Material Concrete ? VIEW / EDIT

MATERIAL: CONCRETE

CARBONATION CORROSION RATES AT 20°C

Class	Description	Mean ($\mu A/cm^2$)	SD ($\mu A/cm^2$)	Distribution
CB1	Dry	0	0	lognormal
CB2	Wet-rarely dry (unsheltered)	0.345	0.259	lognormal
CB3	Moderate humidity (sheltered)	0.172	0.086	lognormal
CB4	Cyclic wet-dry (unsheltered)	0.431	0.259	lognormal

EDIT

CHLORIDE CORROSION RATES AT 20°C

Class	Description	Mean ($\mu A/cm^2$)	SD ($\mu A/cm^2$)	Distribution
CL1	Wet-rarely dry	0.345	0.259	lognormal
CL2	Cyclic wet-dry	2.586	1.724	lognormal
CL3	Airborne sea water	2.586	1.724	lognormal
CL4	Submerged	0	0	lognormal
CL5	Tidal zone	6.035	3.448	lognormal

EDIT

CO_2 DIFFUSION COEFFICIENT

w/c	$D_1 \times 10^{-4}$ (cm^2/s)	n_d
0.30	0.1034	0.1910
0.35	0.1914	0.2002
0.40	0.3543	0.2099

Figure 41: Material properties view

Figure 42: Structural element definitions view

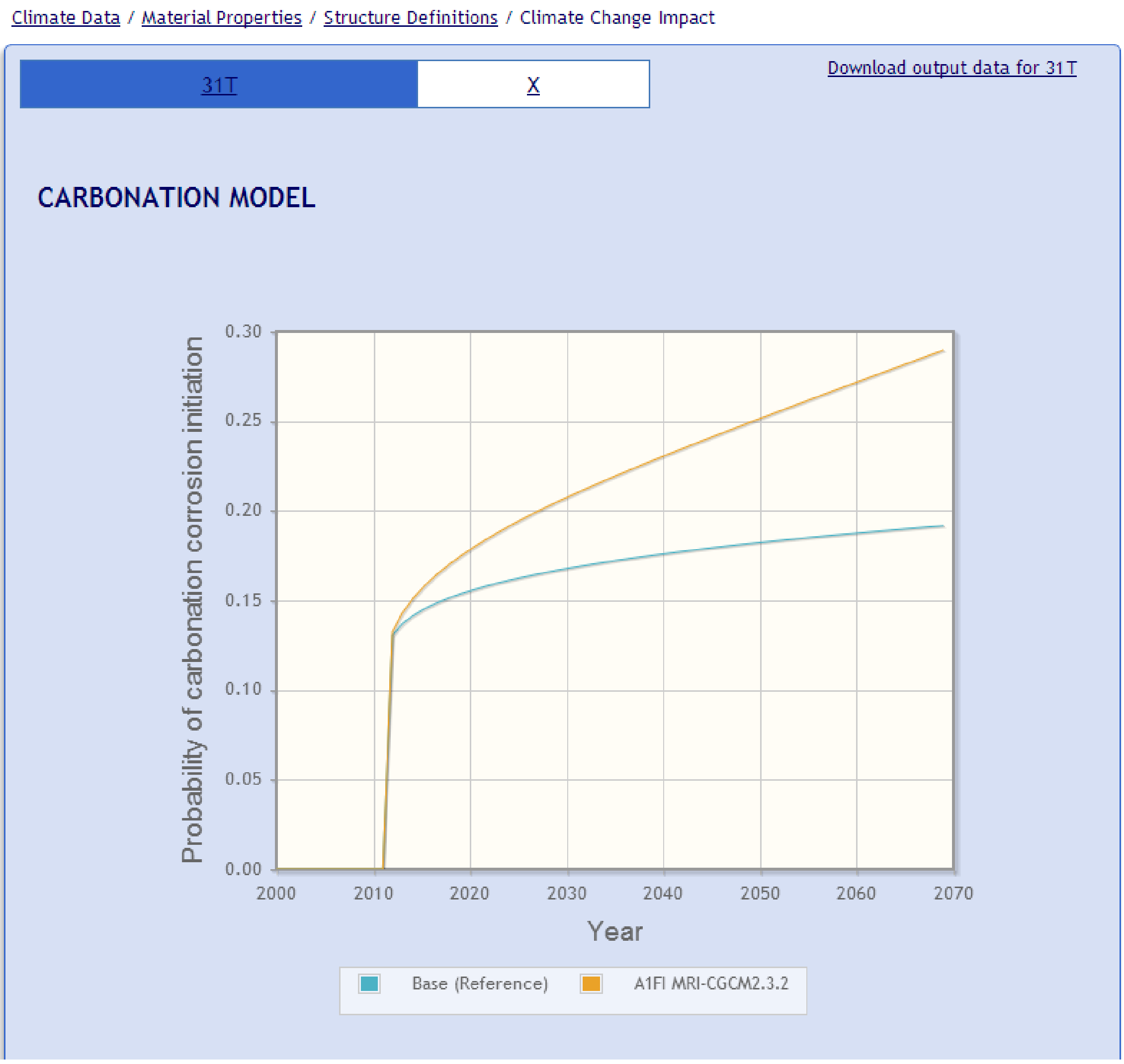


Figure 43: Results view

5.2 *Using the software tool*

Upon accessing the tool web address (http://203.143.39.3/CCIMT/), the management form appears. This form, shown in Figure 44, is divided into four sections. The tool was designed to ask queries of the climate database. A query requests the location of the analysis. As there are multiple carbon emission scenarios and climate futures models, the user can be specific about the data they wish to extract from the query.

This query management form can be divided into four groups, being:

- Location selection
- Carbon emission scenario selection
- Climate futures selection
- Start year for analysis

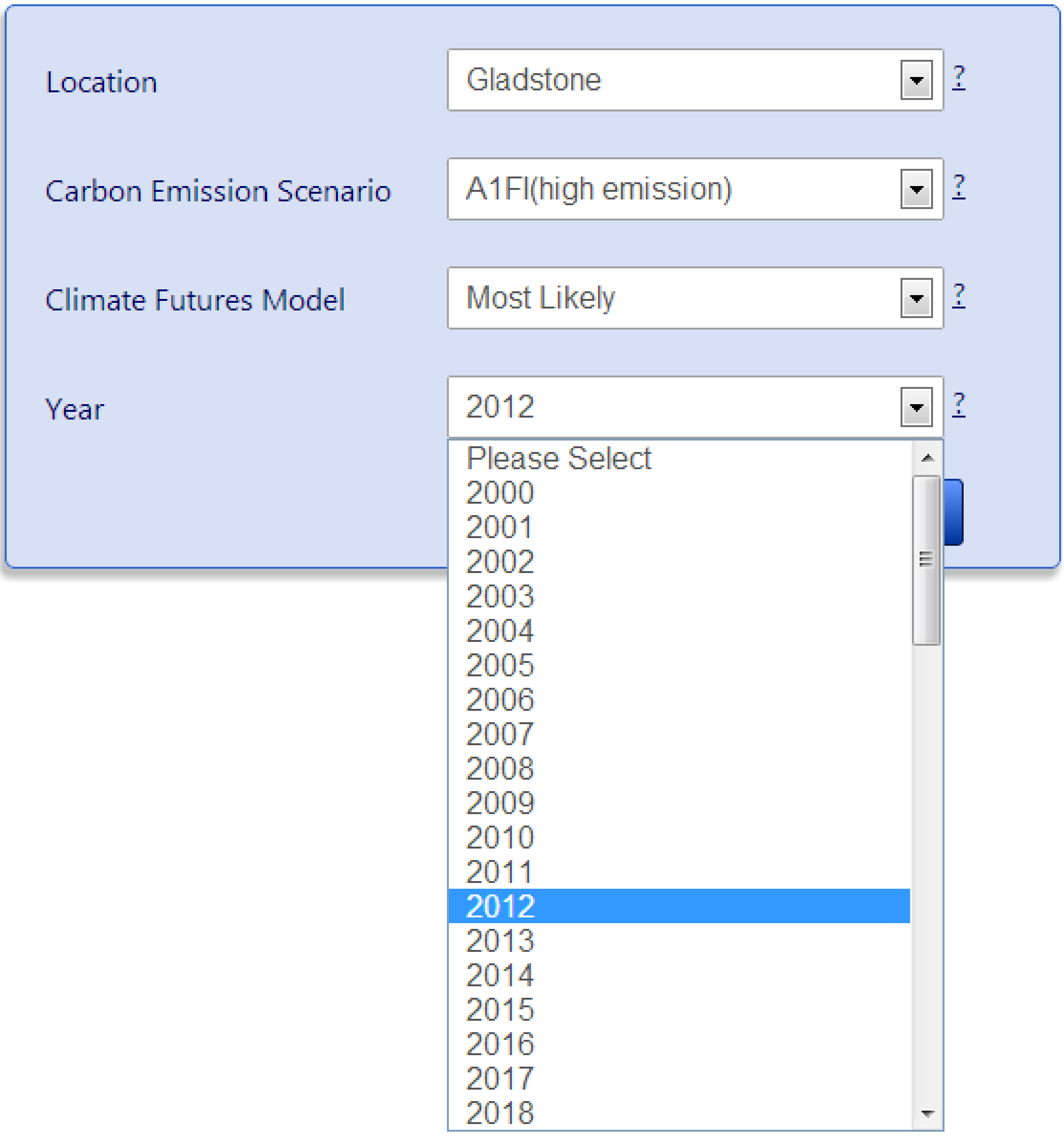


Figure 44: Query management form

5.2.1 Location selection

The first task is for the user to select the location that requires climate information. At this stage, the tool provides 3 location options (Gladstone, Port Kembla and Sydney).

5.2.2 Carbon emission scenario selection

Once the location has been selected, the user must then select the carbon emission scenario for the analysis. The user can either select base climate, high (A1FI) or medium (A1B) emissions.

5.2.3 Climate futures selection

The climate futures selection follows that of the carbon emission selection. The user selects which climate future they wish the time series queries extracted for. The projected data was developed for three different futures: a ‘most likely’ future, a ‘hotter and drier’ future and a ‘cooler and wetter’ future.

5.2.4 Start year for analysis

Lastly, the user has to select the preferred year to start the analysis. By default, the current year is selected but the user is allowed to select between 2000 to 2070.

5.2.5 Construction material

After a selection of climate has been made, the query can be run by pressing the ‘Next’ button. This will extract the time series requested for the given location, emission and future selected. The user can then select the construction material required. This tool incorporates concrete, steel and timber deterioration models discussed in Section 3.2. Once the selection is made (see Figure 45), the user can then view the selected material’s properties and coefficients data.

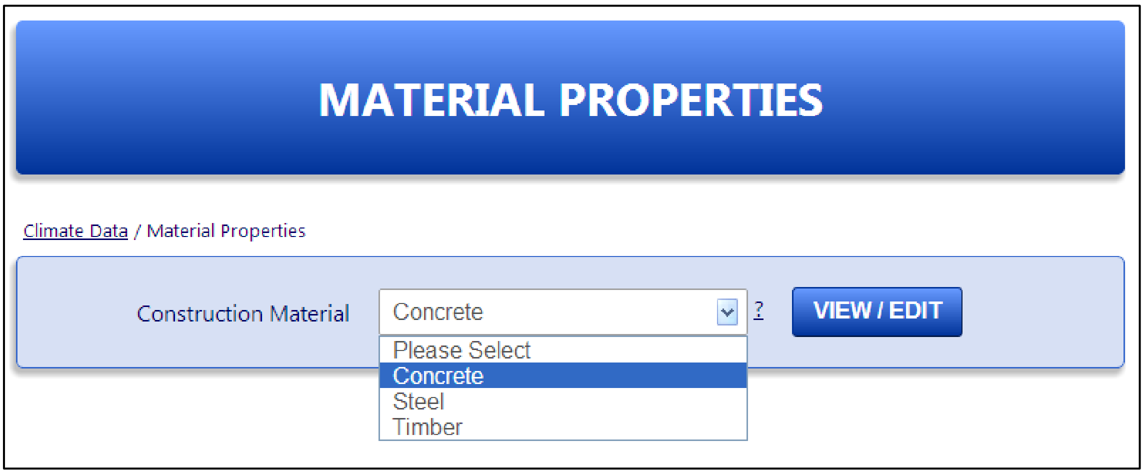


Figure 45: Construction material selection form

Figure 46 shows a typical material properties form. The users can quickly view and make adjustments to the material parameters and coefficients. If no adjustments is selected, the default values will be used for the analysis. If the user chooses to edit the parameters and coefficients, this can be achieved by clicking the 'Edit' button.

Construction Material Concrete ? VIEW / EDIT

MATERIAL: CONCRETE

CARBONATION CORROSION RATES AT 20°C

Class	Description	Mean (μA/cm^2)	SD (μA/cm^2)	Distribution
CB1	Dry	0	0	lognormal
CB2	Wet-rarely dry (unsheltered)	0.345	0.259	lognormal
CB3	Moderate humidity (sheltered)	0.172	0.086	lognormal
CB4	Cyclic wet-dry (unsheltered)	0.431	0.259	lognormal

EDIT

CHLORIDE CORROSION RATES AT 20°C

Class	Description	Mean (μA/cm^2)	SD (μA/cm^2)	Distribution
CL1	Wet-rarely dry	0.345	0.259	lognormal
CL2	Cyclic wet-dry	2.586	1.724	lognormal
CL3	Airborne sea water	2.586	1.724	lognormal
CL4	Submerged	0	0	lognormal
CL5	Tidal zone	6.035	3.448	lognormal

SAVE CANCEL

Figure 46: Typical materials properties form

5.2.6 Structural definitions

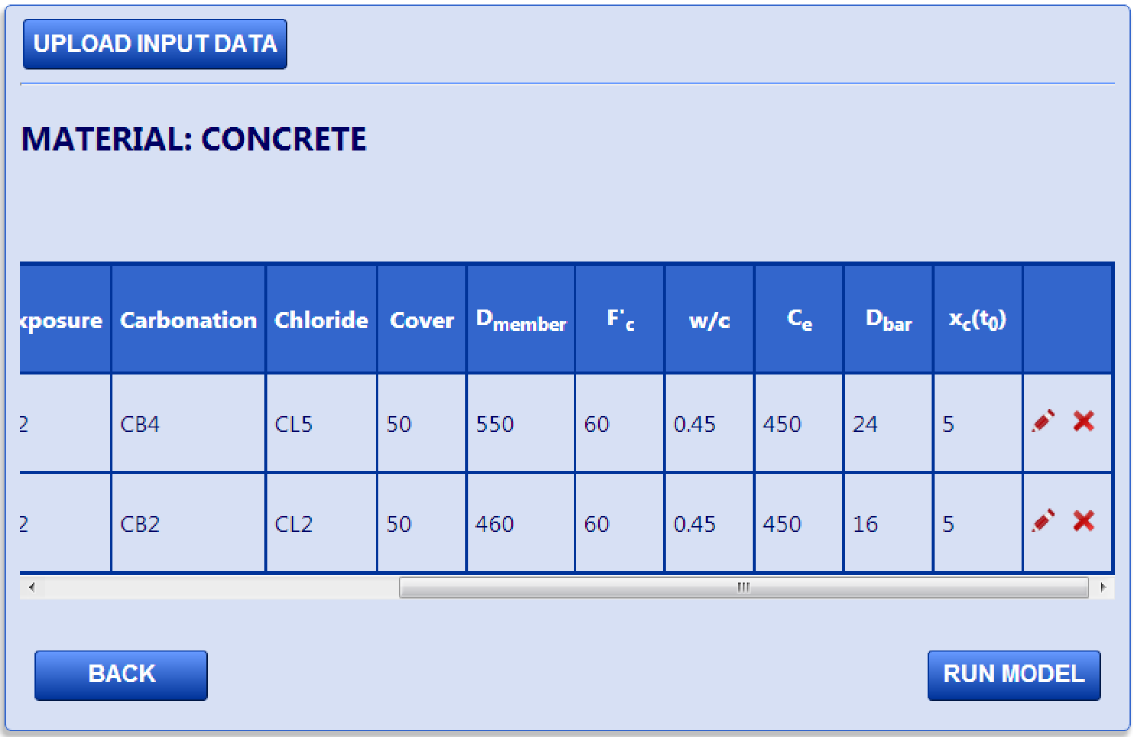
Once the material properties have been accepted, users will be brought to the structural definitions section where two options are provided:

Option 1: Upload input data
Selecting the 'Upload input data' button presents an open dialog box whereby the user selects an Excel (.xlsx) file prepared for import. Once imported, the tool will check each entry to ensure it meets the requirements of the analysis. It places the information of each entry in a row in the datasheet

Option 2: Manual input data using form
Rather than importing through a prepared .xlsx file, the user may enter the data directly using the form (Figure 47). Information from the filled form will be entered as an entry in a row in the datasheet.

Figure 47: Typical structural element form

There is no limitation to the amount of data entries for the datasheet. The data within the data sheet can be easily viewed, edited and deleted using the necessary buttons on the sheet (see Figure 48). The user may then run the model after the datasheet is complete.



xposure	Carbonation	Chloride	Cover	D_{member}	F'_c	w/c	C_e	D_{bar}	$x_c(t_0)$	
2	CB4	CL5	50	550	60	0.45	450	24	5	
2	CB2	CL2	50	460	60	0.45	450	16	5	

Figure 48: Datasheet view showing entry edit and delete buttons

5.2.7 Example outputs

Figure 49 shows the sample output of the concrete carbonation model. The user has the option to export the data using the 'Download output data' from the link on the top corner of the interface.

Figure 49: Sample results sheet

5.3 *Limitations*

The software tool described here has been developed and was tested in September 2012. It is being considered as a starting point for implementation of systems in ports faced with similar challenges. From this experience, the developers and engineers have determined that creating a system of this nature requires several key considerations:

- Follow the principle of “keep it simple”. Although it is more or less self-evident that a simpler system makes for simpler exchange, this principle is very important in a system process. Without granular management of data exchanges, it would be difficult to troubleshoot and extend support to new exchanges. As a particular design consideration, the rules should not be overloaded to behave differently in different situations. A new unambiguous rule should be made instead.
- Follow an enterprise data model. Inconsistent data definitions within an agency for apparently equivalent attributes are a bugbear for a system of this nature. The rule table in this system assumes that it is linking identical attributes between the systems.
- Incorporate logging and auditing.

6. CONCLUDING REMARKS AND DISCUSSION

Any forecast is subject to uncertainty to varying degrees, and this report is no exception. There are considerable uncertainties throughout the process described, and these uncertainties are compounded as outputs from one model become inputs to other models and so on. This level of uncertainty begins with the choice of emission scenario. The IPCC (2007) has published a wide range of scenarios, but only two could be used as the basis of modelling. One particular scenario chosen (A1FI) is one of the highest with an almost fourfold increase in the rate of emission between now and 2100. Under the lowest scenarios, emissions in 2100 fall below the current level. A second level of uncertainty relates to the climate projections from the CSIRO climate future models. Further levels of uncertainty are introduced by the modelling processes that take the CSIRO projections as inputs to estimate impacts of deterioration on port construction materials. Finally, the life cycle analysis uses a discount rate to project future cost in relation to today's costing.

The numerical results in the report should therefore be regarded as broad indications only and even the qualitative conclusions should be considered with caution. All things considered, the study should be regarded as painting a story of a possible future from which can be gleaned some indication of likely directions over the coming decades.

The research presented in this report identified key types of port infrastructure according to their operational environment (i.e. landside, seaside and transport), then identified the four major climate variables that would influence their resilience (i.e. changes in sea-level, precipitation, wave conditions and temperature).

Following a review of existing climate models, six scenarios were identified as the framework for analysis. To identify appropriate methods, a comprehensive review of structural assets and available climate data were considered.

This allowed for key structural materials (concrete, steel and timber – from which port structures are commonly constructed) to be identified and selected as a basis for analysis. Climate variables which would affect long term performance of the port infrastructure were identified as sea level rise, water table, temperature, rainfall/runoff, wave, wind, salinity and humidity.

Further, a methodology to assess deterioration probability of structural assets was developed based on the model structure, time-series inputs and various climate variables. This report includes a number of mathematical models for material degradation and structural performance over time. Advanced probabilistic modelling was used to ensure that the variability of (and uncertainly associated with) different input parameters could be properly included in the simulation of material deterioration mechanisms.

Key analysis outcomes of these typical structural assets indicate the following:

- Carbonation induced corrosion in concrete is the deterioration that is most aggravated by climate change. The intervention time required could be as early as 16 years compared to the current climate.
- Chloride induced corrosion is significantly affected by the surface temperatures. The resilience of concrete materials decreases from high to low at 2070.
- The splash and tidal zones are usually the most vulnerable and are characterised by cracking and spalling of concrete due to wetting and drying and corrosion of reinforcements. These zones will alter over time due to sea level rise and increased storm surge as a result of climate change.

- Marine timber attack is affected by sea surface salinity. Under 2050 medium, 2070 high and 2070 medium emissions, this effect is projected to no longer influence the probability of borer attack however the depth of the attack on timber is still significantly affected.
- The resilience of steel structures is projected to increase over time with relative humidity identified as the most influential climate variable.

A user-friendly software tool was developed using the methodology and analytical process to allow a port engineer to run the analysis for any given structural asset. This software tool, which can be accessed at http://203.143.39.3/CCIMT/, is capable of carrying out cascading classification so that a particular element type can be classified on the basis of numerous factors, e.g. design type, material type and exposure type.

A design and maintenance cost management tool was developed to optimise maintenance sequence and determine the effectiveness of maintenance options in the form of net present value return. The life cycle costing comparison indicated that climate change will have a significant effect on the whole of life cost of port infrastructure. However, this cost appears to have little variation under the climate scenarios used in this study. This is because the deteriorations themselves do not display a significant range of variation across all climate scenarios.

Other gaps and future research opportunities include:

- Improvement of probabilistic analysis to further address the uncertainties discussed. A larger sample could be considered and introduced to the mathematical modelling component of the work presented in this report.
- Life cycle cost analysis is limited to the element level - most rehabilitation and upgrade works are assessed at an element level. To improve the life cycle cost component of the work conducted in this report, the analysis could be extended to the structural level. This work entails structural load analysis and structural deterioration modelling.
- Exploration of links between deterioration projections and its impacts on element conditional states. A better understanding is needed of conditional data from asset inspections and their relationship to the deterioration curves generated from this work. This will not only enhance the value of the research but will also enhance decision making in terms of inspection, maintenance, and rehabilitation strategies by asset managers.

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Appendix 1 CLIMATE PROJECTIONS

A1.1 Emission scenarios and global circulation models

A high emission scenario (A1FI) and a medium scenario (A1B) have been chosen to generate the projections derived from 18 AOGCMs as listed in Table 42. These projections and emission scenarios will be used in the simulation of material degradation under climate change.

Table 42: AOGCMs used for climate projections

Models	Developers
BCCR-BCM2.0	Bjerknes Centre for Climate Research, Norway
CCSM3	National Center for Atmospheric Research, USA
CGCM3.1(T47) CGCM3.1(T63)	Canadian Centre for Climate Modelling and Analysis, Canada
CNRM-CM3	Météo-France/Centre National de Recherches Météorologiques, France
CSIRO-Mk3.0 CSIRO-Mk3.5	Commonwealth Scientific and Industrial Research Organisation, Australia
ECHAM5/MPI-OM	Max-Planck Institute for Meteorology, Germany
ECHO-G	Meteorological Institute of the University of Bonn Meteorological Research Institute of the Korea Meteorological Administration Model and Data Group, Germany/Korea
FGOALS-g1.0	National Key Laboratory of Numerical Modeling for Atmospheric Sciences Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics, China
GFDL-CM2.0 GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory, US
IPSL-CM4	Institut Pierre Simon Laplace, France
MIROC3.2(hires) MIROC3.2(medres)	Center for Climate System Research (University of Tokyo) National Institute for Environmental Studies Frontier Research Center for Global Change (JAMSTEC), Japan
MRI-CGCM2.3.2	Meteorological Research Institute, Japan
UKMO-HadCM3 UKMO-HadGEM1	Hadley Centre for Climate Prediction and Research/Met Office, UK

CSIRO Climate Futures program (development version) uses a 5° geographical grid and groups the individual AOGCM projections into a cluster of possible climate futures. This allows a better understanding of the likelihood of a particular climate future based on the number of models showing a similar future. Subsequently, one AOGCM will be selected to represent each of the climate futures chosen in this study. AOGCM selection was also governed by the availability of the climate variables required by each deterioration model. For more information, please refer to WORK PACKAGE 1: Understanding Future Risks.

A1.2 Baseline data

Baseline information is derived from current and historical data sourced online from the OzClim database. Table 43 provides a summary of the climate data used as a baseline (reference) and climate projections (Appendix 1.3) for the deterioration modelling.

Table 43: Baseline climate data

Location	Botany Bay		Gladstone		Port Kembla	
Baseline	1975 - 2004		1975 - 2004		1975 - 2004	
	Annual	DJF	Annual	DJF	Annual	DJF
Temperature	17.3	-	22.2	-	16.4	-
Rainfall	1030	-	850	-	1094	-
Relative Humidity	74.5	-	76.3	-	74.1	-
Sea surface salinity	35.5	35.5	35.3	35.34	35.5	35.5
Sea surface temperature	19.3	21.5	23.2	25.4	19.3	21.5
CO_2 concentration	352.5	-	352.5	-	352.5	-

A1.3 Climate raw data

Climate data used for deterioration and life cycle cost optimisation models are obtained for the following 3 locations:

- Botany Bay
- Gladstone
- Port Kembla

The projected concentration emissions are taken from annual plotted CO_2 concentration projections based on the Fourth Assessment Report (IPCC, 2007). Results from two models (BERN and ISAM) were used and their projections are shown in Tables 44 and 45 respectively.

Table 44: Projected CO_2 concentration using ISAM model

Year	A1B	A1T	A1FI	A2	B1	B2	A1p	A2p	B1p	B2p	IS92a	IS92a/SAR
1970	325	325	325	325	325	325	325	325	325	325	325	326
1980	337	337	337	337	337	337	337	337	337	337	337	338
1990	353	353	353	353	353	353	353	353	353	353	353	354
2000	369	369	369	369	369	369	369	369	369	369	369	372
2010	391	389	389	390	388	388	393	391	388	390	390	393
2020	420	412	417	417	412	408	425	419	409	414	415	418
2030	454	440	455	451	437	429	461	453	429	438	444	446
2040	491	471	504	490	463	453	499	492	450	462	475	476
2050	532	501	567	532	488	478	538	535	472	486	508	509
2060	572	528	638	580	509	504	577	583	497	512	543	544
2070	611	550	716	635	525	531	615	637	522	539	582	580
2080	649	567	799	698	537	559	652	699	544	567	623	620
2090	685	577	885	771	545	589	685	771	563	597	670	664
2100	717	582	970	856	549	621	715	856	578	630	723	715

Table 45: Projected CO_2 concentration using BERN model

Year	A1B	A1T	A1FI	A2	B1	B2	A1p	A2p	B1p	B2p	IS92a	IS92a/SAR
1970	325	325	325	325	325	325	325	325	325	325	325	325
1980	337	337	337	337	337	337	337	337	337	337	337	337
1990	352	352	352	352	352	352	352	352	352	352	352	353
2000	367	367	367	367	367	367	367	367	367	367	367	370
2010	388	386	386	386	386	385	390	388	385	387	387	391
2020	418	410	415	414	410	406	421	416	407	412	413	416
2030	447	435	449	444	432	425	454	447	425	433	439	444
2040	483	466	495	481	457	448	490	484	445	457	468	475
2050	522	496	555	522	482	473	529	525	467	481	499	507
2060	563	523	625	568	503	499	569	571	492	506	533	541
2070	601	545	702	620	518	524	606	622	515	532	568	577
2080	639	563	786	682	530	552	642	683	537	559	607	616
2090	674	572	872	754	538	581	674	754	555	588	653	660
2100	703	575	958	836	540	611	702	836	569	618	703	709

The aggregated CO_2 concentrations (given in Figure 7) were then applied to the deterioration models.

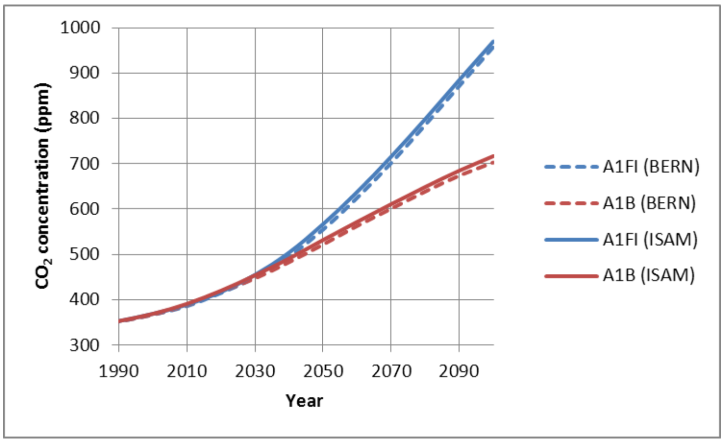


Figure 50: Projected annual mean atmospheric CO_2 concentration

The next section shows the projections of changes in surface temperature, annual rainfall, relative humidity, sea surface temperatures and sea surface salinity.

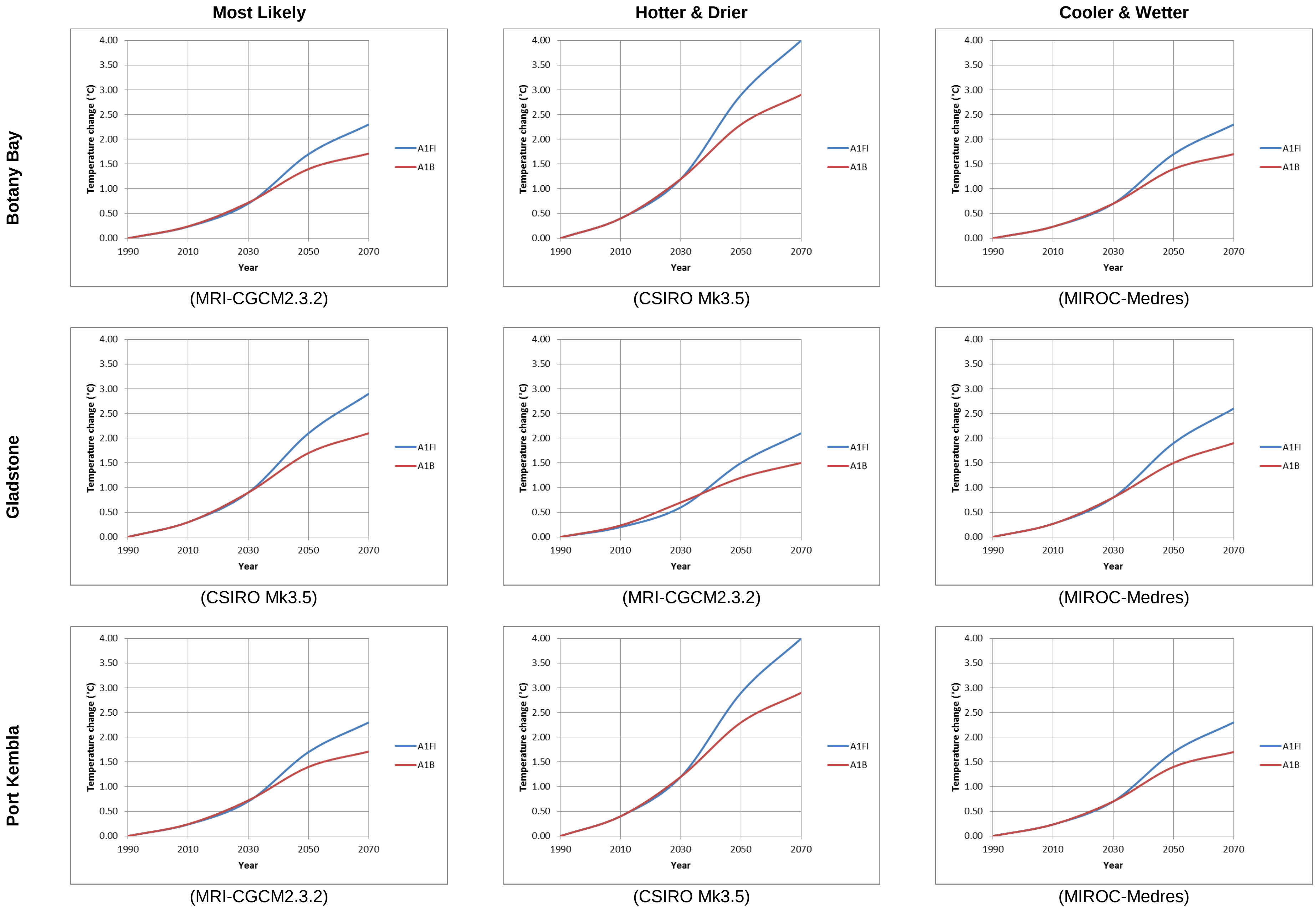


Figure 51: Projected change in surface temperature

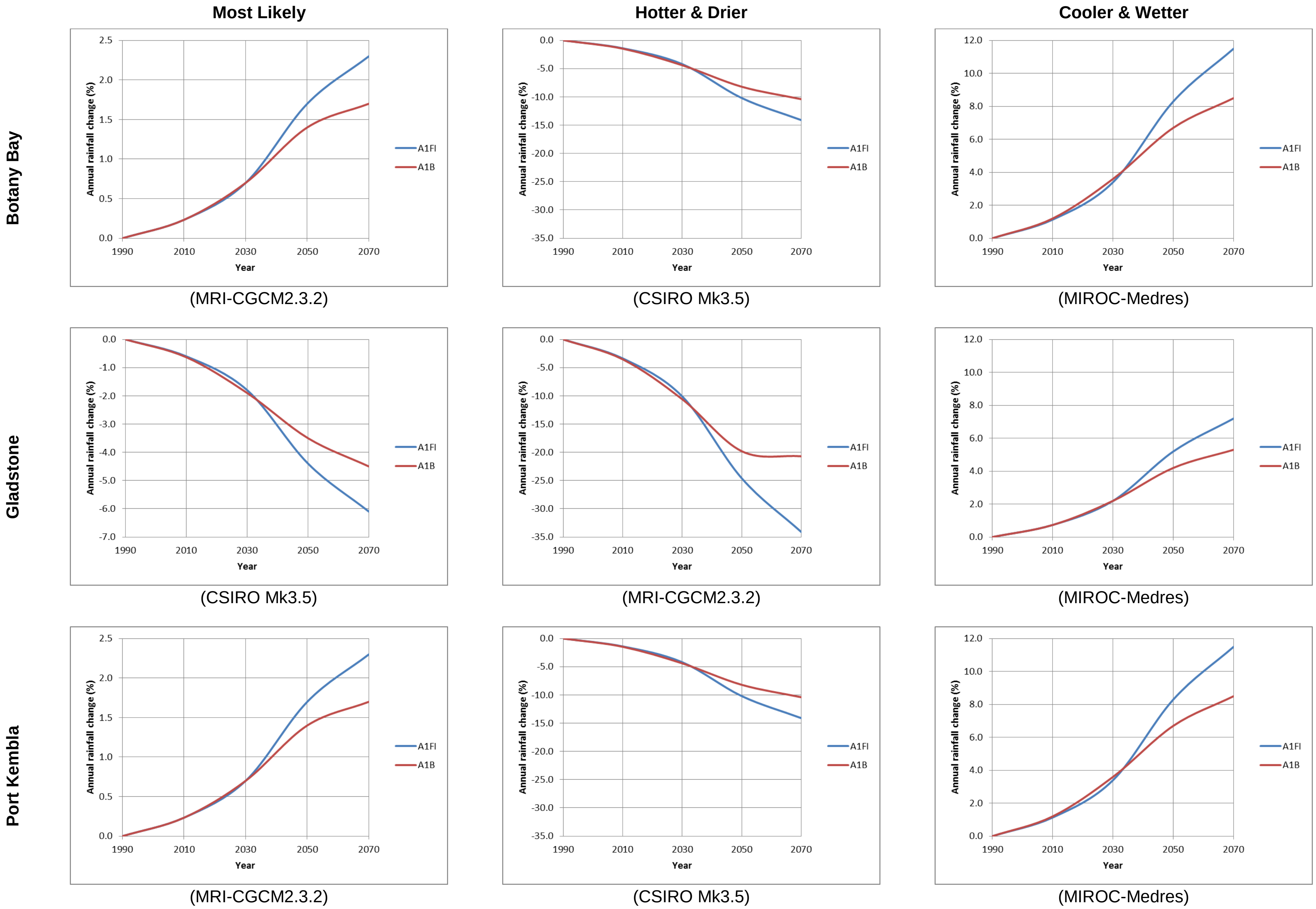


Figure 52: Projected change in annual rainfall

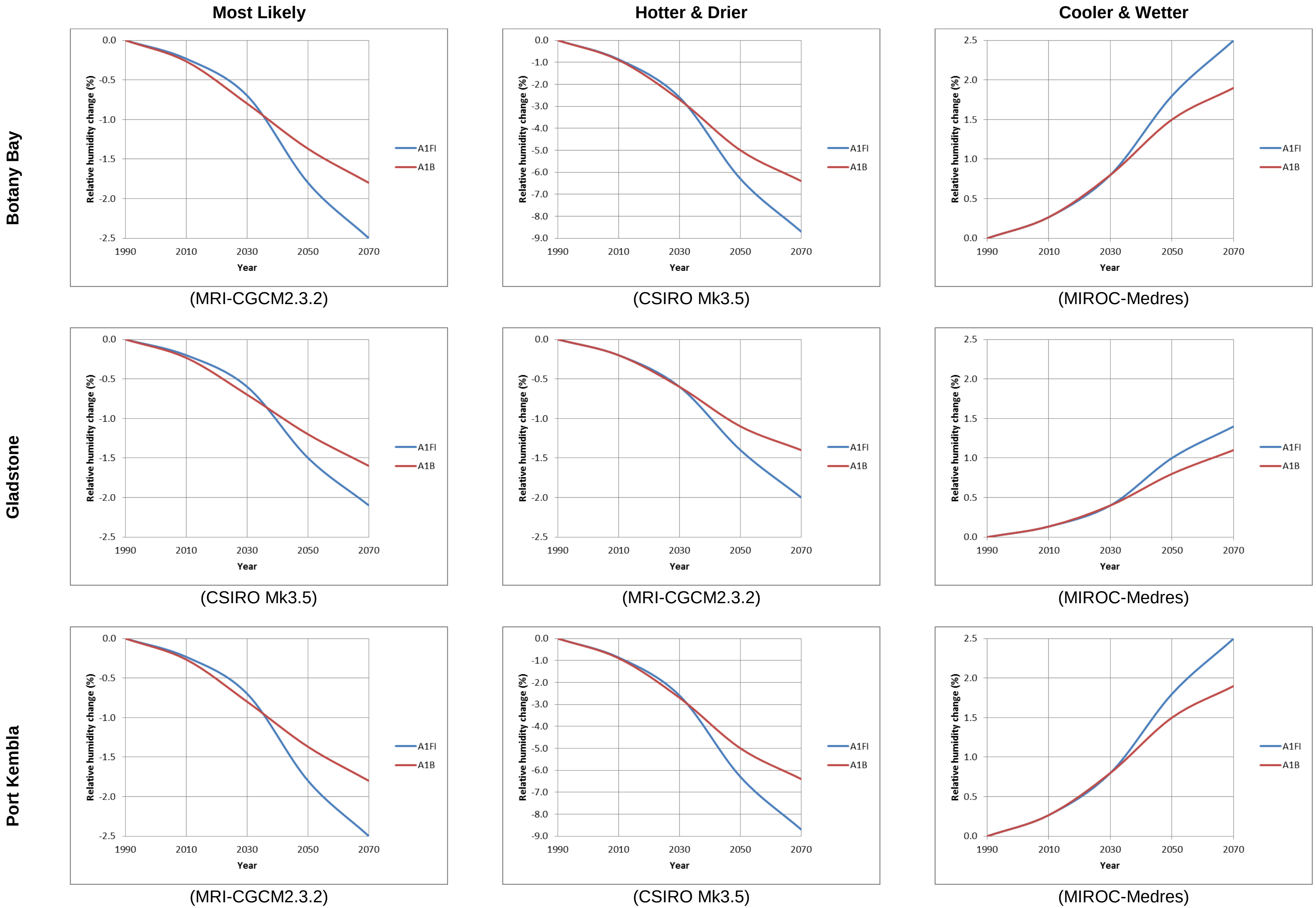


Figure 53: Projected change in relative humidity

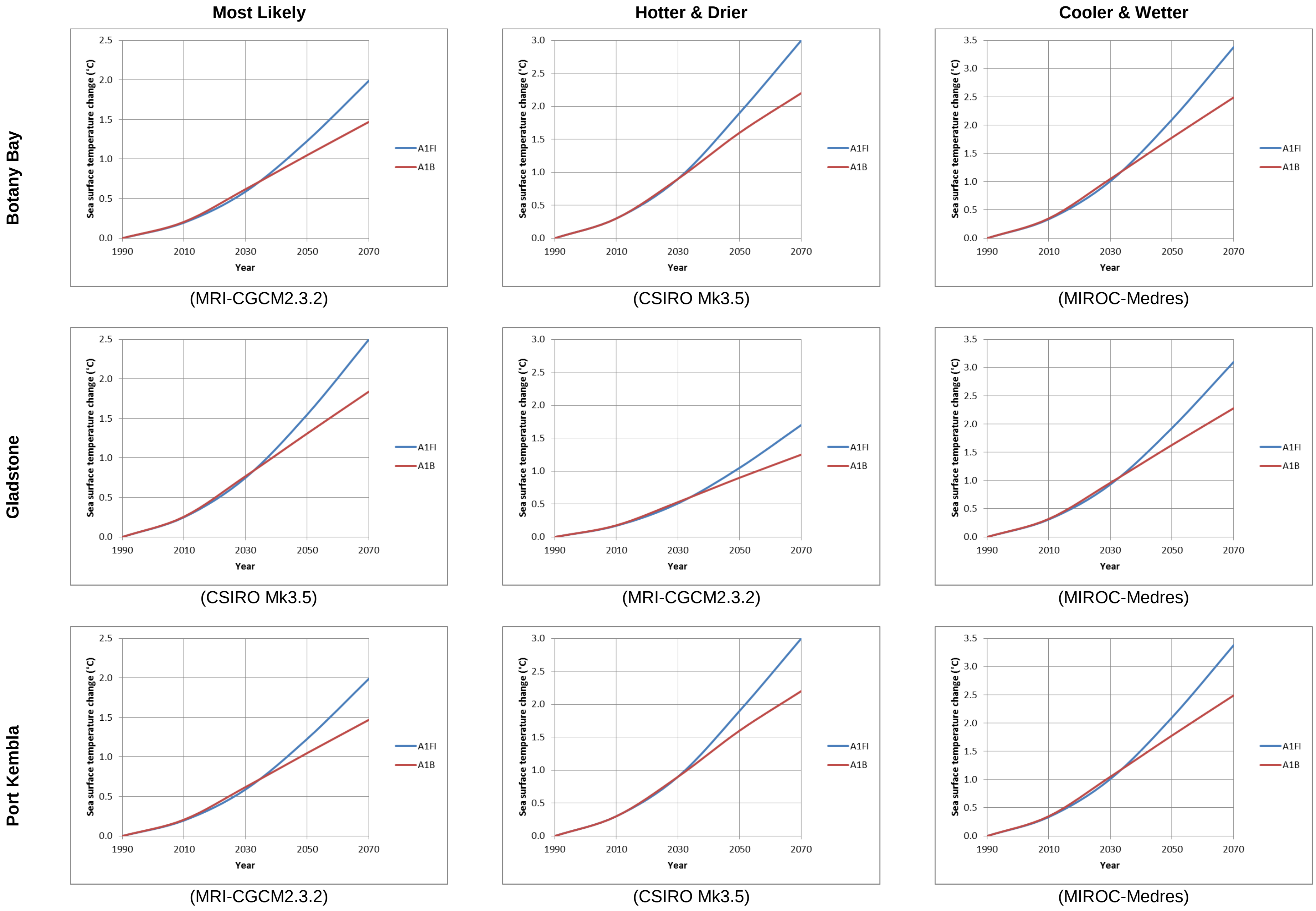


Figure 54: Projected change in sea surface temperature

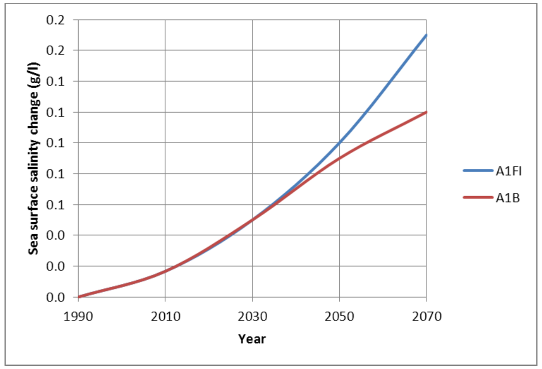
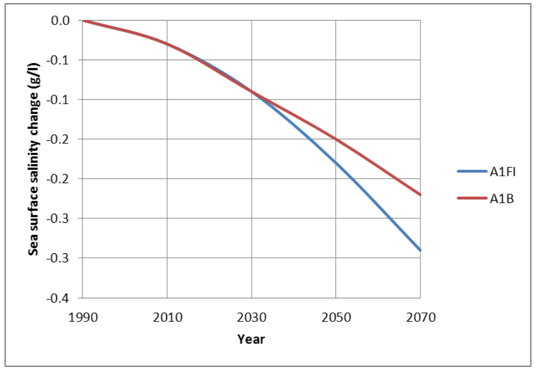
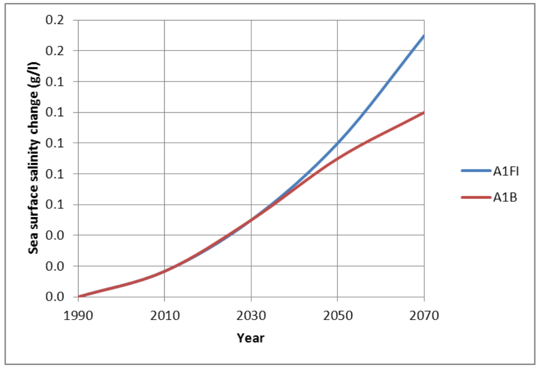
	Most Likely	**Hotter & Drier**	**Cooler & Wetter**
Botany Bay	NOT AVAILABLE	NOT AVAILABLE	 (MIROC-Hires)
Gladstone	NOT AVAILABLE	NOT AVAILABLE	 (MIROC-Hires)
Port Kembla	NOT AVAILABLE	NOT AVAILABLE	 (MIROC- Hires)

Figure 55: Projected change in sea surface salinity

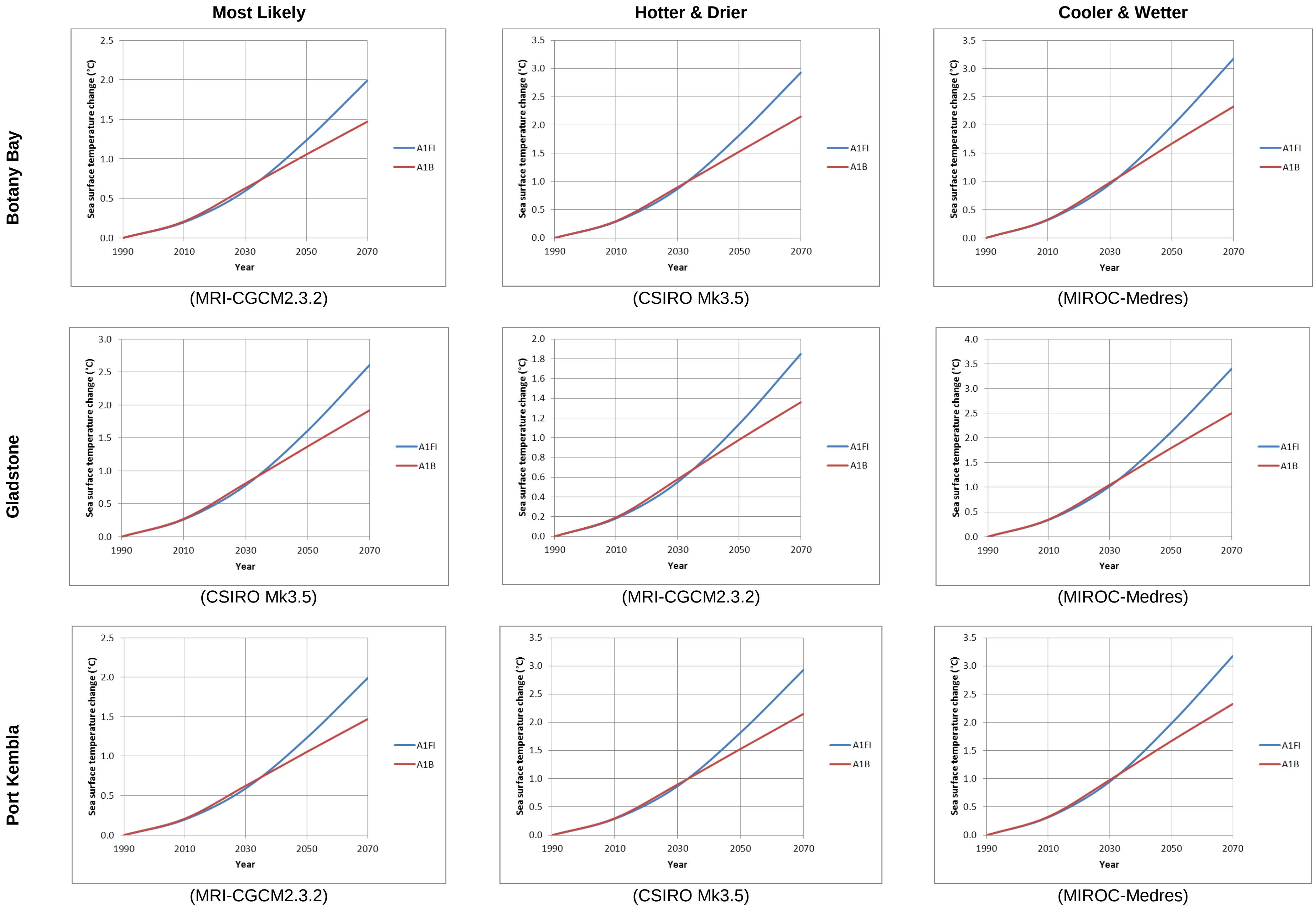


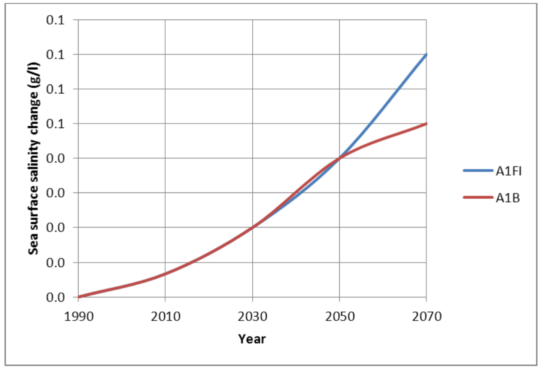
Figure 56: Projected change in summer sea surface temperature

Most Likely | **Hotter & Drier** | **Cooler & Wetter**

Botany Bay

NOT AVAILABLE

NOT AVAILABLE

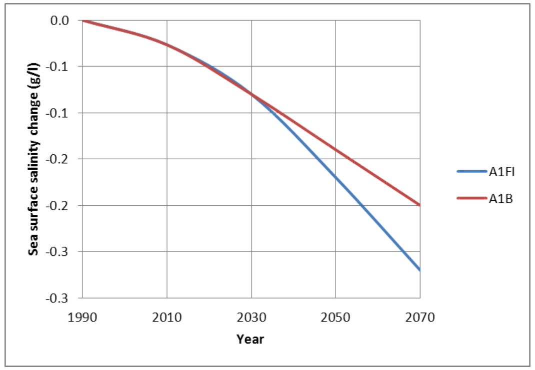


(MIROC-Hires)

Gladstone

NOT AVAILABLE

NOT AVAILABLE

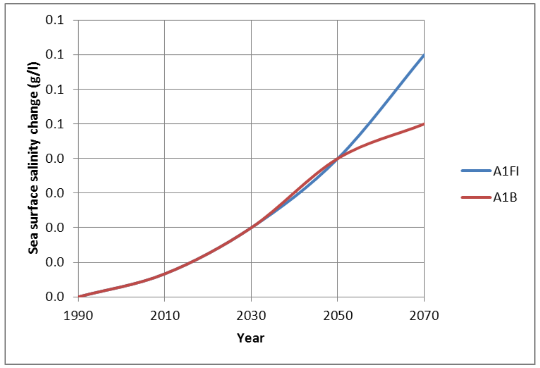


(MIROC-Hires)

Port Kembla

NOT AVAILABLE

NOT AVAILABLE



(MIROC- Hires)

Figure 57: Projected change in summer sea surface salinity

Tables 46 to 54 presents the processed data that was used to model a changing climate in the time dependent material deterioration models.

