Department for Environment Food & Rural Affairs

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delivering benefits through evidence

Impact of climate change on asset deterioration

Appendix B – Asset deterioration assessments

Report - SC120005/R3

Flood and Coastal Erosion Risk Management Research and Development Programme

We are the Environment Agency. We protect and improve the environment.

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We protect and improve the quality of water, making sure there is enough for people, businesses, agriculture and the environment. Our work helps to ensure people can enjoy the water environment through angling and navigation.

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We can't do this alone. We work with government, local councils, businesses, civil society groups and communities to make our environment a better place for people and wildlife.

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This report is the result of research commissioned and funded by the Joint Flood and Coastal Erosion Risk Management Research and Development Programme. The Joint Programme is jointly overseen by Defra, the Environment Agency, Natural Resources Wales and the Welsh Government on behalf of all Risk Management Authorities in England and Wales:
https://www.gov.uk/government/organisations/flood-and-coastal-erosion-risk-management-research-and-development-programme

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If you have any comments or questions about this report or the Environment Agency's other scientific work, please contact research@environment-agency.gov.uk.

Professor Doug Wilson
Director, Research, Analysis and Evaluation

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1 Approach

1.1 Introduction

This appendix provides core outputs from this project, mapping the potential changes in deterioration of different assets in different settings as a result of a series of climate change factors. These are presented as deterioration process diagrams. Associated with each of those is a qualitative assessment of the potential change in vulnerability of those asset types to those changes. Sections 2 and 3.3 of the main report provide further details on the approach applied here, with an overall summary of the findings presented within Section 4.2 of that.

This appendix contains the full qualitative assessments for a range of asset types in different settings identifying potential changes in deterioration due to the primary climate change factors and from that assigning a relative level of potential vulnerability.

Further to the main assessments, and to avoid too much repetition of detail, a number of supplementary assessments were performed. These were assets for which a full qualitative assessment under coastal or fluvial had been undertaken, but also exist in another environment and warrant consideration. Although some assets in an estuary environment have been fully assessed and reported upon, the supplementary assessments were 'light touch' reviews of some of those additional cases to determine whether, in a different environment, the impacts of climate change may be of a different magnitude.

The development of deterioration processes and impacts of climate change upon those, also identified areas of commonality. There were some basic descriptions which could apply to, or be adapted for, more than one asset type. These included some material types, for example concrete, and some element types, for example steel sheet piled toe. Deterioration process assessments for those were therefore produced.

Also included are a number of additional assessments for assets which have already had a full qualitative assessment, but where it was noted that there might be notable deterioration effects from climate change factors other than the primary hydrodynamic ones, and warranted further consideration.

Further details on the definition of deterioration, including the distinction between deterioration and performance are included in the main study report (Section 2.1). Likewise, details on the climate change factors against which this potential for deterioration has been assessed, are also detailed in the main study report (Section 2.3).

1.2 Qualitative assessment

Background

There exist a range of levels and associated techniques at which an assessment of impacts might be performed, with varying levels of complexity and data requirements, which were explored as part of the scoping study. Based upon the conclusions of that, qualitative assessments have been undertaken to identify how each asset might experience a change in deterioration from climate change, and what the relative magnitudes of that vulnerability might be.

The scoping study considered different qualitative approaches to assess the vulnerability of assets to climate change. These showed that sound engineering judgement could be used to build up frameworks for HML (High/Medium/Low) assessments. Rigorous development of such methods is useful, although it is important that such assessments do not lead to oversimplifying the issues. It is also only possible to make a broad (and highly subjective) relative assessment, i.e. comparing one asset type with another, without still being able to determine the degree of vulnerability and actual risk. These also illustrate that it is often important to understand the environmental setting of the asset, which can vary considerably, e.g. whether it is in a fluvial or coastal setting, whether the bed material is silt or gravel, etc, and the construction of the asset, e.g. whether it is made of timber or concrete.

In developing the qualitative approach for this study, these points have been taken into account and from the initial list of 47 FCERM asset types (outlined in Section 2.2 of the main study report), consideration has been given to changes in environmental setting and differences in construction forms and materials. This assessment remains 'high level' but even with these additional considerations to the generic asset type, the ability to define deterioration processes and assess each asset has been improved considerably.

Approach Adopted

The focus has been on identifying the deterioration processes that would be impacted by climate change, and making a purely qualitative assessment of those. In all cases more than a single expert has been engaged to develop and challenge the assessments.

In defining the deterioration processes, impacts upon those and qualitative assessment, the approach has been as follows:

1. Define the asset
    a. Consider the definition for each asset type – how might this vary and to what extent will that variability affect the deterioration of that asset type.
    b. Consider the different environmental settings for each asset type – how might that vary and to what extent could that affect the deterioration of that asset type.
2. Determine the deterioration processes
    a. Consider for each asset type the various deterioration/failure processes and types of maintenance regime; define/describe those processes
    b. Consider how the effects of defined climate change factors and loadings might impact upon each of those.
    c. Develop schematic representation of these potential impacts on the deterioration processes
3. Carry out Qualitative Assessment
    a. Identify the key vulnerability(ies) for that asset type
    b. Describe how/why this asset is/is not vulnerable to support the Qualitative Assessment (High, Moderate, Low, Negligible – see below)

c. Identify any variations to this assessment (e.g. for different settings, materials etc)

4. At the same time, identification of the following were made:

   a. any potential for other climate change factors to be of significance for this asset type, and

   b. any performance related impacts or effects from the deterioration of other assets that may impact upon this asset

5. For those assets where other (non-hydrodynamic) climate change factors could affect their deterioration, further assessments have been made in the same manner as (1) to (3) described above.

Qualitative Definitions

In order to achieve some consistency in conclusions from the qualitative assessments, and to be able to be able to determine which assets were most vulnerable, it was necessary to assign some description of magnitude. Although subjective, as is the nature of qualitative assessment, it was considered most logical to try and relate the change in deterioration to the effort that would be needed to address that change. It was decided that an assets vulnerability to deterioration would be described as either 'High', 'Moderate', 'Low' or 'Negligible', and the definitions below were used.

HIGH

change could result in **a significant (large or rapid) increase** in maintenance commitment and/or chance of failure due to deterioration

MODERATE

change likely to result in **a notable increase** in maintenance requirements or repair/replacement of elements due to deterioration but **without significantly increasing** failure probability

LOW

impacts may result in **some small increases** to the level of maintenance due to deterioration, e.g. the potential for some increase in the frequency of routine activities

NEGLIGIBLE

the impact of climate change factors on deterioration will result in **little if any change** to the maintenance of the asset

1.3 Assessment and Reporting Templates

To achieve consistency in capturing and relaying the outputs from the expert reviews, a template was developed for use.

This template (shown on next page) provides a definition of the asset type as presented in CAMC, with further description provided to give more detail on the typical form and characteristics of that asset type. This enables the user to get a better appreciation of those asset types and the variations that can exist, which is not always clear from the CAMC definitions. As a consequence of this variability even at a generic level, for some asset types there is more than one assessment made, which are presented separately (e.g. Embankment-Turfed, Embankment with Permeable Revetment and Embankment with Impermeable Revetment). There are also separate assessments made for similar asset types that may be found in different settings (i.e. Coastal, Fluvial, and Estuary).

The description then moves on to list the climate change factors that have been considered in that particular assessment, which are primarily determined by the setting of that asset. Also noted here are whether any other climate change factors may have potential to produce a notable effect on deterioration, with that potential noted.

Embedded within the template are the deterioration process diagrams, showing users of these assessments the relationships between the climate change factors and effects on deterioration. The processes identified here are not intended to be exhaustive of all deterioration processes, just the main areas where climate change might have an impact. Further, within these the processes that have been assessed to be likely to have little influence relative to the others shown, are identified as dashed lines, whilst those processes that are likely to be most significant relative to the others, are indicated as bolder red lines. A key to those diagrams is also shown below.

The remainder of the assessment template then provides a narrative of what is presented in those diagrams, focussing on the more significant mechanisms for changes in deterioration. Also noted here are possible implications for maintenance and repairs as a consequence of this, which should be useful to asset operators and managers, supporting the subsequent conclusion on the potential magnitude of the impact upon that asset type.

The final section of the template includes any further notes on other potential impacts which are not specific to this asset or deterioration specific, but worth noting by those responsible for managing or assessing these assets.

In addition to these assessments, a number of supplementary assessments were carried out, plus assessments of the impacts from other climate change factors for a small selection of asset types, as described in section 1.1 above. Further templates were developed along similar lines for those, which are again shown below.

Key to Qualitative Assessment Reports

ASSET TYPE: e.g. **Weir**	ENVIRONMENT: e.g. **Fluvial**

DESCRIPTION

<u>DEFINITION IN CAMC:</u>
Quote the description used in CAMC for this asset type

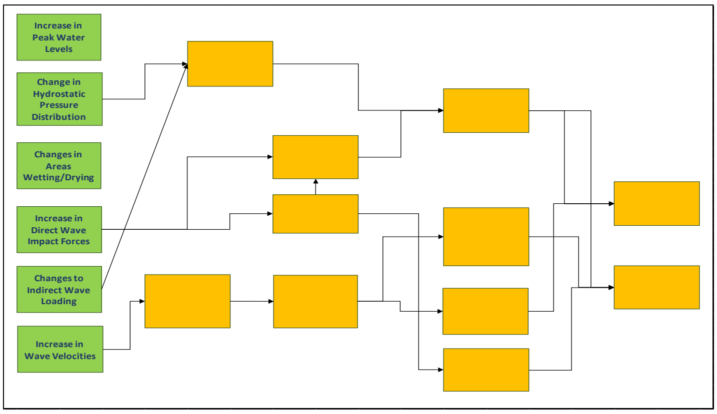
Add to above description. Discuss variations etc (form, type, setting etc) or other general notes relevant to the subsequent assessment

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes/No	Yes/No	Yes/No	Yes/No	Yes/No

Anything to note on 'other' climate change factors considered

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

Mapping of deterioration processes and climate change influences on those.



QUALITATIVE ASSESSMENT

Description of key aspects of climate change impacts on deterioration of the asset
What does this mean for increased maintenance/repairs etc?

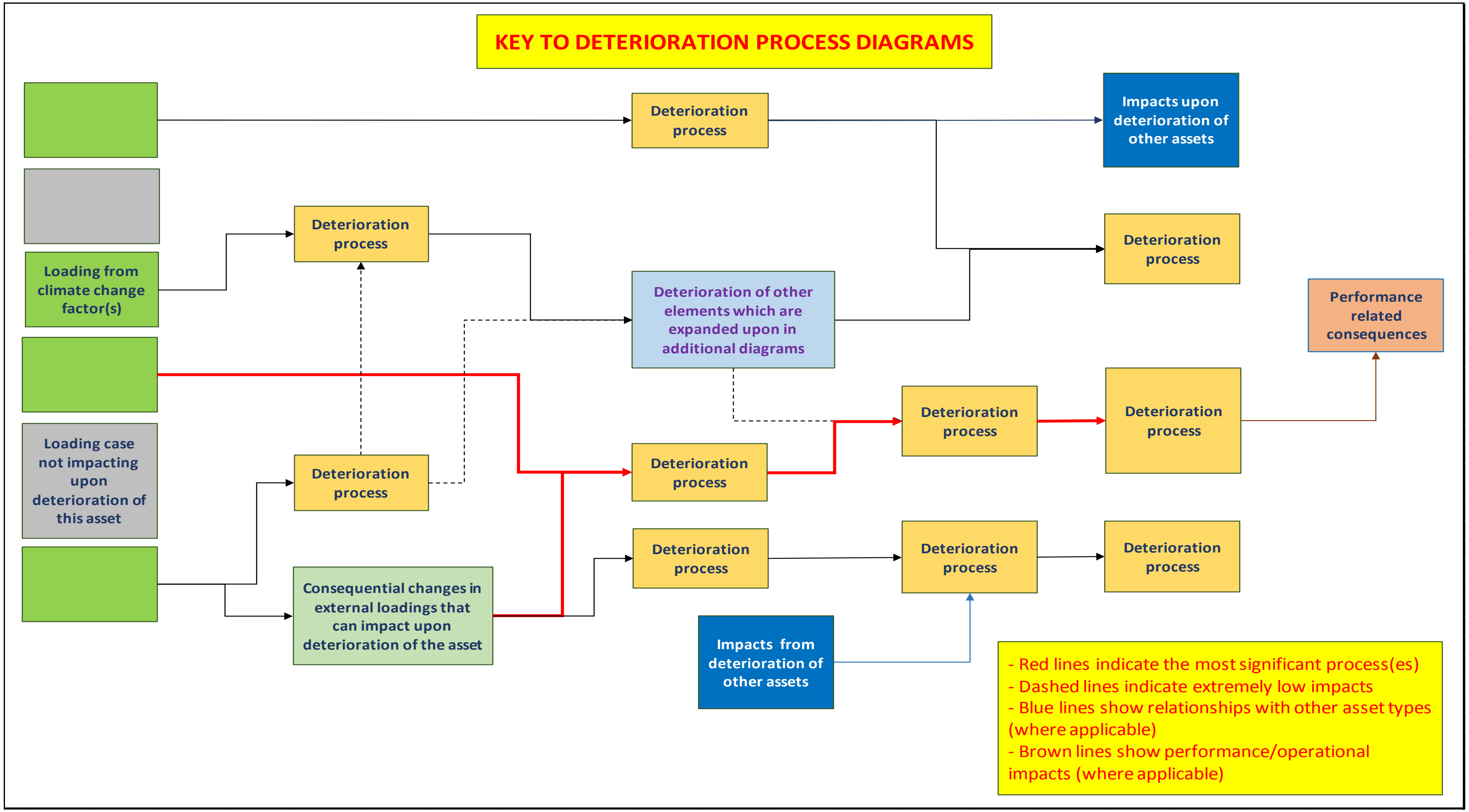
Provide supporting information for qualitative magnitude of vulnerability

MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
?	?	?	?

OTHER POTENTIAL IMPACTS

Performance related impacts/issues (as above text should relate to <u>deterioration</u> only)
Comment on systems/wider effects (as above text should relate to <u>the asset</u> only)

Key to Deterioration Process Diagrams



Key to Supplementary Assessment Reports

SUPPLEMENTARY ASSESSMENTS

DESCRIPTION (GENERIC)

Typically the description of the asset will be made in the full qualitative assessment for that asset; only where differences in another environment are notable and pertinent to that supplementary assessment are these details presented.

Typically, the climate change factors considered for all of these supplementary assessments will be as follows:

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
Yes	Yes	No	Yes	No

There are also a few instances where the full assessment has been carried out in one of those environments (including estuary) but may also be found in a coastal or fluvial environment. In those cases, refer to the main assessment to determine which climate change factors will have been considered.

DETERIORATION PROCESS DIAGRAMS

In these light touch reviews deterioration process diagrams have not been produced.

QUALITATIVE ASSESSMENT

A brief overview of any differences between the impacts of climate change in the estuary environment and the primary assessment is presented, to support the assessment of magnitude.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE

OTHER POTENTIAL IMPACTS

These have not been included in the supplementary assessments.

Key to Supplementary Assessment Reports

ADDITIONAL CLIMATE CHANGE FACTORS

ADDITIONAL CLIMATE CHANGE FACTORS

Typically the description of the asset is included in the full qualitative assessment for that asset and is therefore not repeated here. Mention is only made of any specific characteristics for the asset type that is being considered by this this assessment.

The climate change factors considered for all of these assessments will be as follows:

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
Yes/No	Yes/No	Yes/No	Yes/No

VULNERABILITY

A description of key aspects of climate change effects upon the deterioration of the asset and what that might mean for increased maintenance etc.

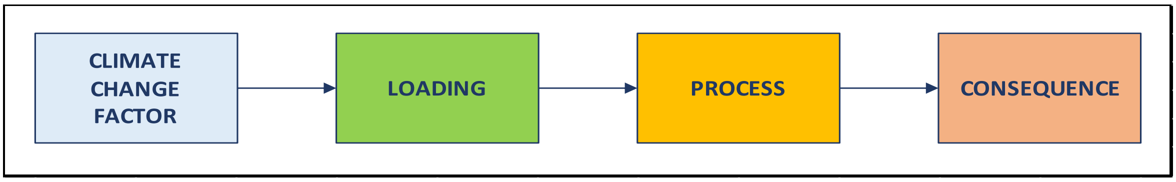
A qualitative assessment of the magnitude of impact from these additional climate change factors is considered and compared with that determined for the primary hydrodynamic factors.

DETERIORATION PROCESS DIAGRAMS

Further diagrams are provided mapping the influence of these additional climate change factors upon deterioration processes.

1.4 Relationships between Climate Change Factors and Asset Loading

As well as considering each climate change factor individually, it is important to look at the cumulative effects of these. Several of them lead to the same consequences in terms of changes in loading or force on the asset. Therefore, in considering deterioration processes, a framework (illustrated here) has been developed by which the climate change factors are translated into potential loadings, and from that deterioration processes and consequences.



This has been adopted for developing relationships that can help to qualitatively and quantitatively establish how climate change will affect deterioration of an asset, where the key areas of vulnerability lie, and what the impact of that might be. It provides transparency with the contributing factors for any consequence upon the asset readily traceable. The subsections below demonstrate how the loadings presented with the qualitative assessments have been derived from the climate change factors.

Coastal

Coastal is open coast, i.e. the sea, and saltwater, and the following climate change factors have to be considered:

- Sea Level Rise;
- Storm Surge; and
- Wave Climate.

The relationship between these climate change factors (blue boxes) and asset loading conditions (green boxes) are set out in Figure B1.1 below.

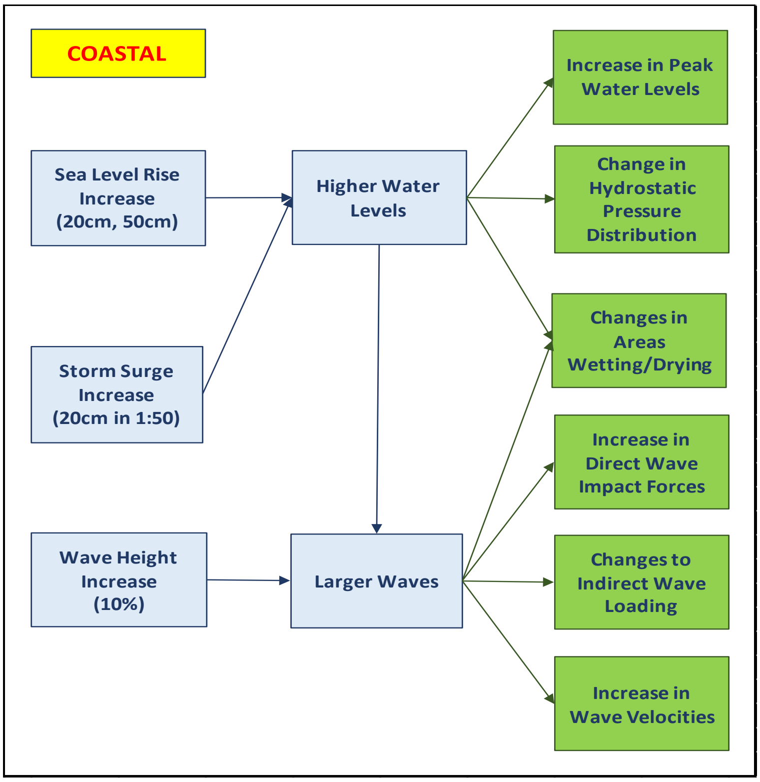


Figure B1.1 Relationship between climate change factors and asset loading (Coastal)

Within the coastal environment, waves at the shoreline are generally depth-limited; that is, the water depth has a direct influence on the maximum size of wave that can reach the shoreline and thus impact upon any asset.

Sea level rise will have a constant (day-to-day) impact upon assets, which in itself can have a day-to-day impact upon the size of waves reaching the shoreline. However, storm surges, and wave height increases are impacts which are only accounted for in extreme events (i.e. storms).

Fluvial

This is defined as a river, i.e. a channel, and freshwater, with no tidal influence, and in the context of the climate change factors being considered her, only the following applies:

- Fluvial Flows.

The relationship between this climate change factor (blue boxes) and asset loading conditions (green boxes) are set out Figure B1.2.

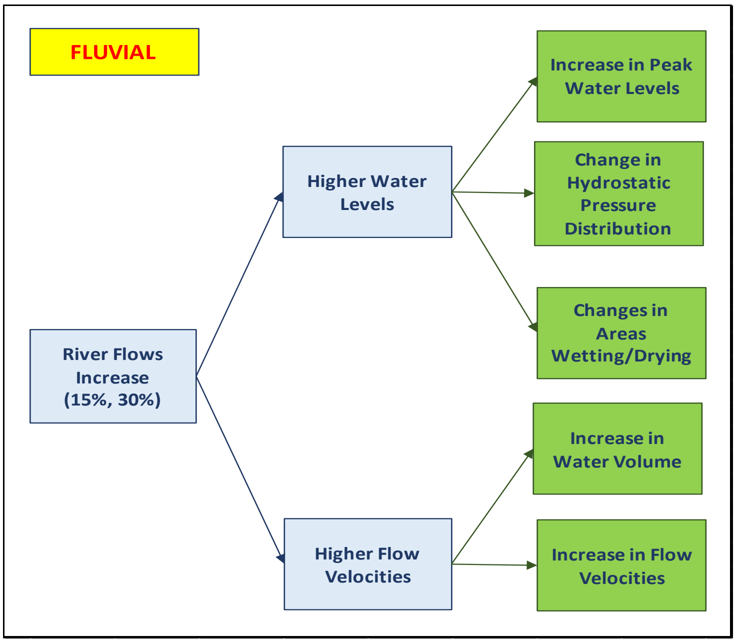


Figure B1.2 Relationship between climate change factors and asset loading (Fluvial)

Fluvial flow increases will not have a constant (day-to-day) impact but would have a regular impact, i.e. coincident with any periods of higher rainfall.

This is the area upstream of any tidal or storm surge influence, but it is also worth noting that with sea level rise that tidal boundary will shift move further upstream. The extent of that will be geographically dependent as tidal range varies, as well as dependent upon the specific characteristics of that river.

Estuary

Between the river and the sea lies the tidally influenced areas referred to variously but including 'Estuary' and 'Tidal River'. For the purposes of this project, they have been collectively referred to as Estuary, albeit noting below that some differences in the dominant influences will occur within these water bodies.

Estuary

An estuary can often take the form of a large (wider) water body, i.e. not river channel, primarily saltwater dominated. The following climate change factors therefore need to be considered:

- Sea Level Rise;
- Storm Surge; and
- Fluvial Flows (maybe).

It is possible that increases in river flows could have a small influence here, but in the context of this study it is assumed that those might be dissipated to a large extent once the wider estuary is reached, and it is also assumed that within the larger water body of an estuary any changes in water volume would not be significant in terms of raising water levels.

The relationship between these climate change factors (blue boxes) and asset loading conditions (green boxes) are set out in the Figure B1.3 below.

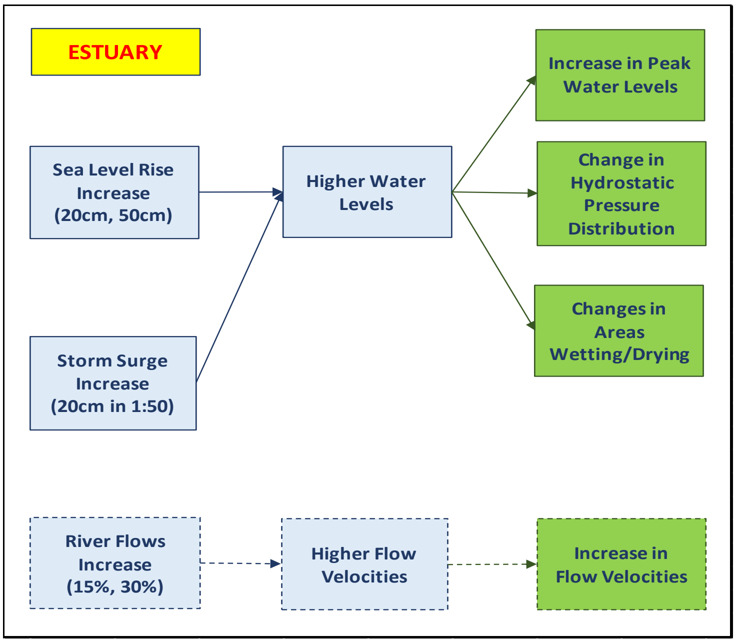


Figure B1.3 Relationship between climate change factors and asset loading (Estuary)

Sea level rise will have a constant (day-to-day) impact upon assets. Increased water levels due to storm surges would be a factor in extreme events (i.e. storms). If river flow increases are of consequence for an asset in an estuary environment, this would not be a constant (day-to-day) issue, but would be a regular (several times per year) occurrence.