Table 46: Processed most likely climate projections for Botany Bay

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	17.30	17.30	1030.00	1030.00	74.50	74.50	19.30	19.30	-	-	21.50	21.50	-	-
1991	354.05	354.05	17.31	17.31	1030.12	1030.12	74.49	74.49	19.31	19.31	-	-	21.51	21.51	-	-
1992	355.60	355.60	17.32	17.32	1030.24	1030.24	74.48	74.48	19.32	19.32	-	-	21.52	21.52	-	-
1993	357.15	357.15	17.34	17.34	1030.36	1030.36	74.47	74.47	19.33	19.33	-	-	21.53	21.53	-	-
1994	358.70	358.70	17.35	17.35	1030.48	1030.48	74.47	74.46	19.34	19.34	-	-	21.54	21.54	-	-
1995	360.25	360.25	17.36	17.36	1030.60	1030.60	74.46	74.45	19.35	19.35	-	-	21.55	21.55	-	-
1996	361.80	361.80	17.37	17.37	1030.72	1030.72	74.45	74.44	19.36	19.36	-	-	21.56	21.56	-	-
1997	363.35	363.35	17.38	17.38	1030.84	1030.84	74.44	74.43	19.37	19.37	-	-	21.57	21.57	-	-
1998	364.90	364.90	17.39	17.40	1030.96	1030.96	74.43	74.42	19.38	19.38	-	-	21.58	21.58	-	-
1999	366.45	366.45	17.41	17.41	1031.08	1031.08	74.42	74.41	19.39	19.39	-	-	21.59	21.59	-	-
2000	368.00	368.00	17.42	17.42	1031.20	1031.20	74.41	74.40	19.40	19.40	-	-	21.60	21.60	-	-
2001	369.95	370.15	17.43	17.43	1031.32	1031.32	74.40	74.39	19.41	19.41	-	-	21.61	21.61	-	-
2002	371.90	372.30	17.44	17.44	1031.44	1031.44	74.40	74.38	19.42	19.42	-	-	21.62	21.63	-	-
2003	373.85	374.45	17.45	17.46	1031.56	1031.56	74.39	74.37	19.43	19.43	-	-	21.63	21.64	-	-
2004	375.80	376.60	17.46	17.47	1031.68	1031.68	74.38	74.36	19.44	19.44	-	-	21.64	21.65	-	-
2005	377.75	378.75	17.48	17.48	1031.80	1031.80	74.37	74.35	19.45	19.46	-	-	21.65	21.66	-	-
2006	379.70	380.90	17.49	17.49	1031.92	1031.92	74.36	74.34	19.46	19.47	-	-	21.66	21.67	-	-
2007	381.65	383.05	17.50	17.50	1032.04	1032.04	74.35	74.33	19.47	19.48	-	-	21.67	21.68	-	-
2008	383.60	385.20	17.51	17.52	1032.16	1032.16	74.34	74.32	19.48	19.49	-	-	21.68	21.69	-	-
2009	385.55	387.35	17.52	17.53	1032.28	1032.28	74.33	74.31	19.49	19.50	-	-	21.69	21.70	-	-
2010	387.50	389.50	17.53	17.54	1032.40	1032.40	74.33	74.30	19.50	19.51	-	-	21.70	21.71	-	-
2011	390.35	392.45	17.56	17.56	1032.64	1032.64	74.31	74.28	19.52	19.53	-	-	21.72	21.73	-	-
2012	393.20	395.40	17.58	17.59	1032.88	1032.88	74.29	74.26	19.54	19.55	-	-	21.74	21.75	-	-
2013	396.05	398.35	17.60	17.61	1033.12	1033.12	74.27	74.24	19.56	19.57	-	-	21.76	21.77	-	-
2014	398.90	401.30	17.63	17.64	1033.36	1033.36	74.26	74.22	19.58	19.59	-	-	21.78	21.79	-	-
2015	401.75	404.25	17.65	17.66	1033.61	1033.61	74.24	74.20	19.60	19.61	-	-	21.80	21.81	-	-
2016	404.60	407.20	17.67	17.68	1033.85	1033.85	74.22	74.18	19.61	19.63	-	-	21.82	21.83	-	-
2017	407.45	410.15	17.70	17.71	1034.09	1034.09	74.20	74.16	19.63	19.65	-	-	21.84	21.85	-	-
2018	410.30	413.10	17.72	17.73	1034.33	1034.33	74.19	74.14	19.65	19.67	-	-	21.86	21.88	-	-
2019	413.15	416.05	17.74	17.76	1034.57	1034.57	74.17	74.12	19.67	19.69	-	-	21.88	21.90	-	-
2020	416.00	419.00	17.77	17.78	1034.81	1034.81	74.15	74.10	19.69	19.71	-	-	21.90	21.92	-	-
2021	419.60	422.15	17.79	17.80	1035.05	1035.05	74.13	74.08	19.71	19.73	-	-	21.92	21.94	-	-
2022	423.20	425.30	17.81	17.83	1035.29	1035.29	74.12	74.06	19.73	19.75	-	-	21.94	21.96	-	-
2023	426.80	428.45	17.84	17.85	1035.53	1035.53	74.10	74.04	19.75	19.78	-	-	21.95	21.98	-	-
2024	430.40	431.60	17.86	17.88	1035.77	1035.77	74.08	74.02	19.77	19.80	-	-	21.97	22.00	-	-
2025	434.00	434.75	17.88	17.90	1036.01	1036.01	74.07	74.00	19.79	19.82	-	-	21.99	22.02	-	-

2026	437.60	437.90	17.91	17.92	1036.25	1036.25	74.05	73.98	19.81	19.84	-	-	22.01	22.04	-	-
2027	441.20	441.05	17.93	17.95	1036.49	1036.49	74.03	73.96	19.83	19.86	-	-	22.03	22.06	-	-
2028	444.80	444.20	17.95	17.97	1036.73	1036.73	74.01	73.94	19.85	19.88	-	-	22.05	22.08	-	-
2029	448.40	447.35	17.98	18.00	1036.97	1036.97	74.00	73.92	19.87	19.90	-	-	22.07	22.11	-	-
2030	452.00	450.50	18.00	18.02	1037.21	1037.21	73.98	73.90	19.89	19.92	-	-	22.09	22.13	-	-
2031	456.75	454.15	18.05	18.05	1037.73	1037.57	73.94	73.88	19.92	19.94	-	-	22.13	22.15	-	-
2032	461.50	457.80	18.10	18.09	1038.24	1037.93	73.90	73.86	19.95	19.96	-	-	22.16	22.17	-	-
2033	466.25	461.45	18.15	18.12	1038.76	1038.29	73.86	73.84	19.99	19.98	-	-	22.19	22.19	-	-
2034	471.00	465.10	18.20	18.16	1039.27	1038.65	73.81	73.82	20.02	20.01	-	-	22.22	22.21	-	-
2035	475.75	468.75	18.25	18.19	1039.79	1039.01	73.77	73.80	20.05	20.03	-	-	22.25	22.23	-	-
2036	480.50	472.40	18.30	18.22	1040.30	1039.37	73.73	73.78	20.08	20.05	-	-	22.29	22.25	-	-
2037	485.25	476.05	18.35	18.26	1040.82	1039.73	73.69	73.76	20.11	20.07	-	-	22.32	22.28	-	-
2038	490.00	479.70	18.40	18.29	1041.33	1040.09	73.65	73.73	20.15	20.09	-	-	22.35	22.30	-	-
2039	494.75	483.35	18.45	18.33	1041.85	1040.45	73.61	73.71	20.18	20.11	-	-	22.38	22.32	-	-
2040	499.50	487.00	18.50	18.36	1042.36	1040.82	73.57	73.69	20.21	20.14	-	-	22.41	22.34	-	-
2041	505.65	491.00	18.55	18.39	1042.88	1041.18	73.53	73.67	20.24	20.16	-	-	22.45	22.36	-	-
2042	511.80	495.00	18.60	18.43	1043.39	1041.54	73.49	73.65	20.27	20.18	-	-	22.48	22.38	-	-
2043	517.95	499.00	18.65	18.46	1043.91	1041.90	73.45	73.63	20.31	20.20	-	-	22.51	22.40	-	-
2044	524.10	503.00	18.70	18.50	1044.42	1042.26	73.40	73.61	20.34	20.22	-	-	22.54	22.43	-	-
2045	530.25	507.00	18.75	18.53	1044.94	1042.62	73.36	73.59	20.37	20.24	-	-	22.57	22.45	-	-
2046	536.40	511.00	18.80	18.56	1045.45	1042.98	73.32	73.56	20.40	20.26	-	-	22.60	22.47	-	-
2047	542.55	515.00	18.85	18.60	1045.97	1043.34	73.28	73.54	20.43	20.29	-	-	22.64	22.49	-	-
2048	548.70	519.00	18.90	18.63	1046.48	1043.70	73.24	73.52	20.47	20.31	-	-	22.67	22.51	-	-
2049	554.85	523.00	18.95	18.67	1047.00	1044.06	73.20	73.50	20.50	20.33	-	-	22.70	22.53	-	-
2050	561.00	527.00	19.00	18.70	1047.51	1044.42	73.16	73.48	20.53	20.35	-	-	22.73	22.55	-	-
2051	568.05	531.05	19.03	18.72	1047.82	1044.57	73.13	73.46	20.57	20.37	-	-	22.77	22.57	-	-
2052	575.10	535.10	19.06	18.73	1048.13	1044.73	73.11	73.45	20.61	20.39	-	-	22.81	22.60	-	-
2053	582.15	539.15	19.09	18.75	1048.44	1044.88	73.08	73.43	20.64	20.41	-	-	22.85	22.62	-	-
2054	589.20	543.20	19.12	18.76	1048.75	1045.04	73.05	73.42	20.68	20.43	-	-	22.88	22.64	-	-
2055	596.25	547.25	19.15	18.78	1049.06	1045.19	73.03	73.40	20.72	20.46	-	-	22.92	22.66	-	-
2056	603.30	551.30	19.18	18.79	1049.36	1045.35	73.00	73.38	20.76	20.48	-	-	22.96	22.68	-	-
2057	610.35	555.35	19.21	18.81	1049.67	1045.50	72.98	73.37	20.80	20.50	-	-	23.00	22.70	-	-
2058	617.40	559.40	19.24	18.82	1049.98	1045.66	72.95	73.35	20.83	20.52	-	-	23.04	22.72	-	-
2059	624.45	563.45	19.27	18.84	1050.29	1045.81	72.92	73.34	20.87	20.54	-	-	23.07	22.74	-	-
2060	631.50	567.50	19.30	18.86	1050.60	1045.97	72.90	73.32	20.91	20.56	-	-	23.11	22.76	-	-
2061	639.25	571.35	19.33	18.87	1050.91	1046.12	72.87	73.30	20.95	20.58	-	-	23.15	22.78	-	-
2062	647.00	575.20	19.36	18.89	1051.22	1046.27	72.85	73.29	20.99	20.60	-	-	23.19	22.80	-	-
2063	654.75	579.05	19.39	18.90	1051.53	1046.43	72.82	73.27	21.02	20.62	-	-	23.23	22.82	-	-
2064	662.50	582.90	19.42	18.92	1051.84	1046.58	72.79	73.26	21.06	20.64	-	-	23.26	22.85	-	-
2065	670.25	586.75	19.45	18.93	1052.15	1046.74	72.77	73.24	21.10	20.67	-	-	23.30	22.87	-	-
2066	678.00	590.60	19.48	18.95	1052.45	1046.89	72.74	73.22	21.14	20.69	-	-	23.34	22.89	-	-
2067	685.75	594.45	19.51	18.96	1052.76	1047.05	72.72	73.21	21.18	20.71	-	-	23.38	22.91	-	-
2068	693.50	598.30	19.54	18.98	1053.07	1047.20	72.69	73.19	21.21	20.73	-	-	23.41	22.93	-	-
2069	701.25	602.15	19.57	18.99	1053.38	1047.36	72.66	73.18	21.25	20.75	-	-	23.45	22.95	-	-
2070	709.00	606.00	19.60	19.01	1053.69	1047.51	72.64	73.16	21.29	20.77	-	-	23.49	22.97	-	-

Table 47: Processed hotter and drier climate projections for Botany Bay

Year	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	17.30	17.30	1030.00	1030.00	74.50	74.50	19.30	19.30	-	-	21.50	21.50	-	-
1991	354.05	354.05	17.32	17.32	1029.28	1029.24	74.47	74.47	19.32	19.32	-	-	21.51	21.52	-	-
1992	355.60	355.60	17.34	17.34	1028.56	1028.49	74.44	74.43	19.33	19.33	-	-	21.53	21.53	-	-
1993	357.15	357.15	17.36	17.36	1027.84	1027.73	74.40	74.40	19.35	19.35	-	-	21.54	21.55	-	-
1994	358.70	358.70	17.38	17.38	1027.12	1026.98	74.37	74.37	19.36	19.36	-	-	21.56	21.56	-	-
1995	360.25	360.25	17.40	17.40	1026.40	1026.22	74.34	74.33	19.38	19.38	-	-	21.57	21.58	-	-
1996	361.80	361.80	17.42	17.42	1025.67	1025.47	74.31	74.30	19.39	19.39	-	-	21.59	21.59	-	-
1997	363.35	363.35	17.44	17.44	1024.95	1024.71	74.27	74.27	19.41	19.41	-	-	21.60	21.61	-	-
1998	364.90	364.90	17.46	17.46	1024.23	1023.96	74.24	74.23	19.42	19.42	-	-	21.62	21.62	-	-
1999	366.45	366.45	17.48	17.48	1023.51	1023.20	74.21	74.20	19.44	19.44	-	-	21.63	21.64	-	-
2000	368.00	368.00	17.50	17.50	1022.79	1022.45	74.18	74.16	19.45	19.45	-	-	21.65	21.65	-	-
2001	369.95	370.15	17.52	17.52	1022.07	1021.69	74.14	74.13	19.47	19.47	-	-	21.66	21.67	-	-
2002	371.90	372.30	17.54	17.54	1021.35	1020.94	74.11	74.10	19.48	19.48	-	-	21.67	21.68	-	-
2003	373.85	374.45	17.56	17.56	1020.63	1020.18	74.08	74.06	19.50	19.50	-	-	21.69	21.70	-	-
2004	375.80	376.60	17.58	17.58	1019.91	1019.43	74.05	74.03	19.51	19.51	-	-	21.70	21.71	-	-
2005	377.75	378.75	17.60	17.60	1019.19	1018.67	74.02	74.00	19.53	19.53	-	-	21.72	21.73	-	-
2006	379.70	380.90	17.62	17.62	1018.46	1017.91	73.98	73.96	19.54	19.54	-	-	21.73	21.74	-	-
2007	381.65	383.05	17.64	17.64	1017.74	1017.16	73.95	73.93	19.56	19.56	-	-	21.75	21.76	-	-
2008	383.60	385.20	17.66	17.66	1017.02	1016.40	73.92	73.90	19.57	19.57	-	-	21.76	21.77	-	-
2009	385.55	387.35	17.68	17.68	1016.30	1015.65	73.89	73.86	19.59	19.59	-	-	21.78	21.79	-	-
2010	387.50	389.50	17.70	17.70	1015.58	1014.89	73.85	73.83	19.60	19.60	-	-	21.79	21.80	-	-
2011	390.35	392.45	17.74	17.74	1014.14	1013.38	73.79	73.76	19.63	19.63	-	-	21.82	21.83	-	-
2012	393.20	395.40	17.78	17.78	1012.70	1011.87	73.73	73.70	19.66	19.66	-	-	21.85	21.86	-	-
2013	396.05	398.35	17.82	17.82	1011.25	1010.36	73.66	73.63	19.69	19.69	-	-	21.88	21.89	-	-
2014	398.90	401.30	17.86	17.86	1009.81	1008.85	73.60	73.56	19.72	19.72	-	-	21.91	21.92	-	-
2015	401.75	404.25	17.90	17.90	1008.37	1007.34	73.53	73.49	19.75	19.75	-	-	21.94	21.95	-	-
2016	404.60	407.20	17.94	17.94	1006.93	1005.83	73.47	73.43	19.78	19.78	-	-	21.96	21.98	-	-
2017	407.45	410.15	17.98	17.98	1005.49	1004.32	73.40	73.36	19.81	19.81	-	-	21.99	22.01	-	-
2018	410.30	413.10	18.02	18.02	1004.04	1002.81	73.34	73.29	19.84	19.84	-	-	22.02	22.04	-	-
2019	413.15	416.05	18.06	18.06	1002.60	1001.30	73.27	73.23	19.87	19.87	-	-	22.05	22.07	-	-
2020	416.00	419.00	18.10	18.10	1001.16	999.79	73.21	73.16	19.90	19.90	-	-	22.08	22.10	-	-
2021	419.60	422.15	18.14	18.14	999.72	998.28	73.14	73.09	19.93	19.93	-	-	22.11	22.13	-	-
2022	423.20	425.30	18.18	18.18	998.28	996.77	73.08	73.02	19.96	19.96	-	-	22.14	22.16	-	-
2023	426.80	428.45	18.22	18.22	996.83	995.25	73.01	72.96	19.99	19.99	-	-	22.17	22.19	-	-
2024	430.40	431.60	18.26	18.26	995.39	993.74	72.95	72.89	20.02	20.02	-	-	22.20	22.22	-	-
2025	434.00	434.75	18.30	18.30	993.95	992.23	72.89	72.82	20.05	20.05	-	-	22.23	22.25	-	-

2026	437.60	437.90	18.34	18.34	992.51	990.72	72.82	72.76	20.08	20.08	-	-	22.25	22.28	-	-
2027	441.20	441.05	18.38	18.38	991.07	989.21	72.76	72.69	20.11	20.11	-	-	22.28	22.31	-	-
2028	444.80	444.20	18.42	18.42	989.62	987.70	72.69	72.62	20.14	20.14	-	-	22.31	22.34	-	-
2029	448.40	447.35	18.46	18.46	988.18	986.19	72.63	72.56	20.17	20.17	-	-	22.34	22.37	-	-
2030	452.00	450.50	18.50	18.50	986.74	984.68	72.56	72.49	20.20	20.20	-	-	22.37	22.40	-	-
2031	456.75	454.15	18.59	18.56	983.65	982.72	72.43	72.40	20.25	20.24	-	-	22.42	22.43	-	-
2032	461.50	457.80	18.67	18.61	980.56	980.77	72.29	72.32	20.30	20.27	-	-	22.47	22.46	-	-
2033	466.25	461.45	18.76	18.67	977.47	978.81	72.15	72.23	20.35	20.31	-	-	22.51	22.49	-	-
2034	471.00	465.10	18.84	18.72	974.38	976.85	72.01	72.15	20.40	20.34	-	-	22.56	22.53	-	-
2035	475.75	468.75	18.93	18.78	971.29	974.90	71.87	72.06	20.45	20.38	-	-	22.61	22.56	-	-
2036	480.50	472.40	19.01	18.83	968.20	972.94	71.74	71.97	20.50	20.41	-	-	22.66	22.59	-	-
2037	485.25	476.05	19.10	18.89	965.11	970.98	71.60	71.89	20.55	20.45	-	-	22.70	22.62	-	-
2038	490.00	479.70	19.18	18.94	962.02	969.02	71.46	71.80	20.60	20.48	-	-	22.75	22.65	-	-
2039	494.75	483.35	19.27	19.00	958.93	967.07	71.32	71.72	20.65	20.52	-	-	22.80	22.68	-	-
2040	499.50	487.00	19.35	19.05	955.84	965.11	71.18	71.63	20.70	20.55	-	-	22.85	22.72	-	-
2041	505.65	491.00	19.44	19.11	952.75	963.15	71.05	71.55	20.75	20.59	-	-	22.89	22.75	-	-
2042	511.80	495.00	19.52	19.16	949.66	961.20	70.91	71.46	20.80	20.62	-	-	22.94	22.78	-	-
2043	517.95	499.00	19.61	19.22	946.57	959.24	70.77	71.37	20.85	20.66	-	-	22.99	22.81	-	-
2044	524.10	503.00	19.69	19.27	943.48	957.28	70.63	71.29	20.90	20.69	-	-	23.04	22.84	-	-
2045	530.25	507.00	19.78	19.33	940.39	955.33	70.50	71.20	20.95	20.73	-	-	23.08	22.87	-	-
2046	536.40	511.00	19.86	19.38	937.30	953.37	70.36	71.12	21.00	20.76	-	-	23.13	22.90	-	-
2047	542.55	515.00	19.95	19.44	934.21	951.41	70.22	71.03	21.05	20.80	-	-	23.18	22.94	-	-
2048	548.70	519.00	20.03	19.49	931.12	949.45	70.08	70.95	21.10	20.83	-	-	23.23	22.97	-	-
2049	554.85	523.00	20.12	19.55	928.03	947.50	69.94	70.86	21.15	20.87	-	-	23.27	23.00	-	-
2050	561.00	527.00	20.20	19.60	924.94	945.54	69.81	70.78	21.20	20.90	-	-	23.32	23.03	-	-
2051	568.05	531.05	20.26	19.63	922.93	944.41	69.72	70.72	21.26	20.93	-	-	23.38	23.06	-	-
2052	575.10	535.10	20.31	19.66	920.92	943.27	69.63	70.67	21.31	20.96	-	-	23.43	23.09	-	-
2053	582.15	539.15	20.37	19.69	918.91	942.14	69.54	70.62	21.37	20.99	-	-	23.49	23.12	-	-
2054	589.20	543.20	20.42	19.72	916.91	941.01	69.45	70.57	21.42	21.02	-	-	23.54	23.15	-	-
2055	596.25	547.25	20.48	19.75	914.90	939.88	69.36	70.51	21.48	21.05	-	-	23.60	23.19	-	-
2056	603.30	551.30	20.53	19.78	912.89	938.74	69.27	70.46	21.53	21.08	-	-	23.65	23.22	-	-
2057	610.35	555.35	20.59	19.81	910.88	937.61	69.18	70.41	21.59	21.11	-	-	23.71	23.25	-	-
2058	617.40	559.40	20.64	19.84	908.87	936.48	69.09	70.36	21.64	21.14	-	-	23.76	23.28	-	-
2059	624.45	563.45	20.70	19.87	906.86	935.34	69.00	70.31	21.70	21.17	-	-	23.82	23.31	-	-
2060	631.50	567.50	20.75	19.90	904.86	934.21	68.91	70.25	21.75	21.20	-	-	23.88	23.34	-	-
2061	639.25	571.35	20.81	19.93	902.85	933.08	68.82	70.20	21.81	21.23	-	-	23.93	23.37	-	-
2062	647.00	575.20	20.86	19.96	900.84	931.94	68.73	70.15	21.86	21.26	-	-	23.99	23.40	-	-
2063	654.75	579.05	20.92	19.99	898.83	930.81	68.64	70.10	21.92	21.29	-	-	24.04	23.43	-	-
2064	662.50	582.90	20.97	20.02	896.82	929.68	68.55	70.04	21.97	21.32	-	-	24.10	23.46	-	-
2065	670.25	586.75	21.03	20.05	894.81	928.55	68.47	69.99	22.03	21.35	-	-	24.15	23.50	-	-
2066	678.00	590.60	21.08	20.08	892.80	927.41	68.38	69.94	22.08	21.38	-	-	24.21	23.53	-	-
2067	685.75	594.45	21.14	20.11	890.80	926.28	68.29	69.89	22.14	21.41	-	-	24.26	23.56	-	-
2068	693.50	598.30	21.19	20.14	888.79	925.15	68.20	69.84	22.19	21.44	-	-	24.32	23.59	-	-
2069	701.25	602.15	21.25	20.17	886.78	924.01	68.11	69.78	22.25	21.47	-	-	24.37	23.62	-	-
2070	709.00	606.00	21.30	20.20	884.77	922.88	68.02	69.73	22.30	21.50	-	-	24.43	23.65	-	-

Table 48: Processed cooler and wetter climate projections for Botany Bay

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	17.30	17.30	1030.00	1030.00	74.50	74.50	19.30	19.30	35.50	35.50	21.50	21.50	35.50	35.50
1991	354.05	354.05	17.31	17.31	1030.58	1030.62	74.51	74.51	19.32	19.32	35.50	35.50	21.52	21.52	35.50	35.50
1992	355.60	355.60	17.32	17.32	1031.17	1031.24	74.52	74.52	19.33	19.34	35.50	35.50	21.53	21.53	35.50	35.50
1993	357.15	357.15	17.34	17.34	1031.75	1031.85	74.53	74.53	19.35	19.35	35.50	35.50	21.55	21.55	35.50	35.50
1994	358.70	358.70	17.35	17.35	1032.33	1032.47	74.54	74.54	19.37	19.37	35.50	35.50	21.56	21.57	35.50	35.50
1995	360.25	360.25	17.36	17.36	1032.92	1033.09	74.55	74.55	19.38	19.39	35.50	35.50	21.58	21.58	35.50	35.50
1996	361.80	361.80	17.37	17.37	1033.50	1033.71	74.56	74.56	19.40	19.41	35.51	35.51	21.60	21.60	35.50	35.50
1997	363.35	363.35	17.38	17.38	1034.09	1034.33	74.57	74.57	19.42	19.42	35.51	35.51	21.61	21.61	35.50	35.50
1998	364.90	364.90	17.39	17.39	1034.67	1034.94	74.58	74.58	19.43	19.44	35.51	35.51	21.63	21.63	35.50	35.50
1999	366.45	366.45	17.41	17.41	1035.25	1035.56	74.59	74.59	19.45	19.46	35.51	35.51	21.64	21.65	35.50	35.50
2000	368.00	368.00	17.42	17.42	1035.84	1036.18	74.60	74.60	19.47	19.48	35.51	35.51	21.66	21.66	35.50	35.50
2001	369.95	370.15	17.43	17.43	1036.42	1036.80	74.61	74.61	19.49	19.49	35.51	35.51	21.67	21.68	35.50	35.50
2002	371.90	372.30	17.44	17.44	1037.00	1037.42	74.62	74.62	19.50	19.51	35.51	35.51	21.69	21.70	35.50	35.50
2003	373.85	374.45	17.45	17.45	1037.59	1038.03	74.63	74.63	19.52	19.53	35.51	35.51	21.71	21.71	35.50	35.50
2004	375.80	376.60	17.46	17.46	1038.17	1038.65	74.64	74.64	19.54	19.55	35.51	35.51	21.72	21.73	35.50	35.50
2005	377.75	378.75	17.48	17.48	1038.76	1039.27	74.65	74.65	19.55	19.56	35.51	35.51	21.74	21.75	35.51	35.51
2006	379.70	380.90	17.49	17.49	1039.34	1039.89	74.66	74.66	19.57	19.58	35.51	35.51	21.75	21.76	35.51	35.51
2007	381.65	383.05	17.50	17.50	1039.92	1040.51	74.67	74.67	19.59	19.60	35.51	35.51	21.77	21.78	35.51	35.51
2008	383.60	385.20	17.51	17.51	1040.51	1041.12	74.68	74.68	19.60	19.62	35.52	35.52	21.79	21.79	35.51	35.51
2009	385.55	387.35	17.52	17.52	1041.09	1041.74	74.69	74.69	19.62	19.63	35.52	35.52	21.80	21.81	35.51	35.51
2010	387.50	389.50	17.53	17.53	1041.67	1042.36	74.70	74.70	19.64	19.65	35.52	35.52	21.82	21.83	35.51	35.51
2011	390.35	392.45	17.56	17.56	1042.84	1043.60	74.72	74.72	19.67	19.69	35.52	35.52	21.85	21.86	35.51	35.51
2012	393.20	395.40	17.58	17.58	1044.01	1044.83	74.74	74.74	19.70	19.72	35.52	35.52	21.88	21.89	35.51	35.51
2013	396.05	398.35	17.60	17.60	1045.18	1046.07	74.76	74.76	19.74	19.76	35.52	35.52	21.91	21.92	35.51	35.51
2014	398.90	401.30	17.63	17.63	1046.34	1047.30	74.78	74.78	19.77	19.79	35.52	35.52	21.94	21.96	35.51	35.51
2015	401.75	404.25	17.65	17.65	1047.51	1048.54	74.80	74.80	19.81	19.83	35.53	35.53	21.98	21.99	35.51	35.51
2016	404.60	407.20	17.67	17.67	1048.68	1049.78	74.82	74.82	19.84	19.86	35.53	35.53	22.01	22.02	35.51	35.51
2017	407.45	410.15	17.70	17.70	1049.84	1051.01	74.84	74.84	19.87	19.90	35.53	35.53	22.04	22.06	35.51	35.51
2018	410.30	413.10	17.72	17.72	1051.01	1052.25	74.86	74.86	19.91	19.93	35.53	35.53	22.07	22.09	35.51	35.51
2019	413.15	416.05	17.74	17.74	1052.18	1053.48	74.88	74.88	19.94	19.97	35.53	35.53	22.10	22.12	35.51	35.51
2020	416.00	419.00	17.77	17.77	1053.35	1054.72	74.90	74.90	19.97	20.00	35.53	35.53	22.13	22.15	35.51	35.51
2021	419.60	422.15	17.79	17.79	1054.51	1055.96	74.92	74.92	20.01	20.04	35.54	35.54	22.17	22.19	35.51	35.51
2022	423.20	425.30	17.81	17.81	1055.68	1057.19	74.94	74.94	20.04	20.07	35.54	35.54	22.20	22.22	35.51	35.51
2023	426.80	428.45	17.84	17.84	1056.85	1058.43	74.96	74.96	20.07	20.11	35.54	35.54	22.23	22.25	35.52	35.52
2024	430.40	431.60	17.86	17.86	1058.02	1059.66	74.98	74.98	20.11	20.14	35.54	35.54	22.26	22.28	35.52	35.52
2025	434.00	434.75	17.88	17.88	1059.18	1060.90	75.00	75.00	20.14	20.18	35.54	35.54	22.29	22.32	35.52	35.52

2026	437.60	437.90	17.91	17.91	1060.35	1062.14	75.02	75.02	20.18	20.21	35.54	35.54	22.32	22.35	35.52	35.52
2027	441.20	441.05	17.93	17.93	1061.52	1063.37	75.04	75.04	20.21	20.25	35.55	35.55	22.36	22.38	35.52	35.52
2028	444.80	444.20	17.95	17.95	1062.69	1064.61	75.06	75.06	20.24	20.28	35.55	35.55	22.39	22.41	35.52	35.52
2029	448.40	447.35	17.98	17.98	1063.85	1065.84	75.08	75.08	20.28	20.32	35.55	35.55	22.42	22.45	35.52	35.52
2030	452.00	450.50	18.00	18.00	1065.02	1067.08	75.10	75.10	20.31	20.35	35.55	35.55	22.45	22.48	35.52	35.52
2031	456.75	454.15	18.05	18.04	1067.54	1068.68	75.13	75.12	20.36	20.39	35.55	35.55	22.50	22.51	35.52	35.52
2032	461.50	457.80	18.10	18.07	1070.07	1070.27	75.17	75.15	20.42	20.42	35.56	35.55	22.55	22.55	35.52	35.52
2033	466.25	461.45	18.15	18.11	1072.59	1071.87	75.21	75.17	20.47	20.46	35.56	35.56	22.60	22.58	35.52	35.52
2034	471.00	465.10	18.20	18.14	1075.11	1073.47	75.25	75.20	20.53	20.50	35.56	35.56	22.66	22.62	35.52	35.52
2035	475.75	468.75	18.25	18.18	1077.64	1075.06	75.28	75.23	20.58	20.53	35.56	35.56	22.71	22.65	35.53	35.53
2036	480.50	472.40	18.30	18.21	1080.16	1076.66	75.32	75.25	20.64	20.57	35.57	35.56	22.76	22.69	35.53	35.53
2037	485.25	476.05	18.35	18.25	1082.68	1078.26	75.36	75.28	20.69	20.61	35.57	35.56	22.81	22.72	35.53	35.53
2038	490.00	479.70	18.40	18.28	1085.21	1079.85	75.39	75.30	20.75	20.64	35.57	35.57	22.86	22.76	35.53	35.53
2039	494.75	483.35	18.45	18.32	1087.73	1081.45	75.43	75.33	20.80	20.68	35.57	35.57	22.91	22.79	35.53	35.53
2040	499.50	487.00	18.50	18.35	1090.26	1083.05	75.47	75.36	20.86	20.72	35.58	35.57	22.97	22.83	35.53	35.53
2041	505.65	491.00	18.55	18.39	1092.78	1084.64	75.51	75.38	20.91	20.75	35.58	35.57	23.02	22.86	35.53	35.53
2042	511.80	495.00	18.60	18.42	1095.30	1086.24	75.54	75.41	20.96	20.79	35.58	35.57	23.07	22.89	35.53	35.53
2043	517.95	499.00	18.65	18.46	1097.83	1087.83	75.58	75.43	21.02	20.82	35.58	35.58	23.12	22.93	35.53	35.53
2044	524.10	503.00	18.70	18.49	1100.35	1089.43	75.62	75.46	21.07	20.86	35.59	35.58	23.17	22.96	35.53	35.53
2045	530.25	507.00	18.75	18.53	1102.87	1091.03	75.65	75.49	21.13	20.90	35.59	35.58	23.22	23.00	35.54	35.54
2046	536.40	511.00	18.80	18.56	1105.40	1092.62	75.69	75.51	21.18	20.93	35.59	35.58	23.27	23.03	35.54	35.54
2047	542.55	515.00	18.85	18.60	1107.92	1094.22	75.73	75.54	21.24	20.97	35.59	35.58	23.33	23.07	35.54	35.54
2048	548.70	519.00	18.90	18.63	1110.44	1095.82	75.77	75.57	21.29	21.01	35.60	35.59	23.38	23.10	35.54	35.54
2049	554.85	523.00	18.95	18.67	1112.97	1097.41	75.80	75.59	21.35	21.04	35.60	35.59	23.43	23.14	35.54	35.54
2050	561.00	527.00	19.00	18.70	1115.49	1099.01	75.84	75.62	21.40	21.08	35.60	35.59	23.48	23.17	35.54	35.54
2051	568.05	531.05	19.03	18.72	1117.14	1099.94	75.87	75.63	21.46	21.12	35.60	35.59	23.54	23.20	35.54	35.54
2052	575.10	535.10	19.06	18.73	1118.79	1100.86	75.89	75.65	21.53	21.15	35.61	35.59	23.60	23.24	35.54	35.54
2053	582.15	539.15	19.09	18.75	1120.43	1101.79	75.92	75.66	21.59	21.19	35.61	35.59	23.66	23.27	35.54	35.54
2054	589.20	543.20	19.12	18.76	1122.08	1102.72	75.95	75.68	21.66	21.22	35.61	35.60	23.72	23.30	35.55	35.54
2055	596.25	547.25	19.15	18.78	1123.73	1103.65	75.97	75.69	21.72	21.26	35.62	35.60	23.78	23.34	35.55	35.54
2056	603.30	551.30	19.18	18.79	1125.38	1104.57	76.00	75.71	21.78	21.29	35.62	35.60	23.84	23.37	35.55	35.54
2057	610.35	555.35	19.21	18.81	1127.03	1105.50	76.02	75.72	21.85	21.33	35.62	35.60	23.90	23.40	35.55	35.54
2058	617.40	559.40	19.24	18.82	1128.67	1106.43	76.05	75.74	21.91	21.36	35.63	35.60	23.96	23.43	35.55	35.54
2059	624.45	563.45	19.27	18.84	1130.32	1107.35	76.08	75.75	21.98	21.40	35.63	35.60	24.02	23.47	35.55	35.54
2060	631.50	567.50	19.30	18.85	1131.97	1108.28	76.10	75.77	22.04	21.44	35.64	35.61	24.08	23.50	35.56	35.55
2061	639.25	571.35	19.33	18.87	1133.62	1109.21	76.13	75.78	22.10	21.47	35.64	35.61	24.14	23.53	35.56	35.55
2062	647.00	575.20	19.36	18.88	1135.27	1110.13	76.15	75.80	22.17	21.51	35.64	35.61	24.20	23.57	35.56	35.55
2063	654.75	579.05	19.39	18.90	1136.91	1111.06	76.18	75.81	22.23	21.54	35.65	35.61	24.26	23.60	35.56	35.55
2064	662.50	582.90	19.42	18.91	1138.56	1111.99	76.21	75.83	22.30	21.58	35.65	35.61	24.32	23.63	35.56	35.55
2065	670.25	586.75	19.45	18.93	1140.21	1112.92	76.23	75.84	22.36	21.61	35.65	35.61	24.38	23.67	35.56	35.55
2066	678.00	590.60	19.48	18.94	1141.86	1113.84	76.26	75.86	22.42	21.65	35.66	35.61	24.44	23.70	35.56	35.55
2067	685.75	594.45	19.51	18.96	1143.51	1114.77	76.28	75.87	22.49	21.68	35.66	35.62	24.50	23.73	35.57	35.55
2068	693.50	598.30	19.54	18.97	1145.15	1115.70	76.31	75.89	22.55	21.72	35.66	35.62	24.56	23.76	35.57	35.55
2069	701.25	602.15	19.57	18.99	1146.80	1116.62	76.34	75.90	22.62	21.75	35.67	35.62	24.62	23.80	35.57	35.55
2070	709.00	606.00	19.60	19.00	1148.45	1117.55	76.36	75.92	22.68	21.79	35.67	35.62	24.68	23.83	35.57	35.55

Table 49: Processed most likely climate projections for Gladstone

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	22.20	22.20	850.00	850.00	76.30	76.30	23.20	23.20	-	-	25.40	25.40	-	-
1991	354.05	354.05	22.22	22.22	849.75	849.73	76.29	76.29	23.21	23.21	-	-	25.41	25.41	-	-
1992	355.60	355.60	22.23	22.23	849.49	849.46	76.28	76.28	23.23	23.23	-	-	25.43	25.43	-	-
1993	357.15	357.15	22.25	22.25	849.24	849.19	76.28	76.27	23.24	23.24	-	-	25.44	25.44	-	-
1994	358.70	358.70	22.26	22.26	848.98	848.92	76.27	76.26	23.25	23.25	-	-	25.45	25.45	-	-
1995	360.25	360.25	22.28	22.28	848.73	848.65	76.26	76.26	23.26	23.26	-	-	25.47	25.47	-	-
1996	361.80	361.80	22.29	22.29	848.47	848.39	76.25	76.25	23.28	23.28	-	-	25.48	25.48	-	-
1997	363.35	363.35	22.31	22.31	848.22	848.12	76.25	76.24	23.29	23.29	-	-	25.49	25.49	-	-
1998	364.90	364.90	22.32	22.32	847.96	847.85	76.24	76.23	23.30	23.30	-	-	25.50	25.51	-	-
1999	366.45	366.45	22.34	22.34	847.71	847.58	76.23	76.22	23.31	23.32	-	-	25.52	25.52	-	-
2000	368.00	368.00	22.35	22.35	847.45	847.31	76.22	76.21	23.33	23.33	-	-	25.53	25.54	-	-
2001	369.95	370.15	22.37	22.37	847.20	847.04	76.22	76.20	23.34	23.34	-	-	25.54	25.55	-	-
2002	371.90	372.30	22.38	22.38	846.94	846.77	76.21	76.19	23.35	23.35	-	-	25.56	25.56	-	-
2003	373.85	374.45	22.40	22.40	846.69	846.50	76.20	76.18	23.36	23.37	-	-	25.57	25.58	-	-
2004	375.80	376.60	22.41	22.41	846.43	846.23	76.19	76.18	23.38	23.38	-	-	25.58	25.59	-	-
2005	377.75	378.75	22.43	22.43	846.18	845.96	76.19	76.17	23.39	23.39	-	-	25.60	25.60	-	-
2006	379.70	380.90	22.44	22.44	845.92	845.69	76.18	76.16	23.40	23.41	-	-	25.61	25.62	-	-
2007	381.65	383.05	22.46	22.46	845.67	845.42	76.17	76.15	23.41	23.42	-	-	25.62	25.63	-	-
2008	383.60	385.20	22.47	22.47	845.41	845.16	76.16	76.14	23.43	23.43	-	-	25.63	25.64	-	-
2009	385.55	387.35	22.49	22.49	845.16	844.89	76.16	76.13	23.44	23.44	-	-	25.65	25.66	-	-
2010	387.50	389.50	22.50	22.50	844.90	844.62	76.15	76.12	23.45	23.46	-	-	25.66	25.67	-	-
2011	390.35	392.45	22.53	22.53	844.39	844.08	76.13	76.10	23.48	23.48	-	-	25.69	25.70	-	-
2012	393.20	395.40	22.56	22.56	843.88	843.54	76.12	76.09	23.50	23.51	-	-	25.71	25.72	-	-
2013	396.05	398.35	22.59	22.59	843.37	843.00	76.10	76.07	23.53	23.53	-	-	25.74	25.75	-	-
2014	398.90	401.30	22.62	22.62	842.86	842.46	76.09	76.05	23.55	23.56	-	-	25.76	25.78	-	-
2015	401.75	404.25	22.65	22.65	842.35	841.93	76.07	76.03	23.58	23.59	-	-	25.79	25.81	-	-
2016	404.60	407.20	22.68	22.68	841.84	841.39	76.06	76.02	23.60	23.61	-	-	25.82	25.83	-	-
2017	407.45	410.15	22.71	22.71	841.33	840.85	76.04	76.00	23.63	23.64	-	-	25.84	25.86	-	-
2018	410.30	413.10	22.74	22.74	840.82	840.31	76.03	75.98	23.65	23.66	-	-	25.87	25.89	-	-
2019	413.15	416.05	22.77	22.77	840.31	839.77	76.01	75.96	23.68	23.69	-	-	25.89	25.91	-	-
2020	416.00	419.00	22.80	22.80	839.80	839.23	75.99	75.94	23.70	23.71	-	-	25.92	25.94	-	-
2021	419.60	422.15	22.83	22.83	839.29	838.70	75.98	75.93	23.73	23.74	-	-	25.95	25.97	-	-
2022	423.20	425.30	22.86	22.86	838.78	838.16	75.96	75.91	23.75	23.76	-	-	25.97	25.99	-	-
2023	426.80	428.45	22.89	22.89	838.27	837.62	75.95	75.89	23.78	23.79	-	-	26.00	26.02	-	-
2024	430.40	431.60	22.92	22.92	837.76	837.08	75.93	75.87	23.80	23.82	-	-	26.02	26.05	-	-
2025	434.00	434.75	22.95	22.95	837.25	836.54	75.92	75.85	23.83	23.84	-	-	26.05	26.08	-	-