Note that the estuary water body will generally be sheltered from ocean waves, so the impacts of changes in wave climate are likely to be slight. There will though be wave action to take into account in terms of loading on assets, but that will be from locally generated waves not the offshore wave climate. Within estuaries these waves are generally fetch limited, not depth limited, and therefore would not be significantly affected as a consequence of changes in water levels; the main difference would be that waves of similar height to present would impact upon assets at a higher elevation.

Tidal River

Where an estuary narrows, i.e. it becomes a channel but where tidal waters can reach, this is also sometimes referred to as tidal river. This too will have saltwater intrusion but will be primarily freshwater dominated. In those settings, the following climate change factors need to be considered:

- Sea Level Rise;
- Storm Surge; and
- Fluvial Flows.

The relationship between these climate change factors (blue boxes) and asset loading conditions (green boxes) are set out in Figure B1.4.

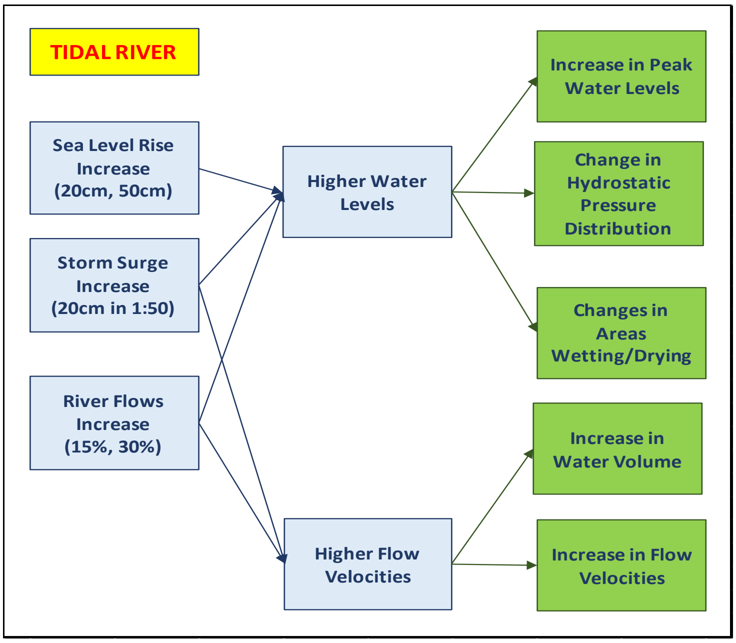


Figure B1.4 Relationship between climate change factors and asset loading (Tidal River)

Within a tidal river there is assumed to be no wave activity, but assets here will be affected by sea level rise and storm surges increasing water levels.

Sea level rise will have a constant (day-to-day) impact upon assets whilst increased water levels due to storm surges would be a factor in extreme events (i.e. storms). But both of these will have a diminishing effect moving upstream. If river flow increases are of consequence for an asset in an estuary environment, this would not be a constant (day-to-day) issue, but would be a regular (several times per year) occurrence.

Additional Climate Change Factors

The above hydrodynamic factors are by no means an exhaustive list of all the climate parameters that could possibly change in the future, and which could impact FCERM assets. Where it is considered that any additional climate change factors could have a potential impact of any significance, this has been identified as part of the deterioration processes assessment. For those asset types where it was considered that these effects should be considered further, then an additional assessment of vulnerability has been undertaken.

For the four ‘additional’ climate change factors included in this appraisal, the initial stage in identifying potential deterioration processes was the definition of seven loading conditions that could directly impact FCERM assets. The relationship between these climate change factors (blue boxes) and asset loading conditions (green boxes) are set out in the figure below.

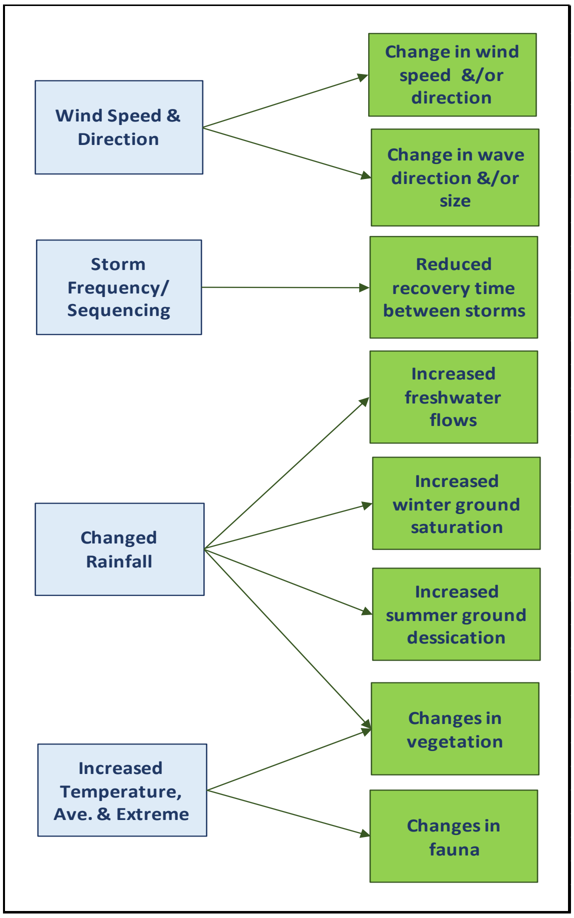
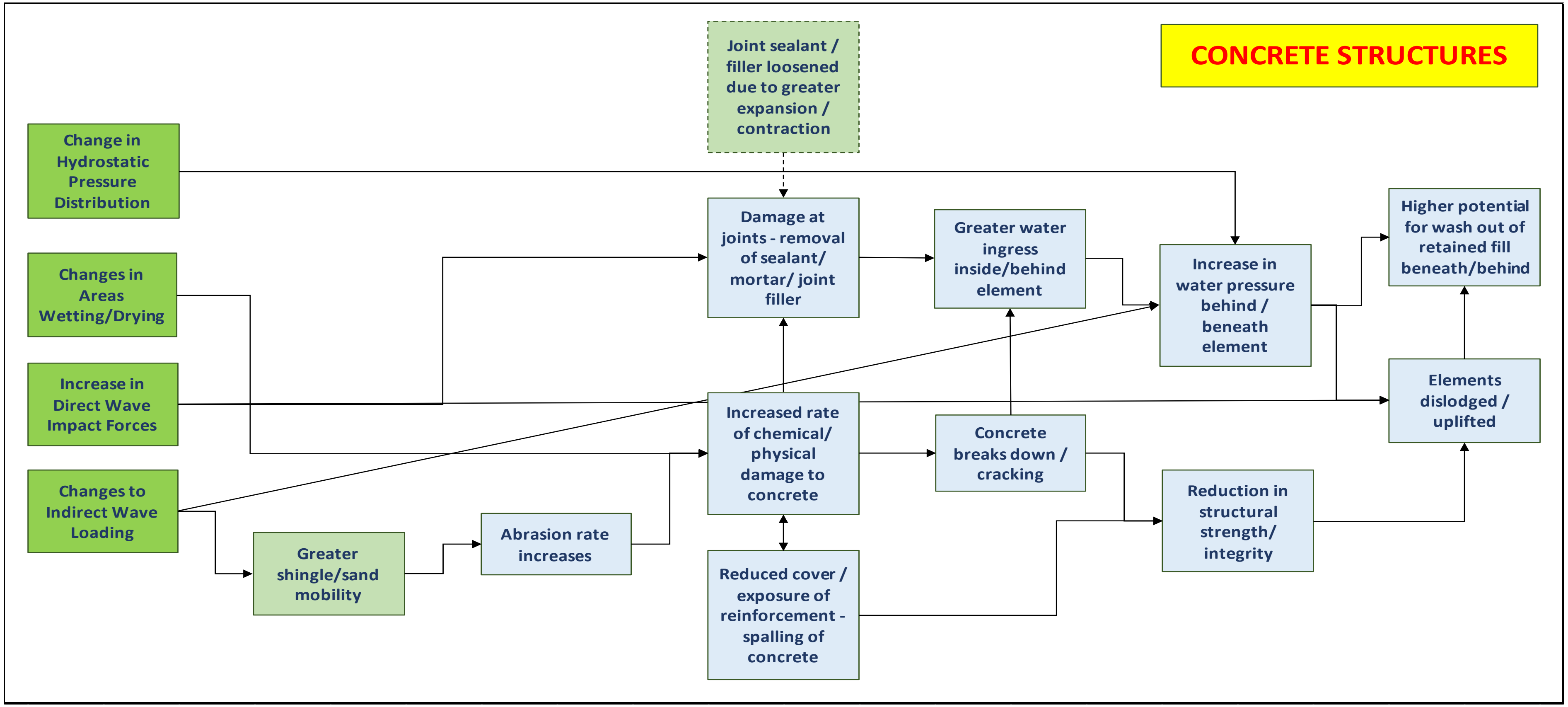
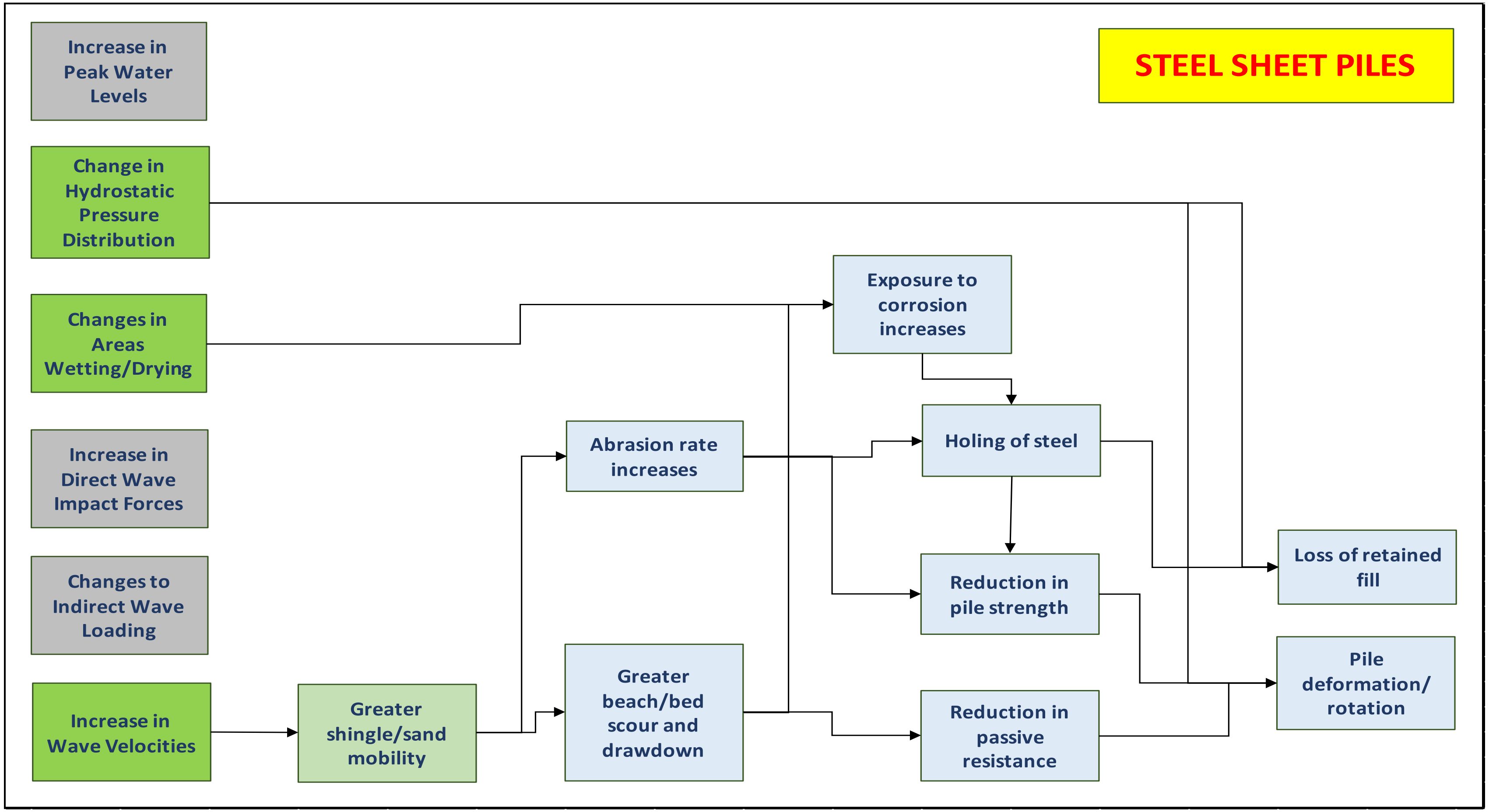


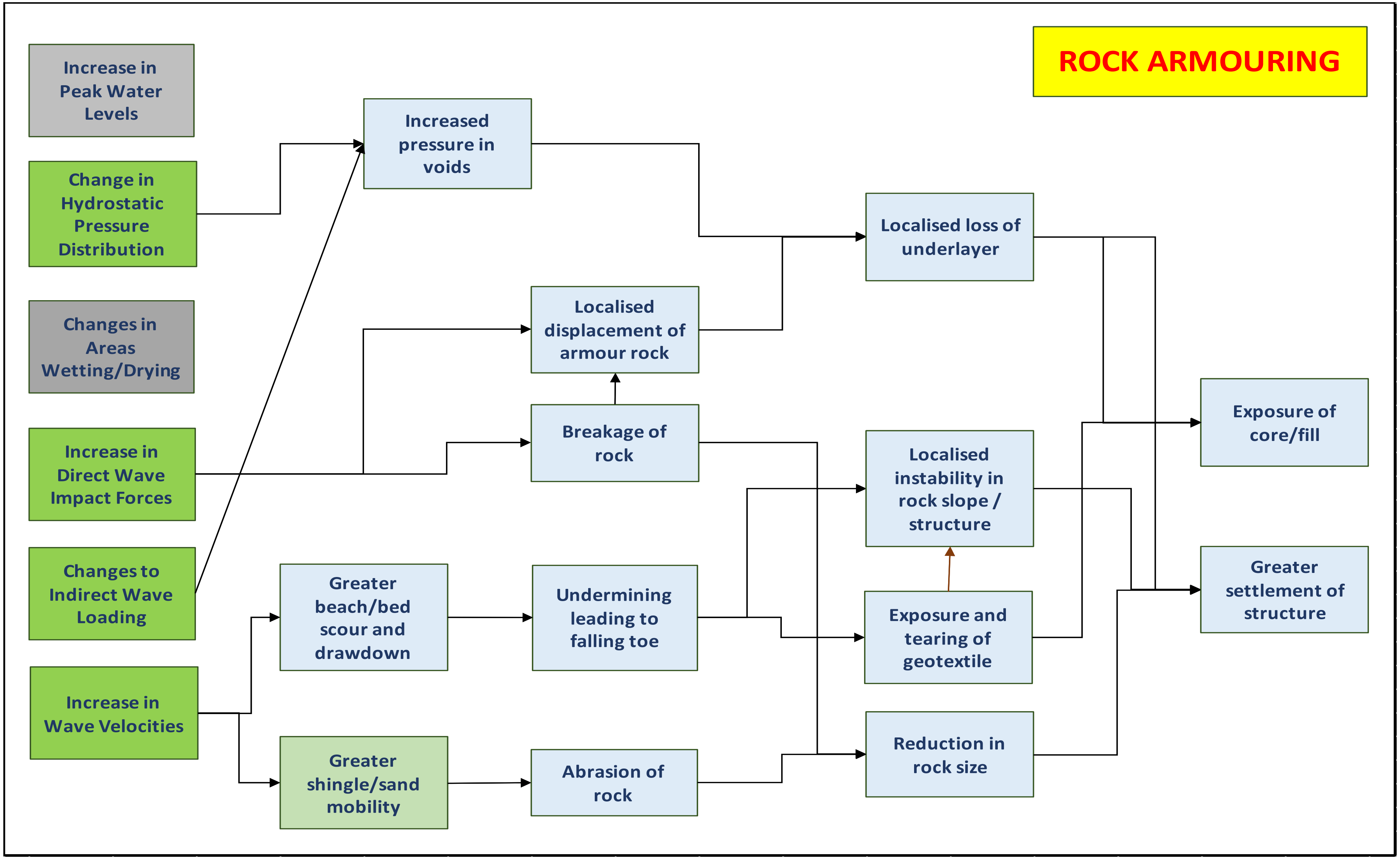
Figure B1.5 Relationship between 'additional' climate change factors and asset loading.

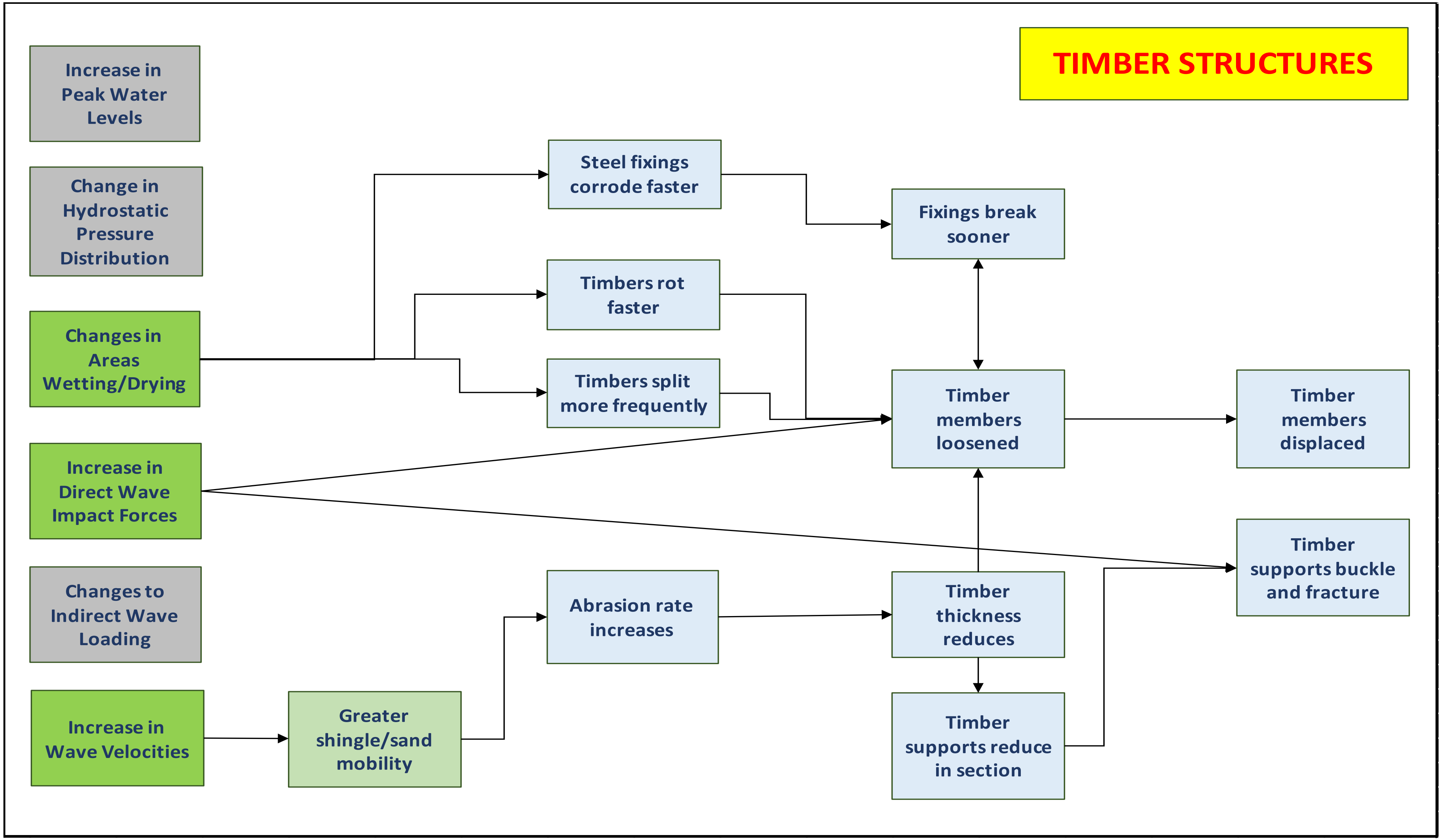
2 Generic Element/Material Types


CONCRETE STRUCTURES
Joint sealant / filler loosened due to greater expansion / contraction
Change in Hydrostatic Pressure Distribution
Changes in Areas Wetting/Drying
Increase in Direct Wave Impact Forces
Changes to Indirect Wave Loading
Damage at joints - removal of sealant/ mortar/ joint filler
Greater water ingress inside/behind element
Increase in water pressure behind / beneath element
Higher potential for wash out of retained fill beneath/behind
Increased rate of chemical/ physical damage to concrete
Concrete breaks down / cracking
Elements dislodged / uplifted
Greater shingle/sand mobility
Abrasion rate increases
Reduced cover / exposure of reinforcement - spalling of concrete
Reduction in structural strength/ integrity

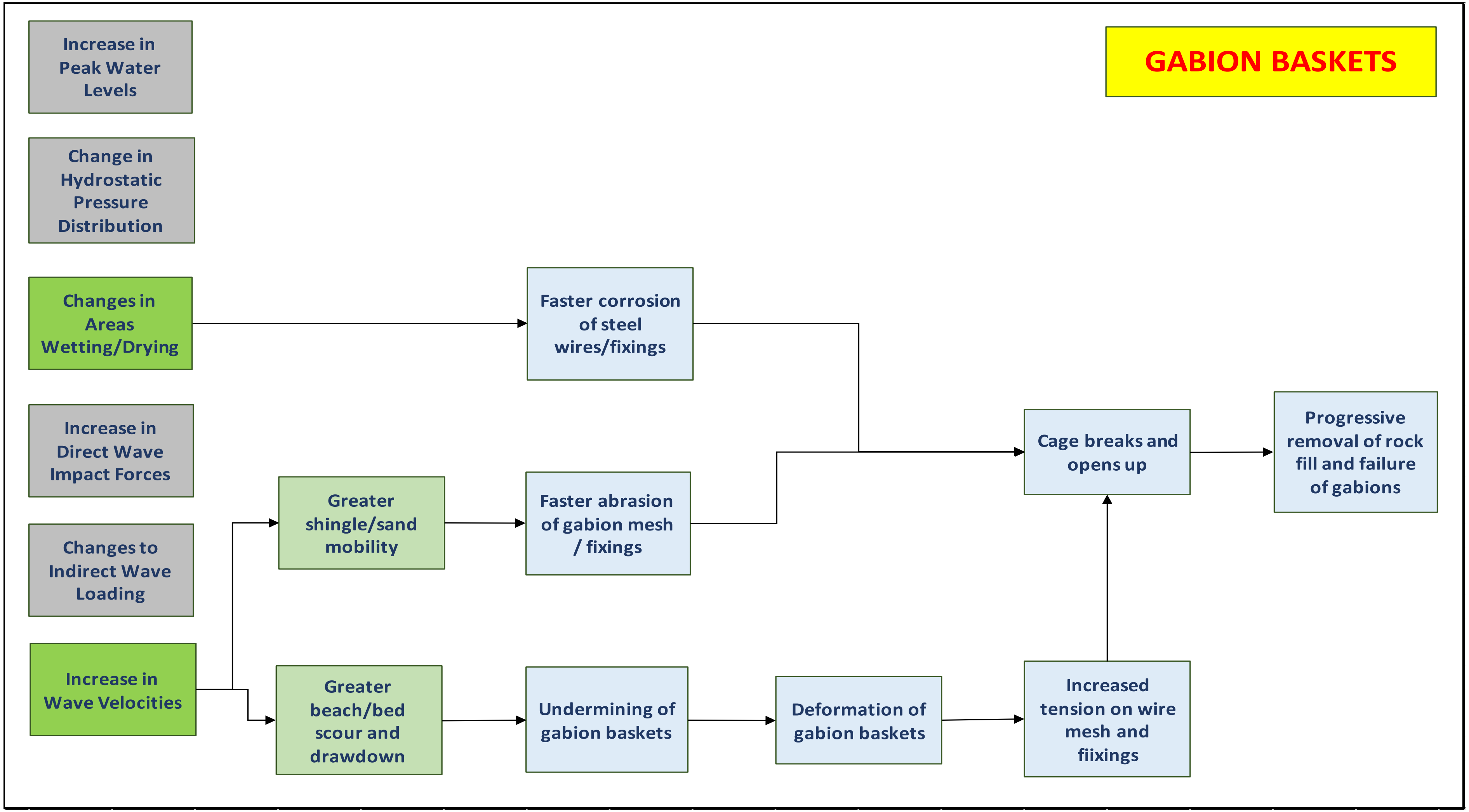


STEEL SHEET PILES
Increase in Peak Water Levels
Change in Hydrostatic Pressure Distribution
Changes in Areas Wetting/Drying
Increase in Direct Wave Impact Forces
Changes to Indirect Wave Loading
Increase in Wave Velocities
Greater shingle/sand mobility
Abrasion rate increases
Greater beach/bed scour and drawdown
Exposure to corrosion increases
Holing of steel
Reduction in pile strength
Reduction in passive resistance
Loss of retained fill
Pile deformation/ rotation