2026	437.60	437.90	22.98	22.98	836.74	836.00	75.90	75.84	23.85	23.87	-	-	26.08	26.10	-	-
2027	441.20	441.05	23.01	23.01	836.23	835.47	75.89	75.82	23.88	23.89	-	-	26.10	26.13	-	-
2028	444.80	444.20	23.04	23.04	835.72	834.93	75.87	75.80	23.90	23.92	-	-	26.13	26.16	-	-
2029	448.40	447.35	23.07	23.07	835.21	834.39	75.86	75.78	23.93	23.94	-	-	26.15	26.18	-	-
2030	452.00	450.50	23.10	23.10	834.70	833.85	75.84	75.77	23.95	23.97	-	-	26.18	26.21	-	-
2031	456.75	454.15	23.16	23.14	833.60	833.17	75.81	75.75	23.99	24.00	-	-	26.22	26.24	-	-
2032	461.50	457.80	23.22	23.18	832.49	832.49	75.77	75.73	24.03	24.02	-	-	26.26	26.27	-	-
2033	466.25	461.45	23.28	23.22	831.39	831.81	75.74	75.71	24.07	24.05	-	-	26.30	26.29	-	-
2034	471.00	465.10	23.34	23.26	830.28	831.13	75.70	75.69	24.11	24.08	-	-	26.35	26.32	-	-
2035	475.75	468.75	23.40	23.30	829.18	830.45	75.67	75.67	24.15	24.11	-	-	26.39	26.35	-	-
2036	480.50	472.40	23.46	23.34	828.07	829.77	75.64	75.65	24.19	24.13	-	-	26.43	26.38	-	-
2037	485.25	476.05	23.52	23.38	826.97	829.09	75.60	75.63	24.23	24.16	-	-	26.47	26.41	-	-
2038	490.00	479.70	23.58	23.42	825.86	828.41	75.57	75.61	24.27	24.19	-	-	26.51	26.43	-	-
2039	494.75	483.35	23.64	23.46	824.76	827.73	75.53	75.59	24.31	24.21	-	-	26.55	26.46	-	-
2040	499.50	487.00	23.70	23.50	823.65	827.05	75.50	75.58	24.35	24.24	-	-	26.60	26.49	-	-
2041	505.65	491.00	23.76	23.54	822.55	826.37	75.46	75.56	24.39	24.27	-	-	26.64	26.52	-	-
2042	511.80	495.00	23.82	23.58	821.44	825.69	75.43	75.54	24.43	24.29	-	-	26.68	26.55	-	-
2043	517.95	499.00	23.88	23.62	820.34	825.01	75.40	75.52	24.47	24.32	-	-	26.72	26.57	-	-
2044	524.10	503.00	23.94	23.66	819.23	824.33	75.36	75.50	24.51	24.35	-	-	26.76	26.60	-	-
2045	530.25	507.00	24.00	23.70	818.13	823.65	75.33	75.48	24.55	24.38	-	-	26.80	26.63	-	-
2046	536.40	511.00	24.06	23.74	817.02	822.97	75.29	75.46	24.59	24.40	-	-	26.84	26.66	-	-
2047	542.55	515.00	24.12	23.78	815.92	822.29	75.26	75.44	24.63	24.43	-	-	26.89	26.69	-	-
2048	548.70	519.00	24.18	23.82	814.81	821.61	75.22	75.42	24.67	24.46	-	-	26.93	26.71	-	-
2049	554.85	523.00	24.24	23.86	813.71	820.93	75.19	75.40	24.71	24.48	-	-	26.97	26.74	-	-
2050	561.00	527.00	24.30	23.90	812.60	820.25	75.16	75.38	24.75	24.51	-	-	27.01	26.77	-	-
2051	568.05	531.05	24.34	23.92	811.88	819.83	75.13	75.37	24.80	24.54	-	-	27.06	26.80	-	-
2052	575.10	535.10	24.38	23.94	811.16	819.40	75.11	75.35	24.85	24.56	-	-	27.11	26.83	-	-
2053	582.15	539.15	24.42	23.96	810.43	818.98	75.09	75.34	24.89	24.59	-	-	27.16	26.85	-	-
2054	589.20	543.20	24.46	23.98	809.71	818.55	75.06	75.32	24.94	24.62	-	-	27.21	26.88	-	-
2055	596.25	547.25	24.50	24.00	808.99	818.13	75.04	75.31	24.99	24.64	-	-	27.26	26.91	-	-
2056	603.30	551.30	24.54	24.02	808.27	817.70	75.02	75.29	25.04	24.67	-	-	27.31	26.94	-	-
2057	610.35	555.35	24.58	24.04	807.54	817.28	75.00	75.28	25.08	24.70	-	-	27.36	26.96	-	-
2058	617.40	559.40	24.62	24.06	806.82	816.85	74.97	75.26	25.13	24.72	-	-	27.41	26.99	-	-
2059	624.45	563.45	24.66	24.08	806.10	816.43	74.95	75.25	25.18	24.75	-	-	27.46	27.02	-	-
2060	631.50	567.50	24.70	24.10	805.38	816.00	74.93	75.23	25.23	24.78	-	-	27.51	27.05	-	-
2061	639.25	571.35	24.74	24.12	804.65	815.58	74.90	75.22	25.27	24.80	-	-	27.56	27.07	-	-
2062	647.00	575.20	24.78	24.14	803.93	815.15	74.88	75.20	25.32	24.83	-	-	27.61	27.10	-	-
2063	654.75	579.05	24.82	24.16	803.21	814.73	74.86	75.19	25.37	24.85	-	-	27.66	27.13	-	-
2064	662.50	582.90	24.86	24.18	802.49	814.30	74.84	75.17	25.42	24.88	-	-	27.71	27.16	-	-
2065	670.25	586.75	24.90	24.20	801.76	813.88	74.81	75.16	25.46	24.91	-	-	27.76	27.18	-	-
2066	678.00	590.60	24.94	24.22	801.04	813.45	74.79	75.14	25.51	24.93	-	-	27.81	27.21	-	-
2067	685.75	594.45	24.98	24.24	800.32	813.03	74.77	75.12	25.56	24.96	-	-	27.86	27.24	-	-
2068	693.50	598.30	25.02	24.26	799.60	812.60	74.74	75.11	25.61	24.99	-	-	27.91	27.27	-	-
2069	701.25	602.15	25.06	24.28	798.87	812.18	74.72	75.09	25.65	25.01	-	-	27.96	27.29	-	-
2070	709.00	606.00	25.10	24.30	798.15	811.75	74.70	75.08	25.70	25.04	-	-	28.01	27.32	-	-

Table 50: Processed hotter and wetter climate projections for Gladstone

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	22.20	22.20	850.00	850.00	76.30	76.30	23.20	23.20	-	-	25.40	25.40	-	-
1991	354.05	354.05	22.21	22.21	848.57	848.50	76.29	76.29	23.21	23.21	-	-	25.41	25.41	-	-
1992	355.60	355.60	22.22	22.22	847.14	847.00	76.28	76.28	23.22	23.22	-	-	25.42	25.42	-	-
1993	357.15	357.15	22.23	22.24	845.71	845.50	76.28	76.28	23.23	23.23	-	-	25.43	25.43	-	-
1994	358.70	358.70	22.24	22.25	844.28	843.99	76.27	76.27	23.23	23.24	-	-	25.44	25.44	-	-
1995	360.25	360.25	22.25	22.26	842.85	842.49	76.26	76.26	23.24	23.24	-	-	25.45	25.45	-	-
1996	361.80	361.80	22.26	22.27	841.42	840.99	76.25	76.25	23.25	23.25	-	-	25.46	25.46	-	-
1997	363.35	363.35	22.27	22.28	839.98	839.49	76.25	76.25	23.26	23.26	-	-	25.46	25.47	-	-
1998	364.90	364.90	22.28	22.29	838.55	837.99	76.24	76.24	23.27	23.27	-	-	25.47	25.48	-	-
1999	366.45	366.45	22.29	22.31	837.12	836.49	76.23	76.23	23.28	23.28	-	-	25.48	25.49	-	-
2000	368.00	368.00	22.30	22.32	835.69	834.98	76.22	76.22	23.29	23.29	-	-	25.49	25.50	-	-
2001	369.95	370.15	22.31	22.33	834.26	833.48	76.22	76.22	23.29	23.30	-	-	25.50	25.51	-	-
2002	371.90	372.30	22.32	22.34	832.83	831.98	76.21	76.21	23.30	23.31	-	-	25.51	25.52	-	-
2003	373.85	374.45	22.33	22.35	831.40	830.48	76.20	76.20	23.31	23.31	-	-	25.52	25.53	-	-
2004	375.80	376.60	22.34	22.36	829.97	828.98	76.19	76.19	23.32	23.32	-	-	25.53	25.54	-	-
2005	377.75	378.75	22.35	22.38	828.54	827.48	76.19	76.19	23.33	23.33	-	-	25.54	25.55	-	-
2006	379.70	380.90	22.36	22.39	827.11	825.97	76.18	76.18	23.34	23.34	-	-	25.55	25.55	-	-
2007	381.65	383.05	22.37	22.40	825.68	824.47	76.17	76.17	23.34	23.35	-	-	25.56	25.56	-	-
2008	383.60	385.20	22.38	22.41	824.25	822.97	76.16	76.16	23.35	23.36	-	-	25.57	25.57	-	-
2009	385.55	387.35	22.39	22.42	822.81	821.47	76.16	76.16	23.36	23.37	-	-	25.57	25.58	-	-
2010	387.50	389.50	22.40	22.43	821.38	819.97	76.15	76.15	23.37	23.38	-	-	25.58	25.59	-	-
2011	390.35	392.45	22.42	22.46	818.52	816.96	76.13	76.13	23.39	23.39	-	-	25.60	25.61	-	-
2012	393.20	395.40	22.44	22.48	815.66	813.96	76.12	76.12	23.40	23.41	-	-	25.62	25.63	-	-
2013	396.05	398.35	22.46	22.50	812.80	810.96	76.10	76.10	23.42	23.43	-	-	25.64	25.65	-	-
2014	398.90	401.30	22.48	22.53	809.94	807.95	76.09	76.09	23.44	23.45	-	-	25.66	25.67	-	-
2015	401.75	404.25	22.50	22.55	807.08	804.95	76.07	76.07	23.46	23.47	-	-	25.68	25.69	-	-
2016	404.60	407.20	22.52	22.57	804.21	801.95	76.06	76.06	23.47	23.48	-	-	25.69	25.71	-	-
2017	407.45	410.15	22.54	22.60	801.35	798.94	76.04	76.04	23.49	23.50	-	-	25.71	25.73	-	-
2018	410.30	413.10	22.56	22.62	798.49	795.94	76.03	76.03	23.51	23.52	-	-	25.73	25.75	-	-
2019	413.15	416.05	22.58	22.64	795.63	792.94	76.01	76.01	23.52	23.54	-	-	25.75	25.77	-	-
2020	416.00	419.00	22.60	22.67	792.77	789.93	75.99	75.99	23.54	23.55	-	-	25.77	25.79	-	-
2021	419.60	422.15	22.62	22.69	789.91	786.93	75.98	75.98	23.56	23.57	-	-	25.79	25.81	-	-
2022	423.20	425.30	22.64	22.71	787.04	783.93	75.96	75.96	23.57	23.59	-	-	25.80	25.83	-	-
2023	426.80	428.45	22.66	22.74	784.18	780.92	75.95	75.95	23.59	23.61	-	-	25.82	25.84	-	-
2024	430.40	431.60	22.68	22.76	781.32	777.92	75.93	75.93	23.61	23.62	-	-	25.84	25.86	-	-
2025	434.00	434.75	22.70	22.78	778.46	774.92	75.92	75.92	23.63	23.64	-	-	25.86	25.88	-	-

2026	437.60	437.90	22.72	22.81	775.60	771.91	75.90	75.90	23.64	23.66	-	-	25.88	25.90	-	-
2027	441.20	441.05	22.74	22.83	772.74	768.91	75.89	75.89	23.66	23.68	-	-	25.90	25.92	-	-
2028	444.80	444.20	22.76	22.85	769.87	765.91	75.87	75.87	23.68	23.69	-	-	25.91	25.94	-	-
2029	448.40	447.35	22.78	22.88	767.01	762.90	75.86	75.86	23.69	23.71	-	-	25.93	25.96	-	-
2030	452.00	450.50	22.80	22.90	764.15	759.90	75.84	75.84	23.71	23.73	-	-	25.95	25.98	-	-
2031	456.75	454.15	22.85	22.93	757.99	755.99	75.81	75.82	23.74	23.75	-	-	25.98	26.00	-	-
2032	461.50	457.80	22.89	22.95	751.83	752.08	75.78	75.80	23.76	23.77	-	-	26.01	26.02	-	-
2033	466.25	461.45	22.94	22.98	745.66	748.17	75.75	75.78	23.79	23.79	-	-	26.04	26.04	-	-
2034	471.00	465.10	22.98	23.00	739.50	744.26	75.72	75.77	23.82	23.80	-	-	26.07	26.06	-	-
2035	475.75	468.75	23.03	23.03	733.34	740.35	75.69	75.75	23.85	23.82	-	-	26.10	26.08	-	-
2036	480.50	472.40	23.07	23.05	727.18	736.44	75.66	75.73	23.87	23.84	-	-	26.13	26.10	-	-
2037	485.25	476.05	23.12	23.08	721.01	732.53	75.63	75.71	23.90	23.86	-	-	26.16	26.12	-	-
2038	490.00	479.70	23.16	23.10	714.85	728.62	75.60	75.69	23.93	23.88	-	-	26.19	26.14	-	-
2039	494.75	483.35	23.21	23.13	708.69	724.71	75.57	75.67	23.95	23.90	-	-	26.22	26.16	-	-
2040	499.50	487.00	23.25	23.15	702.53	720.80	75.54	75.65	23.98	23.92	-	-	26.25	26.18	-	-
2041	505.65	491.00	23.30	23.18	696.36	716.89	75.51	75.63	24.01	23.93	-	-	26.27	26.20	-	-
2042	511.80	495.00	23.34	23.20	690.20	712.98	75.48	75.61	24.03	23.95	-	-	26.30	26.22	-	-
2043	517.95	499.00	23.39	23.23	684.04	709.07	75.45	75.59	24.06	23.97	-	-	26.33	26.24	-	-
2044	524.10	503.00	23.43	23.25	677.88	705.16	75.41	75.58	24.09	23.99	-	-	26.36	26.26	-	-
2045	530.25	507.00	23.48	23.28	671.71	701.25	75.38	75.56	24.12	24.01	-	-	26.39	26.28	-	-
2046	536.40	511.00	23.52	23.30	665.55	697.34	75.35	75.54	24.14	24.03	-	-	26.42	26.30	-	-
2047	542.55	515.00	23.57	23.33	659.39	693.43	75.32	75.52	24.17	24.04	-	-	26.45	26.32	-	-
2048	548.70	519.00	23.61	23.35	653.23	689.52	75.29	75.50	24.20	24.06	-	-	26.48	26.34	-	-
2049	554.85	523.00	23.66	23.38	647.06	685.61	75.26	75.48	24.22	24.08	-	-	26.51	26.36	-	-
2050	561.00	527.00	23.70	23.40	640.90	681.70	75.23	75.46	24.25	24.10	-	-	26.54	26.38	-	-
2051	568.05	531.05	23.73	23.42	636.86	681.32	75.21	75.45	24.28	24.12	-	-	26.58	26.40	-	-
2052	575.10	535.10	23.76	23.43	632.83	680.94	75.19	75.44	24.32	24.14	-	-	26.61	26.42	-	-
2053	582.15	539.15	23.79	23.45	628.79	680.55	75.16	75.43	24.35	24.15	-	-	26.65	26.44	-	-
2054	589.20	543.20	23.82	23.46	624.75	680.17	75.14	75.41	24.38	24.17	-	-	26.68	26.46	-	-
2055	596.25	547.25	23.85	23.48	620.71	679.79	75.12	75.40	24.41	24.19	-	-	26.72	26.48	-	-
2056	603.30	551.30	23.88	23.49	616.68	679.41	75.09	75.39	24.45	24.21	-	-	26.75	26.49	-	-
2057	610.35	555.35	23.91	23.51	612.64	679.02	75.07	75.38	24.48	24.22	-	-	26.79	26.51	-	-
2058	617.40	559.40	23.94	23.52	608.60	678.64	75.05	75.37	24.51	24.24	-	-	26.82	26.53	-	-
2059	624.45	563.45	23.97	23.54	604.56	678.26	75.03	75.36	24.54	24.26	-	-	26.86	26.55	-	-
2060	631.50	567.50	24.00	23.55	600.53	677.88	75.00	75.35	24.58	24.28	-	-	26.90	26.57	-	-
2061	639.25	571.35	24.03	23.57	596.49	677.49	74.98	75.33	24.61	24.29	-	-	26.93	26.59	-	-
2062	647.00	575.20	24.06	23.58	592.45	677.11	74.96	75.32	24.64	24.31	-	-	26.97	26.61	-	-
2063	654.75	579.05	24.09	23.60	588.41	676.73	74.93	75.31	24.67	24.33	-	-	27.00	26.63	-	-
2064	662.50	582.90	24.12	23.61	584.38	676.35	74.91	75.30	24.71	24.35	-	-	27.04	26.65	-	-
2065	670.25	586.75	24.15	23.63	580.34	675.96	74.89	75.29	24.74	24.36	-	-	27.07	26.67	-	-
2066	678.00	590.60	24.18	23.64	576.30	675.58	74.87	75.28	24.77	24.38	-	-	27.11	26.68	-	-
2067	685.75	594.45	24.21	23.66	572.26	675.20	74.84	75.27	24.80	24.40	-	-	27.14	26.70	-	-
2068	693.50	598.30	24.24	23.67	568.23	674.82	74.82	75.25	24.84	24.42	-	-	27.18	26.72	-	-
2069	701.25	602.15	24.27	23.69	564.19	674.43	74.80	75.24	24.87	24.43	-	-	27.21	26.74	-	-
2070	709.00	606.00	24.30	23.70	560.15	674.05	74.77	75.23	24.90	24.45	-	-	27.25	26.76	-	-

Table 51: Processed cooler and wetter climate projections for Gladstone

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	22.20	22.20	850.00	850.00	76.30	76.30	23.20	23.20	35.30	35.30	25.40	25.40	35.34	35.34
1991	354.05	354.05	22.21	22.21	850.31	850.31	76.31	76.31	23.22	23.22	35.30	35.30	25.42	25.42	35.34	35.34
1992	355.60	355.60	22.23	22.23	850.62	850.62	76.31	76.31	23.23	23.23	35.30	35.30	25.43	25.44	35.34	35.34
1993	357.15	357.15	22.24	22.24	850.94	850.94	76.32	76.32	23.25	23.25	35.30	35.30	25.45	25.45	35.34	35.34
1994	358.70	358.70	22.25	22.25	851.25	851.25	76.32	76.32	23.26	23.26	35.29	35.29	25.47	25.47	35.33	35.33
1995	360.25	360.25	22.27	22.27	851.56	851.56	76.33	76.33	23.28	23.28	35.29	35.29	25.49	25.49	35.33	35.33
1996	361.80	361.80	22.28	22.28	851.87	851.87	76.33	76.33	23.29	23.30	35.29	35.29	25.50	25.51	35.33	35.33
1997	363.35	363.35	22.29	22.29	852.18	852.18	76.34	76.34	23.31	23.31	35.29	35.29	25.52	25.52	35.33	35.33
1998	364.90	364.90	22.31	22.31	852.49	852.49	76.34	76.34	23.32	23.33	35.29	35.29	25.54	25.54	35.33	35.33
1999	366.45	366.45	22.32	22.32	852.81	852.81	76.35	76.35	23.34	23.34	35.29	35.29	25.55	25.56	35.33	35.33
2000	368.00	368.00	22.33	22.33	853.12	853.12	76.35	76.35	23.36	23.36	35.29	35.29	25.57	25.58	35.33	35.33
2001	369.95	370.15	22.35	22.35	853.43	853.43	76.36	76.36	23.37	23.38	35.28	35.28	25.59	25.59	35.33	35.33
2002	371.90	372.30	22.36	22.36	853.74	853.74	76.36	76.36	23.39	23.39	35.28	35.28	25.60	25.61	35.32	35.32
2003	373.85	374.45	22.37	22.37	854.05	854.05	76.37	76.37	23.40	23.41	35.28	35.28	25.62	25.63	35.32	35.32
2004	375.80	376.60	22.39	22.39	854.36	854.36	76.37	76.37	23.42	23.42	35.28	35.28	25.64	25.65	35.32	35.32
2005	377.75	378.75	22.40	22.40	854.68	854.68	76.38	76.38	23.43	23.44	35.28	35.28	25.66	25.66	35.32	35.32
2006	379.70	380.90	22.41	22.41	854.99	854.99	76.38	76.38	23.45	23.46	35.28	35.28	25.67	25.68	35.32	35.32
2007	381.65	383.05	22.43	22.43	855.30	855.30	76.39	76.39	23.46	23.47	35.27	35.27	25.69	25.70	35.32	35.32
2008	383.60	385.20	22.44	22.44	855.61	855.61	76.39	76.39	23.48	23.49	35.27	35.27	25.71	25.72	35.32	35.32
2009	385.55	387.35	22.45	22.45	855.92	855.92	76.40	76.40	23.49	23.50	35.27	35.27	25.72	25.73	35.31	35.31
2010	387.50	389.50	22.47	22.47	856.23	856.23	76.40	76.40	23.51	23.52	35.27	35.27	25.74	25.75	35.31	35.31
2011	390.35	392.45	22.49	22.49	856.86	856.86	76.41	76.41	23.54	23.55	35.27	35.27	25.77	25.79	35.31	35.31
2012	393.20	395.40	22.52	22.52	857.48	857.48	76.42	76.42	23.57	23.58	35.26	35.26	25.81	25.82	35.31	35.31
2013	396.05	398.35	22.55	22.55	858.10	858.10	76.43	76.43	23.60	23.62	35.26	35.26	25.84	25.86	35.31	35.31
2014	398.90	401.30	22.57	22.57	858.73	858.73	76.44	76.44	23.63	23.65	35.26	35.26	25.88	25.89	35.30	35.30
2015	401.75	404.25	22.60	22.60	859.35	859.35	76.45	76.45	23.67	23.68	35.26	35.26	25.91	25.93	35.30	35.30
2016	404.60	407.20	22.63	22.63	859.97	859.97	76.46	76.46	23.70	23.71	35.25	35.25	25.94	25.96	35.30	35.30
2017	407.45	410.15	22.65	22.65	860.60	860.60	76.47	76.47	23.73	23.74	35.25	35.25	25.98	26.00	35.29	35.29
2018	410.30	413.10	22.68	22.68	861.22	861.22	76.48	76.48	23.76	23.78	35.25	35.25	26.01	26.03	35.29	35.29
2019	413.15	416.05	22.71	22.71	861.84	861.84	76.49	76.49	23.79	23.81	35.24	35.24	26.05	26.07	35.29	35.29
2020	416.00	419.00	22.73	22.73	862.47	862.47	76.50	76.50	23.82	23.84	35.24	35.24	26.08	26.10	35.29	35.29
2021	419.60	422.15	22.76	22.76	863.09	863.09	76.51	76.51	23.85	23.87	35.24	35.24	26.11	26.14	35.28	35.28
2022	423.20	425.30	22.79	22.79	863.71	863.71	76.52	76.52	23.88	23.90	35.23	35.23	26.15	26.17	35.28	35.28
2023	426.80	428.45	22.81	22.81	864.34	864.34	76.53	76.53	23.91	23.94	35.23	35.23	26.18	26.21	35.28	35.28
2024	430.40	431.60	22.84	22.84	864.96	864.96	76.54	76.54	23.94	23.97	35.23	35.23	26.22	26.24	35.28	35.28
2025	434.00	434.75	22.87	22.87	865.58	865.58	76.55	76.55	23.98	24.00	35.23	35.23	26.25	26.28	35.27	35.27

2026	437.60	437.90	22.89	22.89	866.21	866.21	76.56	76.56	24.01	24.03	35.22	35.22	26.28	26.31	35.27	35.27
2027	441.20	441.05	22.92	22.92	866.83	866.83	76.57	76.57	24.04	24.06	35.22	35.22	26.32	26.35	35.27	35.27
2028	444.80	444.20	22.95	22.95	867.45	867.45	76.58	76.58	24.07	24.10	35.22	35.22	26.35	26.38	35.27	35.27
2029	448.40	447.35	22.97	22.97	868.08	868.08	76.60	76.60	24.10	24.13	35.21	35.21	26.39	26.42	35.26	35.26
2030	452.00	450.50	23.00	23.00	868.70	868.70	76.61	76.61	24.13	24.16	35.21	35.21	26.42	26.45	35.26	35.26
2031	456.75	454.15	23.06	23.04	869.98	869.55	76.63	76.62	24.18	24.19	35.21	35.21	26.47	26.49	35.26	35.26
2032	461.50	457.80	23.11	23.07	871.25	870.40	76.65	76.64	24.23	24.23	35.20	35.20	26.53	26.52	35.25	35.25
2033	466.25	461.45	23.17	23.11	872.53	871.25	76.67	76.65	24.28	24.26	35.20	35.20	26.58	26.56	35.25	35.25
2034	471.00	465.10	23.22	23.14	873.80	872.10	76.70	76.67	24.33	24.29	35.19	35.20	26.64	26.60	35.24	35.25
2035	475.75	468.75	23.28	23.18	875.08	872.95	76.72	76.68	24.38	24.33	35.19	35.20	26.69	26.64	35.24	35.25
2036	480.50	472.40	23.33	23.21	876.35	873.80	76.74	76.70	24.43	24.36	35.18	35.19	26.75	26.67	35.23	35.24
2037	485.25	476.05	23.39	23.25	877.63	874.65	76.77	76.71	24.48	24.39	35.18	35.19	26.80	26.71	35.23	35.24
2038	490.00	479.70	23.44	23.28	878.90	875.50	76.79	76.73	24.53	24.43	35.17	35.19	26.86	26.75	35.22	35.24
2039	494.75	483.35	23.50	23.32	880.18	876.35	76.81	76.74	24.58	24.46	35.17	35.18	26.91	26.78	35.22	35.23
2040	499.50	487.00	23.55	23.35	881.45	877.20	76.83	76.76	24.63	24.50	35.17	35.18	26.97	26.82	35.22	35.23
2041	505.65	491.00	23.61	23.39	882.73	878.05	76.86	76.77	24.68	24.53	35.16	35.18	27.02	26.86	35.21	35.23
2042	511.80	495.00	23.66	23.42	884.00	878.90	76.88	76.79	24.73	24.56	35.16	35.17	27.07	26.89	35.21	35.22
2043	517.95	499.00	23.72	23.46	885.28	879.75	76.90	76.80	24.78	24.60	35.15	35.17	27.13	26.93	35.20	35.22
2044	524.10	503.00	23.77	23.49	886.55	880.60	76.93	76.82	24.83	24.63	35.15	35.17	27.18	26.97	35.20	35.22
2045	530.25	507.00	23.83	23.53	887.83	881.45	76.95	76.83	24.88	24.66	35.14	35.17	27.24	27.01	35.19	35.22
2046	536.40	511.00	23.88	23.56	889.10	882.30	76.97	76.85	24.93	24.70	35.14	35.16	27.29	27.04	35.19	35.21
2047	542.55	515.00	23.94	23.60	890.38	883.15	76.99	76.86	24.98	24.73	35.13	35.16	27.35	27.08	35.18	35.21
2048	548.70	519.00	23.99	23.63	891.65	884.00	77.02	76.88	25.03	24.76	35.13	35.16	27.40	27.12	35.18	35.21
2049	554.85	523.00	24.05	23.67	892.93	884.85	77.04	76.90	25.08	24.80	35.12	35.15	27.46	27.15	35.17	35.20
2050	561.00	527.00	24.10	23.70	894.20	885.70	77.06	76.91	25.13	24.83	35.12	35.15	27.51	27.19	35.17	35.20
2051	568.05	531.05	24.14	23.72	895.05	886.17	77.08	76.92	25.19	24.86	35.11	35.15	27.57	27.23	35.17	35.20
2052	575.10	535.10	24.17	23.74	895.90	886.64	77.09	76.93	25.25	24.90	35.11	35.14	27.64	27.26	35.16	35.19
2053	582.15	539.15	24.21	23.76	896.75	887.10	77.11	76.94	25.31	24.93	35.10	35.14	27.70	27.30	35.16	35.19
2054	589.20	543.20	24.24	23.78	897.60	887.57	77.12	76.96	25.36	24.96	35.10	35.14	27.77	27.33	35.15	35.19
2055	596.25	547.25	24.28	23.80	898.45	888.04	77.14	76.97	25.42	24.99	35.09	35.13	27.83	27.37	35.15	35.19
2056	603.30	551.30	24.31	23.82	899.30	888.51	77.15	76.98	25.48	25.03	35.09	35.13	27.90	27.40	35.14	35.18
2057	610.35	555.35	24.35	23.84	900.15	888.97	77.17	76.99	25.54	25.06	35.08	35.13	27.96	27.44	35.14	35.18
2058	617.40	559.40	24.38	23.86	901.00	889.44	77.19	77.00	25.60	25.09	35.08	35.12	28.03	27.47	35.13	35.18
2059	624.45	563.45	24.42	23.88	901.85	889.91	77.20	77.01	25.66	25.12	35.07	35.12	28.09	27.51	35.13	35.17
2060	631.50	567.50	24.45	23.90	902.70	890.38	77.22	77.02	25.72	25.16	35.07	35.12	28.16	27.55	35.12	35.17
2061	639.25	571.35	24.49	23.92	903.55	890.84	77.23	77.04	25.77	25.19	35.06	35.11	28.22	27.58	35.12	35.17
2062	647.00	575.20	24.52	23.94	904.40	891.31	77.25	77.05	25.83	25.22	35.05	35.11	28.28	27.62	35.11	35.16
2063	654.75	579.05	24.56	23.96	905.25	891.78	77.26	77.06	25.89	25.25	35.05	35.10	28.35	27.65	35.11	35.16
2064	662.50	582.90	24.59	23.98	906.10	892.25	77.28	77.07	25.95	25.29	35.04	35.10	28.41	27.69	35.10	35.16
2065	670.25	586.75	24.63	24.00	906.95	892.71	77.29	77.08	26.01	25.32	35.04	35.10	28.48	27.72	35.10	35.16
2066	678.00	590.60	24.66	24.02	907.80	893.18	77.31	77.09	26.07	25.35	35.03	35.09	28.54	27.76	35.09	35.15
2067	685.75	594.45	24.70	24.04	908.65	893.65	77.32	77.10	26.12	25.38	35.03	35.09	28.61	27.79	35.09	35.15
2068	693.50	598.30	24.73	24.06	909.50	894.12	77.34	77.12	26.18	25.42	35.02	35.09	28.67	27.83	35.08	35.15
2069	701.25	602.15	24.77	24.08	910.35	894.58	77.35	77.13	26.24	25.45	35.02	35.08	28.74	27.86	35.08	35.14
2070	709.00	606.00	24.80	24.10	911.20	895.05	77.37	77.14	26.30	25.48	35.01	35.08	28.80	27.90	35.07	35.14

Table 52: Processed most likely climate projections for Port Kembla

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	16.40	16.40	1094.00	1094.00	74.10	74.10	19.30	19.30	-	-	21.50	21.50	-	-
1991	354.05	354.05	16.41	16.41	1094.13	1094.13	74.09	74.09	19.31	19.31	-	-	21.51	21.51	-	-
1992	355.60	355.60	16.42	16.42	1094.26	1094.26	74.08	74.08	19.32	19.32	-	-	21.52	21.52	-	-
1993	357.15	357.15	16.44	16.44	1094.38	1094.38	74.07	74.07	19.33	19.33	-	-	21.53	21.53	-	-
1994	358.70	358.70	16.45	16.45	1094.51	1094.51	74.07	74.06	19.34	19.34	-	-	21.54	21.54	-	-
1995	360.25	360.25	16.46	16.46	1094.64	1094.64	74.06	74.05	19.35	19.35	-	-	21.55	21.55	-	-
1996	361.80	361.80	16.47	16.47	1094.77	1094.77	74.05	74.04	19.36	19.36	-	-	21.56	21.56	-	-
1997	363.35	363.35	16.48	16.48	1094.89	1094.89	74.04	74.03	19.37	19.37	-	-	21.57	21.57	-	-
1998	364.90	364.90	16.49	16.50	1095.02	1095.02	74.03	74.02	19.38	19.38	-	-	21.58	21.58	-	-
1999	366.45	366.45	16.51	16.51	1095.15	1095.15	74.02	74.01	19.39	19.39	-	-	21.59	21.59	-	-
2000	368.00	368.00	16.52	16.52	1095.28	1095.28	74.01	74.00	19.40	19.40	-	-	21.60	21.60	-	-
2001	369.95	370.15	16.53	16.53	1095.40	1095.40	74.00	73.99	19.41	19.41	-	-	21.61	21.61	-	-
2002	371.90	372.30	16.54	16.54	1095.53	1095.53	74.00	73.98	19.42	19.42	-	-	21.62	21.63	-	-
2003	373.85	374.45	16.55	16.56	1095.66	1095.66	73.99	73.97	19.43	19.43	-	-	21.63	21.64	-	-
2004	375.80	376.60	16.56	16.57	1095.79	1095.79	73.98	73.96	19.44	19.44	-	-	21.64	21.65	-	-
2005	377.75	378.75	16.58	16.58	1095.91	1095.91	73.97	73.95	19.45	19.46	-	-	21.65	21.66	-	-
2006	379.70	380.90	16.59	16.59	1096.04	1096.04	73.96	73.94	19.46	19.47	-	-	21.66	21.67	-	-
2007	381.65	383.05	16.60	16.60	1096.17	1096.17	73.95	73.93	19.47	19.48	-	-	21.67	21.68	-	-
2008	383.60	385.20	16.61	16.62	1096.30	1096.30	73.94	73.92	19.48	19.49	-	-	21.68	21.69	-	-
2009	385.55	387.35	16.62	16.63	1096.43	1096.43	73.94	73.91	19.49	19.50	-	-	21.69	21.70	-	-
2010	387.50	389.50	16.63	16.64	1096.55	1096.55	73.93	73.90	19.50	19.51	-	-	21.70	21.71	-	-
2011	390.35	392.45	16.66	16.66	1096.81	1096.81	73.91	73.88	19.52	19.53	-	-	21.72	21.73	-	-
2012	393.20	395.40	16.68	16.69	1097.06	1097.06	73.89	73.86	19.54	19.55	-	-	21.74	21.75	-	-
2013	396.05	398.35	16.70	16.71	1097.32	1097.32	73.88	73.84	19.56	19.57	-	-	21.76	21.77	-	-
2014	398.90	401.30	16.73	16.74	1097.57	1097.57	73.86	73.82	19.58	19.59	-	-	21.78	21.79	-	-
2015	401.75	404.25	16.75	16.76	1097.83	1097.83	73.84	73.80	19.60	19.61	-	-	21.80	21.81	-	-
2016	404.60	407.20	16.77	16.78	1098.08	1098.08	73.82	73.78	19.61	19.63	-	-	21.82	21.83	-	-
2017	407.45	410.15	16.80	16.81	1098.34	1098.34	73.81	73.76	19.63	19.65	-	-	21.84	21.85	-	-
2018	410.30	413.10	16.82	16.83	1098.59	1098.59	73.79	73.74	19.65	19.67	-	-	21.86	21.88	-	-
2019	413.15	416.05	16.84	16.86	1098.85	1098.85	73.77	73.72	19.67	19.69	-	-	21.88	21.90	-	-
2020	416.00	419.00	16.87	16.88	1099.11	1099.11	73.75	73.70	19.69	19.71	-	-	21.90	21.92	-	-
2021	419.60	422.15	16.89	16.90	1099.36	1099.36	73.74	73.69	19.71	19.73	-	-	21.92	21.94	-	-
2022	423.20	425.30	16.91	16.93	1099.62	1099.62	73.72	73.67	19.73	19.75	-	-	21.94	21.96	-	-
2023	426.80	428.45	16.94	16.95	1099.87	1099.87	73.70	73.65	19.75	19.78	-	-	21.95	21.98	-	-
2024	430.40	431.60	16.96	16.98	1100.13	1100.13	73.69	73.63	19.77	19.80	-	-	21.97	22.00	-	-
2025	434.00	434.75	16.98	17.00	1100.38	1100.38	73.67	73.61	19.79	19.82	-	-	21.99	22.02	-	-

2026	437.60	437.90	17.01	17.02	1100.64	1100.64	73.65	73.59	19.81	19.84	-	-	22.01	22.04	-	-
2027	441.20	441.05	17.03	17.05	1100.89	1100.89	73.63	73.57	19.83	19.86	-	-	22.03	22.06	-	-
2028	444.80	444.20	17.05	17.07	1101.15	1101.15	73.62	73.55	19.85	19.88	-	-	22.05	22.08	-	-
2029	448.40	447.35	17.08	17.10	1101.40	1101.40	73.60	73.53	19.87	19.90	-	-	22.07	22.11	-	-
2030	452.00	450.50	17.10	17.12	1101.66	1101.66	73.58	73.51	19.89	19.92	-	-	22.09	22.13	-	-
2031	456.75	454.15	17.15	17.15	1102.21	1102.04	73.54	73.49	19.92	19.94	-	-	22.13	22.15	-	-
2032	461.50	457.80	17.20	17.19	1102.75	1102.42	73.50	73.46	19.95	19.96	-	-	22.16	22.17	-	-
2033	466.25	461.45	17.25	17.22	1103.30	1102.81	73.46	73.44	19.99	19.98	-	-	22.19	22.19	-	-
2034	471.00	465.10	17.30	17.26	1103.85	1103.19	73.42	73.42	20.02	20.01	-	-	22.22	22.21	-	-
2035	475.75	468.75	17.35	17.29	1104.39	1103.57	73.38	73.40	20.05	20.03	-	-	22.25	22.23	-	-
2036	480.50	472.40	17.40	17.32	1104.94	1103.96	73.34	73.38	20.08	20.05	-	-	22.29	22.25	-	-
2037	485.25	476.05	17.45	17.36	1105.49	1104.34	73.30	73.36	20.11	20.07	-	-	22.32	22.28	-	-
2038	490.00	479.70	17.50	17.39	1106.03	1104.72	73.26	73.34	20.15	20.09	-	-	22.35	22.30	-	-
2039	494.75	483.35	17.55	17.43	1106.58	1105.10	73.21	73.32	20.18	20.11	-	-	22.38	22.32	-	-
2040	499.50	487.00	17.60	17.46	1107.13	1105.49	73.17	73.30	20.21	20.14	-	-	22.41	22.34	-	-
2041	505.65	491.00	17.65	17.49	1107.68	1105.87	73.13	73.27	20.24	20.16	-	-	22.45	22.36	-	-
2042	511.80	495.00	17.70	17.53	1108.22	1106.25	73.09	73.25	20.27	20.18	-	-	22.48	22.38	-	-
2043	517.95	499.00	17.75	17.56	1108.77	1106.64	73.05	73.23	20.31	20.20	-	-	22.51	22.40	-	-
2044	524.10	503.00	17.80	17.60	1109.32	1107.02	73.01	73.21	20.34	20.22	-	-	22.54	22.43	-	-
2045	530.25	507.00	17.85	17.63	1109.86	1107.40	72.97	73.19	20.37	20.24	-	-	22.57	22.45	-	-
2046	536.40	511.00	17.90	17.66	1110.41	1107.78	72.93	73.17	20.40	20.26	-	-	22.60	22.47	-	-
2047	542.55	515.00	17.95	17.70	1110.96	1108.17	72.89	73.15	20.43	20.29	-	-	22.64	22.49	-	-
2048	548.70	519.00	18.00	17.73	1111.50	1108.55	72.85	73.13	20.47	20.31	-	-	22.67	22.51	-	-
2049	554.85	523.00	18.05	17.77	1112.05	1108.93	72.81	73.11	20.50	20.33	-	-	22.70	22.53	-	-
2050	561.00	527.00	18.10	17.80	1112.60	1109.32	72.77	73.08	20.53	20.35	-	-	22.73	22.55	-	-
2051	568.05	531.05	18.13	17.82	1112.93	1109.48	72.74	73.07	20.57	20.37	-	-	22.77	22.57	-	-
2052	575.10	535.10	18.16	17.83	1113.25	1109.64	72.71	73.05	20.61	20.39	-	-	22.81	22.60	-	-
2053	582.15	539.15	18.19	17.85	1113.58	1109.81	72.69	73.04	20.64	20.41	-	-	22.85	22.62	-	-
2054	589.20	543.20	18.22	17.86	1113.91	1109.97	72.66	73.02	20.68	20.43	-	-	22.88	22.64	-	-
2055	596.25	547.25	18.25	17.88	1114.24	1110.14	72.64	73.01	20.72	20.46	-	-	22.92	22.66	-	-
2056	603.30	551.30	18.28	17.89	1114.57	1110.30	72.61	72.99	20.76	20.48	-	-	22.96	22.68	-	-
2057	610.35	555.35	18.31	17.91	1114.90	1110.46	72.58	72.97	20.80	20.50	-	-	23.00	22.70	-	-
2058	617.40	559.40	18.34	17.92	1115.22	1110.63	72.56	72.96	20.83	20.52	-	-	23.04	22.72	-	-
2059	624.45	563.45	18.37	17.94	1115.55	1110.79	72.53	72.94	20.87	20.54	-	-	23.07	22.74	-	-
2060	631.50	567.50	18.40	17.96	1115.88	1110.96	72.51	72.93	20.91	20.56	-	-	23.11	22.76	-	-
2061	639.25	571.35	18.43	17.97	1116.21	1111.12	72.48	72.91	20.95	20.58	-	-	23.15	22.78	-	-
2062	647.00	575.20	18.46	17.99	1116.54	1111.29	72.45	72.89	20.99	20.60	-	-	23.19	22.80	-	-
2063	654.75	579.05	18.49	18.00	1116.86	1111.45	72.43	72.88	21.02	20.62	-	-	23.23	22.82	-	-
2064	662.50	582.90	18.52	18.02	1117.19	1111.61	72.40	72.86	21.06	20.64	-	-	23.26	22.85	-	-
2065	670.25	586.75	18.55	18.03	1117.52	1111.78	72.38	72.85	21.10	20.67	-	-	23.30	22.87	-	-
2066	678.00	590.60	18.58	18.05	1117.85	1111.94	72.35	72.83	21.14	20.69	-	-	23.34	22.89	-	-
2067	685.75	594.45	18.61	18.06	1118.18	1112.11	72.33	72.81	21.18	20.71	-	-	23.38	22.91	-	-
2068	693.50	598.30	18.64	18.08	1118.51	1112.27	72.30	72.80	21.21	20.73	-	-	23.41	22.93	-	-
2069	701.25	602.15	18.67	18.09	1118.83	1112.43	72.27	72.78	21.25	20.75	-	-	23.45	22.95	-	-
2070	709.00	606.00	18.70	18.11	1119.16	1112.60	72.25	72.77	21.29	20.77	-	-	23.49	22.97	-	-

Table 53: Processed hotter and drier climate projections for Port Kembla

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	16.40	16.40	1094.00	1094.00	74.10	74.10	19.30	19.30	-	-	21.50	21.50	-	-
1991	354.05	354.05	16.42	16.42	1093.23	1093.20	74.07	74.07	19.32	19.32	-	-	21.51	21.52	-	-
1992	355.60	355.60	16.44	16.44	1092.47	1092.40	74.04	74.03	19.33	19.33	-	-	21.53	21.53	-	-
1993	357.15	357.15	16.46	16.46	1091.70	1091.59	74.00	74.00	19.35	19.35	-	-	21.54	21.55	-	-
1994	358.70	358.70	16.48	16.48	1090.94	1090.79	73.97	73.97	19.36	19.36	-	-	21.56	21.56	-	-
1995	360.25	360.25	16.50	16.50	1090.17	1089.99	73.94	73.93	19.38	19.38	-	-	21.57	21.58	-	-
1996	361.80	361.80	16.52	16.52	1089.41	1089.19	73.91	73.90	19.39	19.39	-	-	21.59	21.59	-	-
1997	363.35	363.35	16.54	16.54	1088.64	1088.38	73.88	73.87	19.41	19.41	-	-	21.60	21.61	-	-
1998	364.90	364.90	16.56	16.56	1087.87	1087.58	73.84	73.83	19.42	19.42	-	-	21.62	21.62	-	-
1999	366.45	366.45	16.58	16.58	1087.11	1086.78	73.81	73.80	19.44	19.44	-	-	21.63	21.64	-	-
2000	368.00	368.00	16.60	16.60	1086.34	1085.98	73.78	73.77	19.45	19.45	-	-	21.65	21.65	-	-
2001	369.95	370.15	16.62	16.62	1085.58	1085.18	73.75	73.73	19.47	19.47	-	-	21.66	21.67	-	-
2002	371.90	372.30	16.64	16.64	1084.81	1084.37	73.71	73.70	19.48	19.48	-	-	21.67	21.68	-	-
2003	373.85	374.45	16.66	16.66	1084.04	1083.57	73.68	73.67	19.50	19.50	-	-	21.69	21.70	-	-
2004	375.80	376.60	16.68	16.68	1083.28	1082.77	73.65	73.63	19.51	19.51	-	-	21.70	21.71	-	-
2005	377.75	378.75	16.70	16.70	1082.51	1081.97	73.62	73.60	19.53	19.53	-	-	21.72	21.73	-	-
2006	379.70	380.90	16.72	16.72	1081.75	1081.16	73.59	73.57	19.54	19.54	-	-	21.73	21.74	-	-
2007	381.65	383.05	16.74	16.74	1080.98	1080.36	73.55	73.53	19.56	19.56	-	-	21.75	21.76	-	-
2008	383.60	385.20	16.76	16.76	1080.22	1079.56	73.52	73.50	19.57	19.57	-	-	21.76	21.77	-	-
2009	385.55	387.35	16.78	16.78	1079.45	1078.76	73.49	73.47	19.59	19.59	-	-	21.78	21.79	-	-
2010	387.50	389.50	16.80	16.80	1078.68	1077.95	73.46	73.43	19.60	19.60	-	-	21.79	21.80	-	-
2011	390.35	392.45	16.84	16.84	1077.15	1076.35	73.39	73.37	19.63	19.63	-	-	21.82	21.83	-	-
2012	393.20	395.40	16.88	16.88	1075.62	1074.75	73.33	73.30	19.66	19.66	-	-	21.85	21.86	-	-
2013	396.05	398.35	16.92	16.92	1074.09	1073.14	73.27	73.23	19.69	19.69	-	-	21.88	21.89	-	-
2014	398.90	401.30	16.96	16.96	1072.56	1071.54	73.20	73.17	19.72	19.72	-	-	21.91	21.92	-	-
2015	401.75	404.25	17.00	17.00	1071.03	1069.93	73.14	73.10	19.75	19.75	-	-	21.94	21.95	-	-
2016	404.60	407.20	17.04	17.04	1069.49	1068.33	73.07	73.03	19.78	19.78	-	-	21.96	21.98	-	-
2017	407.45	410.15	17.08	17.08	1067.96	1066.72	73.01	72.97	19.81	19.81	-	-	21.99	22.01	-	-
2018	410.30	413.10	17.12	17.12	1066.43	1065.12	72.94	72.90	19.84	19.84	-	-	22.02	22.04	-	-
2019	413.15	416.05	17.16	17.16	1064.90	1063.51	72.88	72.83	19.87	19.87	-	-	22.05	22.07	-	-
2020	416.00	419.00	17.20	17.20	1063.37	1061.91	72.82	72.77	19.90	19.90	-	-	22.08	22.10	-	-
2021	419.60	422.15	17.24	17.24	1061.84	1060.30	72.75	72.70	19.93	19.93	-	-	22.11	22.13	-	-
2022	423.20	425.30	17.28	17.28	1060.30	1058.70	72.69	72.63	19.96	19.96	-	-	22.14	22.16	-	-
2023	426.80	428.45	17.32	17.32	1058.77	1057.10	72.62	72.57	19.99	19.99	-	-	22.17	22.19	-	-
2024	430.40	431.60	17.36	17.36	1057.24	1055.49	72.56	72.50	20.02	20.02	-	-	22.20	22.22	-	-
2025	434.00	434.75	17.40	17.40	1055.71	1053.89	72.49	72.43	20.05	20.05	-	-	22.23	22.25	-	-

2026	437.60	437.90	17.44	17.44	1054.18	1052.28	72.43	72.37	20.08	20.08	-	-	22.25	22.28	-	-
2027	441.20	441.05	17.48	17.48	1052.65	1050.68	72.37	72.30	20.11	20.11	-	-	22.28	22.31	-	-
2028	444.80	444.20	17.52	17.52	1051.12	1049.07	72.30	72.23	20.14	20.14	-	-	22.31	22.34	-	-
2029	448.40	447.35	17.56	17.56	1049.58	1047.47	72.24	72.17	20.17	20.17	-	-	22.34	22.37	-	-
2030	452.00	450.50	17.60	17.60	1048.05	1045.86	72.17	72.10	20.20	20.20	-	-	22.37	22.40	-	-
2031	456.75	454.15	17.69	17.66	1044.77	1043.79	72.04	72.01	20.25	20.24	-	-	22.42	22.43	-	-
2032	461.50	457.80	17.77	17.71	1041.49	1041.71	71.90	71.93	20.30	20.27	-	-	22.47	22.46	-	-
2033	466.25	461.45	17.86	17.77	1038.21	1039.63	71.76	71.84	20.35	20.31	-	-	22.51	22.49	-	-
2034	471.00	465.10	17.94	17.82	1034.92	1037.55	71.63	71.76	20.40	20.34	-	-	22.56	22.53	-	-
2035	475.75	468.75	18.03	17.88	1031.64	1035.47	71.49	71.67	20.45	20.38	-	-	22.61	22.56	-	-
2036	480.50	472.40	18.11	17.93	1028.36	1033.39	71.35	71.59	20.50	20.41	-	-	22.66	22.59	-	-
2037	485.25	476.05	18.20	17.99	1025.08	1031.31	71.21	71.50	20.55	20.45	-	-	22.70	22.62	-	-
2038	490.00	479.70	18.28	18.04	1021.80	1029.24	71.08	71.42	20.60	20.48	-	-	22.75	22.65	-	-
2039	494.75	483.35	18.37	18.10	1018.51	1027.16	70.94	71.33	20.65	20.52	-	-	22.80	22.68	-	-
2040	499.50	487.00	18.45	18.15	1015.23	1025.08	70.80	71.25	20.70	20.55	-	-	22.85	22.72	-	-
2041	505.65	491.00	18.54	18.21	1011.95	1023.00	70.67	71.16	20.75	20.59	-	-	22.89	22.75	-	-
2042	511.80	495.00	18.62	18.26	1008.67	1020.92	70.53	71.08	20.80	20.62	-	-	22.94	22.78	-	-
2043	517.95	499.00	18.71	18.32	1005.39	1018.84	70.39	70.99	20.85	20.66	-	-	22.99	22.81	-	-
2044	524.10	503.00	18.79	18.37	1002.10	1016.76	70.25	70.91	20.90	20.69	-	-	23.04	22.84	-	-
2045	530.25	507.00	18.88	18.43	998.82	1014.69	70.12	70.82	20.95	20.73	-	-	23.08	22.87	-	-
2046	536.40	511.00	18.96	18.48	995.54	1012.61	69.98	70.74	21.00	20.76	-	-	23.13	22.90	-	-
2047	542.55	515.00	19.05	18.54	992.26	1010.53	69.84	70.65	21.05	20.80	-	-	23.18	22.94	-	-
2048	548.70	519.00	19.13	18.59	988.98	1008.45	69.71	70.57	21.10	20.83	-	-	23.23	22.97	-	-
2049	554.85	523.00	19.22	18.65	985.69	1006.37	69.57	70.48	21.15	20.87	-	-	23.27	23.00	-	-
2050	561.00	527.00	19.30	18.70	982.41	1004.29	69.43	70.40	21.20	20.90	-	-	23.32	23.03	-	-
2051	568.05	531.05	19.36	18.73	980.28	1003.09	69.34	70.34	21.26	20.93	-	-	23.38	23.06	-	-
2052	575.10	535.10	19.41	18.76	978.15	1001.89	69.25	70.29	21.31	20.96	-	-	23.43	23.09	-	-
2053	582.15	539.15	19.47	18.79	976.01	1000.68	69.16	70.24	21.37	20.99	-	-	23.49	23.12	-	-
2054	589.20	543.20	19.52	18.82	973.88	999.48	69.08	70.19	21.42	21.02	-	-	23.54	23.15	-	-
2055	596.25	547.25	19.58	18.85	971.75	998.28	68.99	70.14	21.48	21.05	-	-	23.60	23.19	-	-
2056	603.30	551.30	19.63	18.88	969.61	997.07	68.90	70.08	21.53	21.08	-	-	23.65	23.22	-	-
2057	610.35	555.35	19.69	18.91	967.48	995.87	68.81	70.03	21.59	21.11	-	-	23.71	23.25	-	-
2058	617.40	559.40	19.74	18.94	965.35	994.66	68.72	69.98	21.64	21.14	-	-	23.76	23.28	-	-
2059	624.45	563.45	19.80	18.97	963.21	993.46	68.63	69.93	21.70	21.17	-	-	23.82	23.31	-	-
2060	631.50	567.50	19.85	19.00	961.08	992.26	68.54	69.88	21.75	21.20	-	-	23.88	23.34	-	-
2061	639.25	571.35	19.91	19.03	958.95	991.05	68.45	69.82	21.81	21.23	-	-	23.93	23.37	-	-
2062	647.00	575.20	19.96	19.06	956.81	989.85	68.36	69.77	21.86	21.26	-	-	23.99	23.40	-	-
2063	654.75	579.05	20.02	19.09	954.68	988.65	68.28	69.72	21.92	21.29	-	-	24.04	23.43	-	-
2064	662.50	582.90	20.07	19.12	952.55	987.44	68.19	69.67	21.97	21.32	-	-	24.10	23.46	-	-
2065	670.25	586.75	20.13	19.15	950.41	986.24	68.10	69.62	22.03	21.35	-	-	24.15	23.50	-	-
2066	678.00	590.60	20.18	19.18	948.28	985.04	68.01	69.57	22.08	21.38	-	-	24.21	23.53	-	-
2067	685.75	594.45	20.24	19.21	946.15	983.83	67.92	69.51	22.14	21.41	-	-	24.26	23.56	-	-
2068	693.50	598.30	20.29	19.24	944.01	982.63	67.83	69.46	22.19	21.44	-	-	24.32	23.59	-	-
2069	701.25	602.15	20.35	19.27	941.88	981.43	67.74	69.41	22.25	21.47	-	-	24.37	23.62	-	-
2070	709.00	606.00	20.40	19.30	939.75	980.22	67.65	69.36	22.30	21.50	-	-	24.43	23.65	-	-

Table 54: Processed cooler and wetter climate projections for Port Kembla

	Projections															
	CO_2		Mean temp		Mean rainfall		Mean RH		Mean Sea Temp		Mean Sea Salinity		Summer Sea Temp		Summer Sea Salinity	
	ppm		°C		mm		%		°C		g/l		°C		g/l	
Year	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B	A1FI	A1B
1990	352.50	352.50	16.40	16.40	1094.00	1094.00	74.10	74.10	19.30	19.30	35.50	35.50	21.50	21.50	35.50	35.50
1991	354.05	354.05	16.41	16.41	1094.62	1094.66	74.11	74.11	19.32	19.32	35.50	35.50	21.52	21.52	35.50	35.50
1992	355.60	355.60	16.42	16.42	1095.24	1095.31	74.12	74.12	19.33	19.34	35.50	35.50	21.53	21.53	35.50	35.50
1993	357.15	357.15	16.44	16.44	1095.86	1095.97	74.13	74.13	19.35	19.35	35.50	35.50	21.55	21.55	35.50	35.50
1994	358.70	358.70	16.45	16.45	1096.48	1096.63	74.14	74.14	19.37	19.37	35.50	35.50	21.56	21.57	35.50	35.50
1995	360.25	360.25	16.46	16.46	1097.10	1097.28	74.15	74.15	19.38	19.39	35.50	35.50	21.58	21.58	35.50	35.50
1996	361.80	361.80	16.47	16.47	1097.72	1097.94	74.16	74.16	19.40	19.41	35.51	35.51	21.60	21.60	35.50	35.50
1997	363.35	363.35	16.48	16.48	1098.34	1098.59	74.17	74.17	19.42	19.42	35.51	35.51	21.61	21.61	35.50	35.50
1998	364.90	364.90	16.49	16.49	1098.96	1099.25	74.18	74.18	19.43	19.44	35.51	35.51	21.63	21.63	35.50	35.50
1999	366.45	366.45	16.51	16.51	1099.58	1099.91	74.19	74.19	19.45	19.46	35.51	35.51	21.64	21.65	35.50	35.50
2000	368.00	368.00	16.52	16.52	1100.20	1100.56	74.20	74.20	19.47	19.48	35.51	35.51	21.66	21.66	35.50	35.50
2001	369.95	370.15	16.53	16.53	1100.82	1101.22	74.21	74.21	19.49	19.49	35.51	35.51	21.67	21.68	35.50	35.50
2002	371.90	372.30	16.54	16.54	1101.44	1101.88	74.22	74.22	19.50	19.51	35.51	35.51	21.69	21.70	35.50	35.50
2003	373.85	374.45	16.55	16.55	1102.06	1102.53	74.23	74.23	19.52	19.53	35.51	35.51	21.71	21.71	35.50	35.50
2004	375.80	376.60	16.56	16.56	1102.68	1103.19	74.24	74.24	19.54	19.55	35.51	35.51	21.72	21.73	35.50	35.50
2005	377.75	378.75	16.58	16.58	1103.30	1103.85	74.25	74.25	19.55	19.56	35.51	35.51	21.74	21.75	35.51	35.51
2006	379.70	380.90	16.59	16.59	1103.92	1104.50	74.26	74.26	19.57	19.58	35.51	35.51	21.75	21.76	35.51	35.51
2007	381.65	383.05	16.60	16.60	1104.54	1105.16	74.27	74.27	19.59	19.60	35.51	35.51	21.77	21.78	35.51	35.51
2008	383.60	385.20	16.61	16.61	1105.16	1105.82	74.28	74.28	19.60	19.62	35.52	35.52	21.79	21.79	35.51	35.51
2009	385.55	387.35	16.62	16.62	1105.78	1106.47	74.29	74.29	19.62	19.63	35.52	35.52	21.80	21.81	35.51	35.51
2010	387.50	389.50	16.63	16.63	1106.40	1107.13	74.30	74.30	19.64	19.65	35.52	35.52	21.82	21.83	35.51	35.51
2011	390.35	392.45	16.66	16.66	1107.64	1108.44	74.32	74.32	19.67	19.69	35.52	35.52	21.85	21.86	35.51	35.51
2012	393.20	395.40	16.68	16.68	1108.88	1109.75	74.34	74.34	19.70	19.72	35.52	35.52	21.88	21.89	35.51	35.51
2013	396.05	398.35	16.70	16.70	1110.12	1111.07	74.36	74.36	19.74	19.76	35.52	35.52	21.91	21.92	35.51	35.51
2014	398.90	401.30	16.73	16.73	1111.36	1112.38	74.38	74.38	19.77	19.79	35.52	35.52	21.94	21.96	35.51	35.51
2015	401.75	404.25	16.75	16.75	1112.60	1113.69	74.40	74.40	19.81	19.83	35.53	35.53	21.98	21.99	35.51	35.51
2016	404.60	407.20	16.77	16.77	1113.84	1115.00	74.42	74.42	19.84	19.86	35.53	35.53	22.01	22.02	35.51	35.51
2017	407.45	410.15	16.80	16.80	1115.08	1116.32	74.44	74.44	19.87	19.90	35.53	35.53	22.04	22.06	35.51	35.51
2018	410.30	413.10	16.82	16.82	1116.32	1117.63	74.46	74.46	19.91	19.93	35.53	35.53	22.07	22.09	35.51	35.51
2019	413.15	416.05	16.84	16.84	1117.56	1118.94	74.48	74.48	19.94	19.97	35.53	35.53	22.10	22.12	35.51	35.51
2020	416.00	419.00	16.87	16.87	1118.80	1120.26	74.50	74.50	19.97	20.00	35.53	35.53	22.13	22.15	35.51	35.51
2021	419.60	422.15	16.89	16.89	1120.04	1121.57	74.51	74.51	20.01	20.04	35.54	35.54	22.17	22.19	35.51	35.51
2022	423.20	425.30	16.91	16.91	1121.28	1122.88	74.53	74.53	20.04	20.07	35.54	35.54	22.20	22.22	35.51	35.51
2023	426.80	428.45	16.94	16.94	1122.52	1124.19	74.55	74.55	20.07	20.11	35.54	35.54	22.23	22.25	35.52	35.52
2024	430.40	431.60	16.96	16.96	1123.76	1125.51	74.57	74.57	20.11	20.14	35.54	35.54	22.26	22.28	35.52	35.52
2025	434.00	434.75	16.98	16.98	1125.00	1126.82	74.59	74.59	20.14	20.18	35.54	35.54	22.29	22.32	35.52	35.52

2026	437.60	437.90	17.01	17.01	1126.24	1128.13	74.61	74.61	20.18	20.21	35.54	35.54	22.32	22.35	35.52	35.52
2027	441.20	441.05	17.03	17.03	1127.48	1129.45	74.63	74.63	20.21	20.25	35.55	35.55	22.36	22.38	35.52	35.52
2028	444.80	444.20	17.05	17.05	1128.72	1130.76	74.65	74.65	20.24	20.28	35.55	35.55	22.39	22.41	35.52	35.52
2029	448.40	447.35	17.08	17.08	1129.96	1132.07	74.67	74.67	20.28	20.32	35.55	35.55	22.42	22.45	35.52	35.52
2030	452.00	450.50	17.10	17.10	1131.20	1133.38	74.69	74.69	20.31	20.35	35.55	35.55	22.45	22.48	35.52	35.52
2031	456.75	454.15	17.15	17.14	1133.88	1135.08	74.73	74.72	20.36	20.39	35.55	35.55	22.50	22.51	35.52	35.52
2032	461.50	457.80	17.20	17.17	1136.56	1136.78	74.77	74.74	20.42	20.42	35.56	35.55	22.55	22.55	35.52	35.52
2033	466.25	461.45	17.25	17.21	1139.24	1138.47	74.80	74.77	20.47	20.46	35.56	35.56	22.60	22.58	35.52	35.52
2034	471.00	465.10	17.30	17.24	1141.92	1140.17	74.84	74.80	20.53	20.50	35.56	35.56	22.66	22.62	35.52	35.52
2035	475.75	468.75	17.35	17.28	1144.60	1141.86	74.88	74.82	20.58	20.53	35.56	35.56	22.71	22.65	35.53	35.53
2036	480.50	472.40	17.40	17.31	1147.28	1143.56	74.92	74.85	20.64	20.57	35.57	35.56	22.76	22.69	35.53	35.53
2037	485.25	476.05	17.45	17.35	1149.96	1145.25	74.95	74.87	20.69	20.61	35.57	35.56	22.81	22.72	35.53	35.53
2038	490.00	479.70	17.50	17.38	1152.64	1146.95	74.99	74.90	20.75	20.64	35.57	35.57	22.86	22.76	35.53	35.53
2039	494.75	483.35	17.55	17.42	1155.32	1148.65	75.03	74.93	20.80	20.68	35.57	35.57	22.91	22.79	35.53	35.53
2040	499.50	487.00	17.60	17.45	1158.00	1150.34	75.06	74.95	20.86	20.72	35.58	35.57	22.97	22.83	35.53	35.53
2041	505.65	491.00	17.65	17.49	1160.68	1152.04	75.10	74.98	20.91	20.75	35.58	35.57	23.02	22.86	35.53	35.53
2042	511.80	495.00	17.70	17.52	1163.36	1153.73	75.14	75.00	20.96	20.79	35.58	35.57	23.07	22.89	35.53	35.53
2043	517.95	499.00	17.75	17.56	1166.04	1155.43	75.17	75.03	21.02	20.82	35.58	35.58	23.12	22.93	35.53	35.53
2044	524.10	503.00	17.80	17.59	1168.72	1157.12	75.21	75.06	21.07	20.86	35.59	35.58	23.17	22.96	35.53	35.53
2045	530.25	507.00	17.85	17.63	1171.40	1158.82	75.25	75.08	21.13	20.90	35.59	35.58	23.22	23.00	35.54	35.54
2046	536.40	511.00	17.90	17.66	1174.08	1160.52	75.29	75.11	21.18	20.93	35.59	35.58	23.27	23.03	35.54	35.54
2047	542.55	515.00	17.95	17.70	1176.76	1162.21	75.32	75.13	21.24	20.97	35.59	35.58	23.33	23.07	35.54	35.54
2048	548.70	519.00	18.00	17.73	1179.44	1163.91	75.36	75.16	21.29	21.01	35.60	35.59	23.38	23.10	35.54	35.54
2049	554.85	523.00	18.05	17.77	1182.12	1165.60	75.40	75.19	21.35	21.04	35.60	35.59	23.43	23.14	35.54	35.54
2050	561.00	527.00	18.10	17.80	1184.80	1167.30	75.43	75.21	21.40	21.08	35.60	35.59	23.48	23.17	35.54	35.54
2051	568.05	531.05	18.13	17.82	1186.55	1168.28	75.46	75.23	21.46	21.12	35.60	35.59	23.54	23.20	35.54	35.54
2052	575.10	535.10	18.16	17.83	1188.30	1169.27	75.49	75.24	21.53	21.15	35.61	35.59	23.60	23.24	35.54	35.54
2053	582.15	539.15	18.19	17.85	1190.05	1170.25	75.51	75.26	21.59	21.19	35.61	35.59	23.66	23.27	35.54	35.54
2054	589.20	543.20	18.22	17.86	1191.80	1171.24	75.54	75.27	21.66	21.22	35.61	35.60	23.72	23.30	35.55	35.54
2055	596.25	547.25	18.25	17.88	1193.55	1172.22	75.56	75.29	21.72	21.26	35.62	35.60	23.78	23.34	35.55	35.54
2056	603.30	551.30	18.28	17.89	1195.30	1173.21	75.59	75.30	21.78	21.29	35.62	35.60	23.84	23.37	35.55	35.54
2057	610.35	555.35	18.31	17.91	1197.05	1174.19	75.62	75.32	21.85	21.33	35.62	35.60	23.90	23.40	35.55	35.54
2058	617.40	559.40	18.34	17.92	1198.81	1175.17	75.64	75.33	21.91	21.36	35.63	35.60	23.96	23.43	35.55	35.54
2059	624.45	563.45	18.37	17.94	1200.56	1176.16	75.67	75.34	21.98	21.40	35.63	35.60	24.02	23.47	35.55	35.54
2060	631.50	567.50	18.40	17.95	1202.31	1177.14	75.69	75.36	22.04	21.44	35.64	35.61	24.08	23.50	35.56	35.55
2061	639.25	571.35	18.43	17.97	1204.06	1178.13	75.72	75.37	22.10	21.47	35.64	35.61	24.14	23.53	35.56	35.55
2062	647.00	575.20	18.46	17.98	1205.81	1179.11	75.75	75.39	22.17	21.51	35.64	35.61	24.20	23.57	35.56	35.55
2063	654.75	579.05	18.49	18.00	1207.56	1180.10	75.77	75.40	22.23	21.54	35.65	35.61	24.26	23.60	35.56	35.55
2064	662.50	582.90	18.52	18.01	1209.31	1181.08	75.80	75.42	22.30	21.58	35.65	35.61	24.32	23.63	35.56	35.55
2065	670.25	586.75	18.55	18.03	1211.06	1182.07	75.82	75.43	22.36	21.61	35.65	35.61	24.38	23.67	35.56	35.55
2066	678.00	590.60	18.58	18.04	1212.81	1183.05	75.85	75.45	22.42	21.65	35.66	35.61	24.44	23.70	35.56	35.55
2067	685.75	594.45	18.61	18.06	1214.56	1184.04	75.87	75.46	22.49	21.68	35.66	35.62	24.50	23.73	35.57	35.55
2068	693.50	598.30	18.64	18.07	1216.31	1185.02	75.90	75.48	22.55	21.72	35.66	35.62	24.56	23.76	35.57	35.55
2069	701.25	602.15	18.67	18.09	1218.06	1186.01	75.93	75.49	22.62	21.75	35.67	35.62	24.62	23.80	35.57	35.55
2070	709.00	606.00	18.70	18.10	1219.81	1186.99	75.95	75.51	22.68	21.79	35.67	35.62	24.68	23.83	35.57	35.55

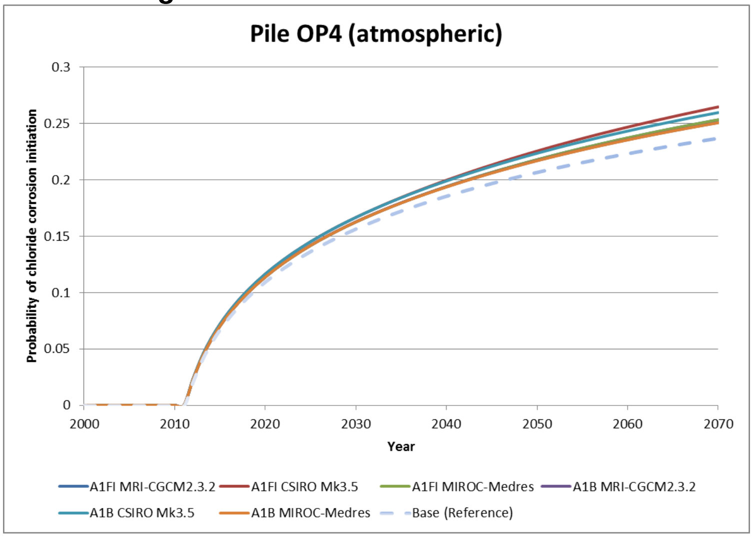
Appendix 2 DETERIORATION MODELLING CASE STUDIES

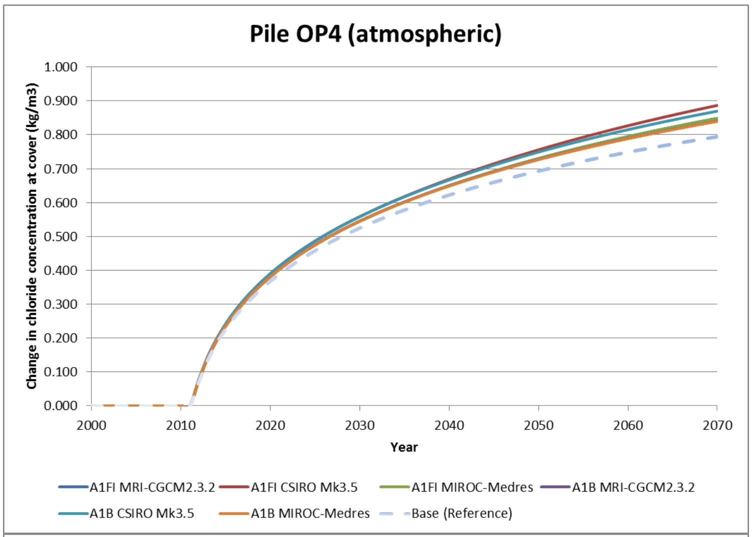
Pile OP4 (Port Kembla)

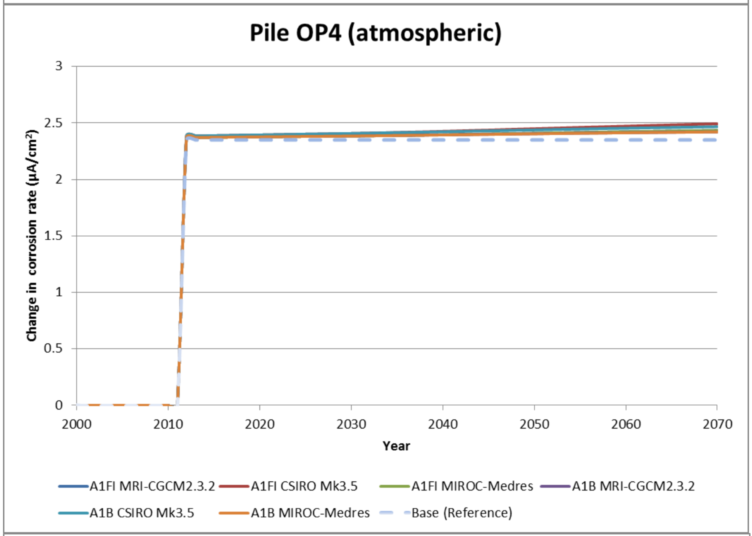
Pile 0P4 is constructed in 1993 is located in Berth 105/106. It is a 350mm square column constructed with 60MPa concrete. The design cover is 35mm. The RL=0.0 m at low tide, RL=2.0m at high tide, RL=3.5m at the top of the pile and RL=-16.5m at seabed. According to PKPC 2006, Mix D was used for all concrete exposed to tidal and splash zones. This mix has a water-to-cement ratio of 0.4 and is designed in accordance to AS3600 specification.

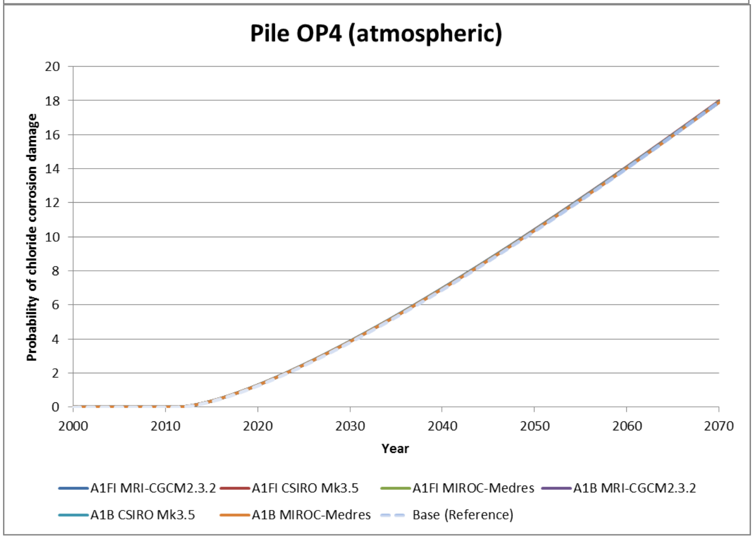
A1FI CSIRO Mk3.5 model shows the highest change in carbonation probability while A1B MIROC3.2 model showed the least change. This seems to agree well with the concept that carbonation is aided by heat, dryness and high CO_2 concentration. The tidal zone appears to have the greatest changes from the baseline model for Pile 0P4, with a nearly 10% increase in probability of corrosion, giving an 18% chance of corrosion by 2070, a 3.5mm increase in carbonation depth and a 0.015µA/cm^2 increase in corrosion rate. In the splash and atmospheric zones, the increase in corrosion probability is about 4% and the increase in carbonation depth is roughly 1.5mm in 2070. The change in the rate of corrosion is approximately 0.025µA/cm^2 for the splash zone and 0.01µA/cm^2 for the atmospheric zone, which is probably due to the dry conditions of the atmospheric zone's exposure and carbonation class. The greatest change in intervention time is seen in the tidal zone, where for an intervention change in depth of 3mm, there is a change in intervention time of 45 years, which is the most extreme case seen. This critical factor underpins the impact that climate change will have on the carbonation process.

Chloride ingress




Pile OP4 (atmospheric)
Change in chloride concentration at cover (kg/m3)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile OP4 (atmospheric)
Change in corrosion rate (µA/cm²)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile OP4 (atmospheric)
Probability of chloride corrosion damage
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

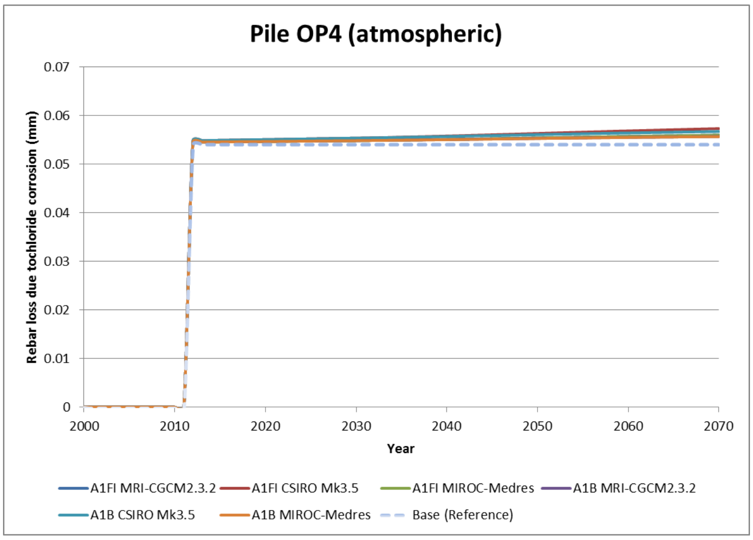
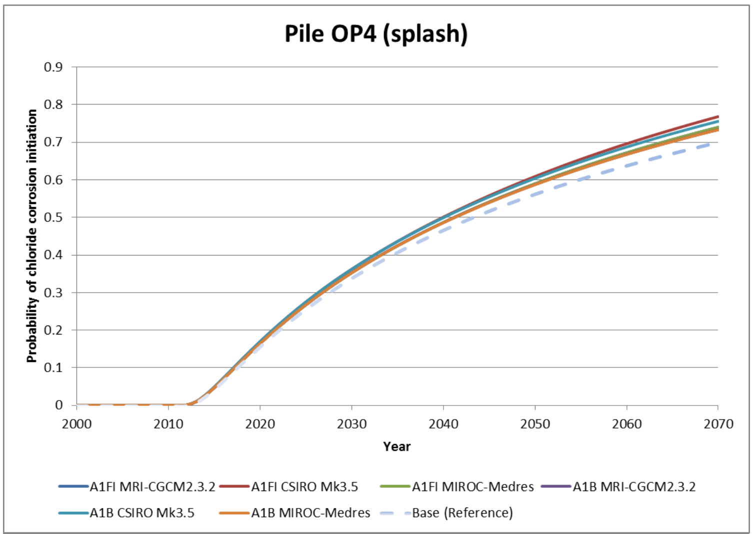
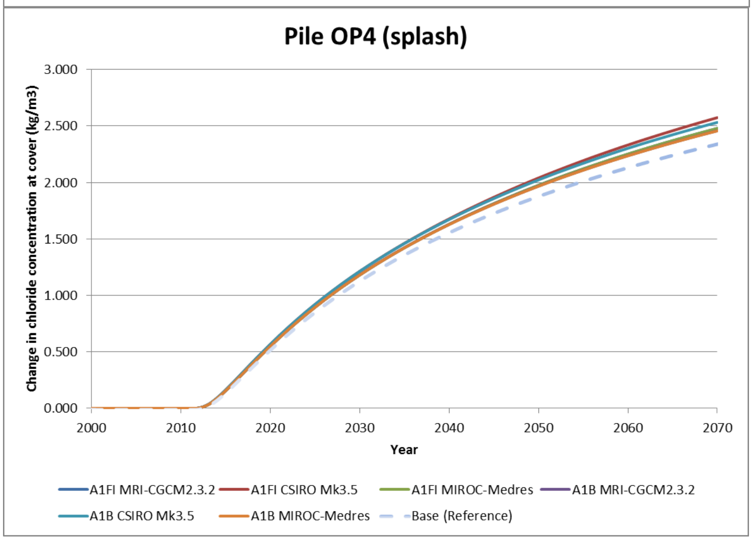


Figure 58: Pile OP4 atmospheric zone chloride results





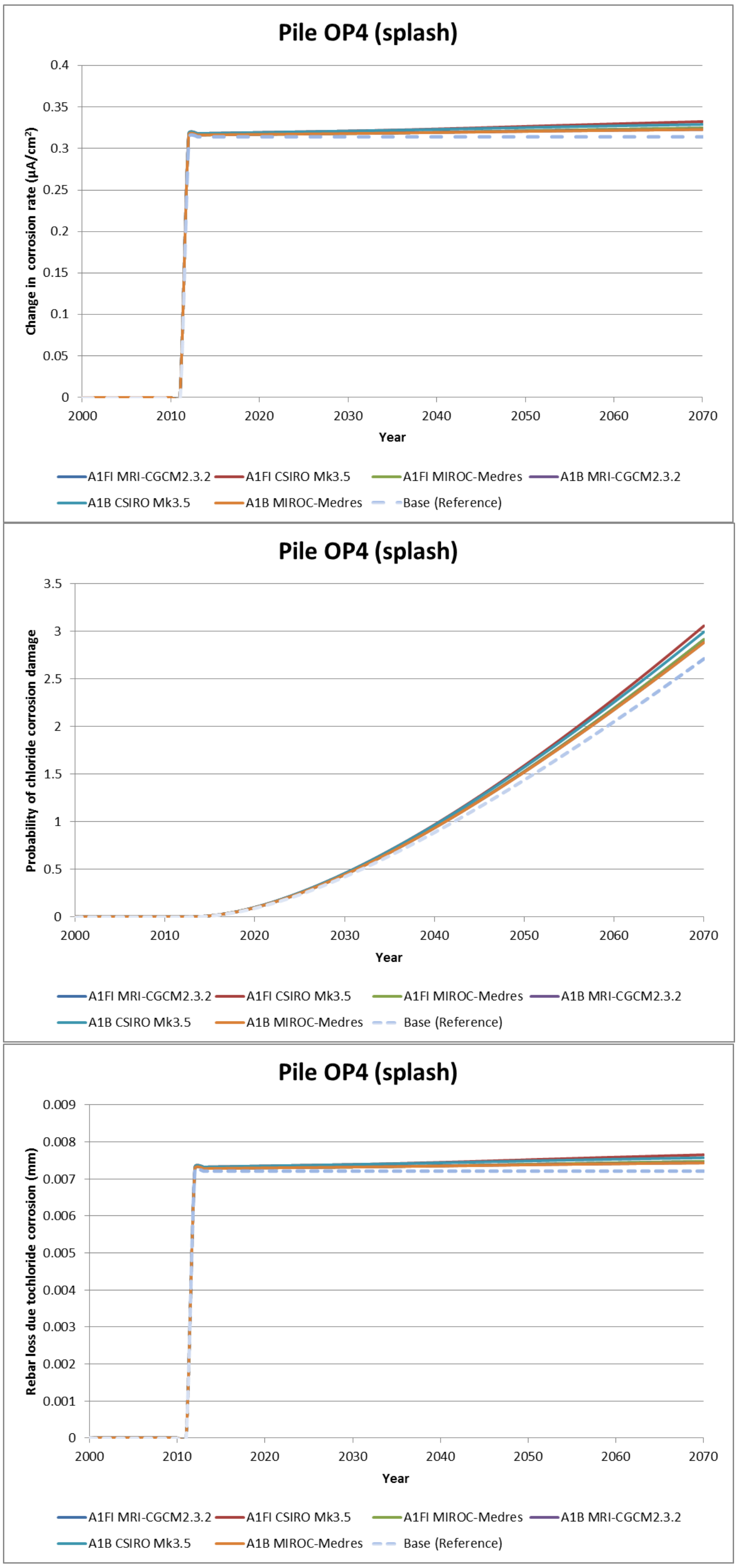
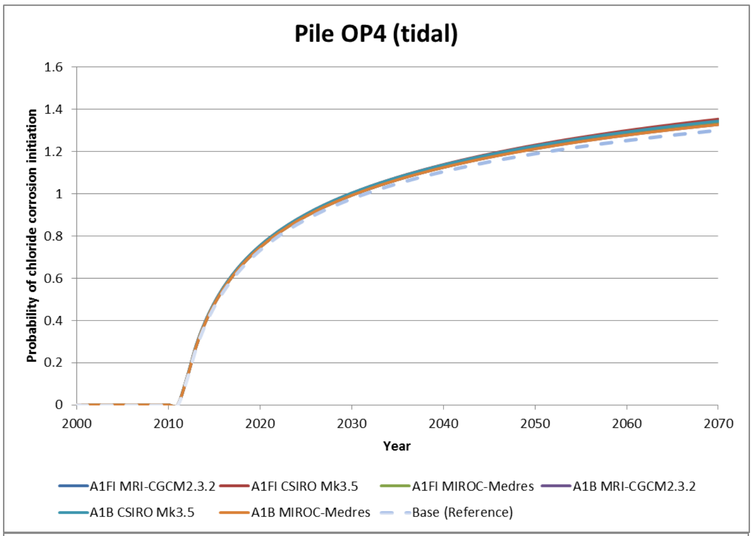
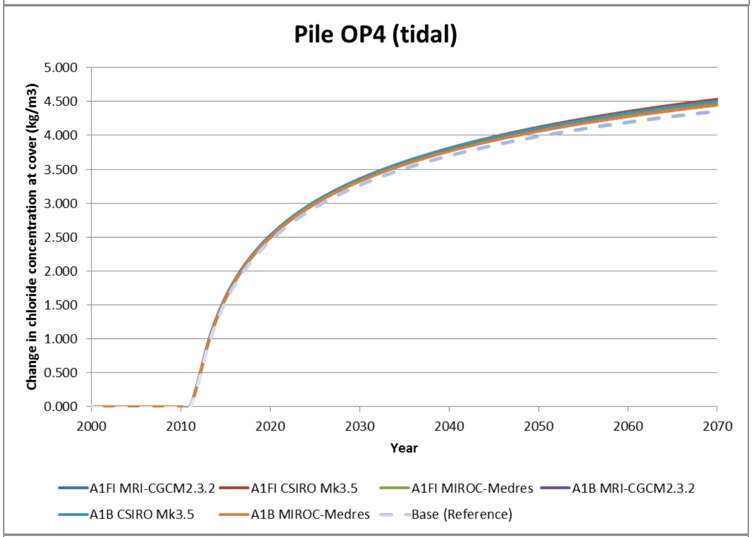


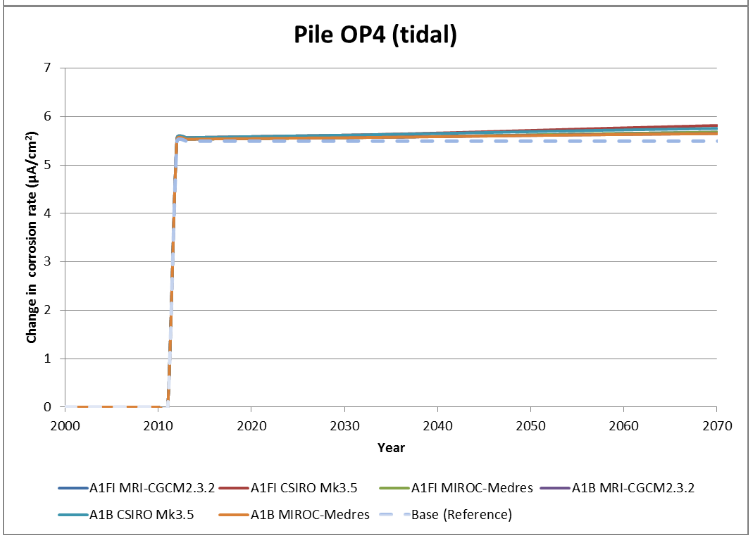
Figure 59: Pile OP4 splash zone chloride results



Pile OP4 (tidal)
Probability of chloride corrosion initiation
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



Pile OP4 (tidal)
Change in chloride concentration at cover (kg/m3)
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



Pile OP4 (tidal)
Change in corrosion rate (μA/cm²)
7
6
5
4
3
2
1
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

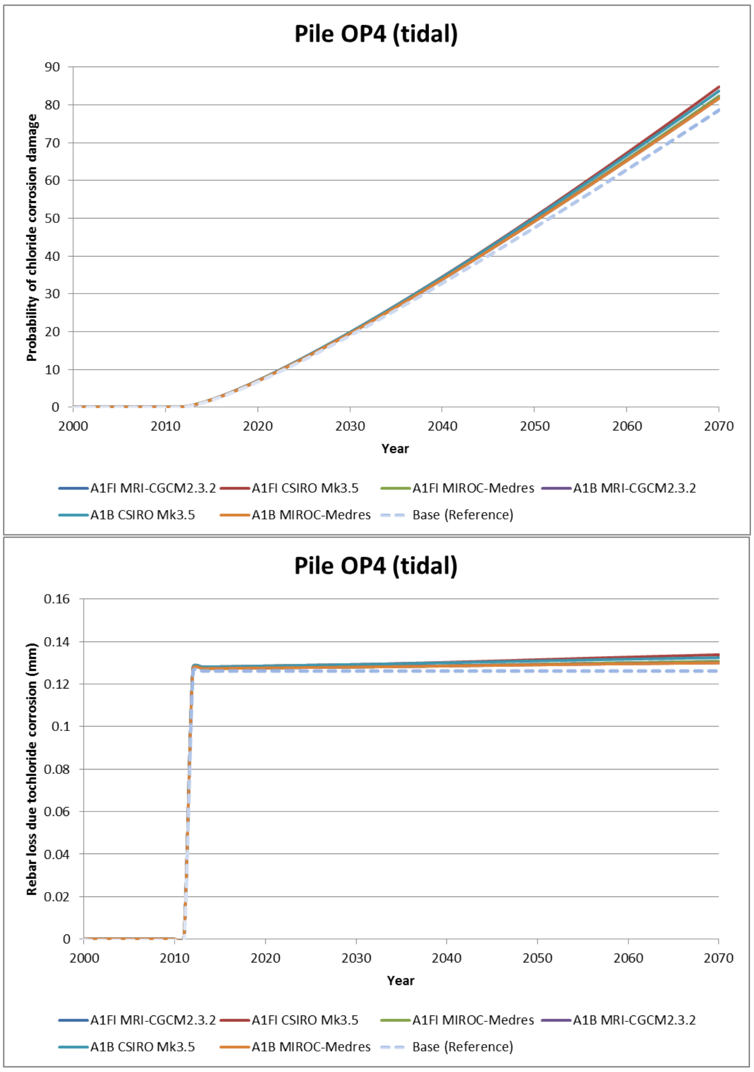
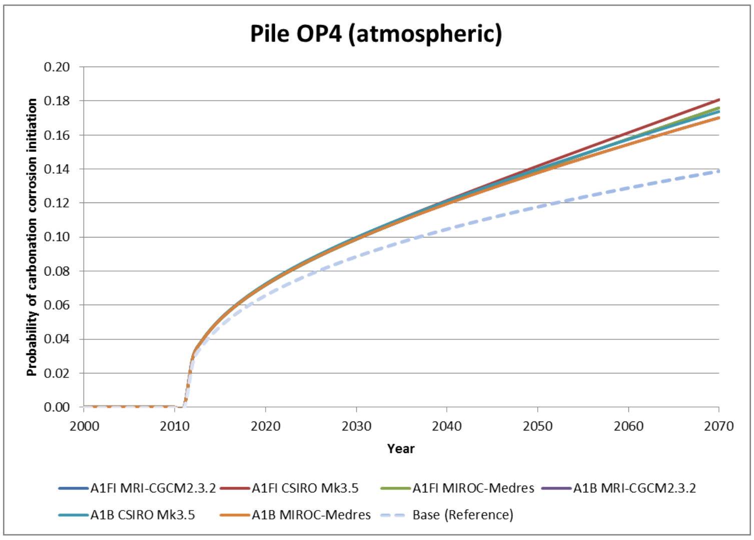
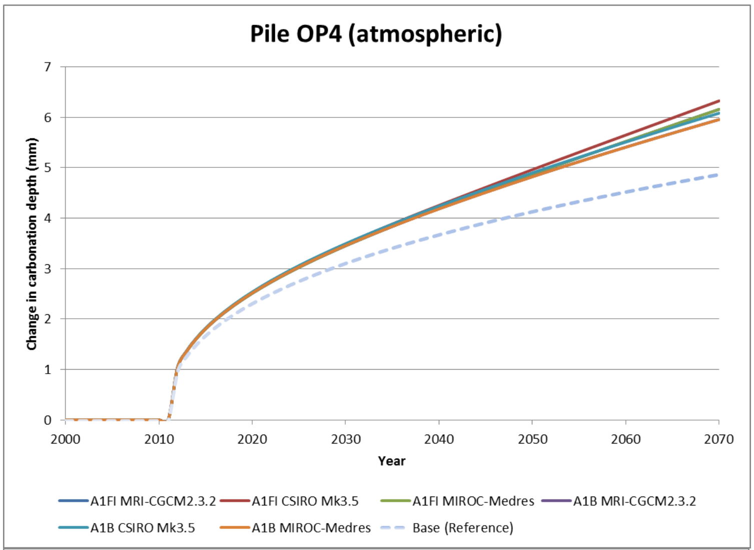


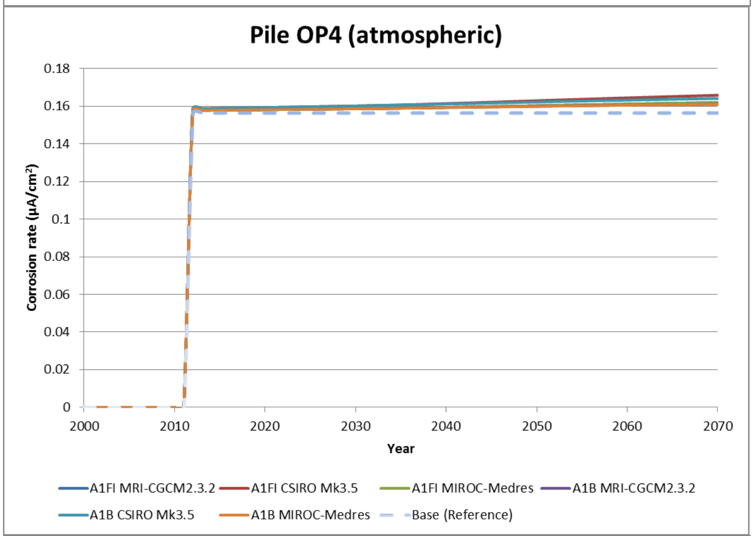
Figure 60: Pile OP4 tidal zone chloride results

Carbonation

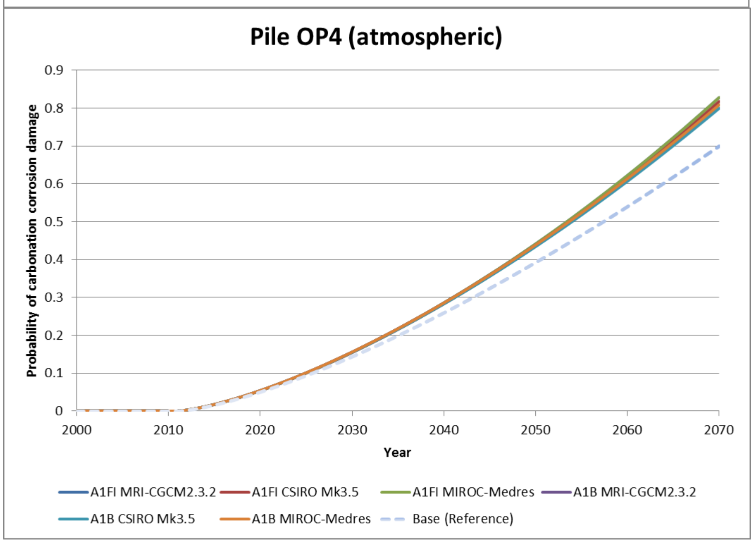




Pile OP4 (atmospheric)
Change in carbonation depth (mm)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



Pile OP4 (atmospheric)
Corrosion rate (μA/cm²)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



Pile OP4 (atmospheric)
Probability of carbonation corrosion damage
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