ROCK ARMOURING
Increase in Peak Water Levels
Change in Hydrostatic Pressure Distribution
Changes in Areas Wetting/Drying
Increase in Direct Wave Impact Forces
Changes to Indirect Wave Loading
Increase in Wave Velocities
Increased pressure in voids
Localised displacement of armour rock
Breakage of rock
Greater beach/bed scour and drawdown
Undermining leading to falling toe
Greater shingle/sand mobility
Abrasion of rock
Localised loss of underlayer
Localised instability in rock slope / structure
Exposure and tearing of geotextile
Reduction in rock size
Exposure of core/fill
Greater settlement of structure



TIMBER STRUCTURES
Increase in Peak Water Levels
Change in Hydrostatic Pressure Distribution
Changes in Areas Wetting/Drying
Increase in Direct Wave Impact Forces
Changes to Indirect Wave Loading
Increase in Wave Velocities
Greater shingle/sand mobility
Steel fixings corrode faster
Timbers rot faster
Timbers split more frequently
Abrasion rate increases
Fixings break sooner
Timber members loosened
Timber thickness reduces
Timber supports reduce in section
Timber members displaced
Timber supports buckle and fracture



GABION BASKETS
Increase in Peak Water Levels
Change in Hydrostatic Pressure Distribution
Changes in Areas Wetting/Drying
Increase in Direct Wave Impact Forces
Changes to Indirect Wave Loading
Increase in Wave Velocities
Faster corrosion of steel wires/fixings
Greater shingle/sand mobility
Faster abrasion of gabion mesh / fixings
Greater beach/bed scour and drawdown
Undermining of gabion baskets
Deformation of gabion baskets
Increased tension on wire mesh and fiixings
Cage breaks and opens up
Progressive removal of rock fill and failure of gabions

3 Coastal Assets

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Embankment	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Defence'

"An embankment is an earthen structure used in fluvial, tidal and coastal environments for flood defence and/or erosion protection. Also covers embankments used in dam structures"

In the context of coastal embankments, these are Seawalls providing flood defence, and will tend to be protected, i.e. have some form of cover layer on their seaward slope and in almost all circumstances have some form of protection on their crest. Many, but not necessarily all, will be likely to have some form of protection on their rear face too. Separate assessments have been made for other seawall types under Seawalls (vertical walls) which also provide flood defence, and Revetment Type walls providing coastal protection.

Front face protection will generally be in the form of a reinforced concrete revetment (sloped seawall) or rock armour with some form of underlayer. This will generally be toed into the beach/foreshore, in the case of concrete slopes commonly with a steel sheet piling, otherwise a concrete toe beam.

Embankments are difficult to evaluate generically due to the variety of construction forms and materials that may exist, so some broad assumptions have to be made at this qualitative levels, considering the various elements separately, as follows:

- FRONT FACE & TOE – Concrete slabs/steps/seawall of various constructions which will be subject to same failure/deterioration mechanisms as other seawall types and concrete structures at the coast. Rock armour slope will be similar failure/deterioration mechanisms as a rock revetment at toe of cliffs and other rock structures at the coast.
- CREST – In a coastal setting this is likely to be similar to promenade, i.e. concrete or asphalt covered pathway/roadway. It might include a crown/capping wall, most likely to be concrete construction.
- INTERNAL – Earth bund, which could be comprised of a range of different materials, or a composite of many.
- REAR FACE – Might be protected (e.g. concrete panels), not protected at all (grassed slope) or grassed with some reinforcement (e.g. voided concrete blocks or similar).

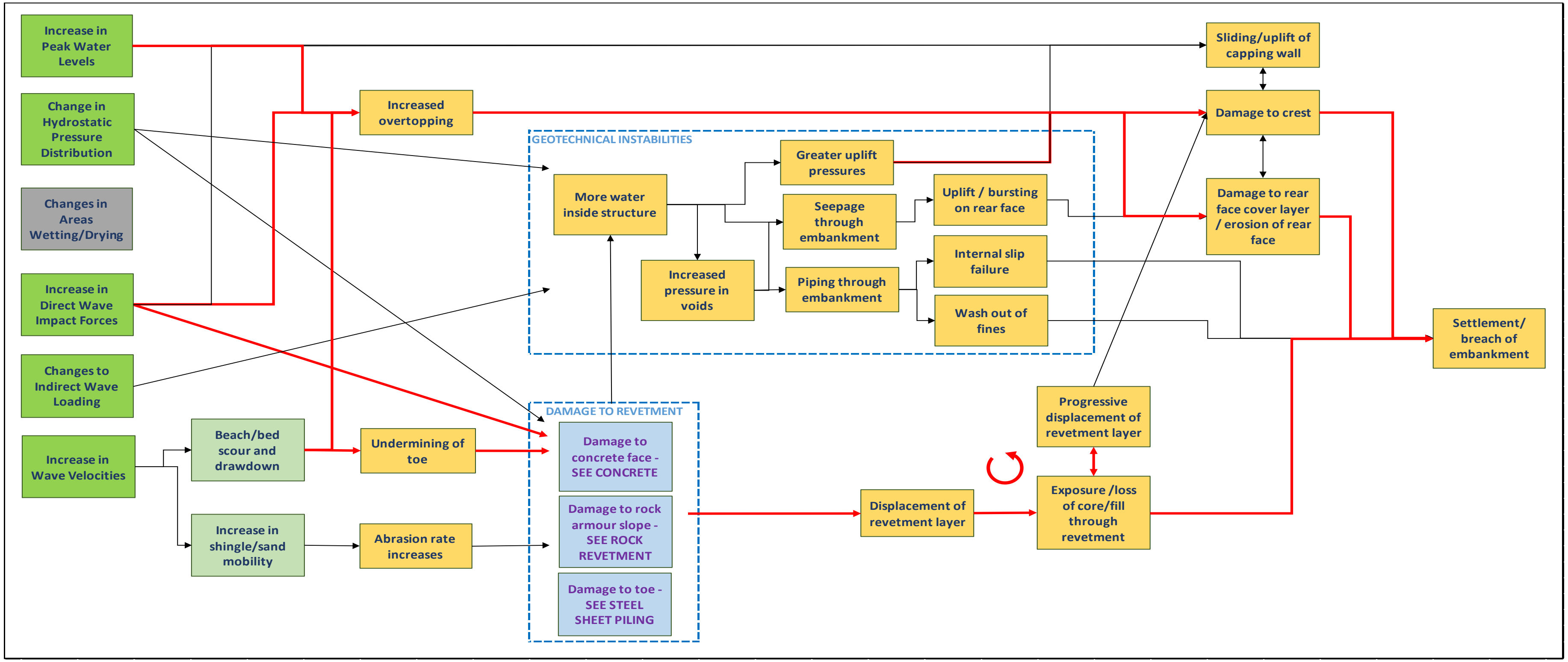
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Embankment	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