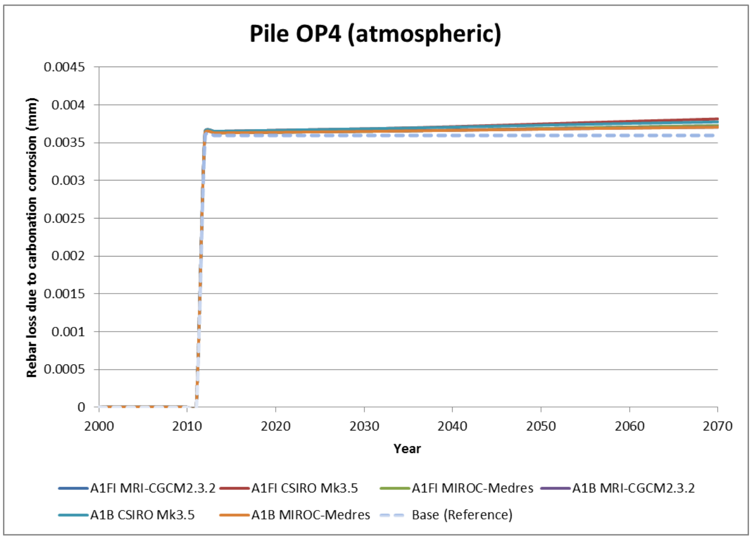
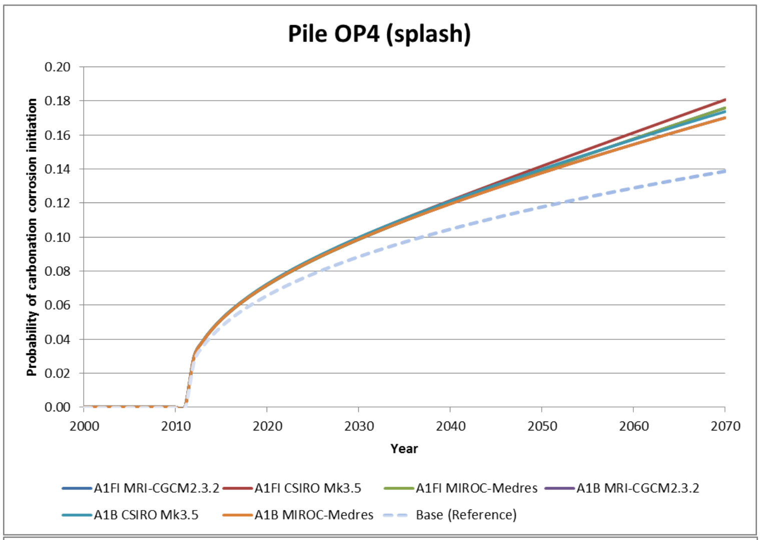
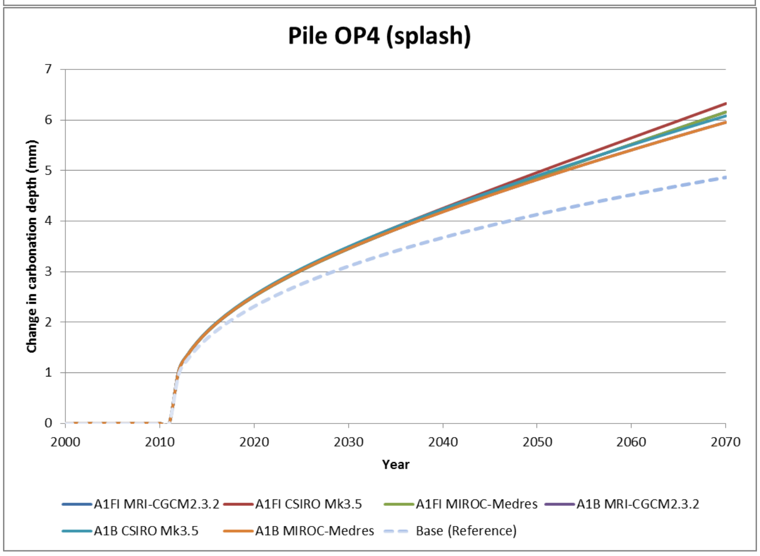


Figure 61: Pile OP4 atmospheric zone carbonation results





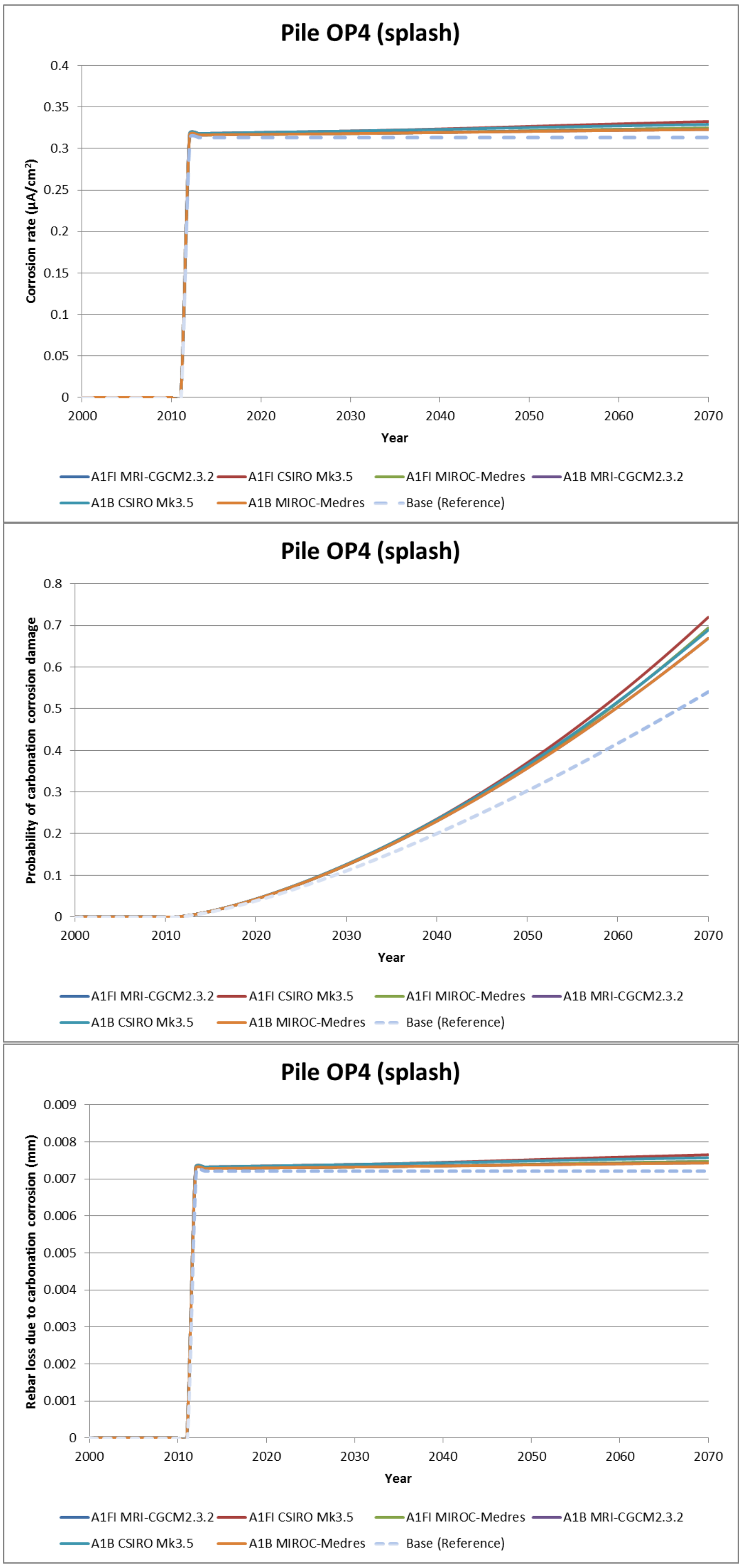
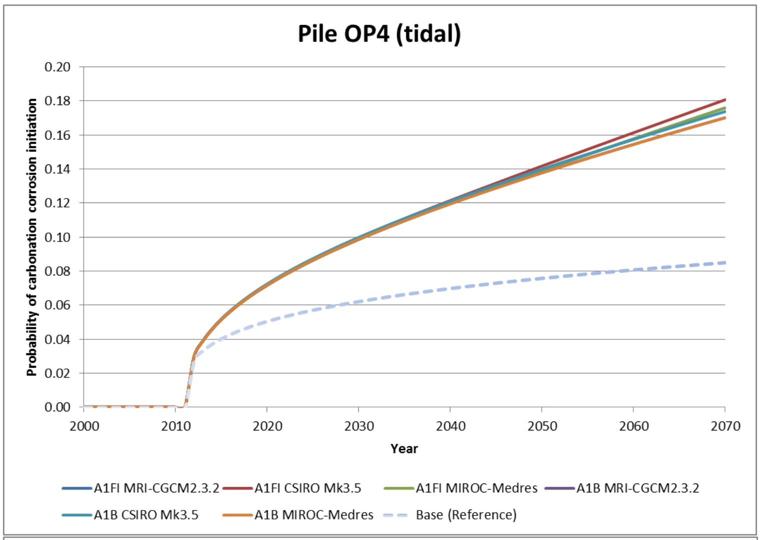
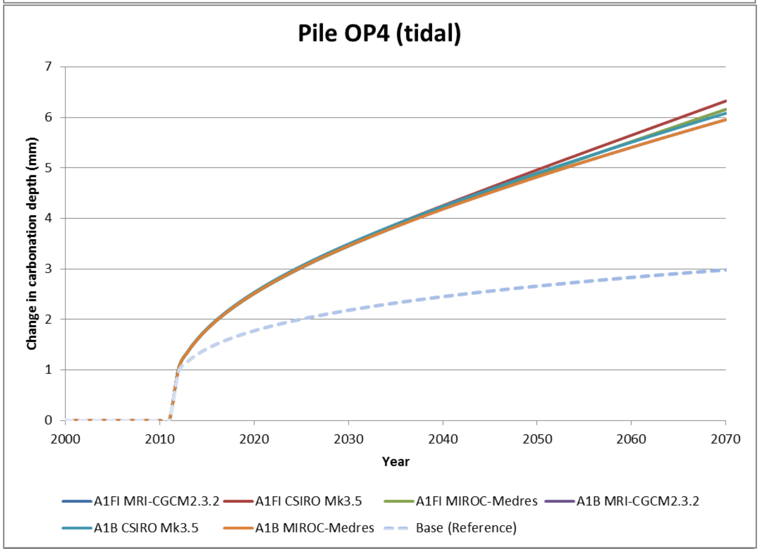
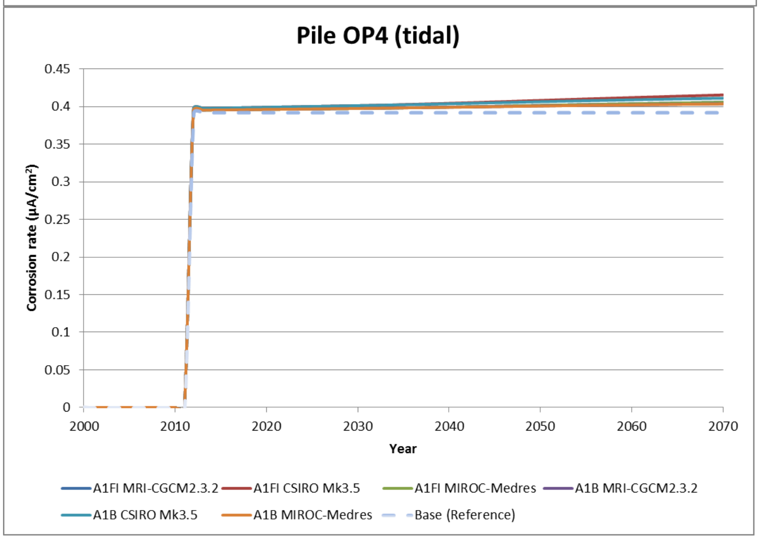
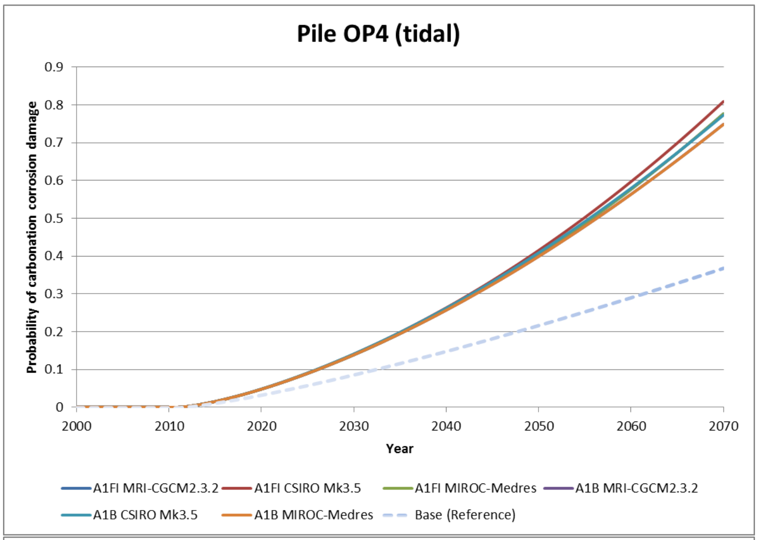


Figure 62: Pile OP4 splash zone carbonation results


Pile OP4 (tidal)
Probability of carbonation corrosion initiation
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile OP4 (tidal)
Change in carbonation depth (mm)
7
6
5
4
3
2
1
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile OP4 (tidal)
Corrosion rate (µA/cm²)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



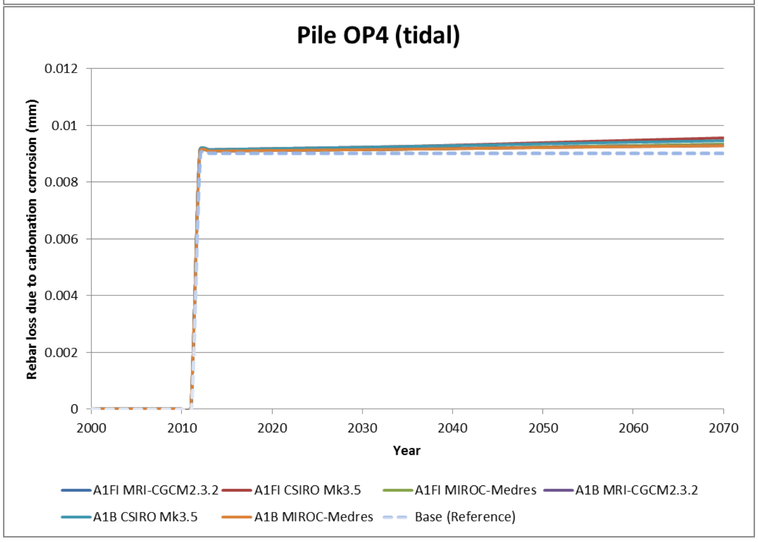


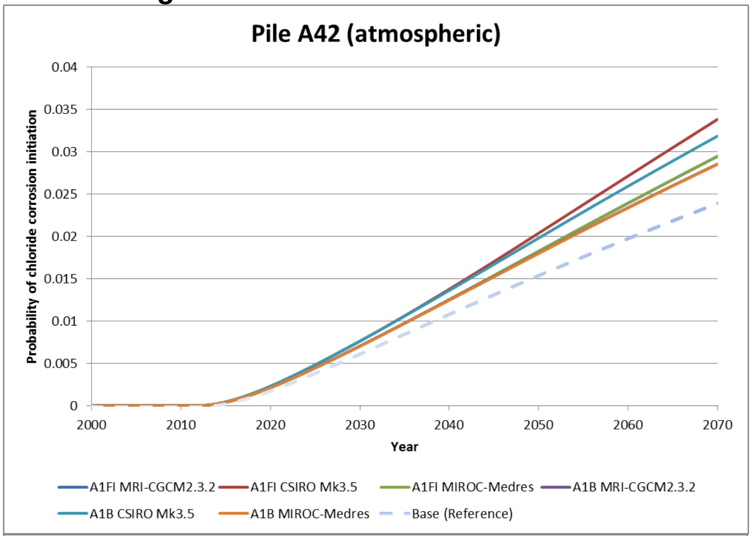
Figure 63: Pile OP4 tidal zone carbonation results

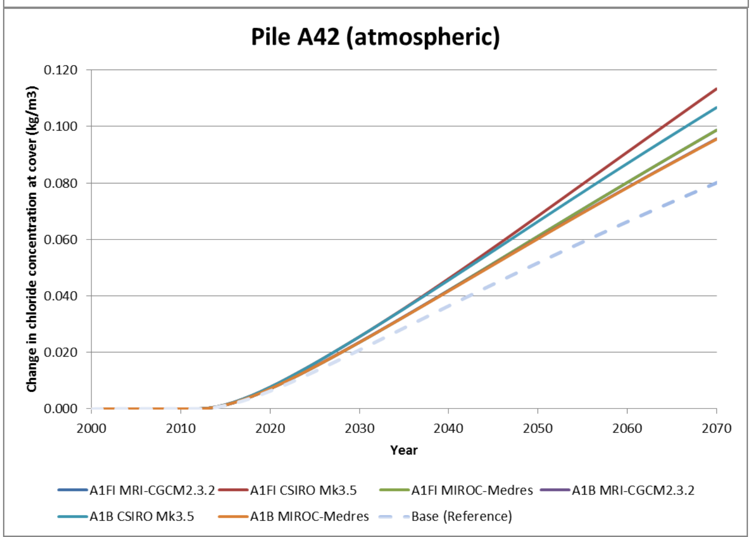
Pile A42 (Port Kembla)

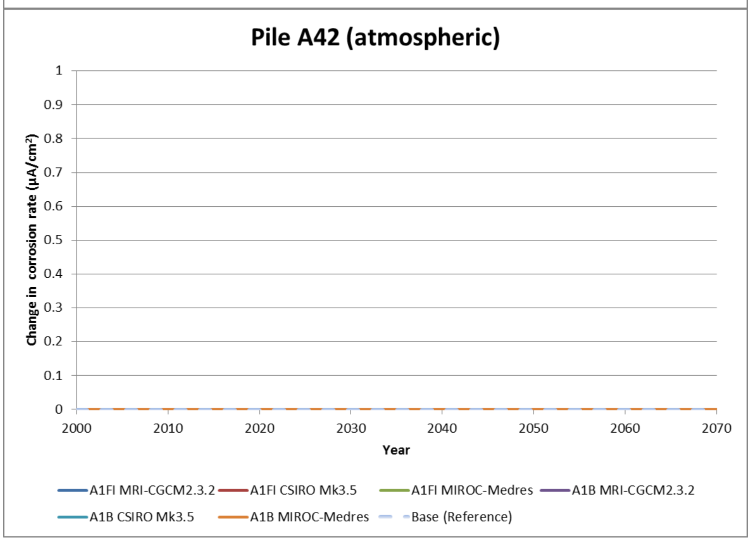
Pile A42's results are quite similar to the results for Pile 0P4, except for the probabilities of corrosion which have almost halved for Pile A42. Once again, the most critical climate projection scenario for this pile is the A1FI CSIRO Mk3.5 model which is Port Kembla's hotter and drier scenario and the least critical is the A1B MIROC3.2 model which is Port Kembla's cooler and wetter scenario. Similarly, the atmospheric zone section of Pile A42 shows a rate of corrosion of 0.165µA/cm^2, an increase of 0.01µA/cm^2 from the baseline. The splash and atmospheric zones show an increase in corrosion probability of 2%, an increase in carbonation depth of approximately 1.5mm and an increase in intervention time of 15 years for depth of 4.5mm. The tidal zone shows an increase of 0.0125µA/cm^2 in corrosion rate, which is not so critical. However, the tidal zone of Pile A42 shows an increase of roughly 5% in the probability of carbonation induced corrosion, an increase of 3.5mm in carbonation depth and an increase in intervention time of 45 years for a depth of 3mm.

The main differences between the results for Pile 0P4 and Pile A42 are their maximum probabilities of corrosion and the increases in corrosion probabilities, with Pile 0P4's probabilities doubling Pile A42's. The only differences in input parameters are distance from the coast, cover and the diameters of the cross sections. It was already shown that the diameters of the members had no effect on the probability of corrosion in the analysis of the Port of Gladstone piles, it can be said that the cover and distance from the coast are the most likely reasons for the difference. However, the most likely cause is the difference in cover since the cover of Pile A42 is twice the cover of Pile 0P4; hence it has half the chance of carbonation induced corrosion initiation. This shows that there is a direct relationship between cover and the risk of corrosion.

Chloride ingress







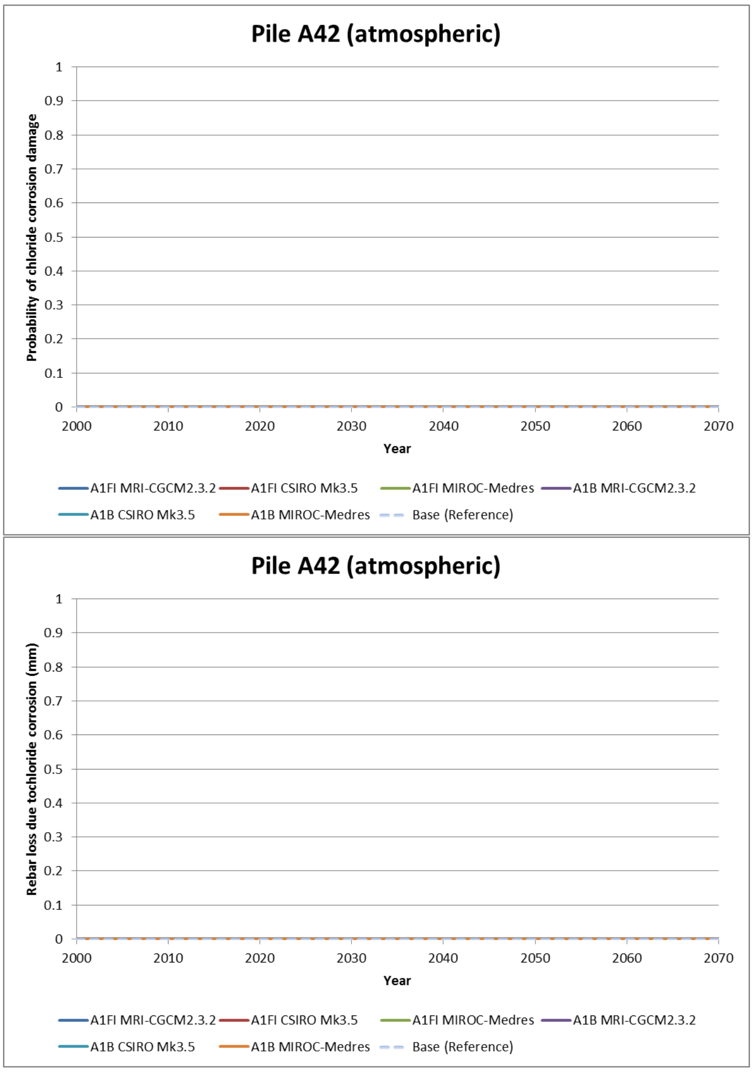
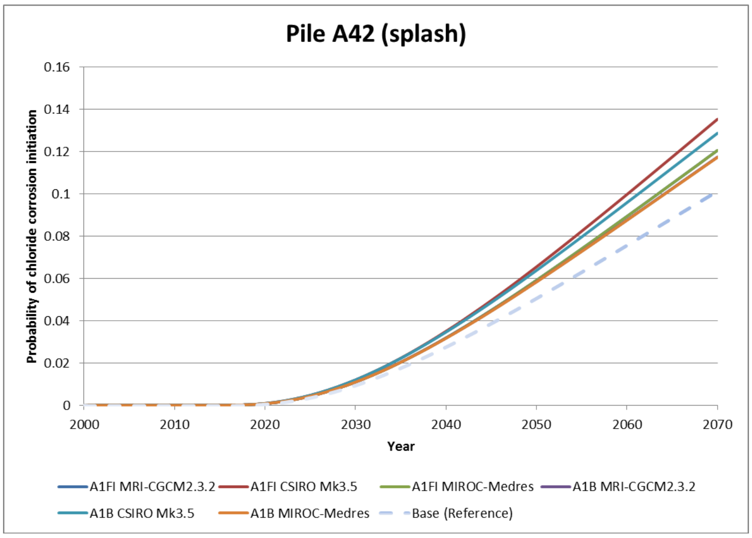
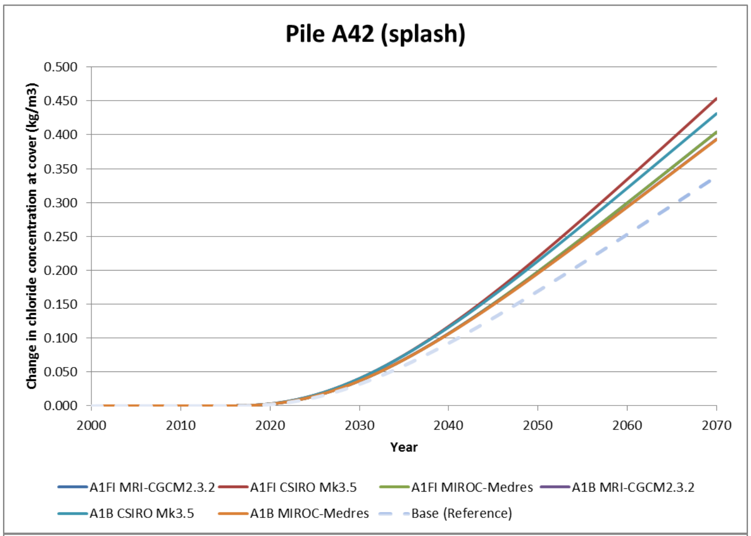
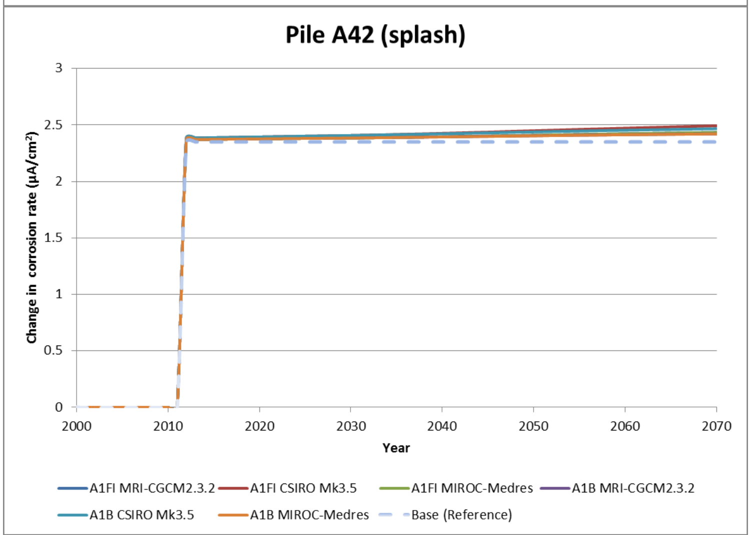
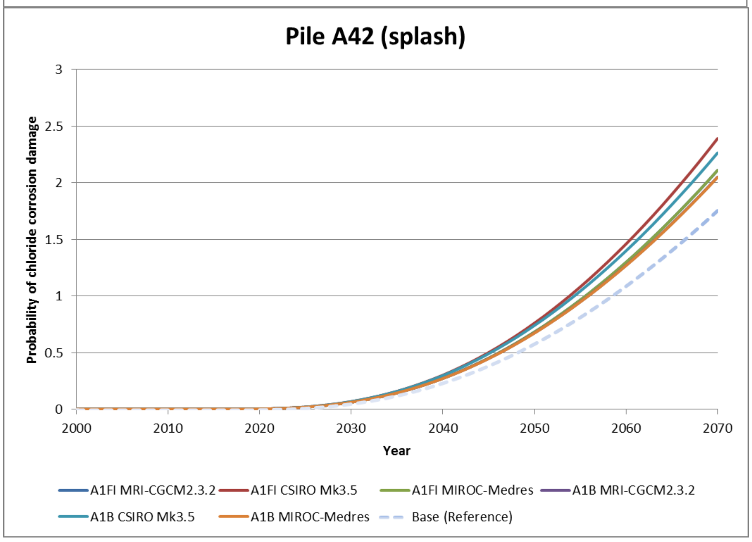


Figure 64: Pile A42 atmospheric zone chloride results




Pile A42 (splash)
Change in chloride concentration at cover (kg/m3)
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (splash)
Change in corrosion rate (μA/cm²)
3
2.5
2
1.5
1
0.5
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (splash)
Probability of chloride corrosion damage
3
2.5
2
1.5
1
0.5
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

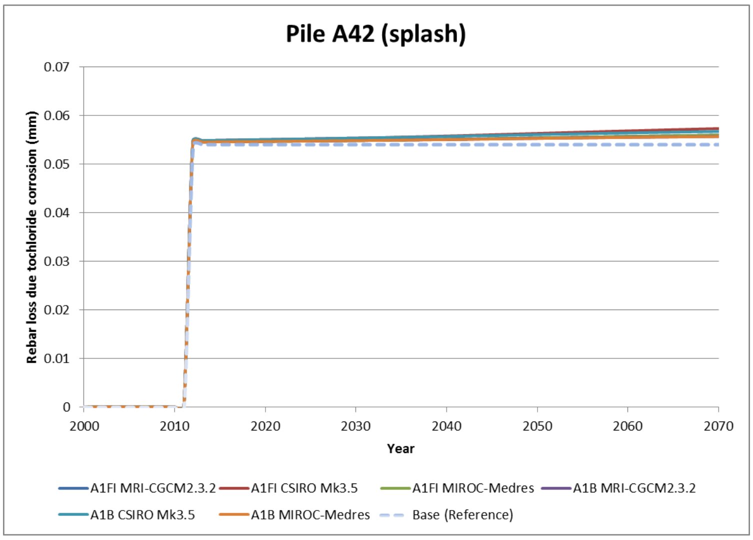
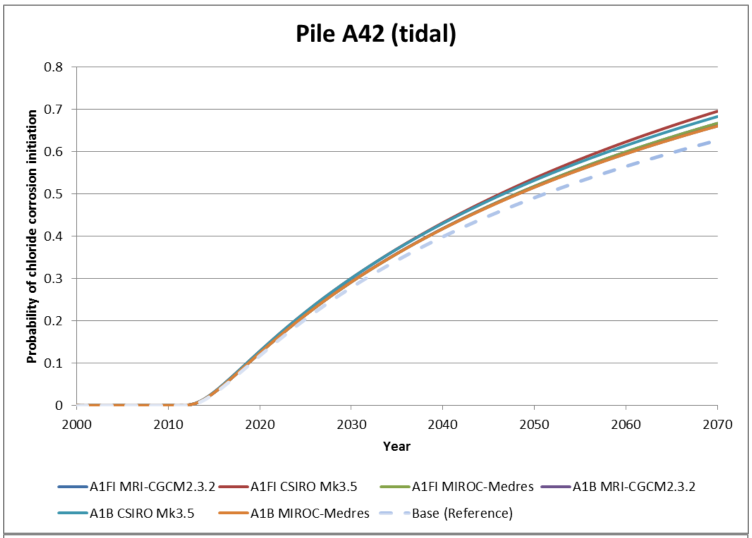
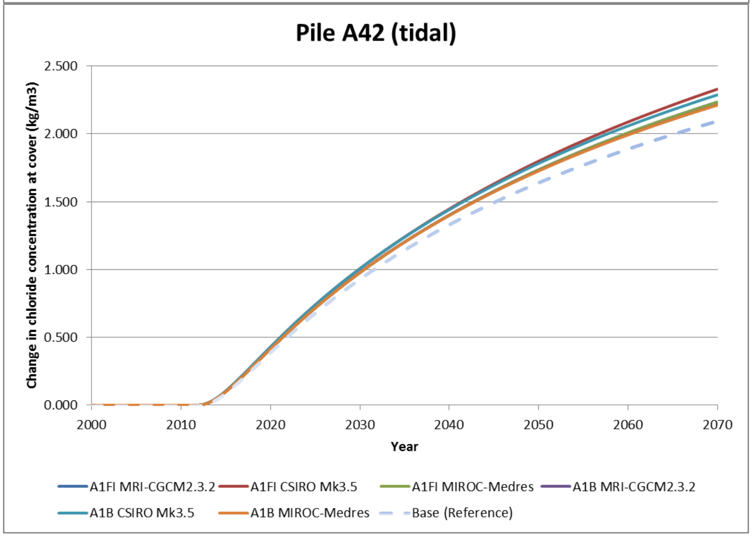


Figure 65: Pile A42 splash zone chloride results





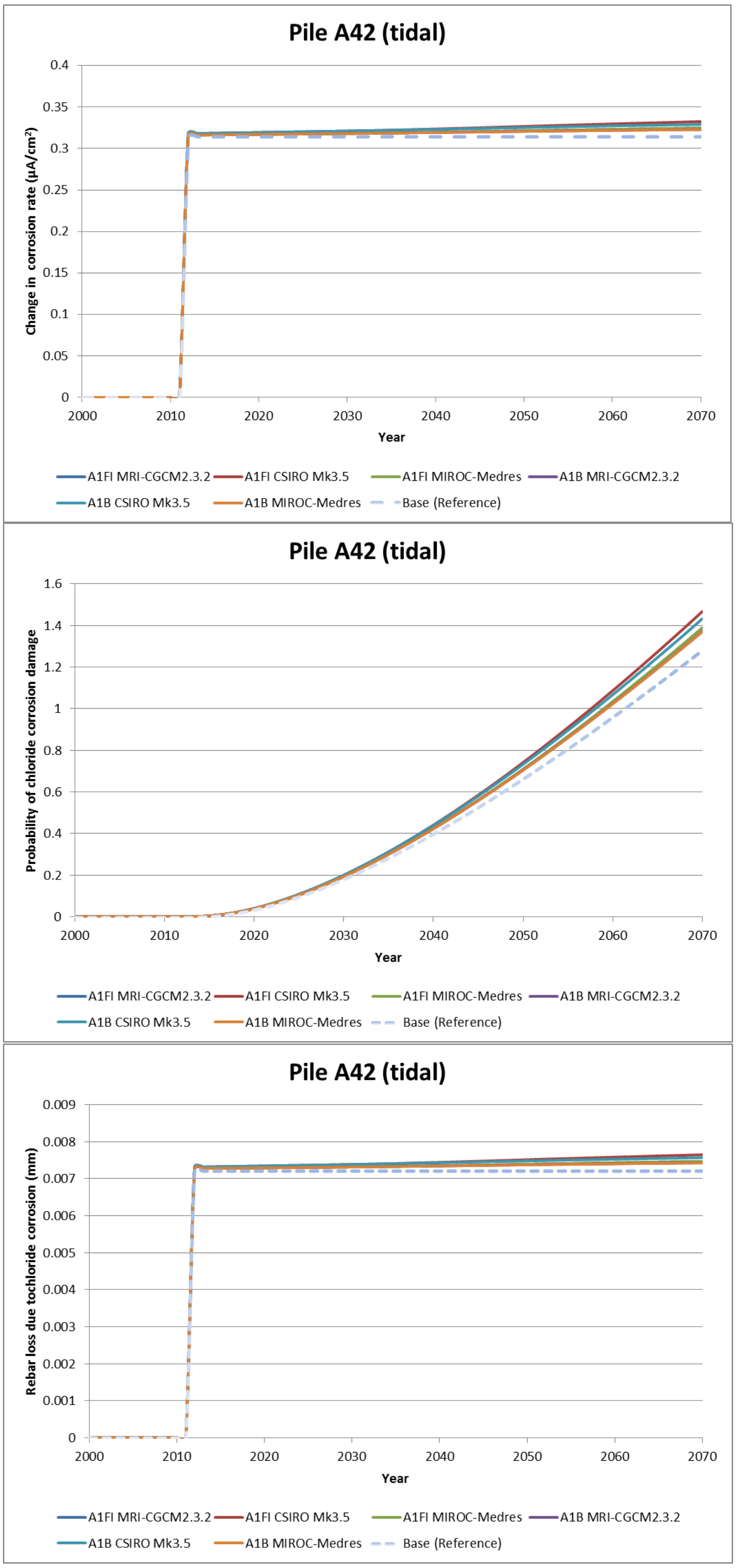
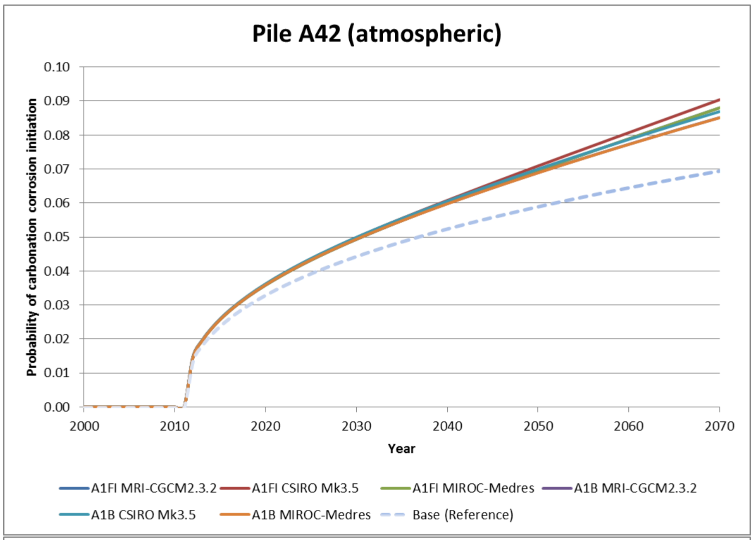
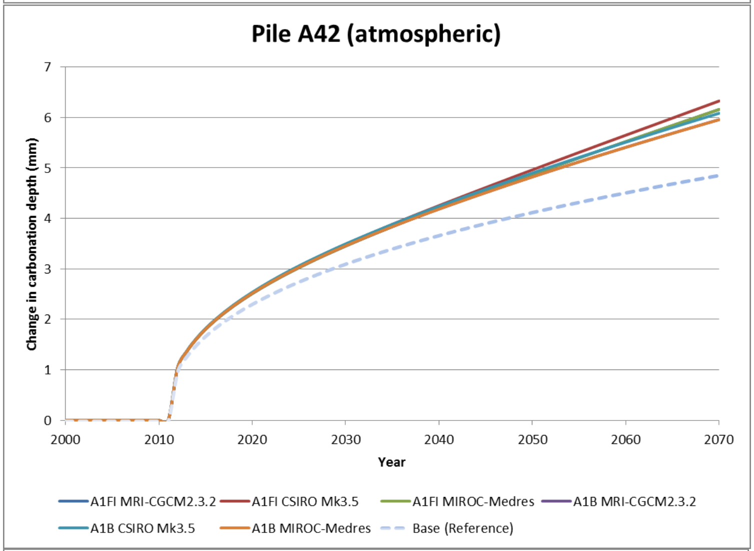
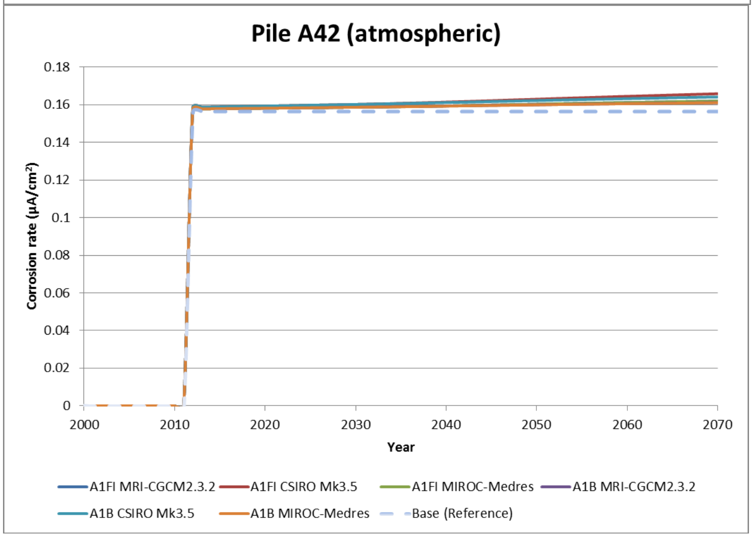


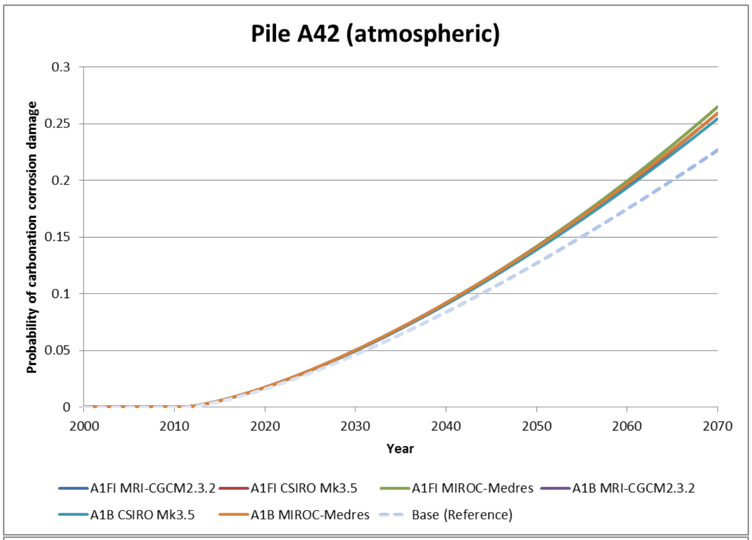
Figure 66: Pile A42 tidal zone chloride results

Carbonation


Pile A42 (atmospheric)
Probability of carbonation corrosion initiation
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (atmospheric)
Change in carbonation depth (mm)
7
6
5
4
3
2
1
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (atmospheric)
Corrosion rate (µA/cm²)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)



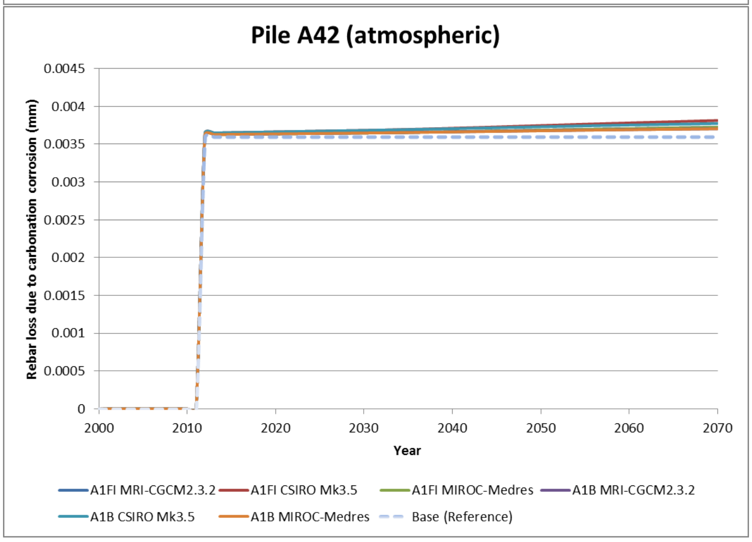
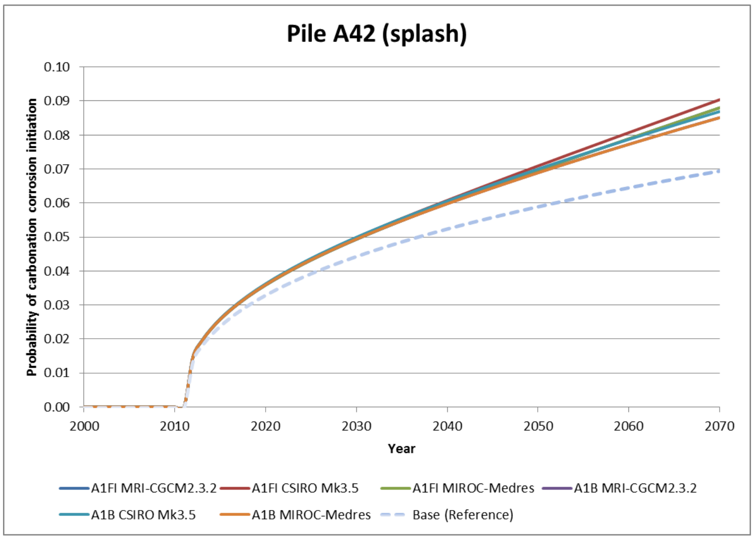
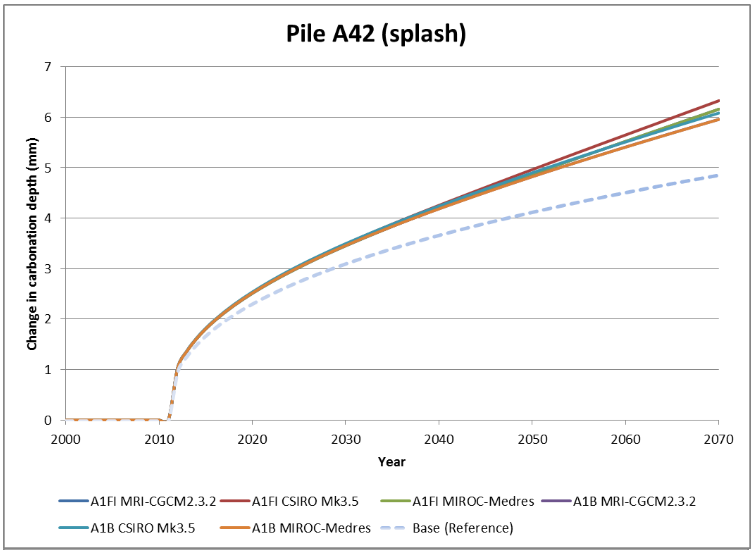
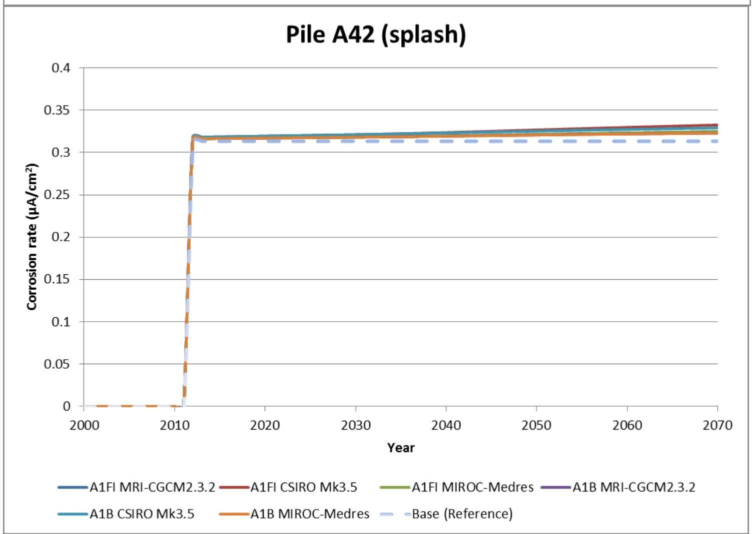
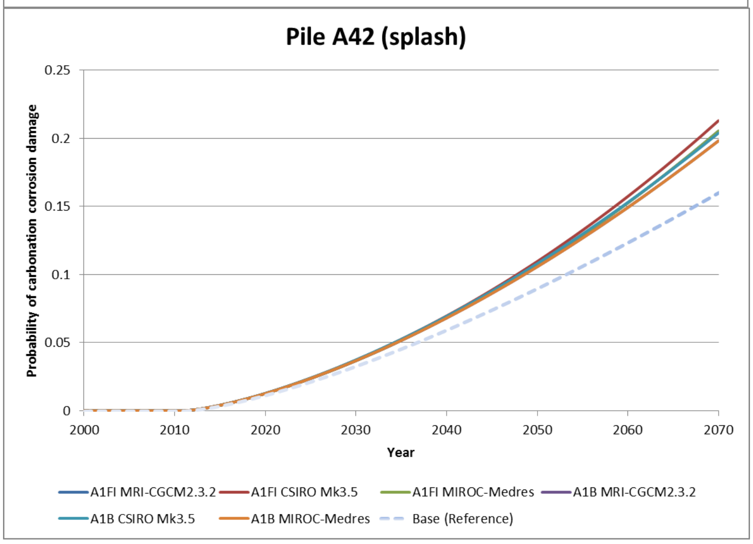


Figure 67: Pile A42 atmospheric zone carbonation results




Pile A42 (splash)
Change in carbonation depth (mm)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (splash)
Corrosion rate (μA/cm²)
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile A42 (splash)
Probability of carbonation corrosion damage
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