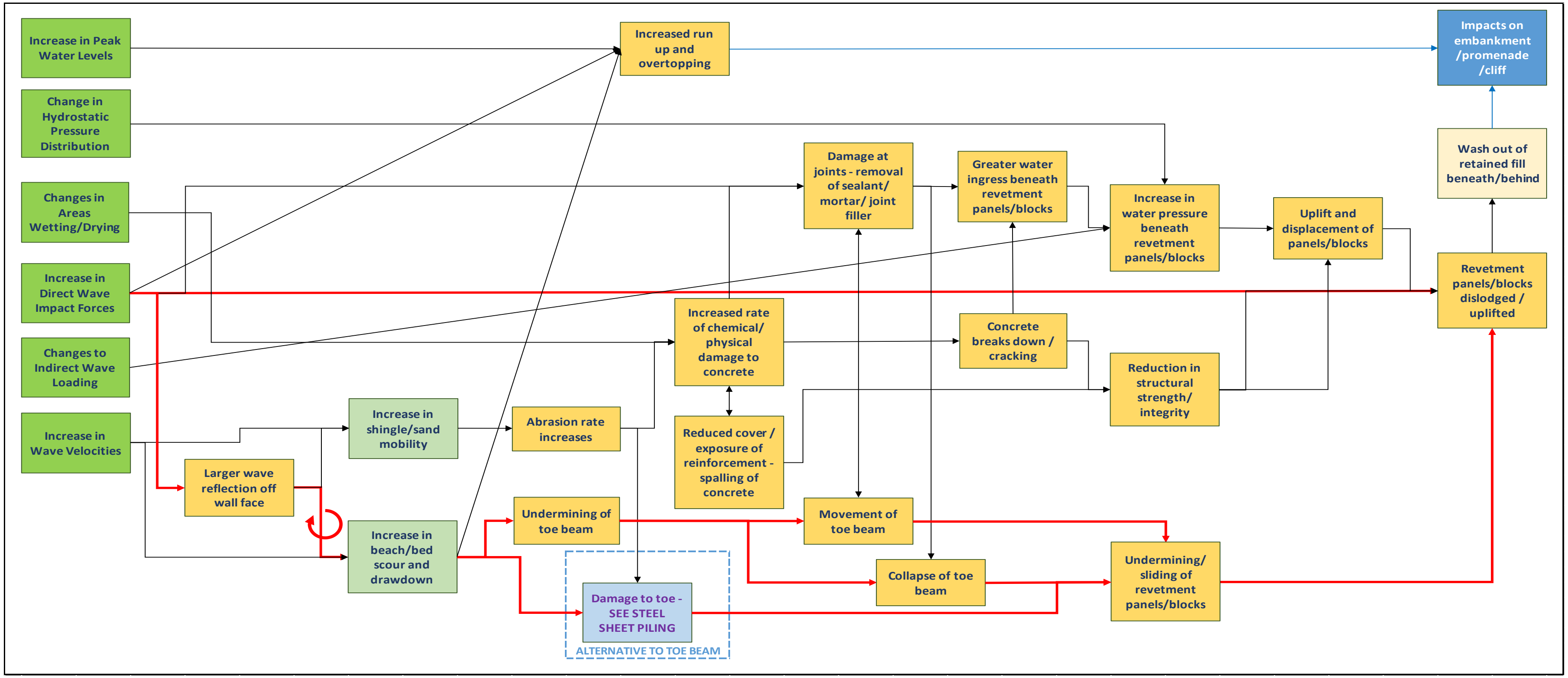
(1) OVERALL



ASSET TYPE: Embankment	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

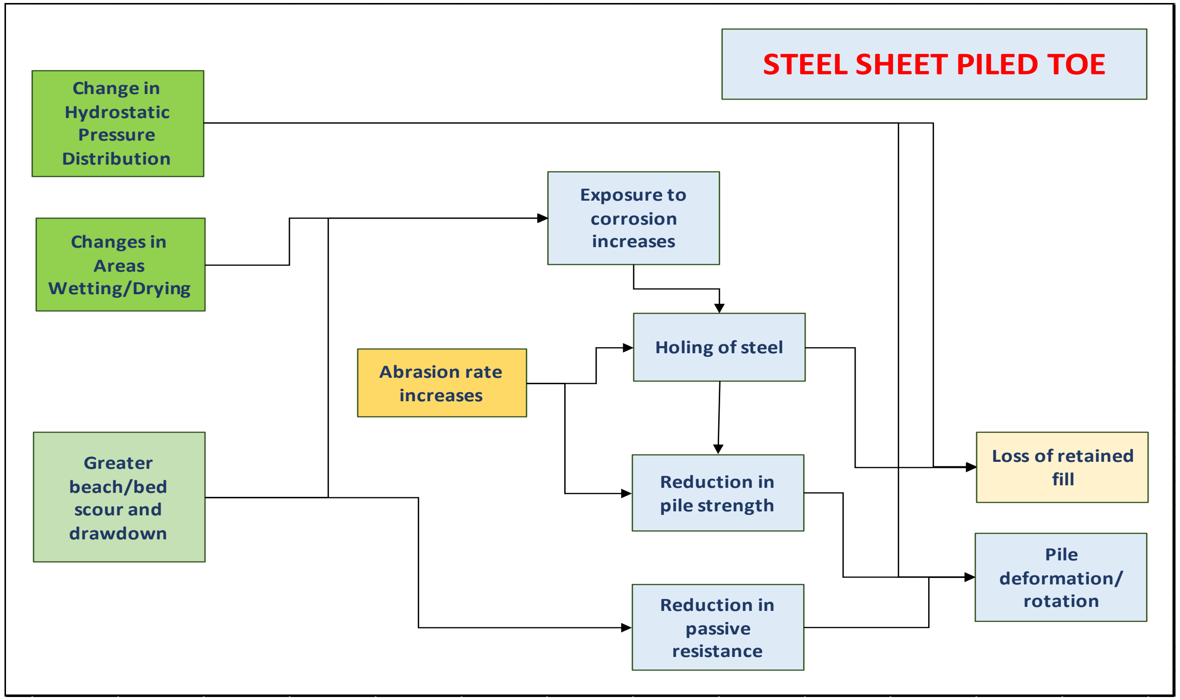
(2) CONCRETE REVETMENT DETAIL



ASSET TYPE: Embankment	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

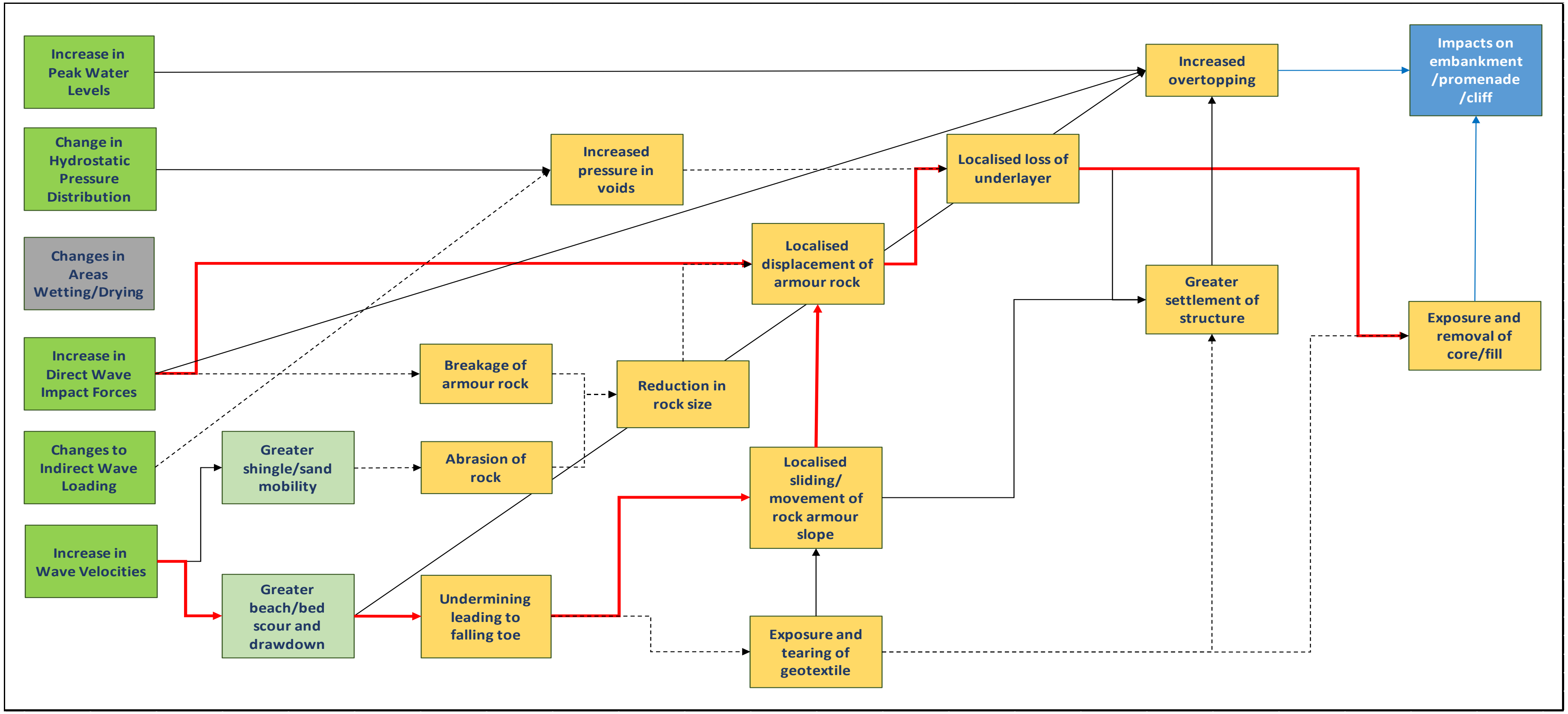
(3) STEEL SHEET PILED TOE DETAIL



ASSET TYPE: Embankment	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(4) ROCK REVETMENT DETAIL



ASSET TYPE: Embankment	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of an embankment include:

- Damage to the revetment as a result of greater exposure to higher waves, resulting from increase in waves and higher water levels reducing depth limitation.
- Higher potential for toe undermining due to falling beach/foreshore levels, leading to instability of revetment, as a result of greater scour from larger waves impacting upon the structure.
- Damage to crest and rear face due to higher run up and overtopping as a result of higher water levels and wave action.
- Internal change to hydrostatic pressures leading to geotechnical instability and failures.

A coastal embankment will be highly vulnerable to these climate change factors in several ways. It will have exposure to high water levels and wave activity, both of which will increase further as a result of climate change – waves considerably as a result of depth limiting effects being significantly reduced. This will be exacerbated by reflections off the structure further reducing beach levels.

The consequences of this include greater instability and damage at the toe of the structure and to the revetment protecting the seaward face of the structure. Changes in pressure distributions may also contribute to displacement of the revetment cover layer. One difference from other seawall types is the potential for suction/uplift and displacement of concrete panels or blocks due to reduction in mass and strength if these have deteriorated. Damage to and localised failure of the revetment can lead to overall loss and instability of the entire structure. Another difference is that any resulting failure of a rock seawall will be progressive, whereas for a concrete revetment this can be sudden.

Increased wave run up and overtopping forces, resulting from higher water levels, will be the main factor contributing to increased vulnerability of any crest protection, whilst there is also potential to be subjected to increased uplift forces due to higher internal pressures, which could displace any cover-layer. In addition to general concrete deterioration processes, higher wave forces on any crown wall structure this could also result in it sliding, exposing underlying fill material.

Various geotechnical failure mechanisms, notably seepage and piping could be altered by the climate change factors. Higher sea levels will change the hydraulic gradient within the structure, and higher wave forces will increase the pore water pressures within the structures – essentially there will be more water within the structure for longer periods of time with a greater differential across it. Seepage could lead to bursting on rear face, locally displacing rear cover layer, high water levels and wave forces could lead to uplift on any crest structure. Piping could lead to washing out of fines through the structures, leading to localised settlements. More serious would be potential for these differences to contribute to slip failure – either shallow slips on front or rear slope, or a slip plane through the structure from front to rear.

The primary deterioration/destabilising force on the rear face would however more likely result from more frequent and substantial overtopping waves damaging/eroding the surface, requiring more frequent maintenance and repair.

Although some of these increases can be dealt with through increased maintenance activities, e.g. repairs to crest and rear slope damage, the nature of these changes will be difficult to address without some more fundamental alterations to the structural elements or substantial repairs after

events. That could involve extending protection up and over the embankment, or even altering the revetment protection type altogether. Without such alterations there is a High potential for a significant increase in the chance of failure.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
X	X		

OTHER POTENTIAL IMPACTS

Wave overtopping also presents a performance issue, as it could result in localised flooding and/or become and increasing danger to the public during storms. To counter this may require major construction works to build the structure higher or new works altogether.

In addition to any structure induced scouring, beach level variability due to climate change could independently lead to levels falling below critical levels for stability of structures, leading to their undermining and collapse without major construction works to prevent this from occurring.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Wall (Vertical Seawall)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Defence'

"A wall is a raised structure used in fluvial, tidal and coastal environments for flood defence and/or erosion protection. Also covers walls used in dam structures. Small wall structures found along channels that offer no flood defence or questionable erosion protection should be defined as high ground"

Walls (in this case Seawalls) can have a range of functions and take a number of forms. In broad terms these functions and forms are:

- Seawall with low lying land directly behind, i.e. protecting against inundation
- Seawall backed by embankment/ridge, with flood plain behind
- Seawall backed by land, i.e. coast protection, often with promenade or infrastructure above and behind
- Seawall protecting cliff face, also coast protection

There is also considerable variation in the wall types, with some of the more typical including:

- Vertical wall (with coping block on top)
- Recurve wall
- Stepped seawall (with recurve or promenade on top)
- Sloping seawall, i.e. revetment (often with another wall structure, such as recurve at rear)

Seawalls are often composites of any combination of a number of different elements, often resulting from works carried out at different times to prevent failure and/or improve the level of protection provided. Some of these can include:

- Concrete plinth foundations
- Flat or sloping concrete aprons
- Toe beam
- Steel sheet piled toe
- Rock armouring at toe/in front of wall
- No toe/foundation

There are a range of construction materials that have been employed to construct seawalls, some of which include:

- Reinforced concrete
- Mass concrete
- Masonry blocks
- Steel sheet piles (primarily for toe protection)
- Rock armour (for revetments but also for toe protection)
- Grouted stone, open stone asphalt (for revetments)

As well as the above, the wider impacts of other assets, in this case beaches, is also a key consideration; beach levels have a critical influence on these structures and their stability (noting that toe failure has in the past been determined as the single greatest cause of seawall failure).

The result of all of these factors is huge variability in the range of seawalls that exist around the country. Despite this, some generalities can be assumed for the purposes of considering deterioration and failure processes.

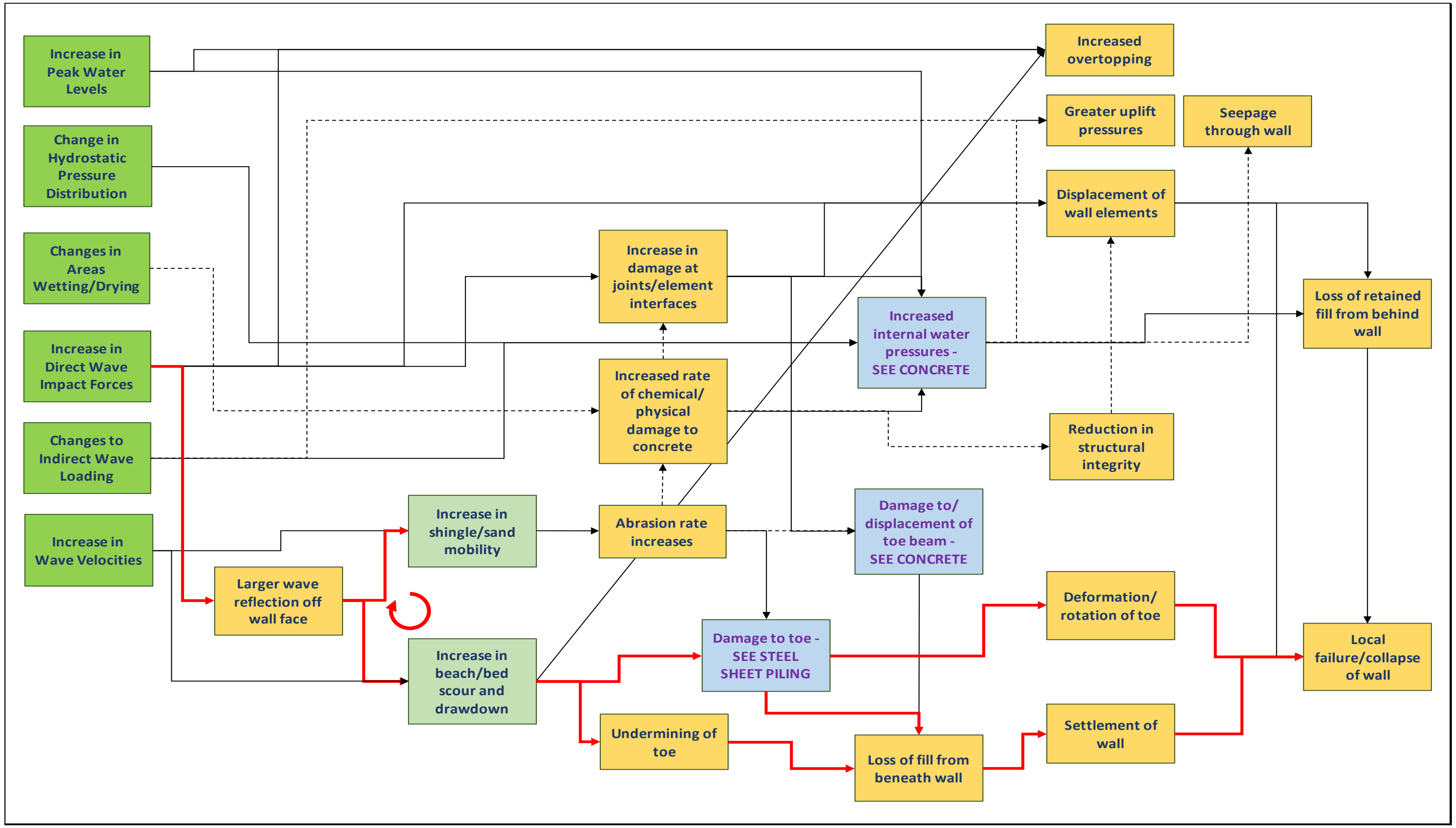
This assessment covers non-revetment ('vertical') seawalls. Separate assessments have been made for revetment seawalls under Embankments and under Cliff Protection.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	No