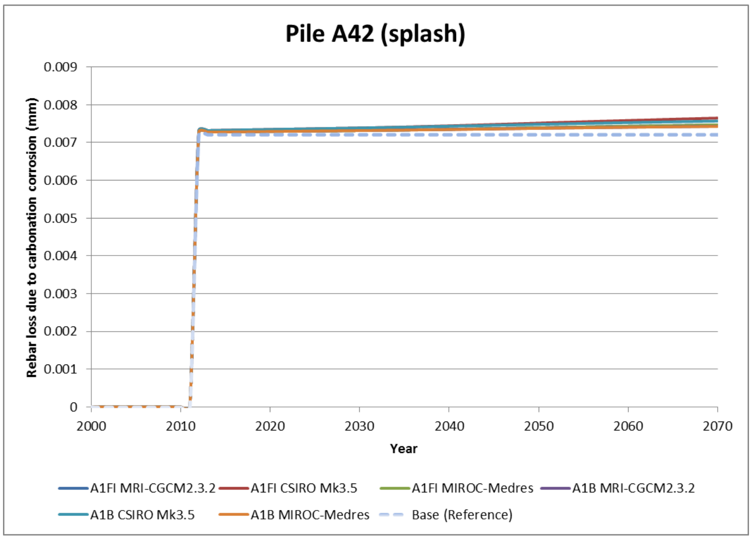
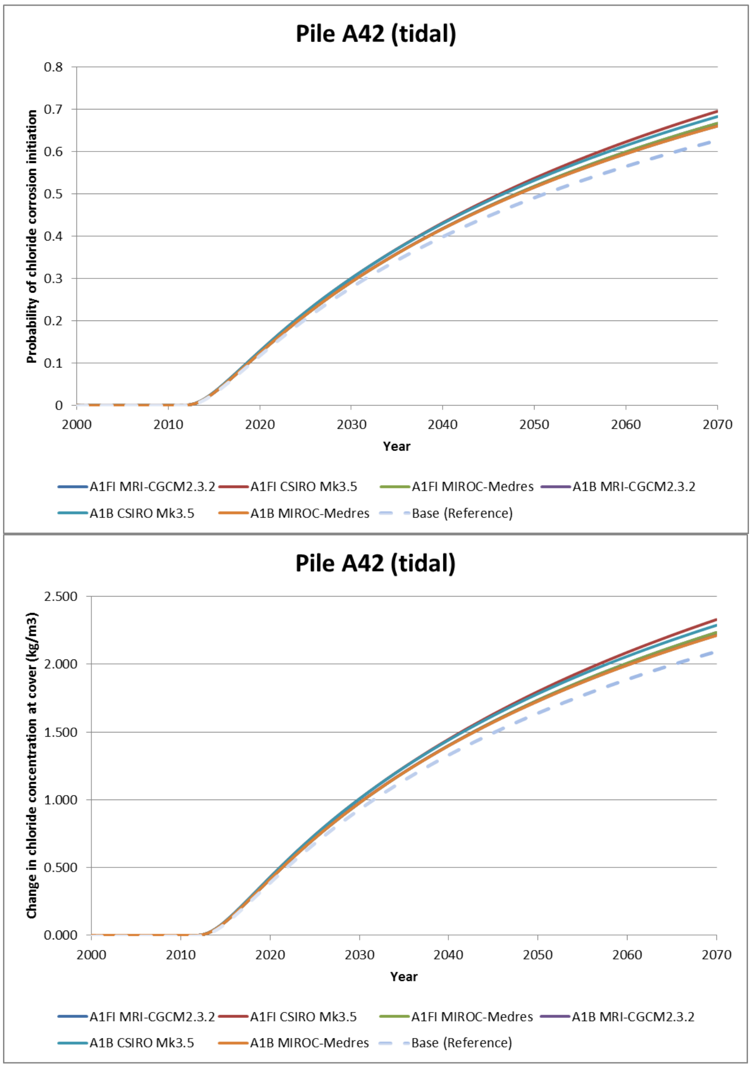


Figure 68: Pile A42 splash zone carbonation results



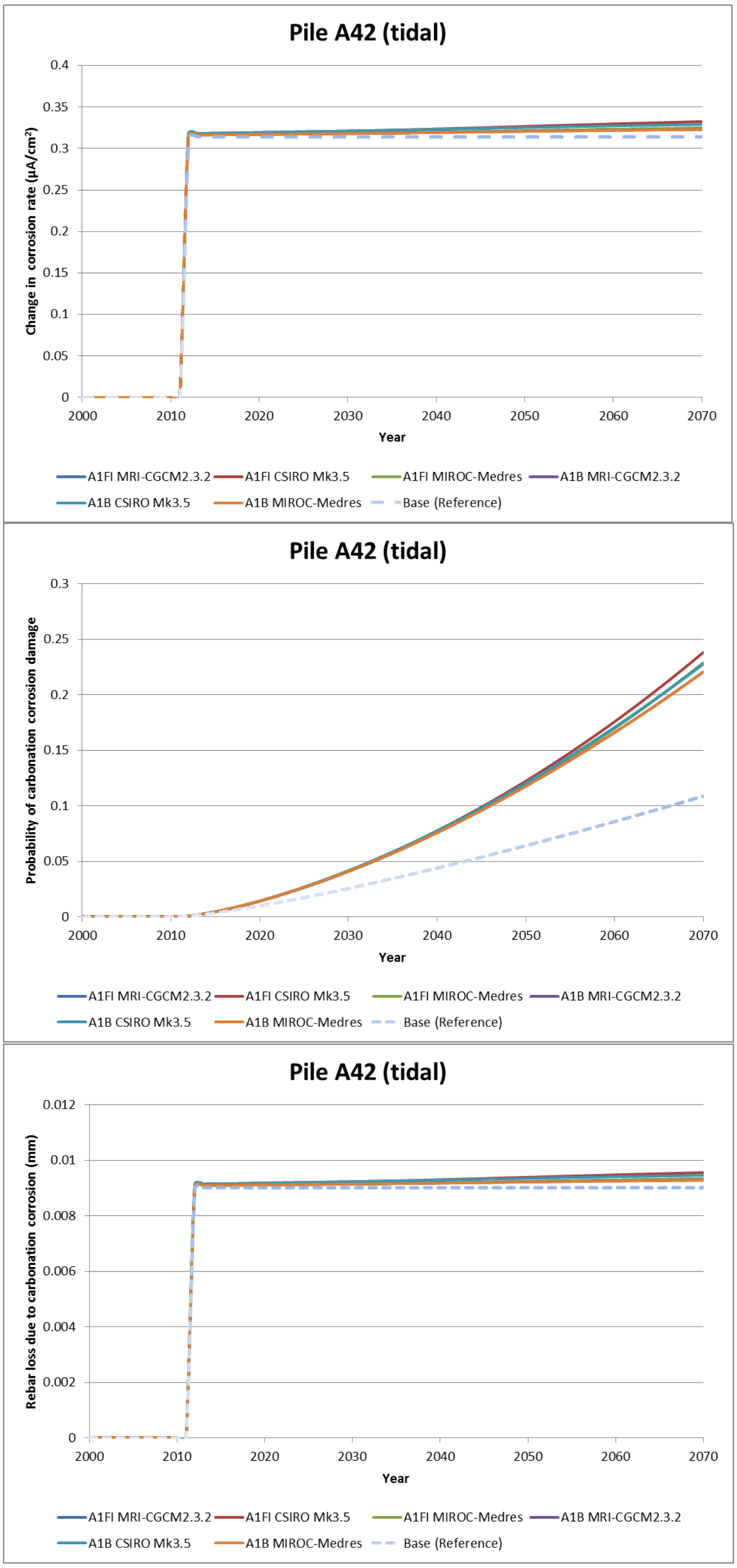
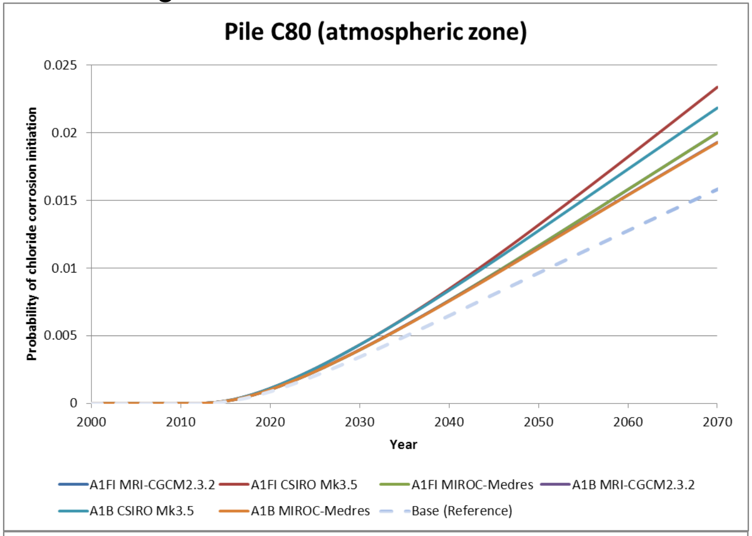


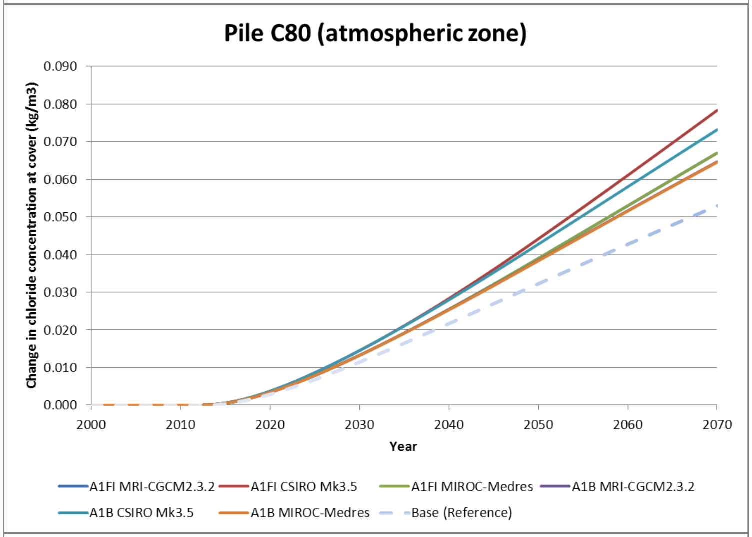
Figure 69: Pile A42 tidal zone carbonation results

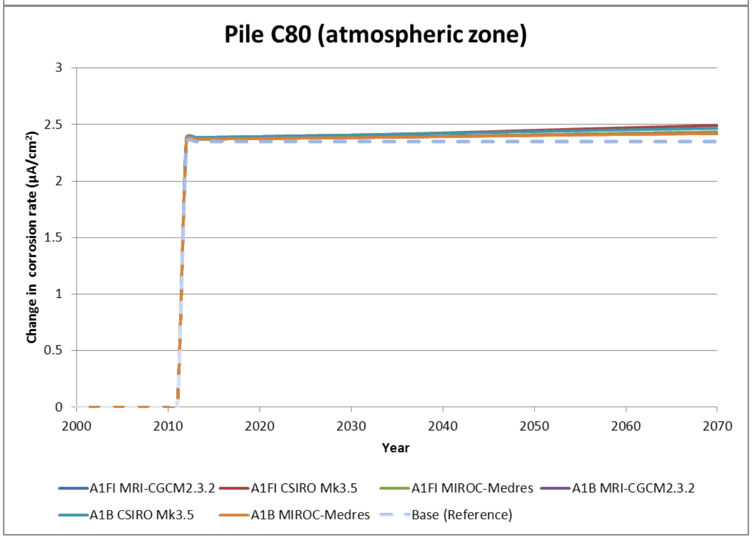
Pile C80 (Port Kembla)

Pile C80 is located on Berth 206 (Jetty 4). This is 1500 mm pile constructed with concrete. The cover was 75mm and has a w/c ratio of 0.4.

Chloride ingress







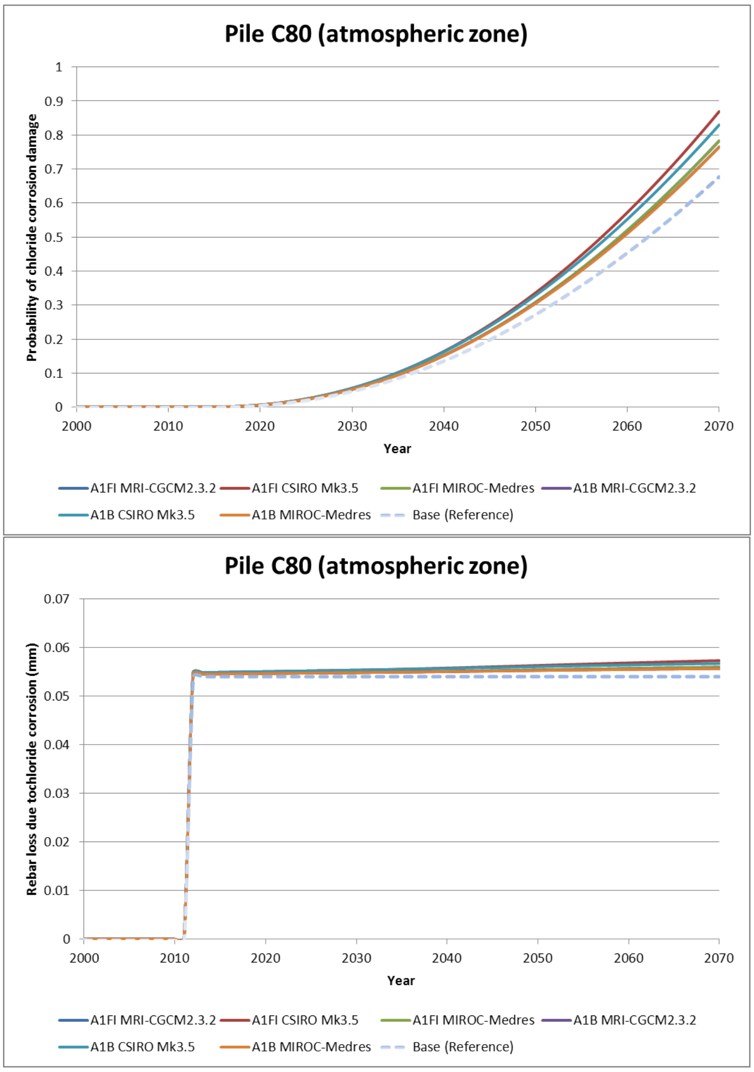
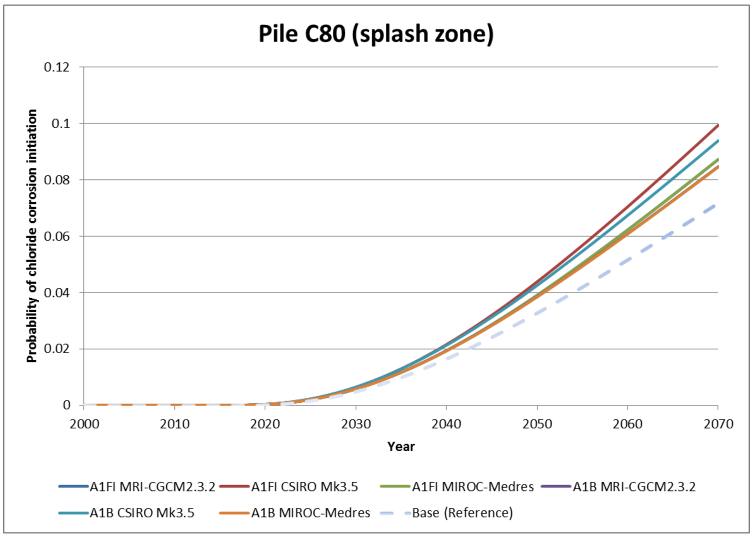
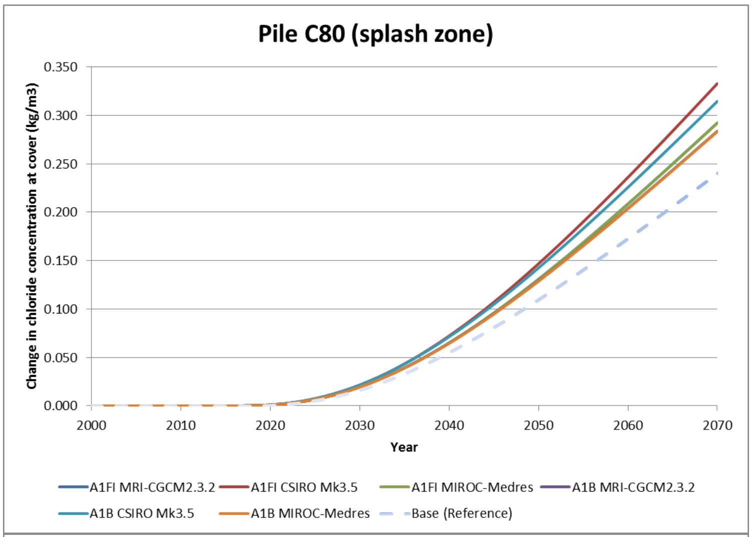
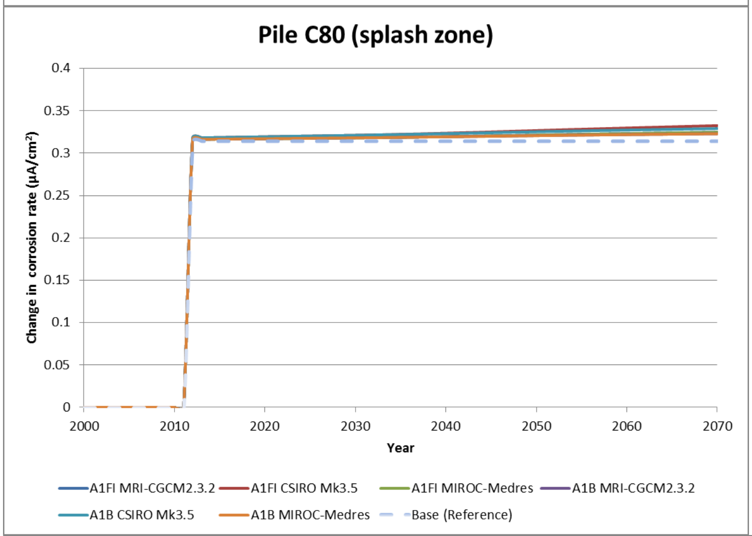
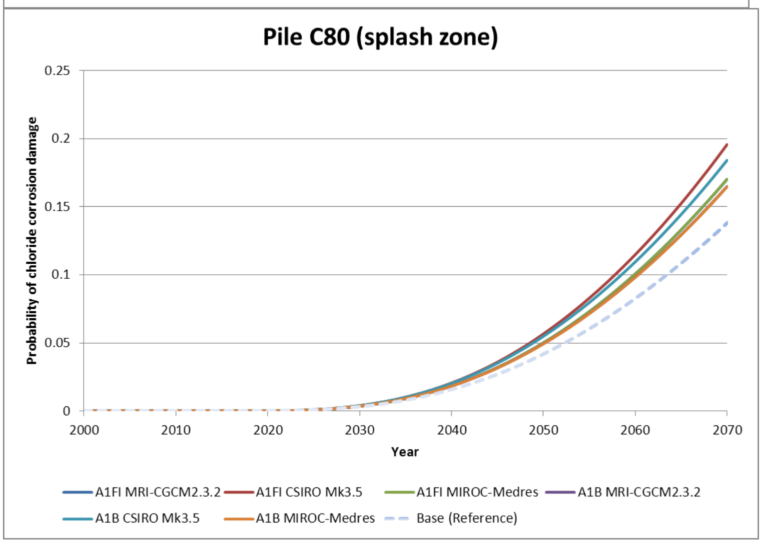


Figure 70: Pile C80 atmospheric zone chloride results




Pile C80 (splash zone)
Change in chloride concentration at cover (kg/m3)
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile C80 (splash zone)
Change in corrosion rate (μA/cm²)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)


Pile C80 (splash zone)
Probability of chloride corrosion damage
0.25
0.2
0.15
0.1
0.05
0
2000
2010
2020
2030
2040
2050
2060
2070
Year
A1FI MRI-CGCM2.3.2
A1FI CSIRO Mk3.5
A1FI MIROC-Medres
A1B MRI-CGCM2.3.2
A1B CSIRO Mk3.5
A1B MIROC-Medres
Base (Reference)

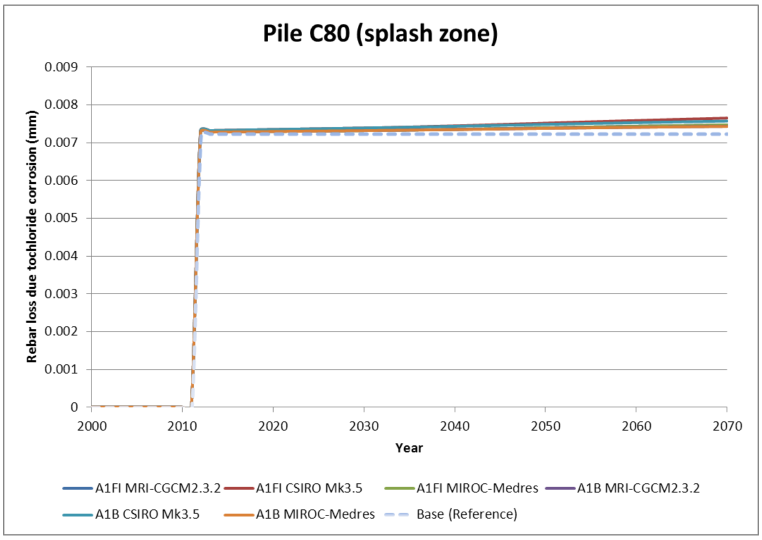
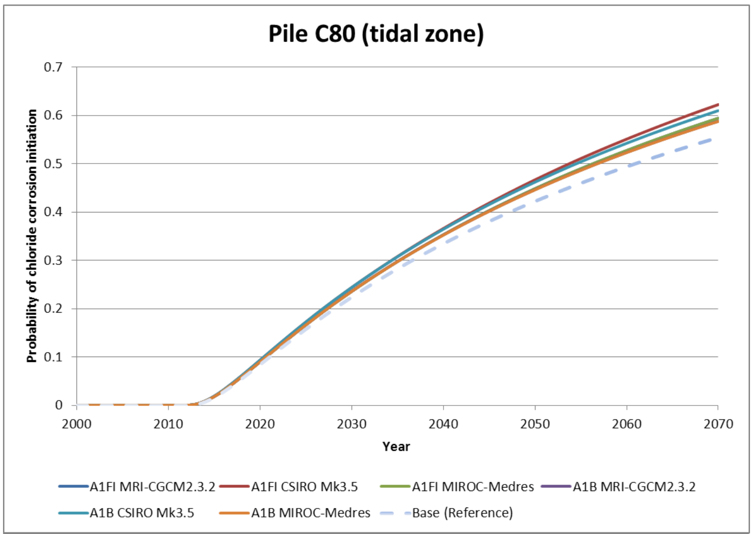
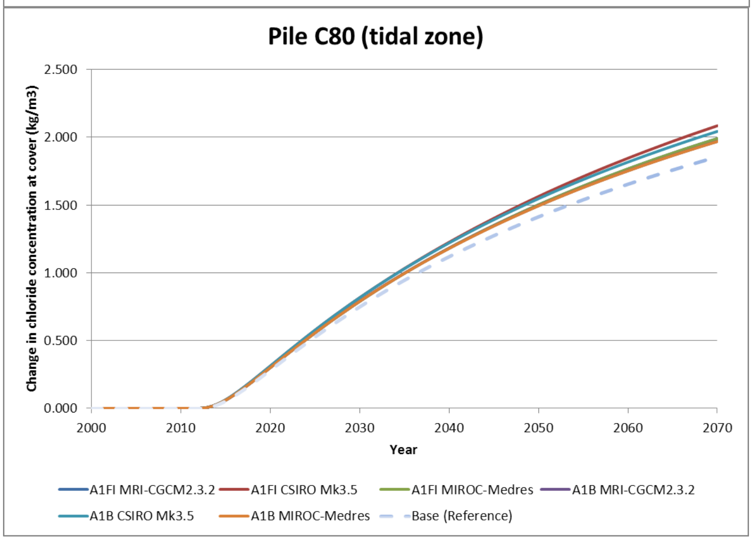
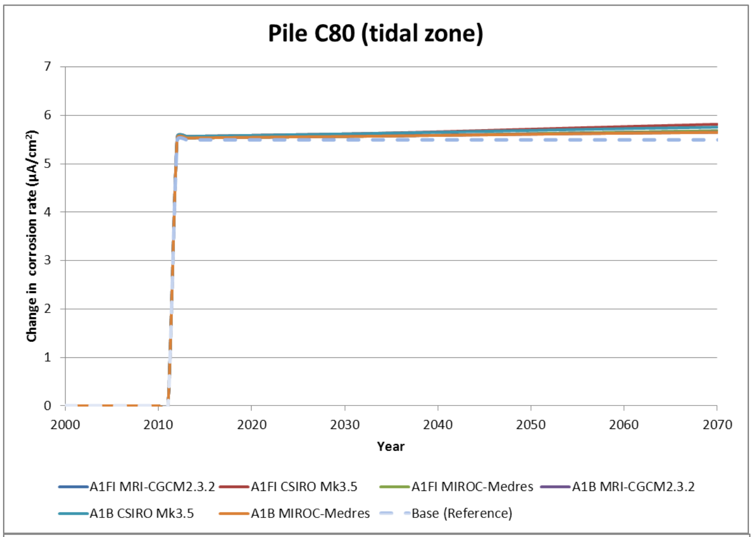
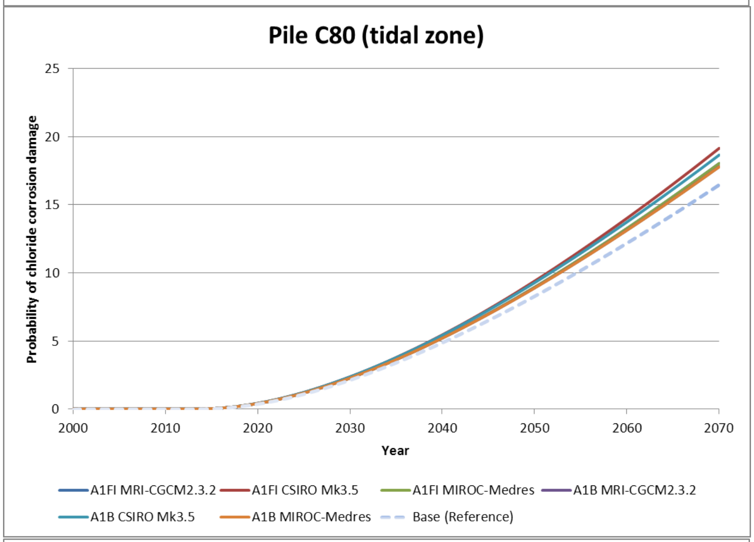


Figure 71: Pile C80 splash zone chloride results









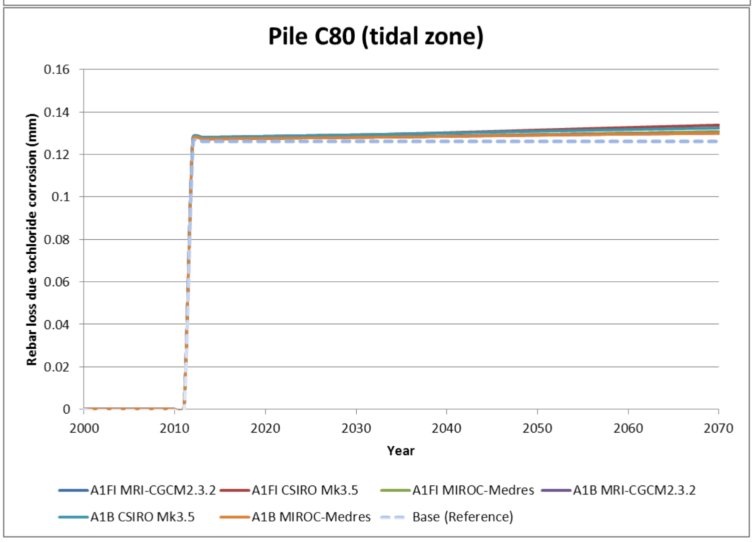


Figure 72: Pile C80 tidal zone chloride results

Carbonation

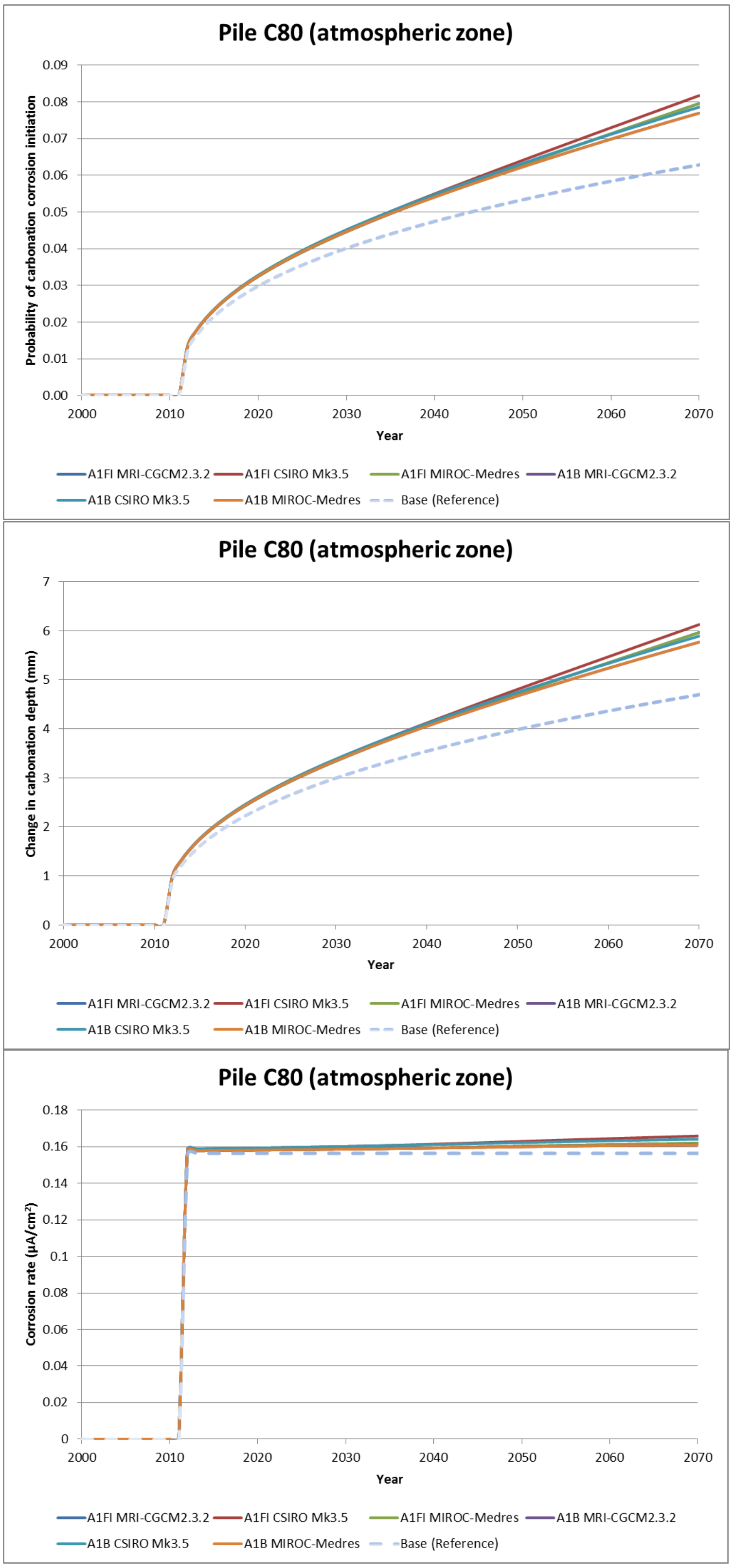


Figure 73: Pile C80 atmospheric zone carbonation results

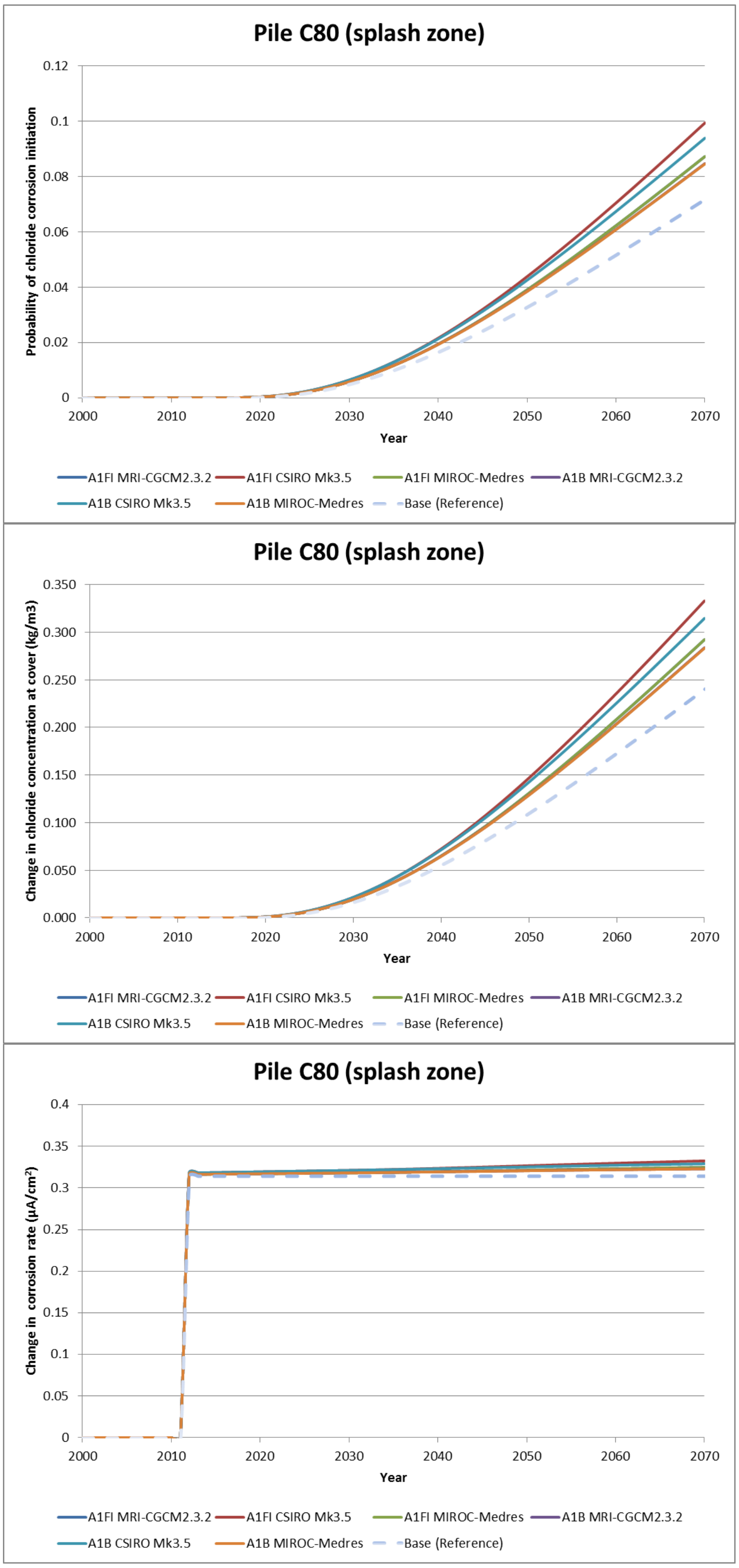


Figure 74: Pile C80 splash zone carbonation results

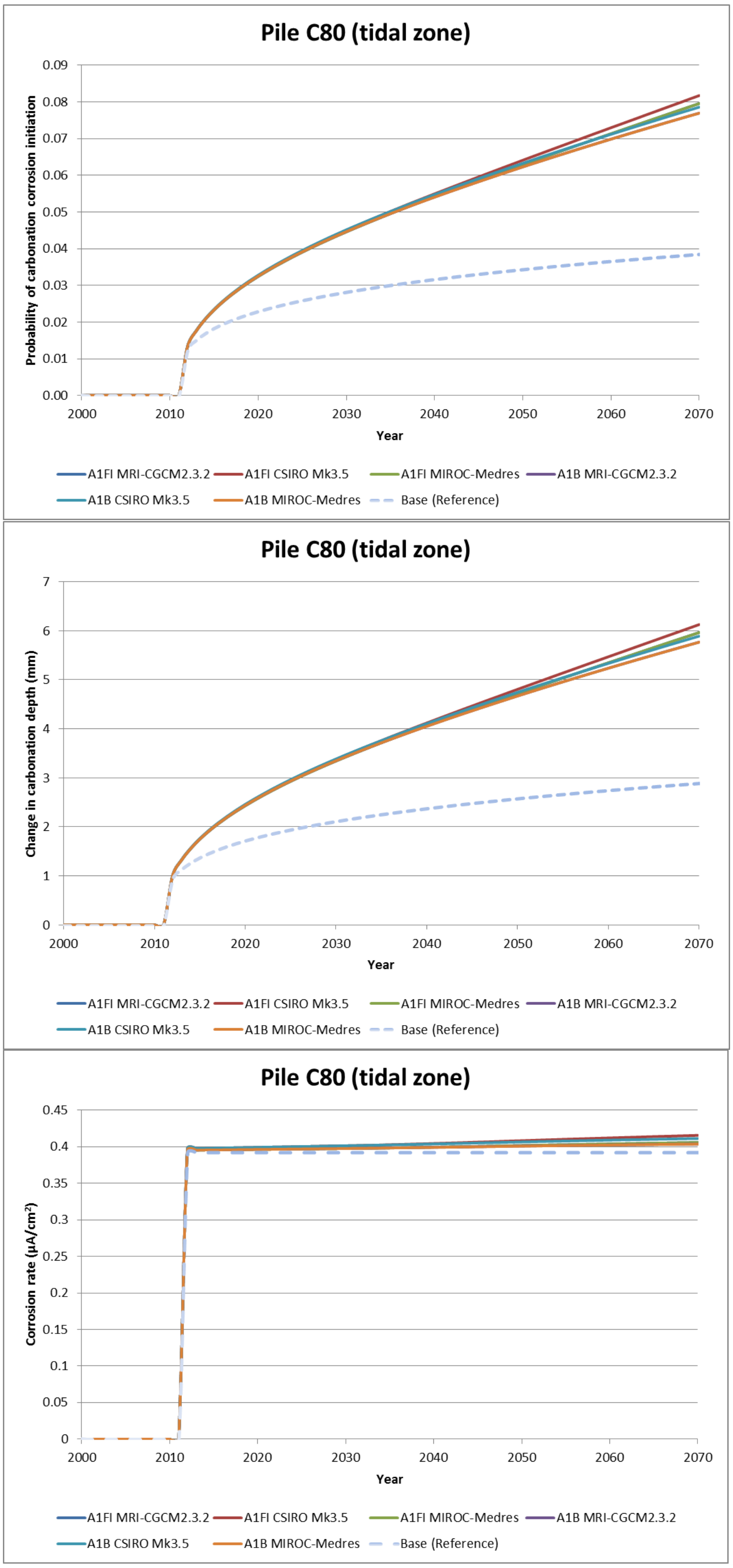
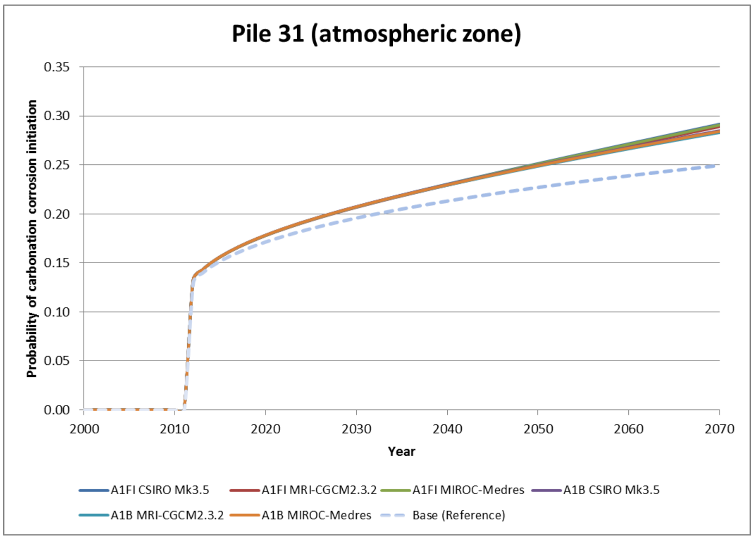


Figure 75: Pile C80 tidal zone carbonation results

Pile 31 (Gladstone)

Figures 76, 77 and 78 below show the results for Pile 31's atmospheric, splash and tidal zones respectively after the carbonation modelling were completed for with pile's input parameters. The results displayed are for all emissions scenarios and all possible future climate models as well as the baseline model which represents no change in climatic variables. It appears that the A1FI CSIRO Mk3.5 scenario, which is Gladstone's most likely scenario, is the most critical case in terms of corrosion rate, change in carbonation depth and probability of carbonation ingress. The results for the tidal zone here appear to have the most change from the baseline model and are therefore considered the most critical. The probability of carbonation induced corrosion initiation under this scenario in 2070 is roughly 29% which is an increase of approximately 10% from the baseline probability. Similarly, there is an increase of about 5mm in carbonation depth in 2070 under the most likely and A1FI model and an increase of about 0.05μA/cm^2 in corrosion rate. All scenario combinations appear to give very similar results and are all in a very similar range, which would indicate that it is highly probable that these results will be close to the actual results observed in 2070. The most drastic result seems to be the depth of carbonation in 2070 when compared to the baseline model. This is most adequately expressed in terms of intervention time. For example, if action needed to be taken when the change in carbonation depth reached 4 mm, under the baseline model, action would occur somewhere in the vicinity of 2045, whereas under the most likely scenario, intervention would need to take place in approximately 2020, which is 25 years earlier. This shows the extent that climate change will affect the need to remedy the risk of carbonation.