ASSET TYPE: Wall (Vertical Seawall)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

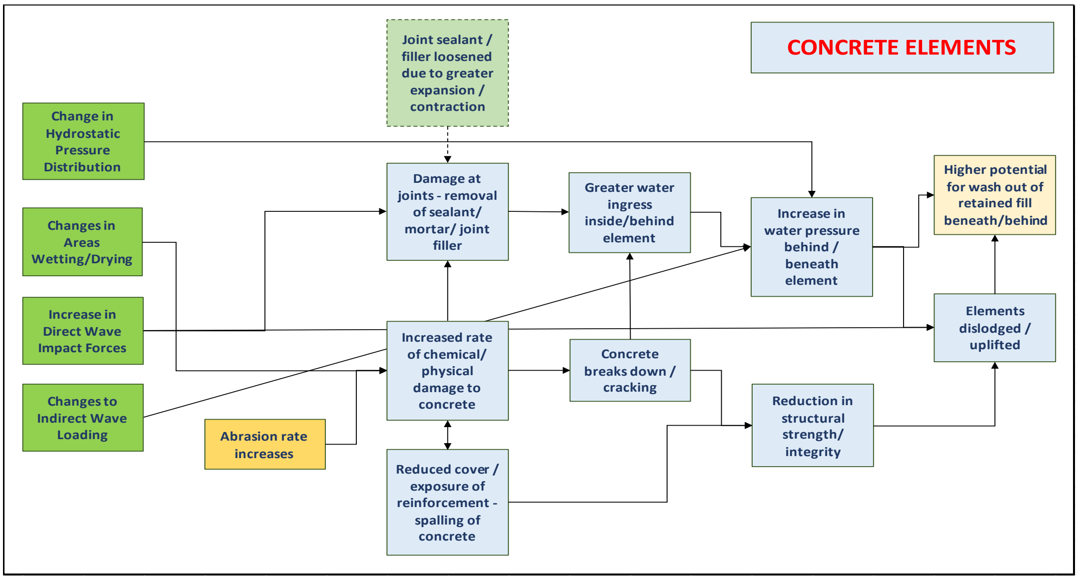
(1) OVERALL

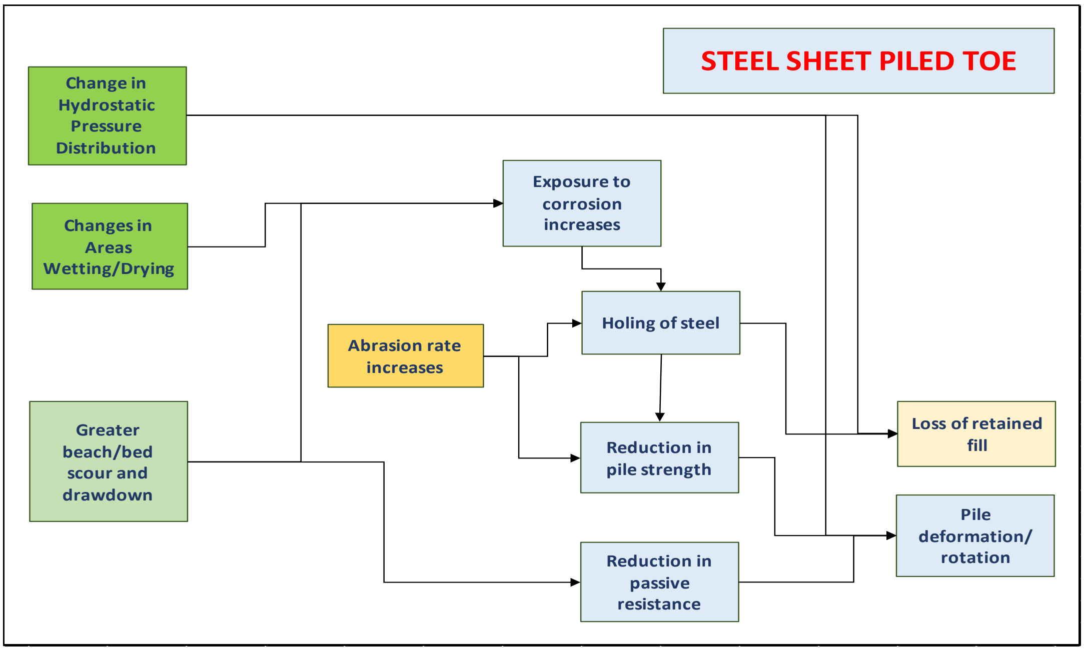


ASSET TYPE: Wall (Vertical Seawall)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) SUPPLEMENTARY DETAILS

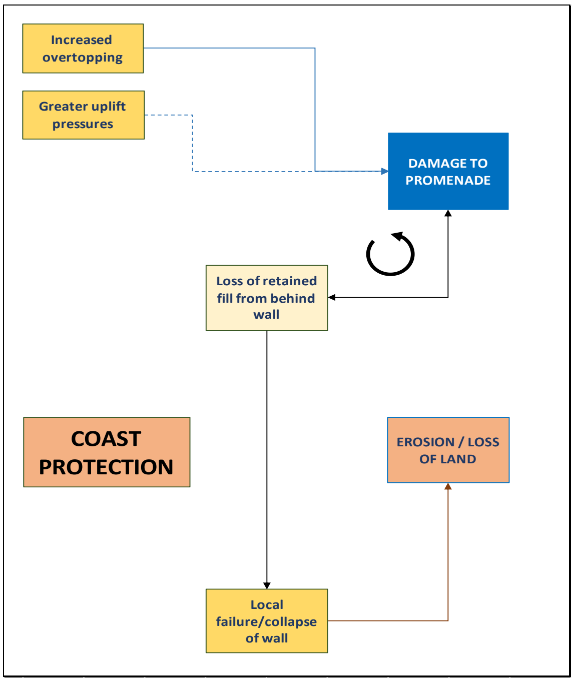


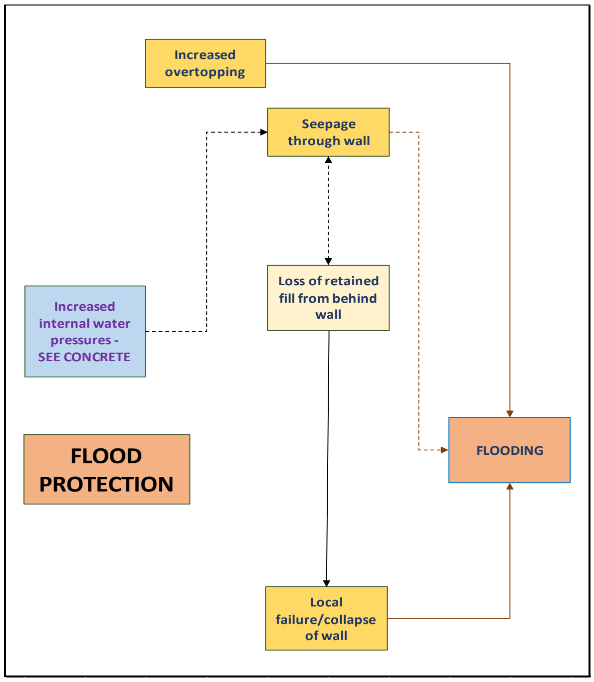


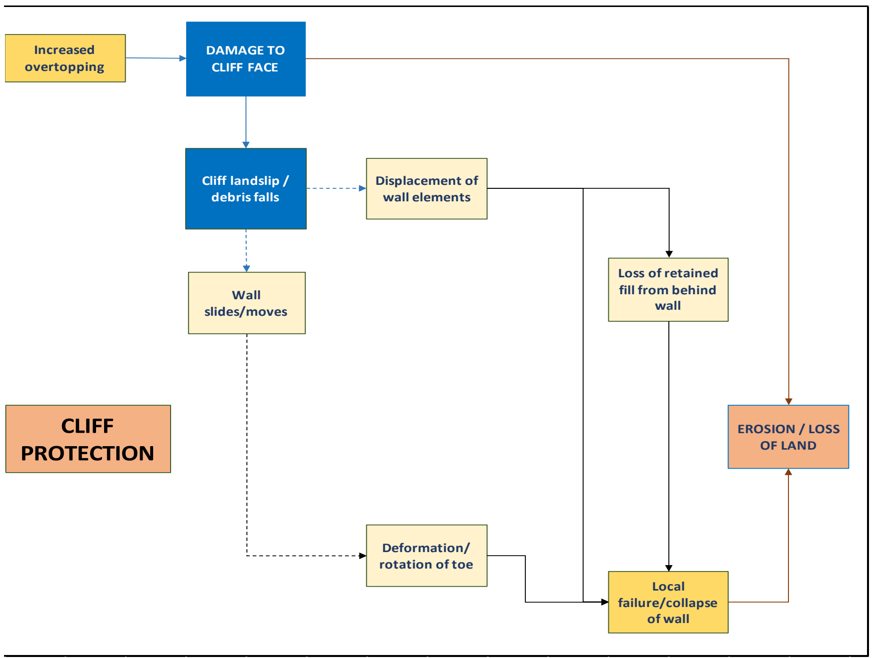
ASSET TYPE: Wall (Vertical Seawall)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(3) INTER-RELATIONSHIP WITH OTHER ASSETS







ASSET TYPE: Wall (Vertical Seawall)	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a seawall include:

- Greater structure induced scouring of fronting beach leading to greater potential for damage to toe, undermining and ultimately collapse of the wall.
- Higher wave forces working at joints and interfaces between structural elements, leading to their displacement and loss of retained fill.
- Increased rate of damage to concrete and steel sheet piling (if present), leading to reduction in their integrity and deterioration of the structure.
- Higher rates of wave overtopping, with damage to adjacent assets (promenade or cliff face) which in turn could lead to damage to the seawall, or flooding.

The types of maintenance actions required to address deterioration of concrete are going to be similar to those at present, i.e. patching and repairing damaged concrete. These are likely to be of low consequence as these are structures that have been designed to be exposed to the sea, although such activities may be required a little more frequently.

More frequent exposure to larger waves will though create greater dynamic forces on the seawalls. The areas most vulnerable to this will be the joints between sections and wall elements, and cracks, where water is able to penetrate into the structure and potentially dislodge elements (blockwork or panels depending on wall type) and/or result in the removal of backing fill. This could require much more frequent maintenance to reseal these weak spots. In extreme cases, where elements are dislodged, more substantial efforts would be required to replace these. This would be regarded to be a Moderate impact.

The biggest impact from climate change factors however is likely to be increased vulnerability of the toe. In addition to higher natural beach volatility (separate asset issue) the combination of higher water levels, leading to higher waves, and the presence of the wall reflecting those waves, will exacerbate scouring of the beach or foreshore at the toe.

This exposure could result in displacement (if concrete beam) or deterioration and/or deformation (if steel sheet piling) of the toe structure itself. This could then lead to loss of fill from beneath the wall, with settlement, or rotation of the wall. In extreme cases, this scouring could lead to complete undermining of the toe structure, leading to loss of fill from beneath the wall and its collapse. Such collapse can be sudden and catastrophic.

General maintenance will not generally be able to address these issues and the works required to address this often associated with seeking to stabilise the beach in front of the wall, else adding new construction in front of the wall such as longer sheet piling or rock armour. These are significant actions and therefore the vulnerability is considered to be High.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

Wave overtopping also presents a performance issue, as it could result in localised flooding and/or become and increasing danger to the public during storms. Increased overtopping of the seawall can also result in damage to other elements, such as a promenade or cliff face, which in turn can impact upon damage and potential stability of the wall.