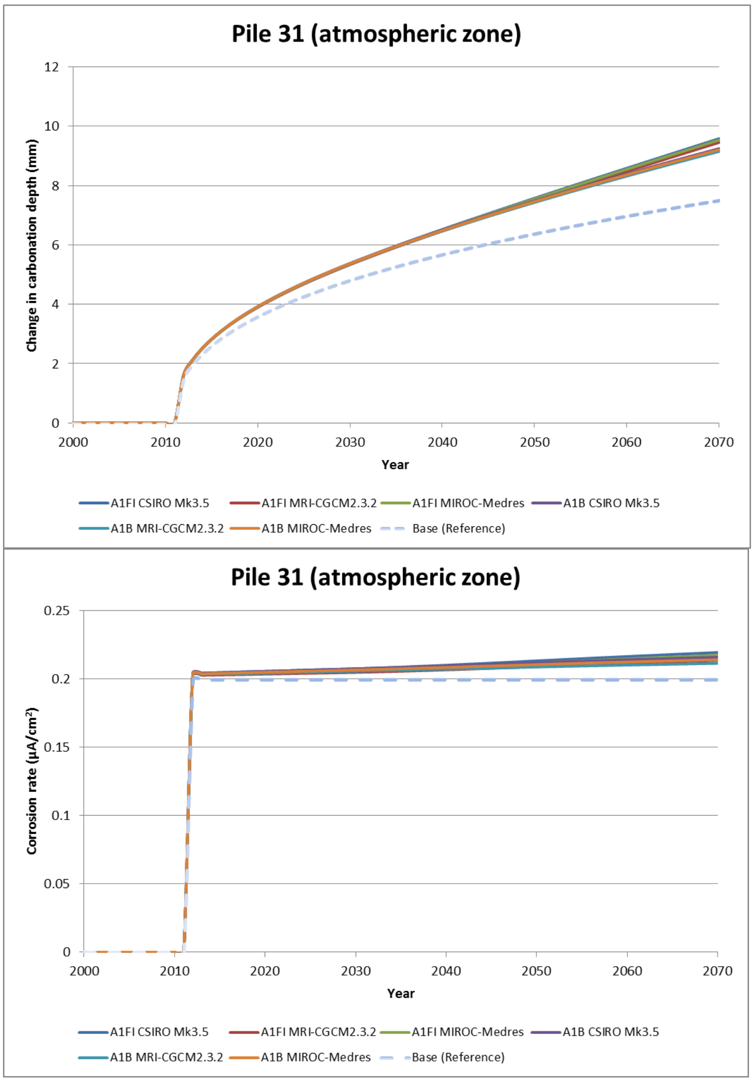
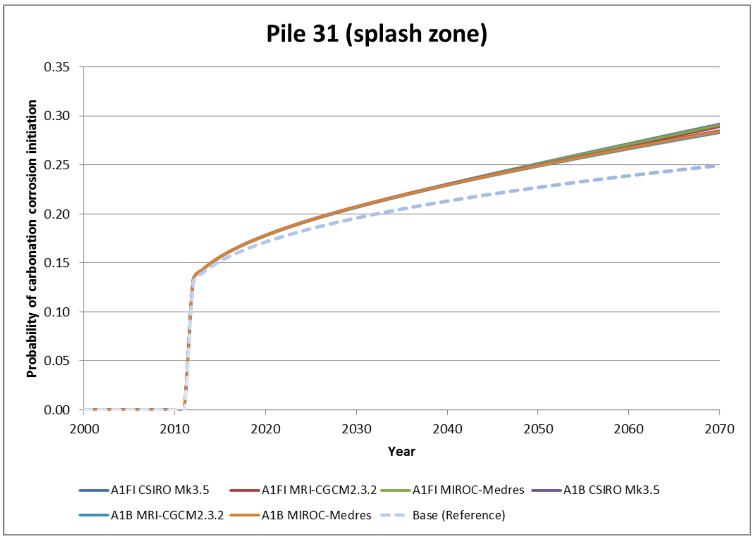
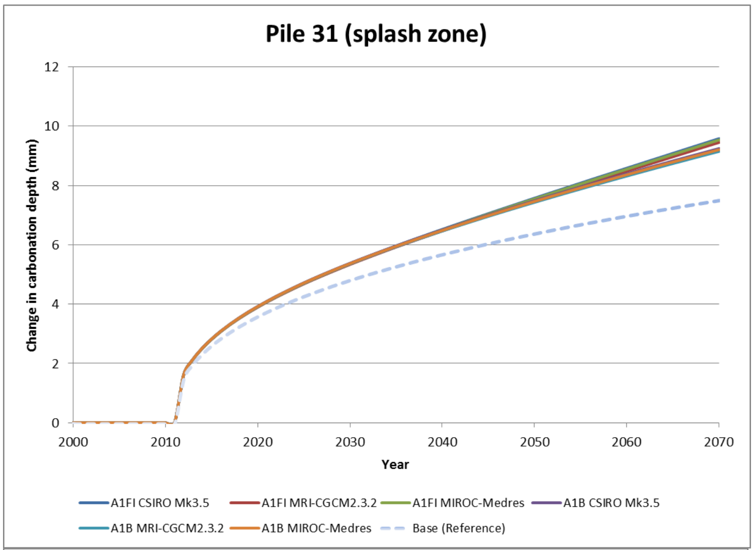


Figure 76: Pile 31 atmospheric zone carbonation results





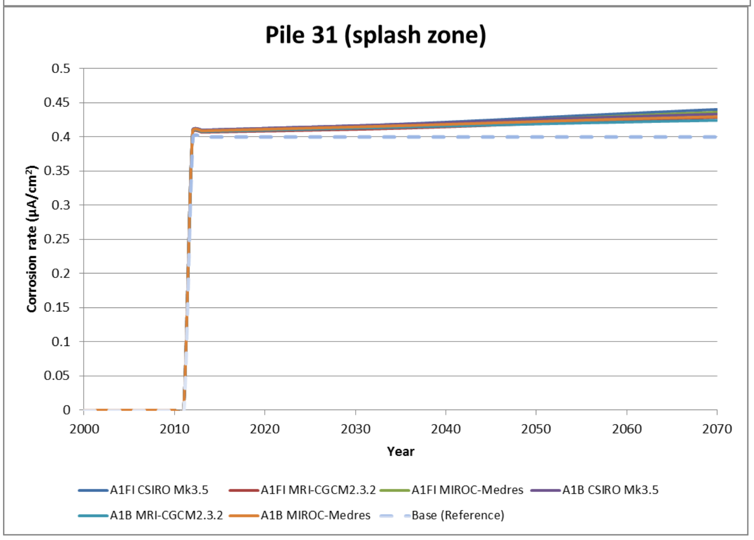
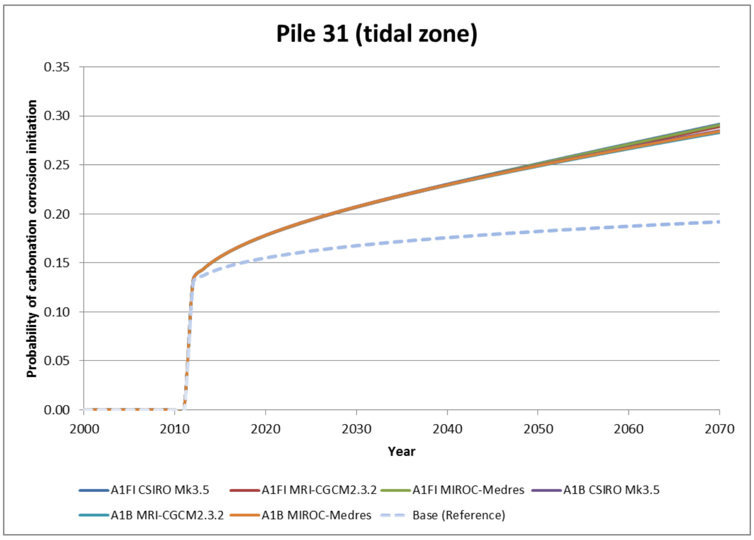
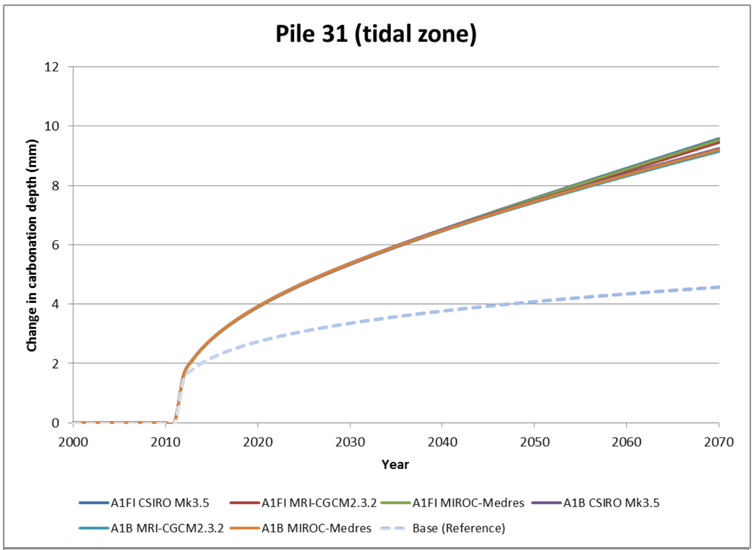


Figure 77: Pile 31 splash zone carbonation results





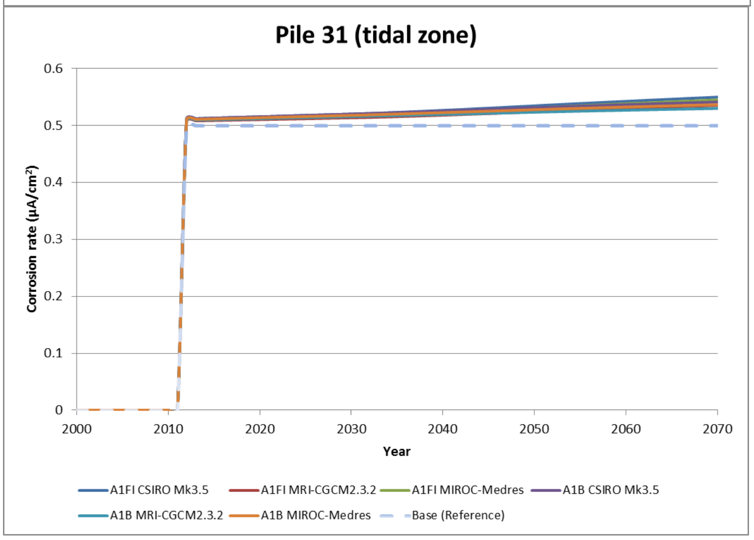


Figure 78: Pile 31 tidal zone carbonation results

Appendix 3 LIFE CYCLE COST ANALYSIS

Table 55: Example output for life cycle treatment cost optimisation where generated scenarios are ranked

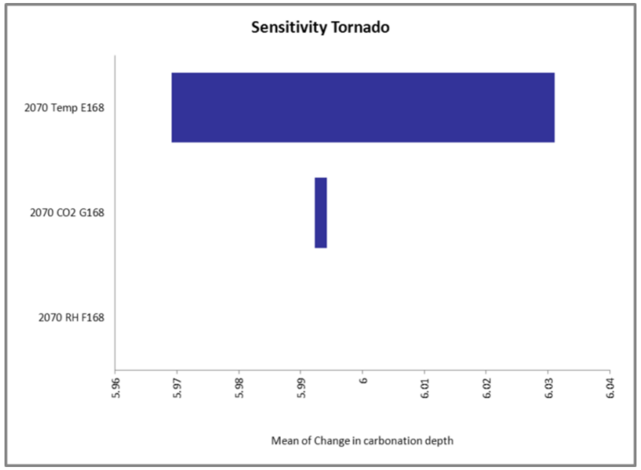
No.	NPV	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1	$4,246	Scenario 29 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
2	$4,248	Scenario 14 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20
3	$4,252	Scenario 41 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
4	$4,253	Scenario 77 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
5	$4,254	Scenario 79 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
6	$4,282	Scenario 52 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
7	$4,288	Scenario 67 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20
8	$4,293	Scenario 59 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
9	$4,294	Scenario 6 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
10	$4,314	Scenario 83 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20
11	$4,318	Scenario 80 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
12	$4,323	Scenario 58 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
13	$4,402	Scenario 1 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
14	$4,413	Scenario 12 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
15	$4,413	Scenario 43 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20
16	$4,418	Scenario 16 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
17	$4,419	Scenario 54 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
18	$4,420	Scenario 97 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
19	$4,444	Scenario 15 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820
20	$4,456	Scenario 36 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20
21	$4,460	Scenario 56 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870
22	$4,570	Scenario 93 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
23	$4,600	Scenario 39 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30
24	$4,658	Scenario 22 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670
25	$4,699	Scenario 20 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670
26	$4,816	Scenario 2 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10
27	$4,824	Scenario 5 - Total	$50	$50	$50	$50	$50	$3,850	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670
28	$4,851	Scenario 34 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10
29	$4,881	Scenario 8 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10
30	$4,989	Scenario 4 - Total	$50	$50	$50	$50	$50	$2,900	$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10
31	$5,368	Scenario 9 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
32	$5,369	Scenario 11 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
33	$5,404	Scenario 3 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
34	$5,409	Scenario 86 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
35	$5,435	Scenario 96 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
36	$5,534	Scenario 44 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
37	$5,542	Scenario 7 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
38	$5,577	Scenario 31 - Total	$50	$50	$50	$50	$50	$6,700	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10

2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30	$30	$30	$30	$30	$30
$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30	$30	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30
$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20	$20	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20	$20	$20	$20	$3,820	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$2,870	$30	$30	$30	$30	$30	$30	$30	$30	$30
$30	$30	$30	$30	$3,830	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670	$10	$10	$10	$10
$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670	$10	$10	$10	$10	$10	$10	$10	$10	$10
$20	$20	$20	$20	$20	$20	$20	$20	$20	$6,670	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$30	$30	$30	$30	$6,680	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$3,810	$20	$20	$20	$20
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30
$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$6,660	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$3,810	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30	$30	$30	$30	$30	$30	$3,830	$20	$20	$20	$20
$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30
$10	$10	$10	$10	$10	$10	$10	$10	$10	$3,810	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30	$30	$30	$30	$30	$30	$2,880	$30	$30	$30	$30
$10	$10	$10	$10	$10	$10	$10	$10	$10	$3,810	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20	$20
$10	$10	$10	$10	$10	$10	$10	$10	$10	$2,860	$30	$30	$30	$30	$30	$30	$30	$30	$30	$6,680	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10	$10	$10	$10	$6,660	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10	$10

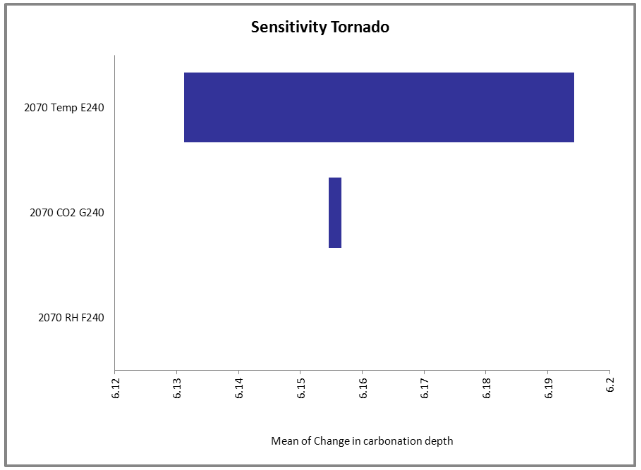
2057	2058	2059	2060	2061	2062
$20	$20	$20	$20	$20	$20
$2,870	$30	$30	$30	$30	$30
$2,870	$30	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20
$2,880	$30	$30	$30	$30	$30
$30	$30	$30	$30	$30	$2,880
$3,820	$20	$20	$20	$20	$20
$3,820	$20	$20	$20	$20	$20
$3,830	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$3,830
$30	$30	$30	$30	$30	$3,830
$20	$20	$20	$20	$20	$3,820
$30	$30	$30	$30	$30	$6,680
$20	$20	$20	$20	$20	$6,670
$6,670	$10	$10	$10	$10	$10
$6,670	$10	$10	$10	$10	$10
$6,680	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$2,860
$10	$10	$10	$10	$10	$3,810
$2,860	$30	$30	$30	$30	$30
$3,810	$20	$20	$20	$20	$20
$20	$20	$20	$20	$20	$20
$6,660	$10	$10	$10	$10	$10
$30	$30	$30	$30	$30	$2,880
$30	$30	$30	$30	$30	$3,830
$10	$10	$10	$10	$10	$10
$2,870	$30	$30	$30	$30	$30
$20	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$2,880
$3,820	$20	$20	$20	$20	$20
$30	$30	$30	$30	$30	$3,830
$6,670	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10
$10	$10	$10	$10	$10	$10

Appendix 4 SENSITIVITY ANALYSIS

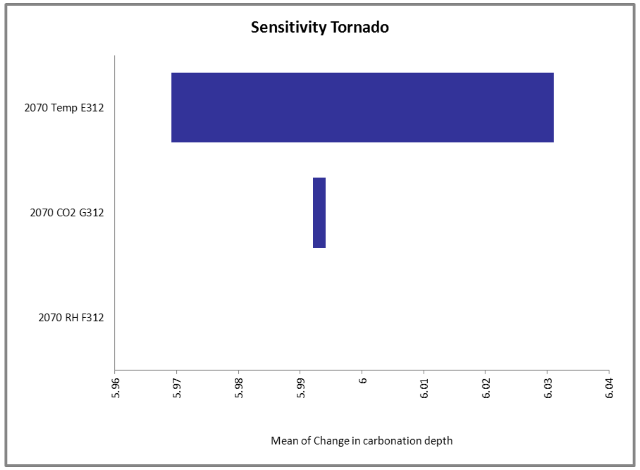
Most Likely | **Hotter & Drier** | **Cooler & Wetter**



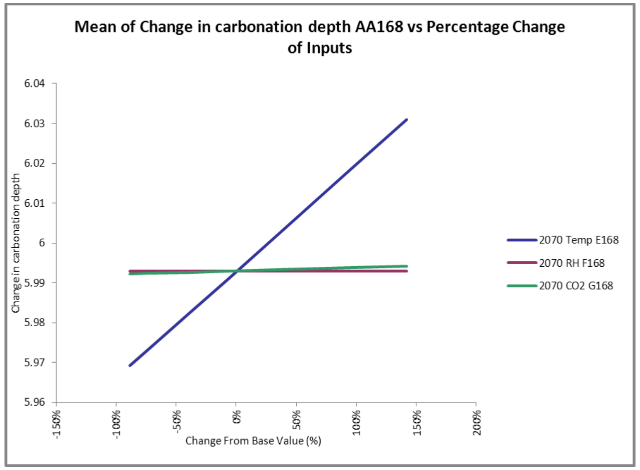
(MRI-CGCM2.3.2)



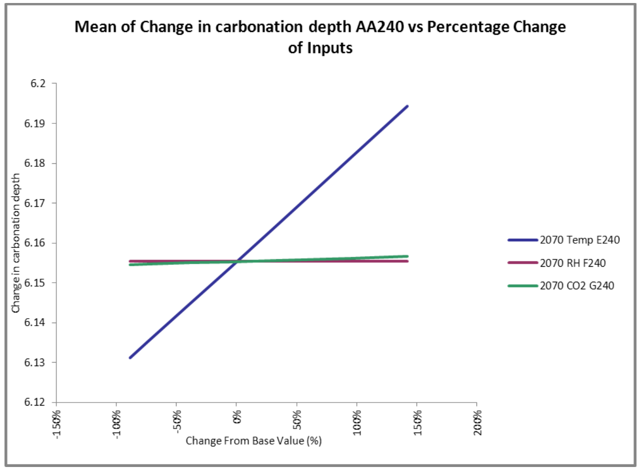
(CSIRO Mk3.5)



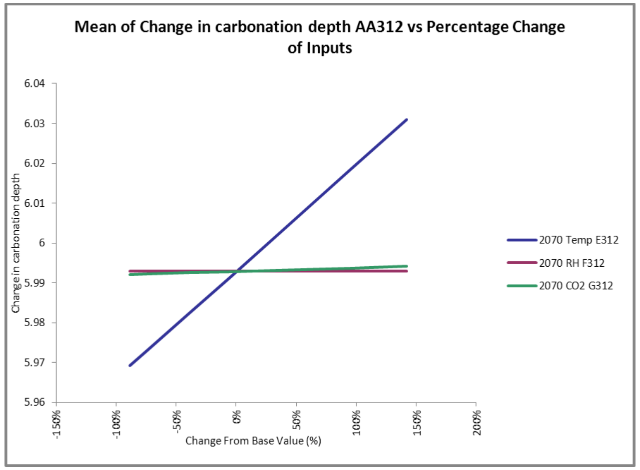
(MIROC-Medres)



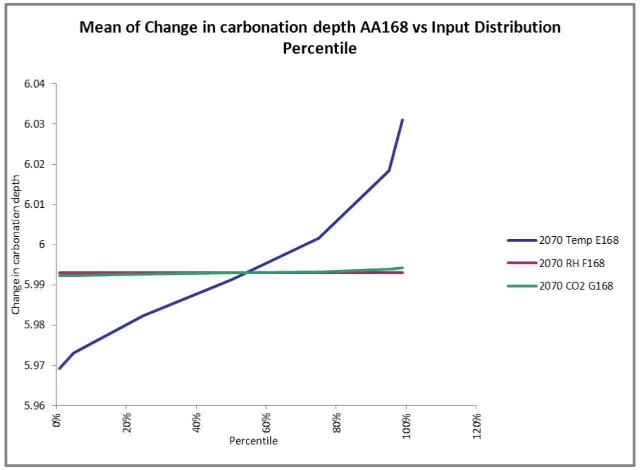
(CSIRO Mk3.5)



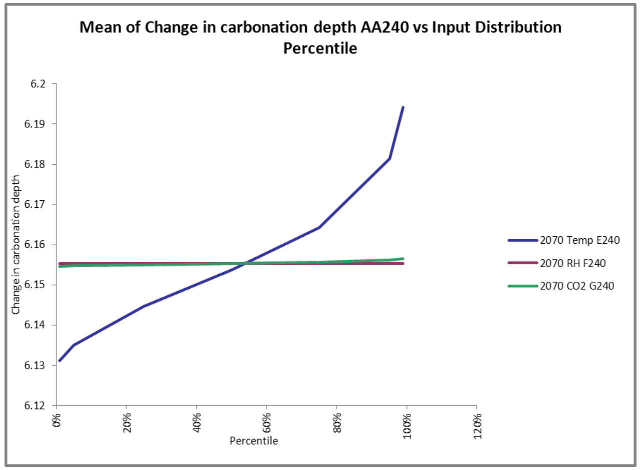
(MRI-CGCM2.3.2)



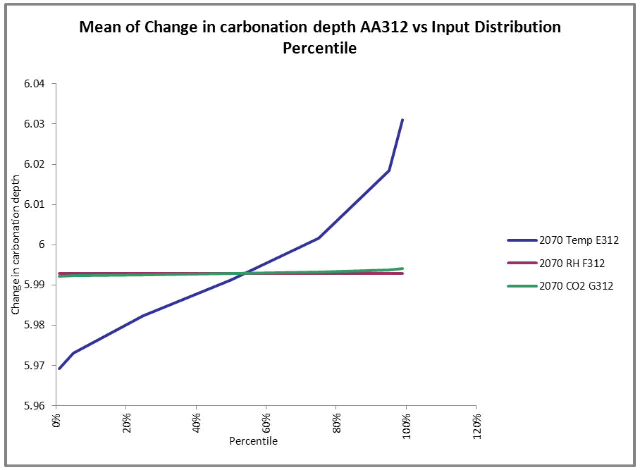
(MIROC-Medres)



(MRI-CGCM2.3.2)



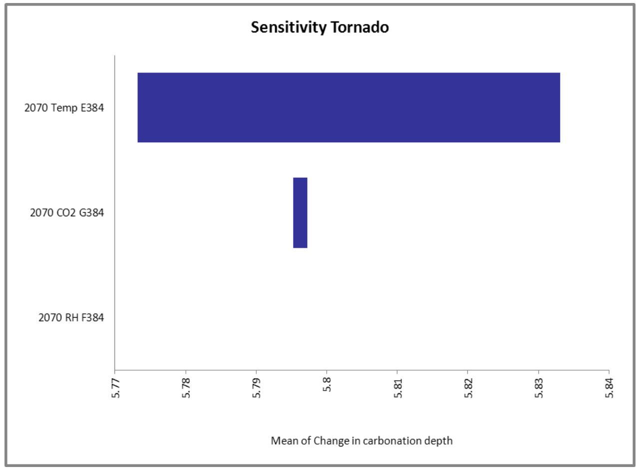
(CSIRO Mk3.5)



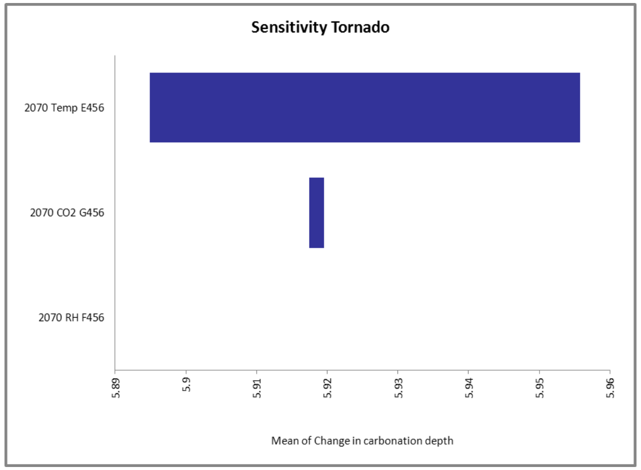
(MIROC-Medres)

Figure 79: Sensitivity of carbonation depth at 2070 under A1FI emission

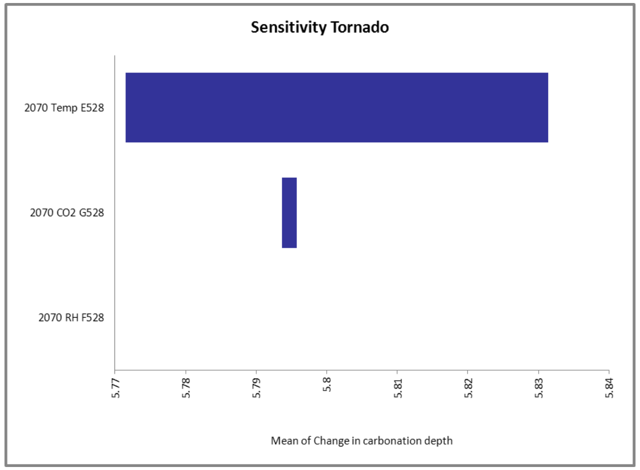
Most Likely	Hotter & Drier	Cooler & Wetter



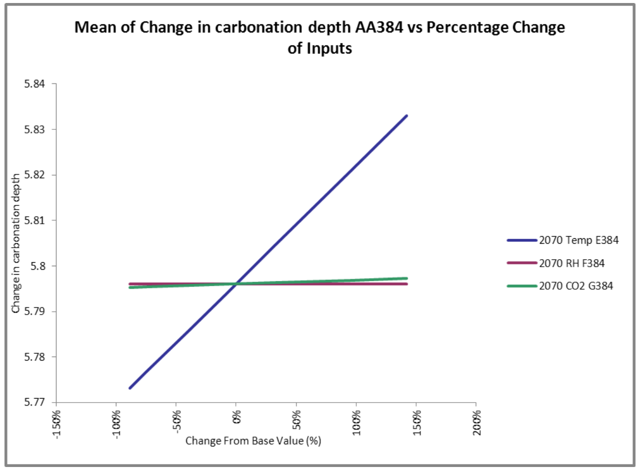
(MRI-CGCM2.3.2)



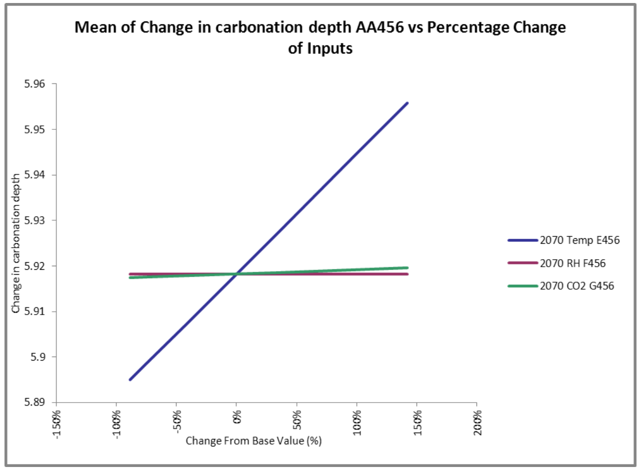
(CSIRO Mk3.5)



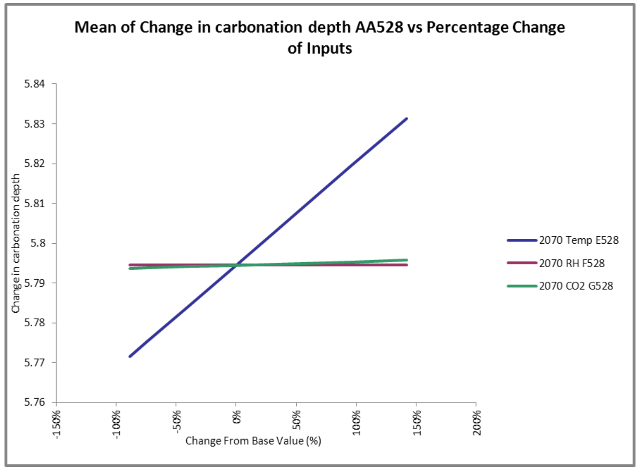
(MIROC-Medres)



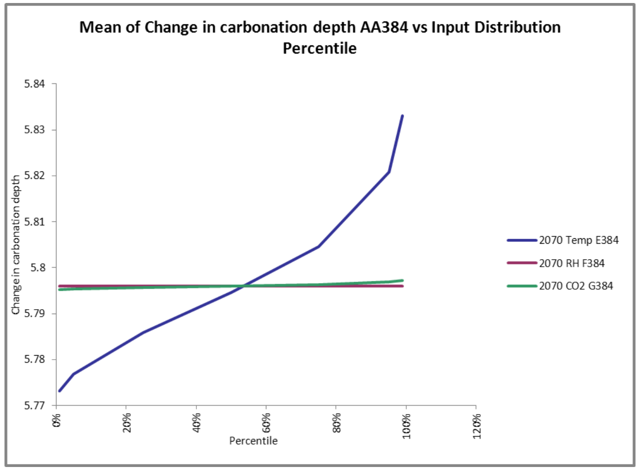
(CSIRO Mk3.5)



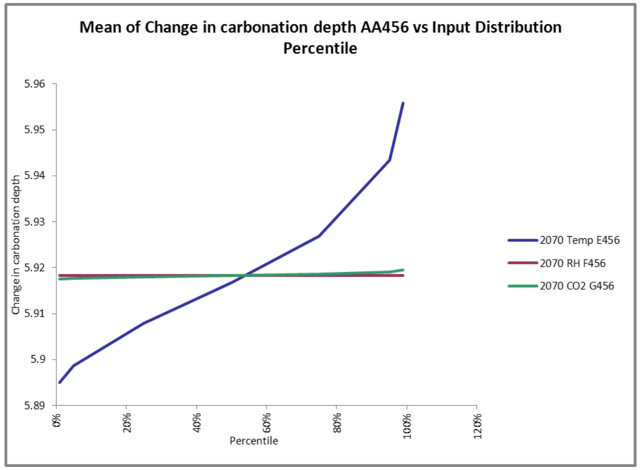
(MRI-CGCM2.3.2)



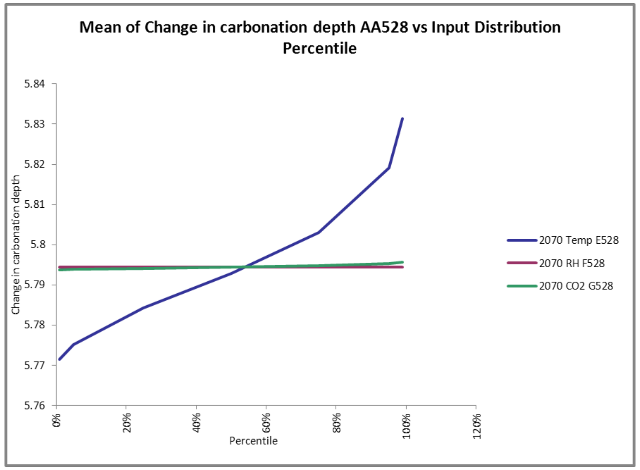
(MIROC-Medres)



(MRI-CGCM2.3.2)



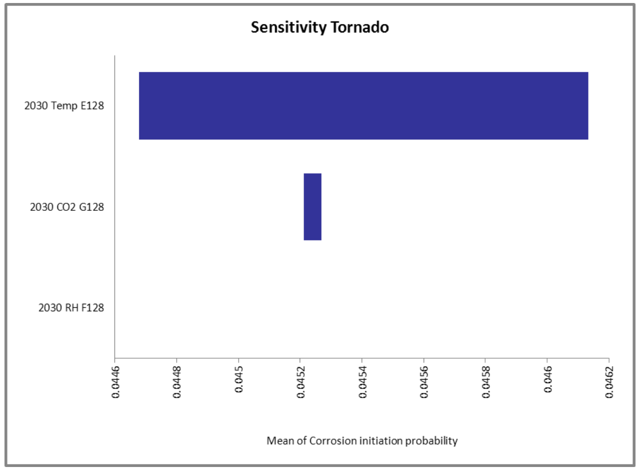
(CSIRO Mk3.5)



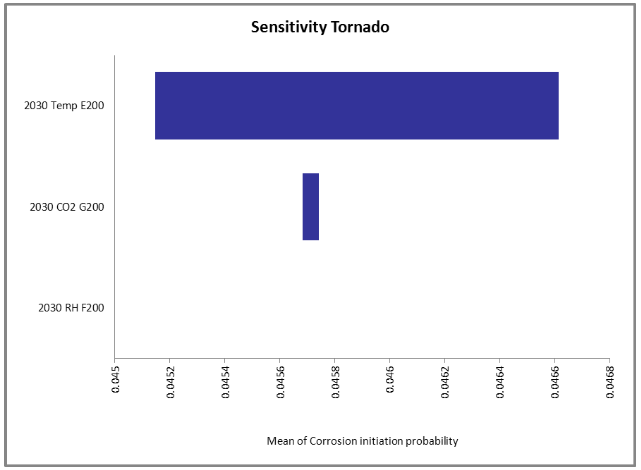
(MIROC-Medres)

Figure 80: Sensitivity of carbonation depth at 2070 under A1B emission

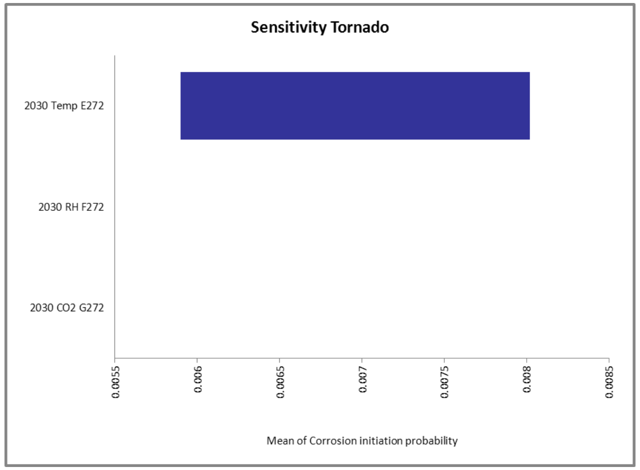
Most Likely | **Hotter & Drier** | **Cooler & Wetter**



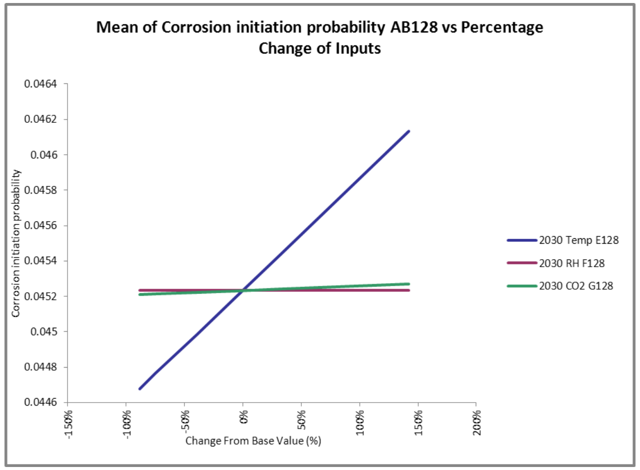
(MRI-CGCM2.3.2)



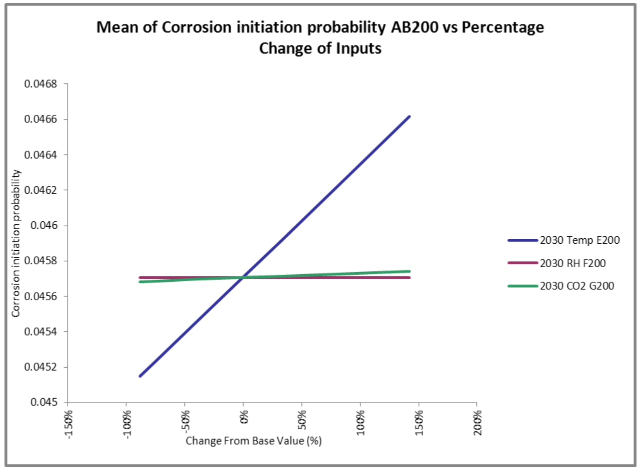
(CSIRO Mk3.5)



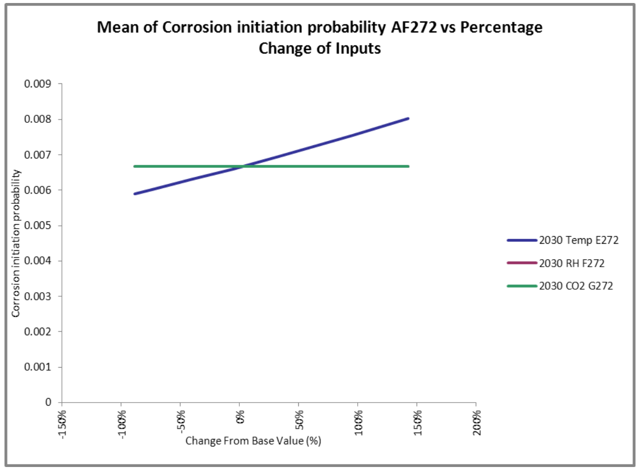
(MIROC-Medres)



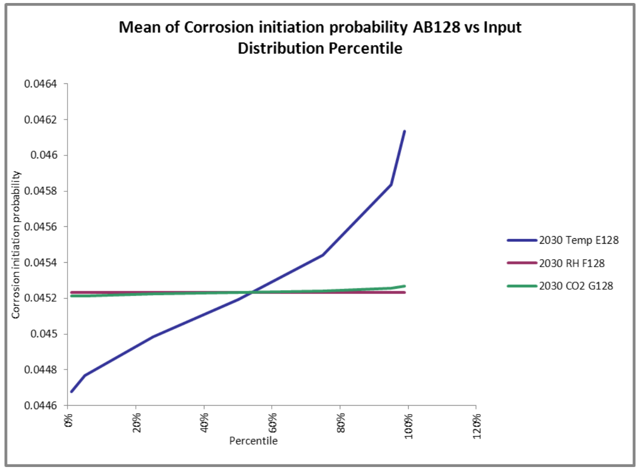
(CSIRO Mk3.5)



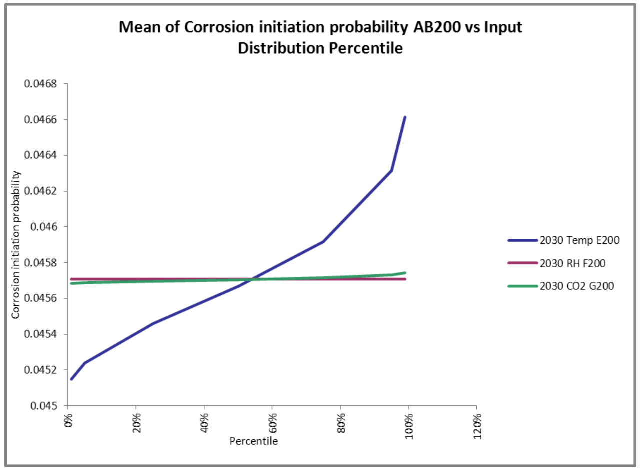
(MRI-CGCM2.3.2)



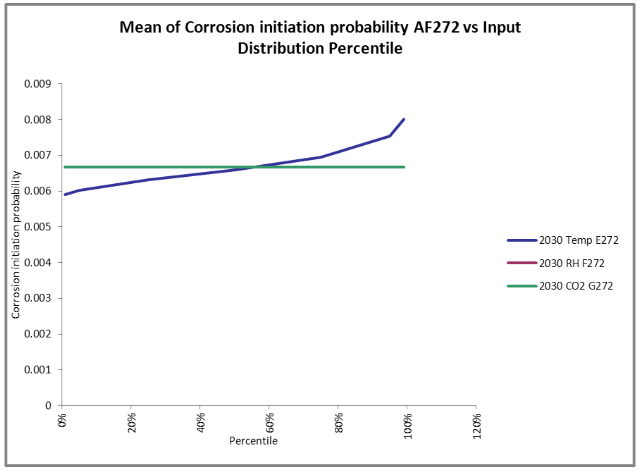
(MIROC-Medres)



(MRI-CGCM2.3.2)



(CSIRO Mk3.5)

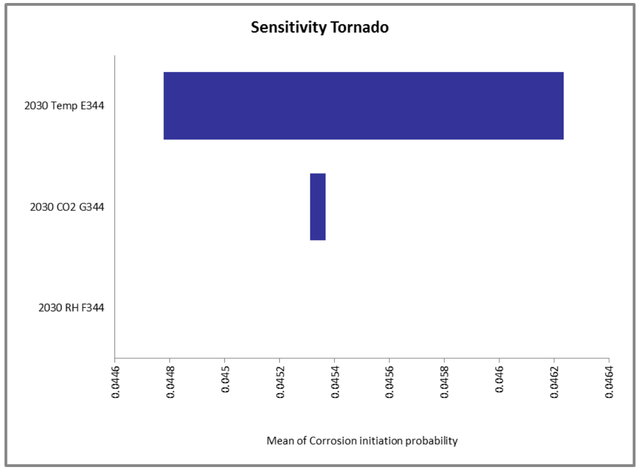


(MIROC-Medres)

Figure 81: Sensitivity of corrosion initiation probability at 2030 under A1FI emission

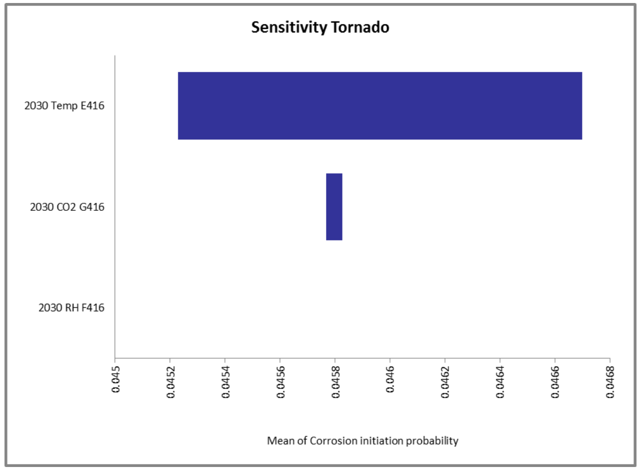
Most Likely	Hotter & Drier	Cooler & Wetter

Most Likely



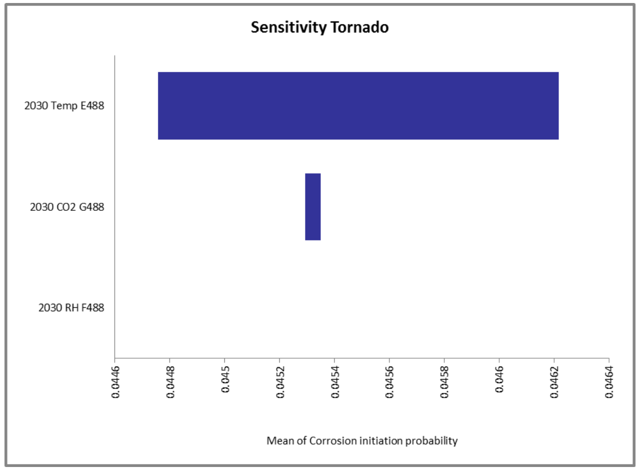
(MRI-CGCM2.3.2)

Hotter & Drier

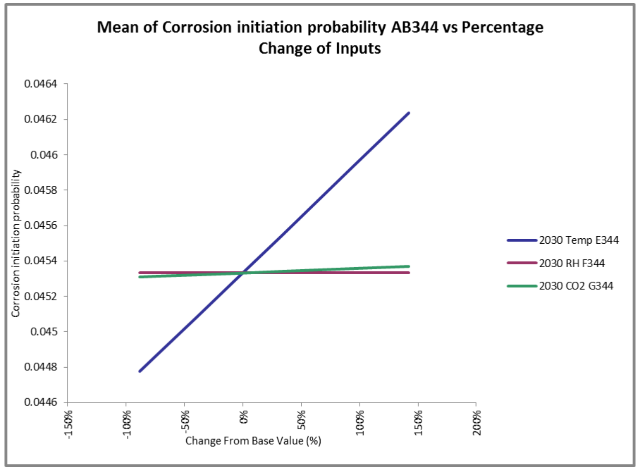


(CSIRO Mk3.5)

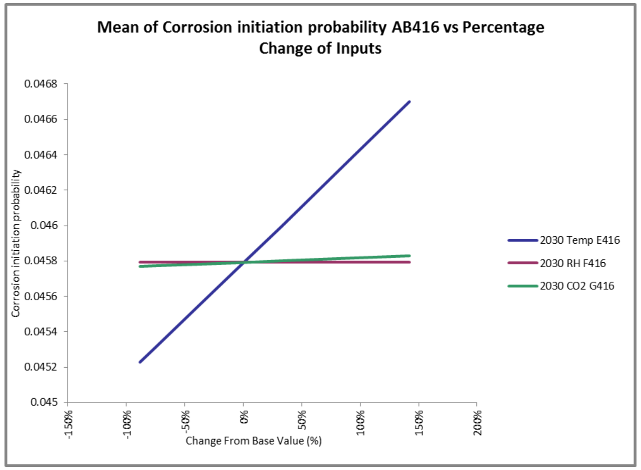
Cooler & Wetter



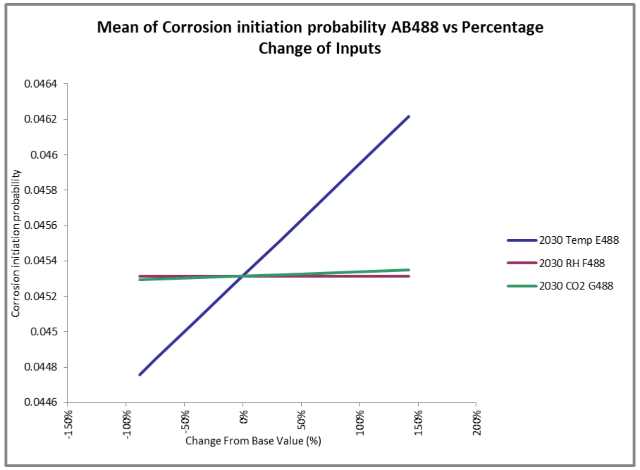
(MIROC-Medres)



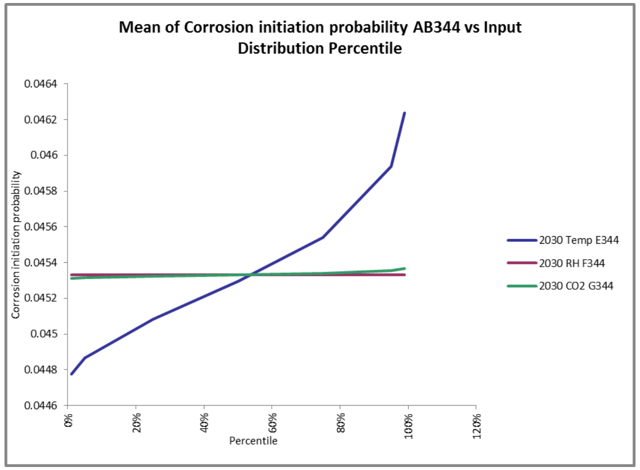
(CSIRO Mk3.5)



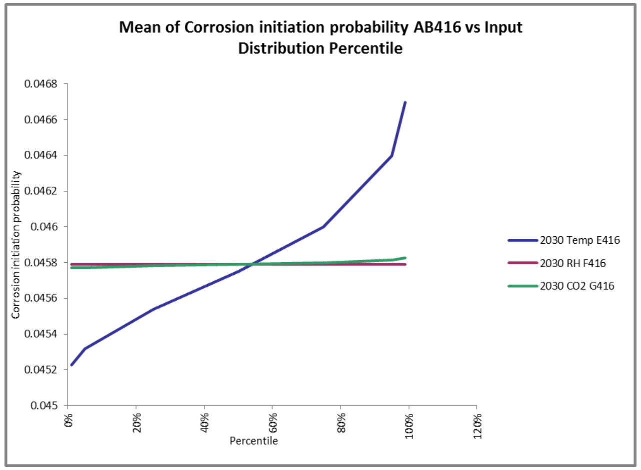
(MRI-CGCM2.3.2)



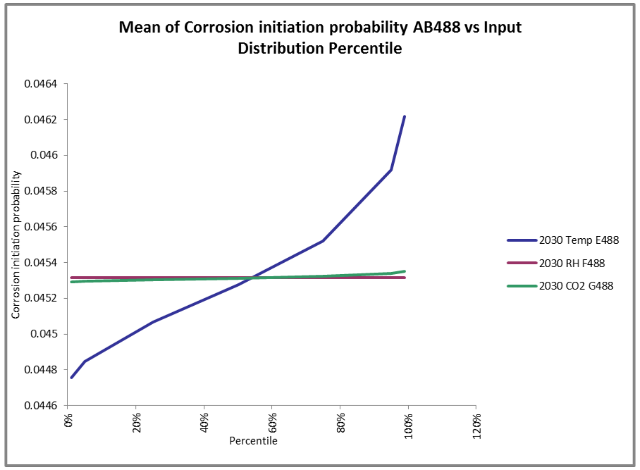
(MIROC-Medres)



(MRI-CGCM2.3.2)



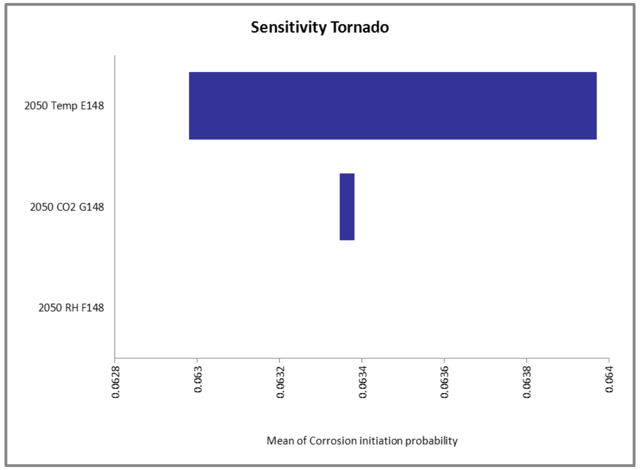
(CSIRO Mk3.5)



(MIROC-Medres)

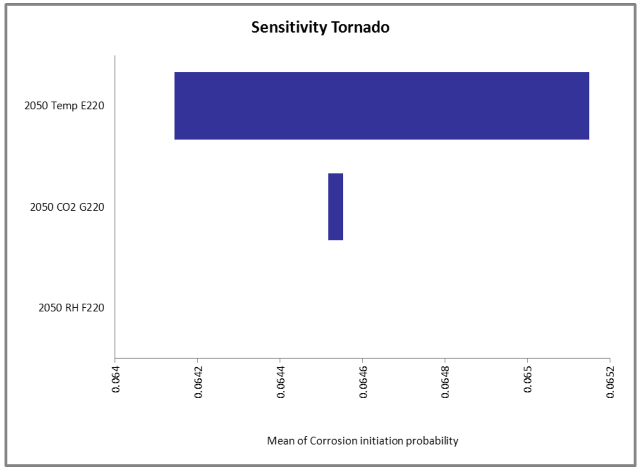
Figure 82: Sensitivity of corrosion initiation probability at 2030 under A1B emission

Most Likely



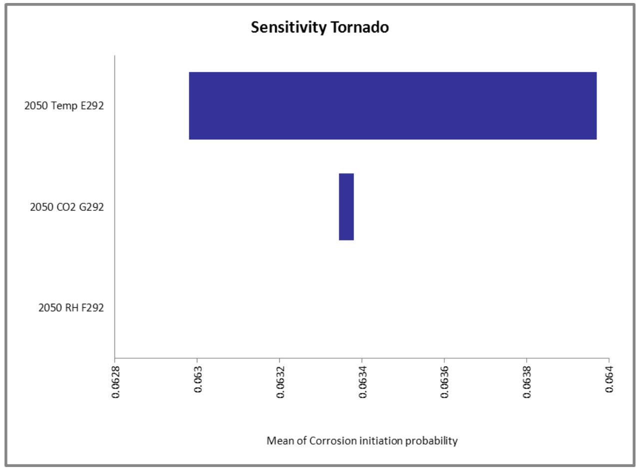
(MRI-CGCM2.3.2)

Hotter & Drier

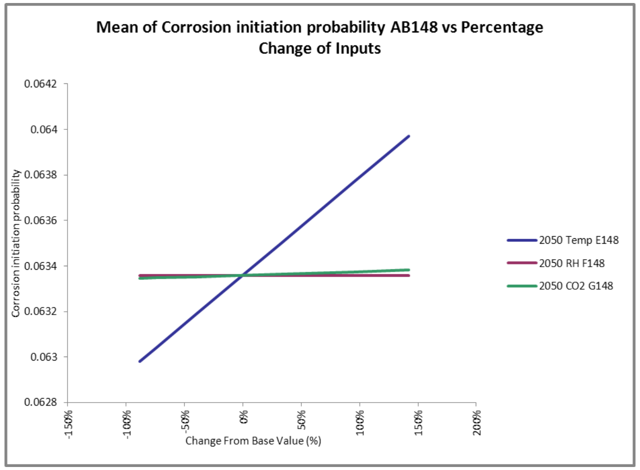


(CSIRO Mk3.5)

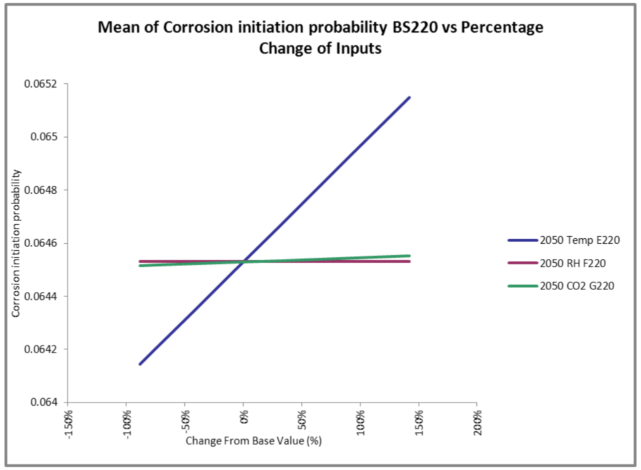
Cooler & Wetter



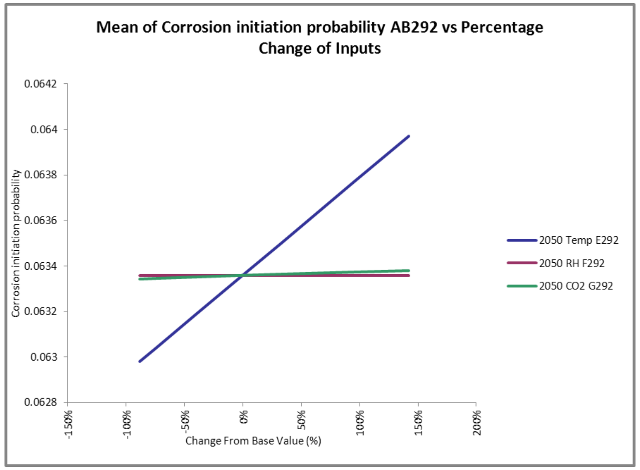
(MIROC-Medres)



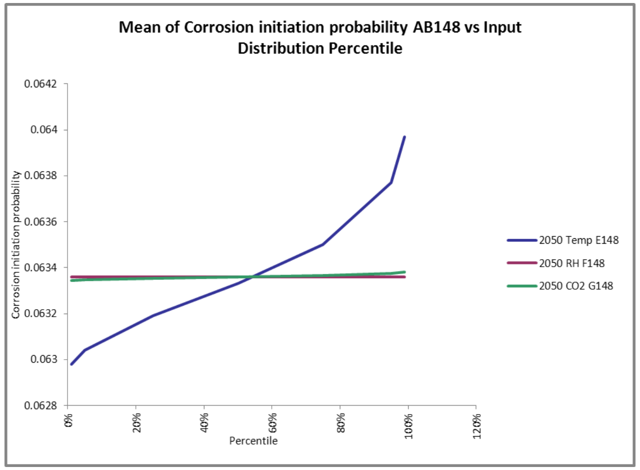
(CSIRO Mk3.5)



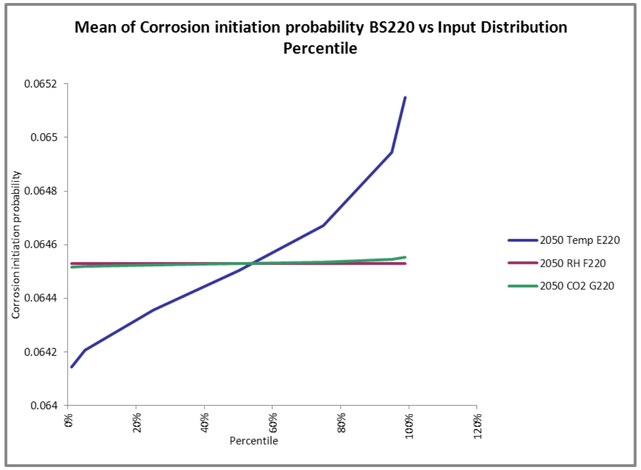
(MRI-CGCM2.3.2)



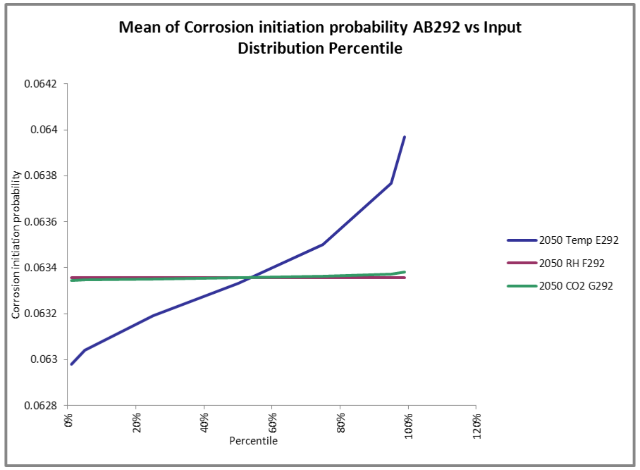
(MIROC-Medres)



(MRI-CGCM2.3.2)



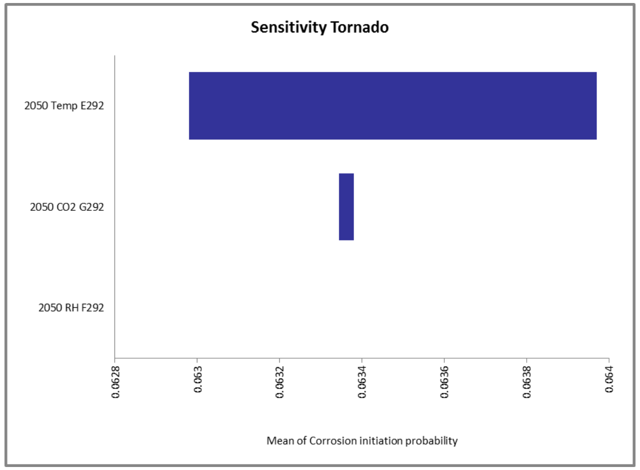
(CSIRO Mk3.5)



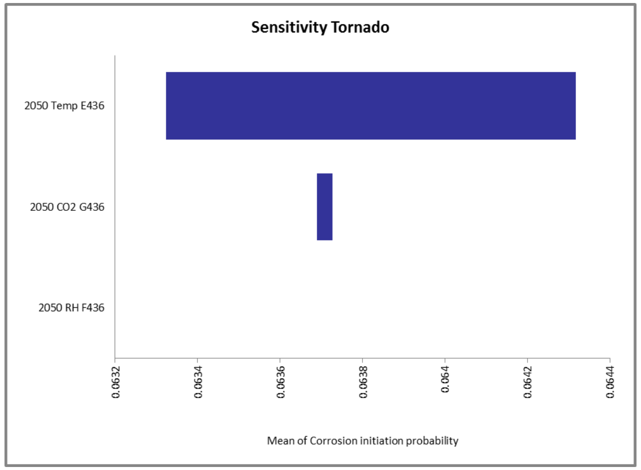
(MIROC-Medres)

Figure 83: Sensitivity of corrosion initiation probability at 2050 under A1FI emission

Most Likely | **Hotter & Drier** | **Cooler & Wetter**



(MRI-CGCM2.3.2)



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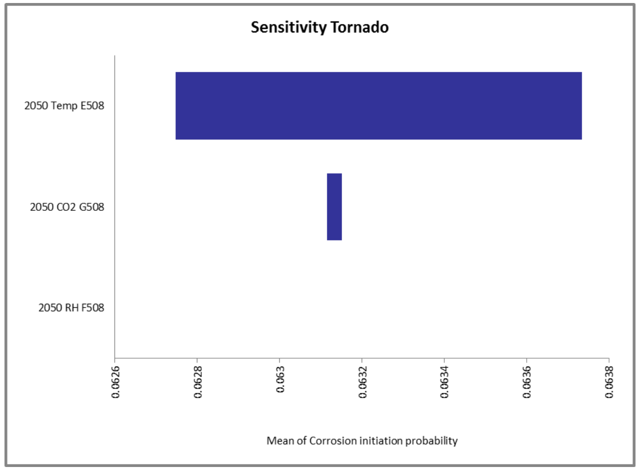
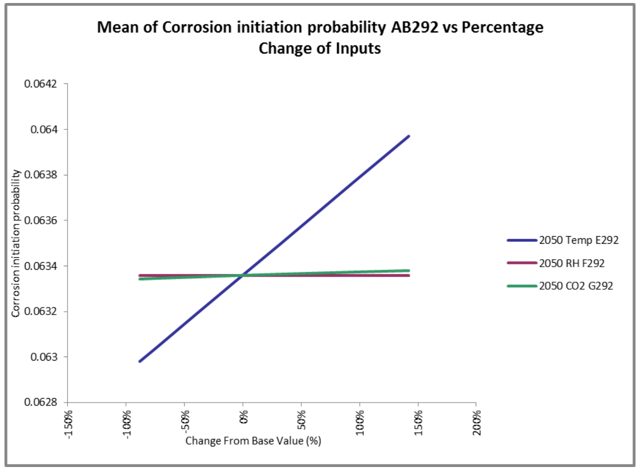


(MIROC-Medres)



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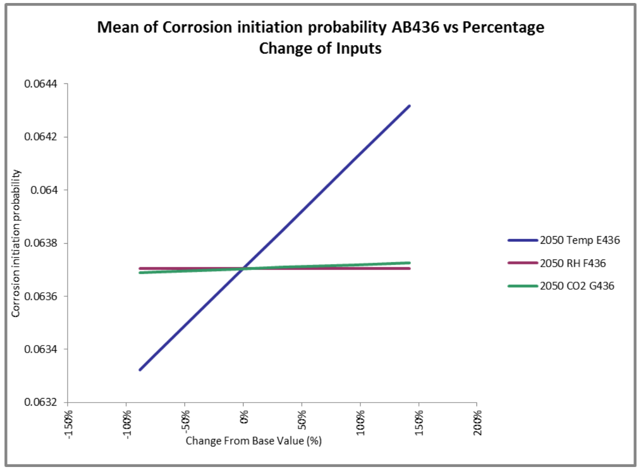

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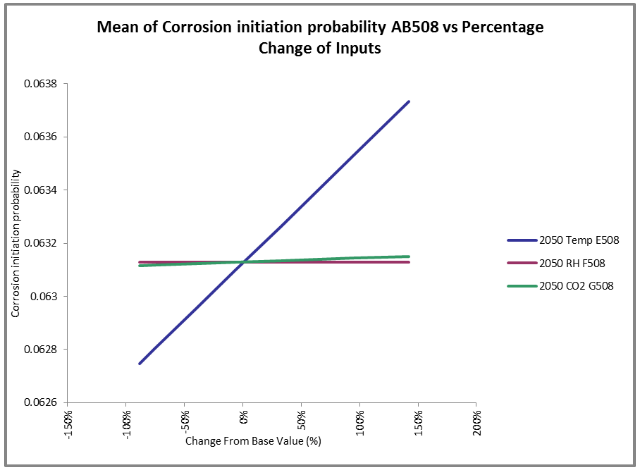

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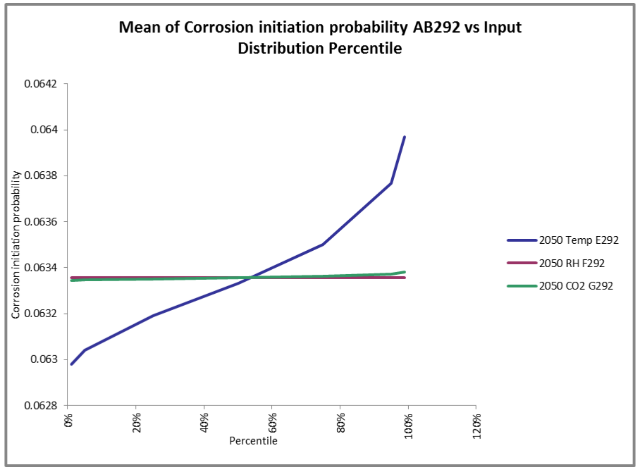

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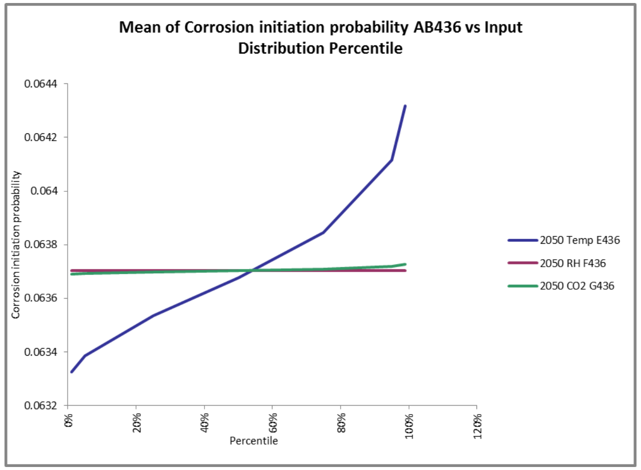

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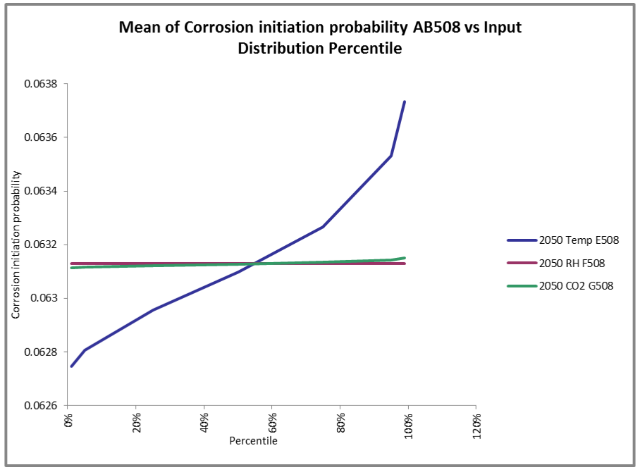
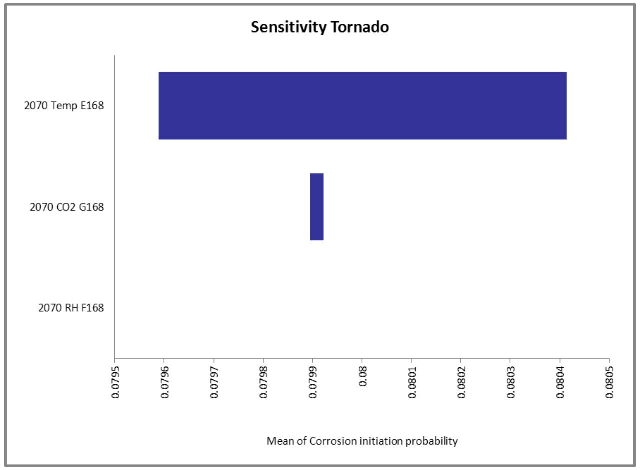


(MIROC-Medres)

Figure 84: Sensitivity of corrosion initiation probability at 2050 under A1B emission

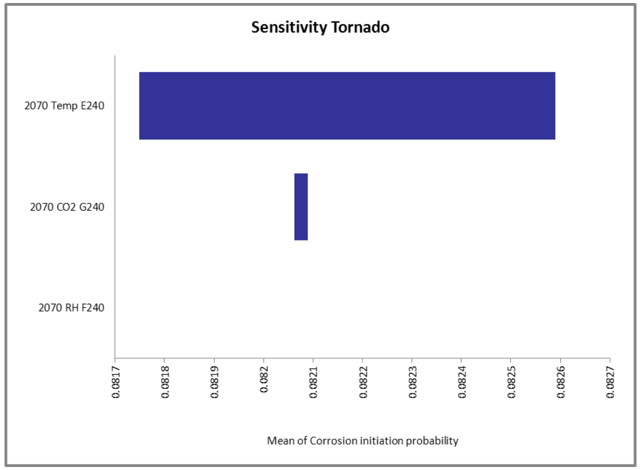
Most Likely **Hotter & Drier** **Cooler & Wetter**

Most Likely



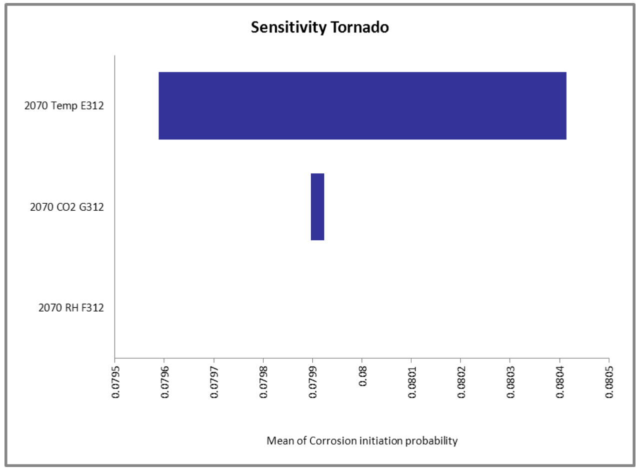
(MRI-CGCM2.3.2)

Hotter & Drier

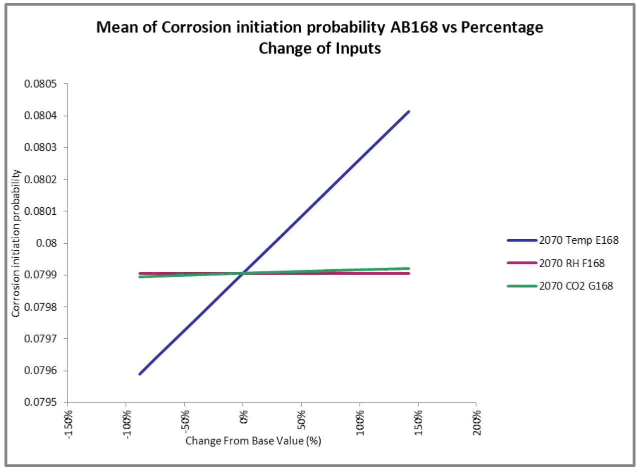


(CSIRO Mk3.5)

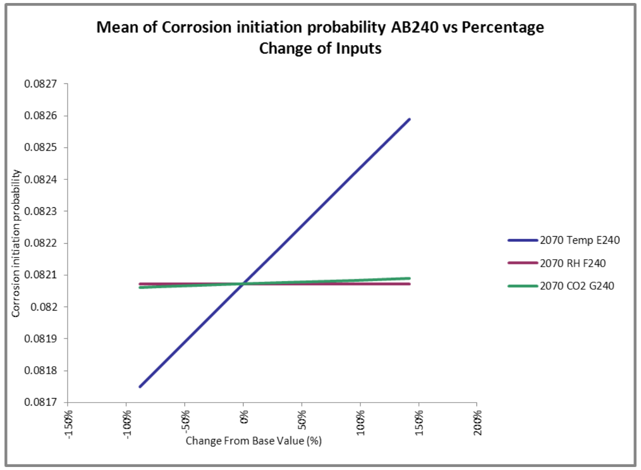
Cooler & Wetter



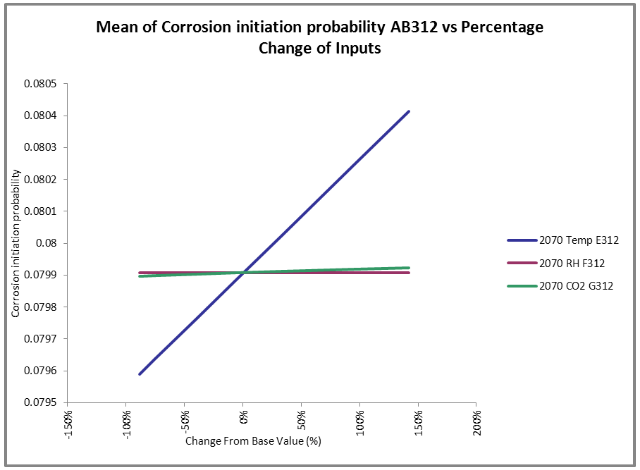
(MIROC-Medres)



(CSIRO Mk3.5)



(MRI-CGCM2.3.2)



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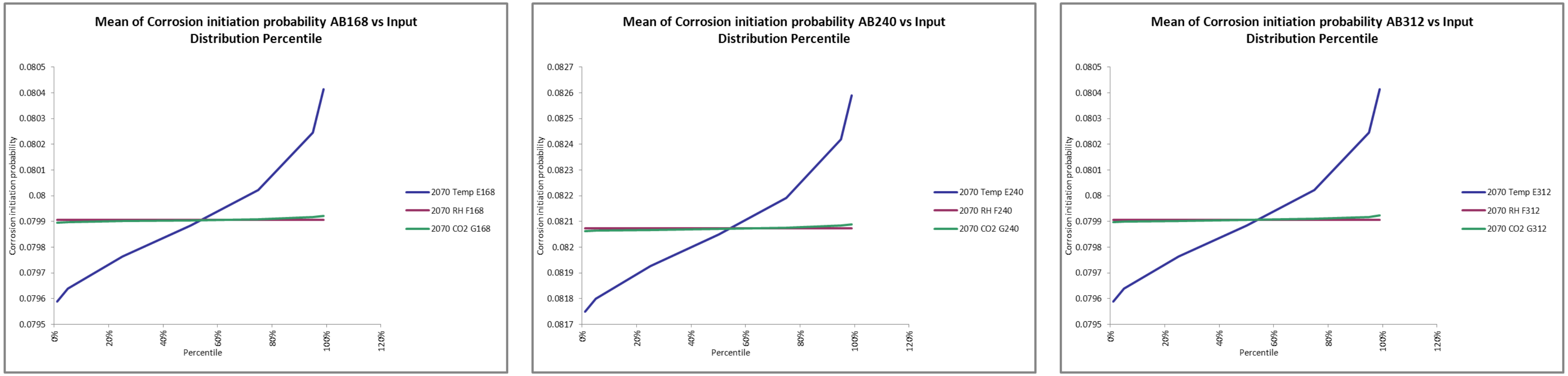
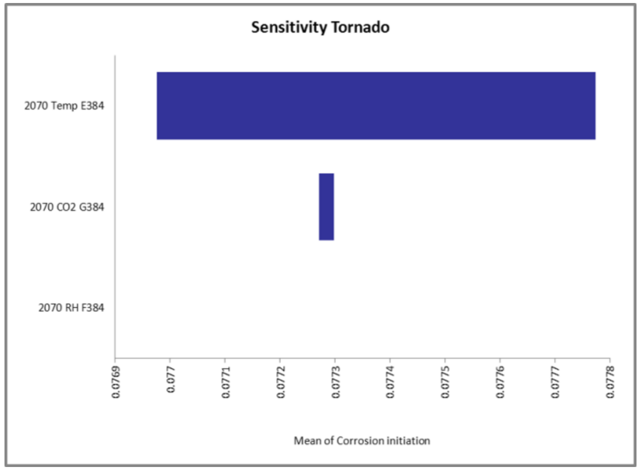


(MRI-CGCM2.3.2) (CSIRO Mk3.5) (MIROC-Medres)

Figure 85: Sensitivity of corrosion initiation probability at 2070 under A1FI emission

Most Likely | **Hotter & Drier** | **Cooler & Wetter**



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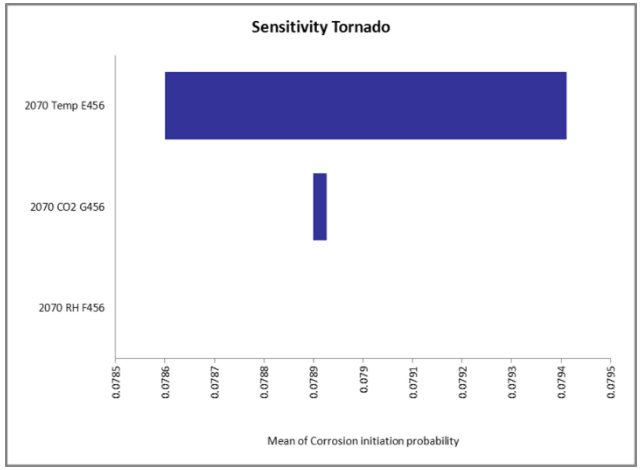
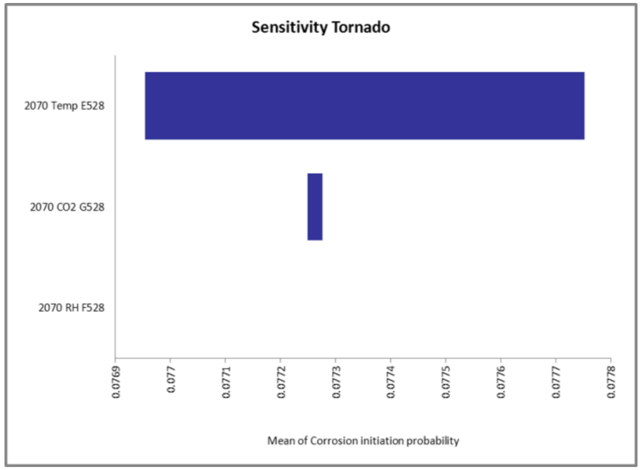
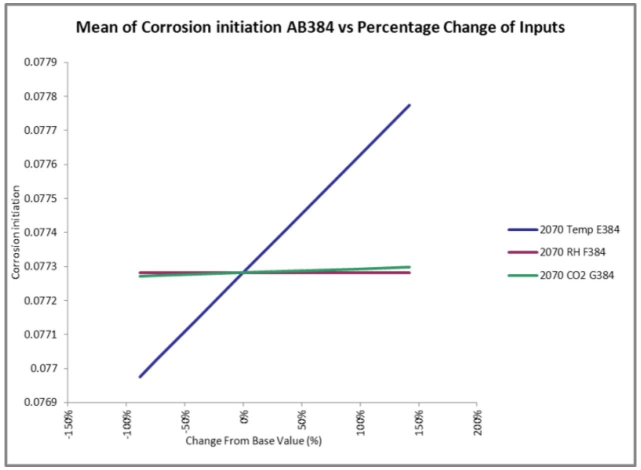


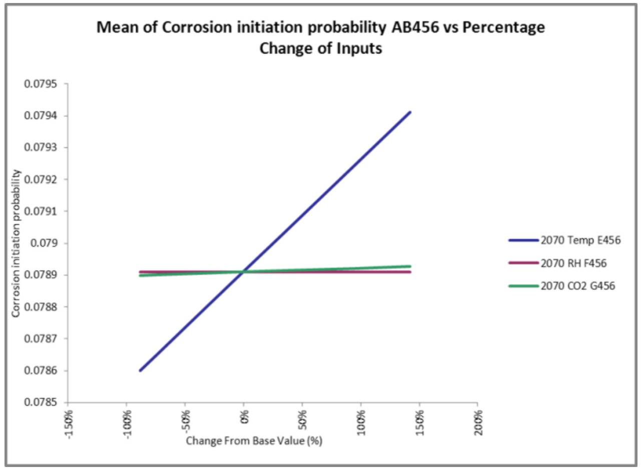
(CSIRO Mk3.5)



(MIROC-Medres)



(CSIRO Mk3.5)



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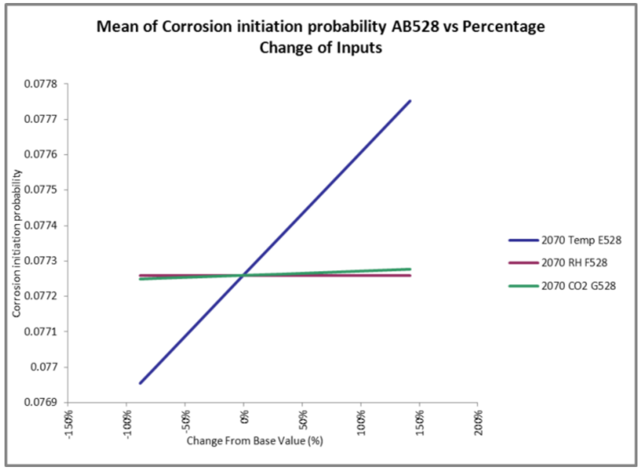
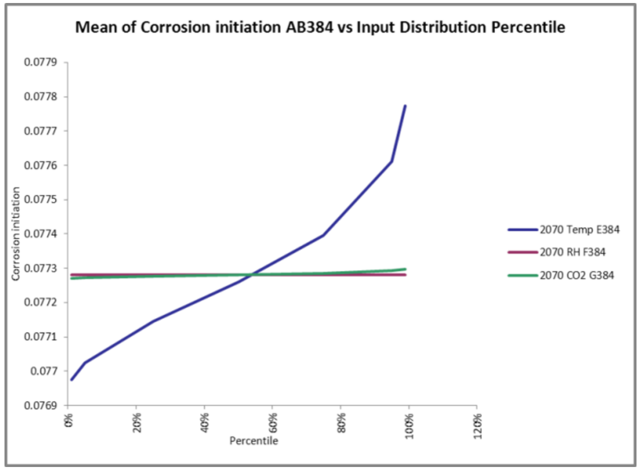


(MIROC-Medres)



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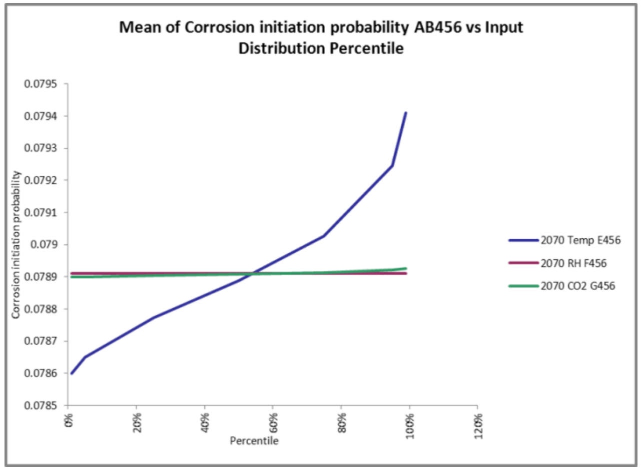
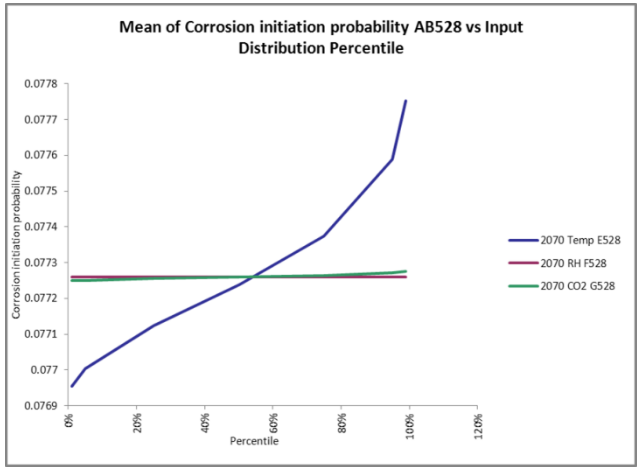


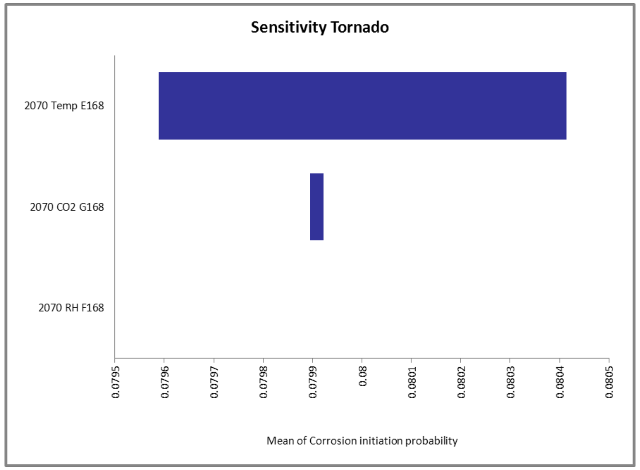
(CSIRO Mk3.5)



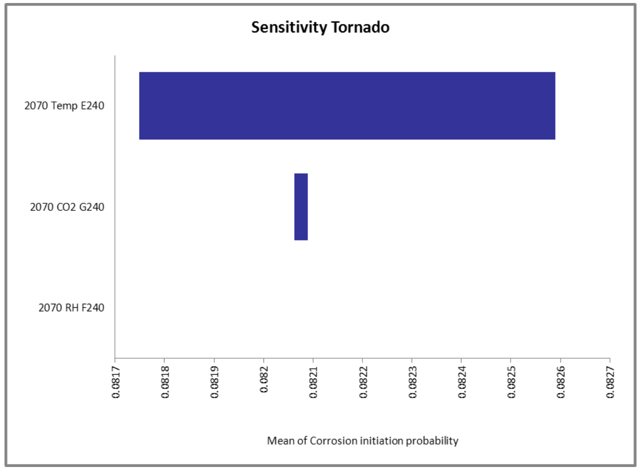
(MIROC-Medres)

Figure 86: Sensitivity of corrosion initiation probability at 2070 under A1B emission

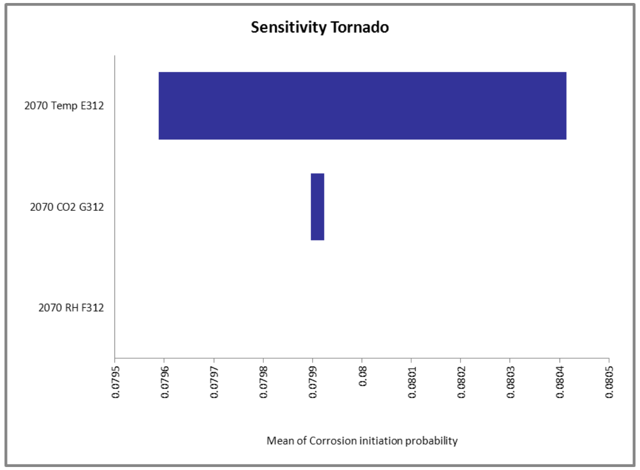
Most Likely	Hotter & Drier	Cooler & Wetter



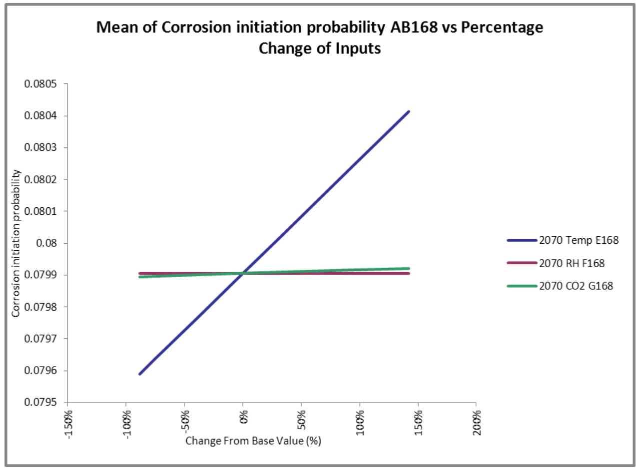
(MRI-CGCM2.3.2)



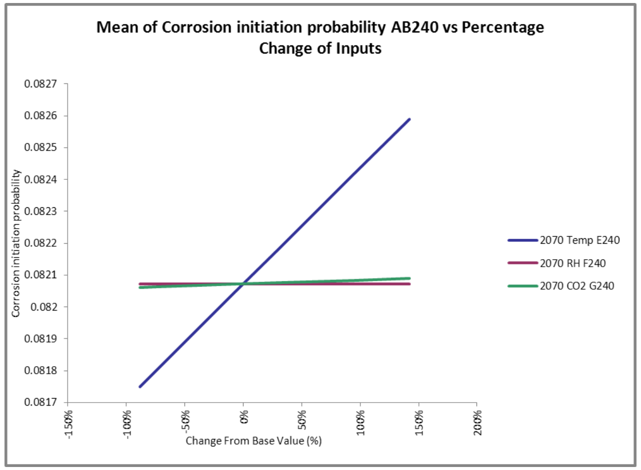
(CSIRO Mk3.5)



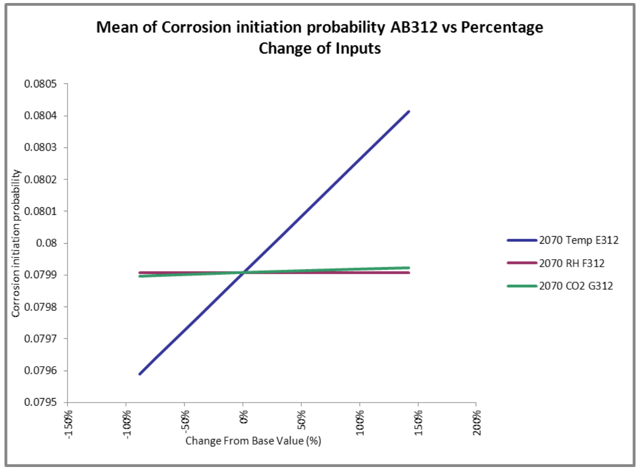
(MIROC-Medres)



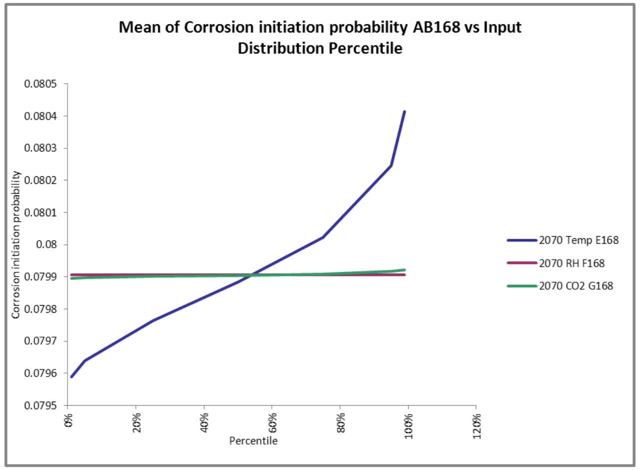
(CSIRO Mk3.5)



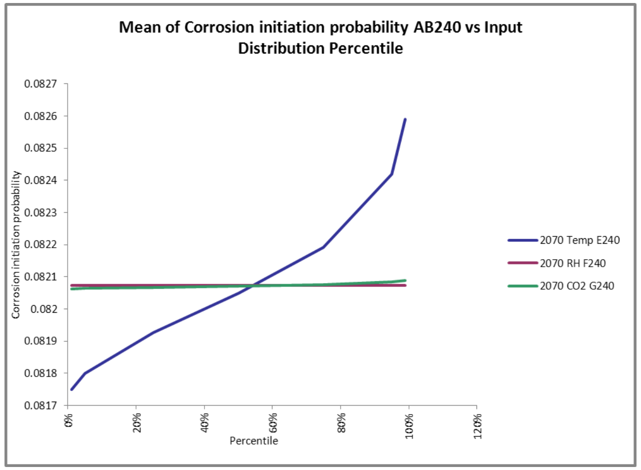
(MRI-CGCM2.3.2)



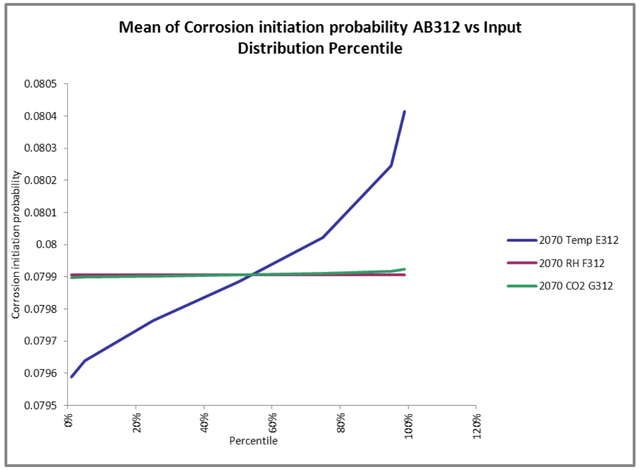
(MIROC-Medres)



(MRI-CGCM2.3.2)



(CSIRO Mk3.5)



(MIROC-Medres)

Figure 87: Sensitivity of crack damage probability at 2070 under A1FI emission

Appendix 5 PORT KEMBLA

Port Kembla is divided into an outer harbour and inner harbour. The berth and terminal areas are listed below:

Asset type	Description
Protection barrier	Eastern breakwater Northern breakwater Revetment (The Cut) West drain revetment Coal loader seawalls
Channels and basins	Outer harbour channel Inner harbour channel The Cut channel Eastern basin channel Western basin channel Multipurpose berth basin Berth 101 basin Berth 102 basin Berth 103 eastern basin Berth 104 basin Berth 201 basin Berths 202-205 north and south basin Berth 206 basin
Berths (jetties and wharves)	Berths 101 and 102 Berth 103 Berth 104 Berth 105-107 Jetty No 3 (Tug berths) Berth 201 Berth 202-205 Berth 206 Old Cut tug berth
Port estate, land and infrastructure	Land – landscaped areas, fallow areas Infrastructure – roads and bridges, drainage systems Services – low voltage power, water, sewerage pumping station
Buildings	Administration building Port operations building Training and conference building Port operations warehouse Signal station Survey boat building Coal terminal Multipurpose berth amenities Multipurpose berth ship repairers amenities Multipurpose berth cargo shed 1 Multipurpose berth cargo shed 2 Grain berth amenities Grain berth substation
Rail	Inner harbour - tracks 14.8 km, 30 turnouts, 5 bridges, 2 weighbridges, 1 level crossing, signalling, communications, electrical Outer harbour - tracks 15.1km, 74 turnouts, 2 bridges, 4 level crossing, signalling, communications, electrical, culverts and drainage systems

Inner harbour

Berth 101 (Bulk products berth)

- Leased to Port Kembla Coal Terminal which has responsibility for maintenance of the asset
- Coal utilisation of this berth has been historically low
- The length of the berth is 215m with a depth of 11.60m

Berth 102 (Coal berth)

- Leased to Port Kembla Coal Terminal which has responsibility for maintenance of the asset
- Utilisation of berth is approximately 73% but is capable of handling more throughput by modifying the stockpile management
- The length of the berth is 250m with a depth of 16.25m.

Berth 103 (Multi-purpose berth)

- Recently constructed berth that is used to handle bulk, breakbulk and containerised cargo
- The area behind the berth is leased to AAT but Port Kembla Port Corporation will remain responsible for berth maintenance up to 40m from berth face
- The length of the berth is 200m with a depth of 16.25m
- Solid berth with a bulkhead wall (tube piles) with tie rods to deadman anchors on sheet pile. A dolphin is located south of the berthing facility
- Concrete mix C, exposure class B2, 40 MPa, 60 mm cover (pile sockets, storm water pits, storm water trench drains, mass concrete and service pits)
- Concrete mix D, exposure class C1&C2, 50 MPa, 70 mm cover (wharf members (incl. precast), capping beams, reinforced pile plugs)
- Reinforcing bars grade 500N
- Bitumen surface
- Storm water design criteria ARI 1:20 years for paved, landscaped areas and roofed areas. Rainfall intensities designed for duration of 15 minutes for 1:20 years = 147 mm/hr
- HAT = RL 2.1m, MHWS = RL 1.6m, MSL = RL 1.0m, MLWS = RL 0.3m, LAT = 0.0m (datum)

Berth 104 (Grain berth)

- Ownership and responsibility of maintenance resides with PKPC
- Land behind berth is leased to Graincorp
- The length of the berth is 260m with a depth of 16.25m
- Due to recent drought conditions, occupancy of berth has been minimal and resulted in non-grain related use

Berth 105-107

- Port Kembla Port Corporation will remain responsible for berth maintenance up to 42 metres behind fender line
- AAT has an exclusive licence to use these berths and all land behind the berths
- The lengths of Berths 105, 106 and 107 are 124m, 130m and 290m respectively. The depth of these berths is 9.20m.
- Berth 105E was constructed in 2008
- Equipped with a Liebherr LHM 400 mobile crane
- Open pile berth except 107 (bulkhead)

- Concrete mix C, exposure class B2, 40 MPa, 60 mm cover (pile sockets, unreinforaced pile plugs, stormwater pits, mooring point, reinforced pile toe plugs and mass concrete)
- Concrete mix D, exposure class C1&C2, 50 MPa, 70 mm cover (wharf members (incl. precast), bulkhead capping beams, stormwater trench drains, reinforced pile top plugs, concrete pavement)
- Storm water design criteria ARI 1:20 years for paved and landscaped areas. Rainfall intensities designed for duration of 15 minutes for 1:20 years = 227 mm/hr
- HAT = RL 2.1m, MHWS = RL 1.6m, MSL = RL 1.0m, MLWS = RL 0.3m, LAT = 0.0m (datum)

Berth 108-113
- Bluescope Steel owned, operated and maintained

Outer harbour
Berth 201 (Oil berth)
- Berth has limited use. Limited by the handling capabilities of bulk liquid products up to 50,000 dwt
- Original T-head timber jetty was constructed in 1939 while concrete dolphins were installed in 1984 with bulk liquids capabilities
- Berth has a restricted depth of 10.3 m and cannot be deepened without reconstruction of T-head jetty and structural modifications to dolphins
- Over 70 years old and beyond original design life
- Annual condition based maintenance of $30k per annum
- Major periodic maintenance of additional $60k every 2 years
- Berth will be demolished in future to make way for Outer Harbour development

Berths 202-205 (Port Kembla Gateway North and South)
- The gateway facility consist of four berths (north and south)
- Average occupancy is 28%
- Gateway is responsible for maintenance of these facilities until 2022
- Berths 202 & 203 are cargo handling berths. Jetty is used for bulk and breakbulk cargoes
- Berth 204 & 205 can only be used by shallow drafted vessels or tie up of barges. Cargo handling over these berths is limited and hardly takes place

Berth 206 (Bulk liquids berth)
- This berth has a low occupancy rate of 3%
- Berth is capable of accommodating additional liquid bulk trades but to date there is limited demand
- Berth 206 was constructed in 1999 as part of an extension to Jetty No 4 which was built in 1929
- Timber jetty is over 80 years old and beyond its original design life
- Concrete deck upgrade in 1999 but still supported by old timber piles
- Deteriorated timber piles has been replaced with steel piles
- To cater for larger ships, berth deepening would be required with rock dredging
- Future plans involve demolishment to make way for Outer Harbour development
- All concrete structures (including pile infills) are 50 MPa. Cover for concrete deck is at a minimum of 50 mm while working platforms and dolphins are at a minimum of 75 mm

Tug berth (Jetty No 3)

- Berth currently occupied by Svitzer for mooring of tugs used to service the port
- Port Kembla Port Corporation has the responsibility to maintain this facility
- Minimal maintenance to ensure safety
- Constructed in 1940 and is now derelict
- Timber jetty is beyond 70 years old and beyond its original design life
- Upgraded in 2000 but only 10 year design life. Total cost of 10 year maintenance plan is $3.425M
- Jetty under footprint of Outer Harbour reclamation

Inner harbour rail infrastructure

- 14.8km plain track
- Coal loop built in 1981
- Grain loop built in 1986
- Track generally in good condition but 16,000 or 25,000 sleepers are timber and require replacement over next 5 years
- 30 turnouts require replacement in next 5-10 years
- 53kg rail needs to be upgraded to 60kg rail

Outer harbour rail infrastructure

- 15.1km plain track
- Track general condition is fair to poor.
- South Yard is leased by Pacific National, responsible for minor maintenance by no renewals
- North Yard is a parking lot and not maintained
- Predominantly timber sleepers, only a few hundred are concrete. Timber sleepers are well beyond 25 year design life and require replacement
- All sidings have 47kg rail, will need to be replaced if heavier axle loadings are required

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