In addition to the structure induced scouring, beach level variability due to climate change could independently lead to levels falling below critical levels for stability of structures, leading to their undermining and sudden collapse.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Defence'

"A wall is a raised structure used in fluvial, tidal and coastal environments for flood defence and/or erosion protection. Also covers walls used in dam structures. Small wall structures found along channels that offer no flood defence or questionable erosion protection should be defined as high ground"

Walls (in this case Seawalls) can have a range of functions and take a number of forms. In broad terms these functions and forms are:

- Seawall with low lying land directly behind, i.e. protecting against inundation
- Seawall backed by embankment/ridge, with flood plain behind
- Seawall backed by land, i.e. coast protection, often with promenade or infrastructure above and behind
- Seawall protecting cliff face, also coast protection

There is also considerable variation in the wall types, with some of the more typical including:

- Vertical wall (with coping block on top)
- Recurve wall
- Stepped seawall (with recurve or promenade on top)
- Sloping seawall, i.e. revetment (often with another wall structure, such as recurve at rear)

This assessment covers revetment type seawalls only providing coastal protection. Separate assessments have been made for other seawall types under Seawalls (vertical walls) providing coast protection and flood defence, and Embankments (which also include revetments) providing flood defence.

Revetment seawalls are often composites of any combination of a number of different elements, often resulting from works carried out at different times to prevent failure and/or improve the level of protection provided. Primarily however these are likely to comprise:

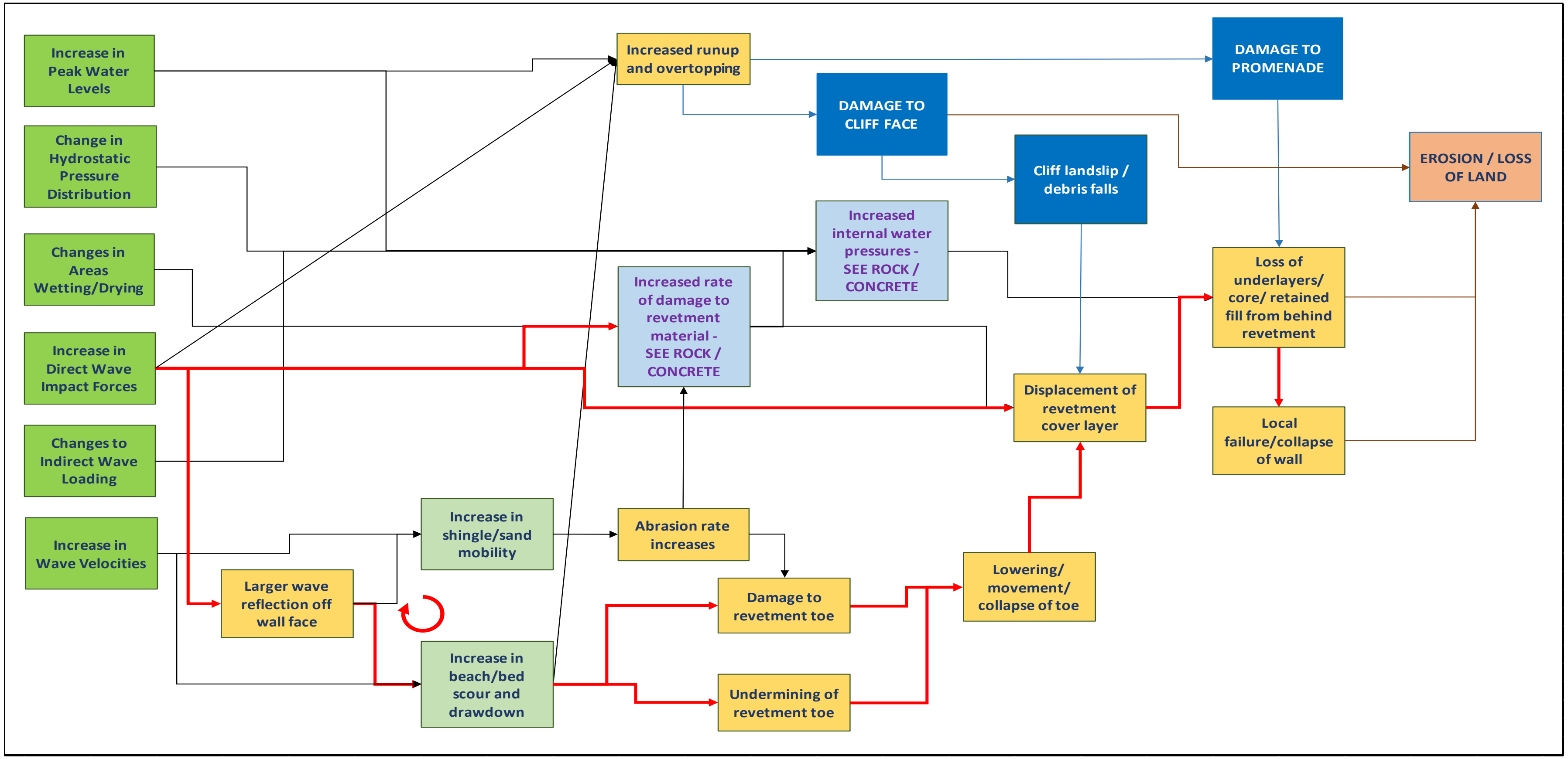
- Reinforced concrete slabs, panels or units, often with a steel sheet piled toe
- Rock armour (for revetments but also for toe protection)
- Grouted stone, open stone asphalt (but much less commonly)

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	No

ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

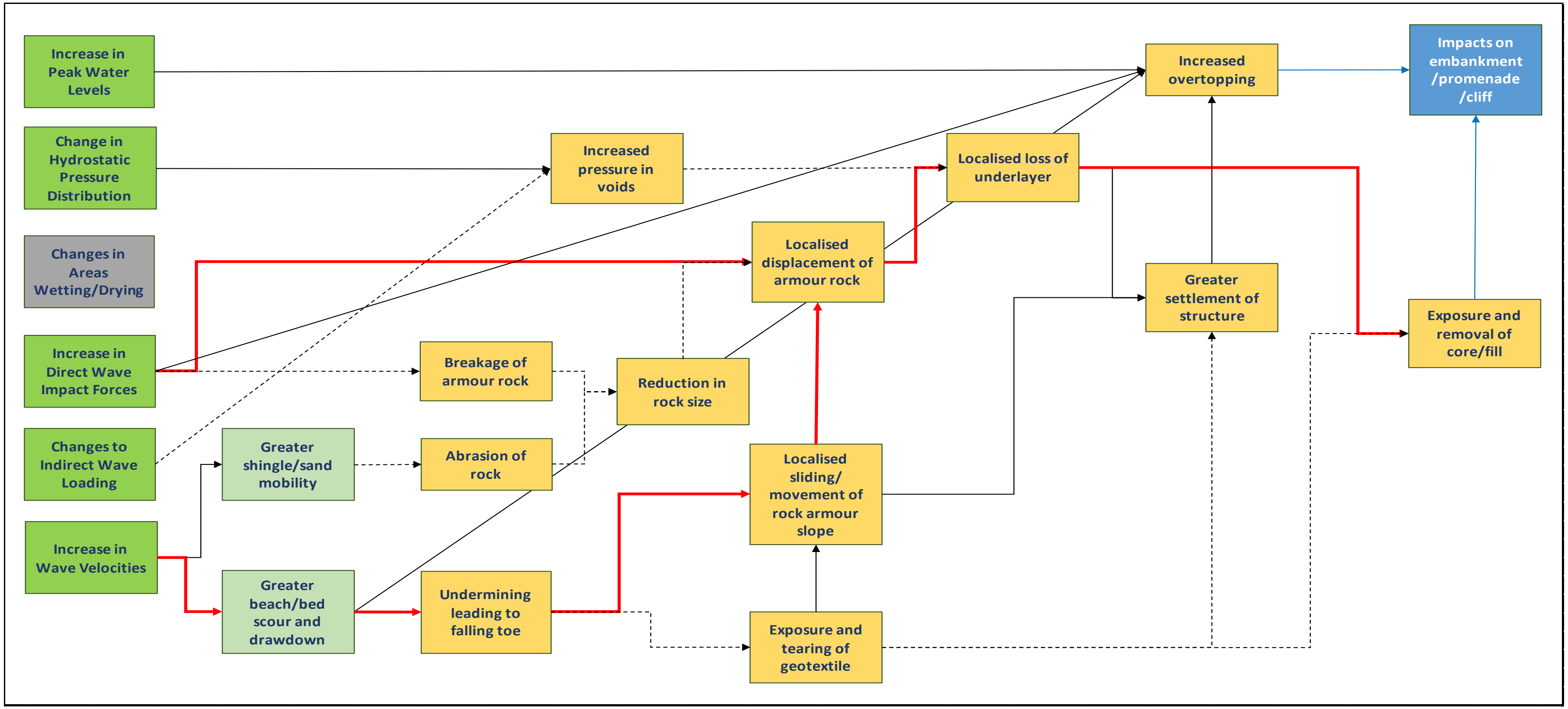
(1) OVERALL



ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

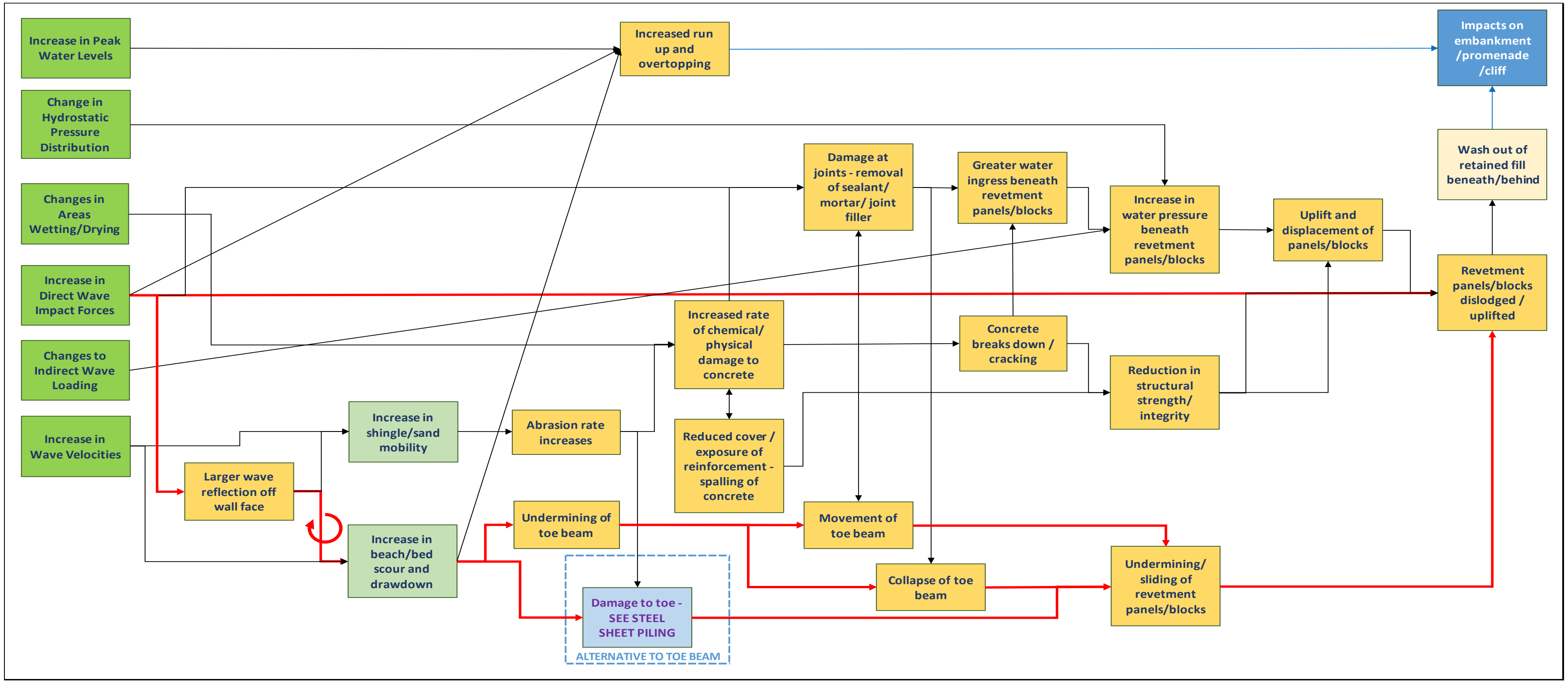
(2) ROCK REVETMENT DETAIL



ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

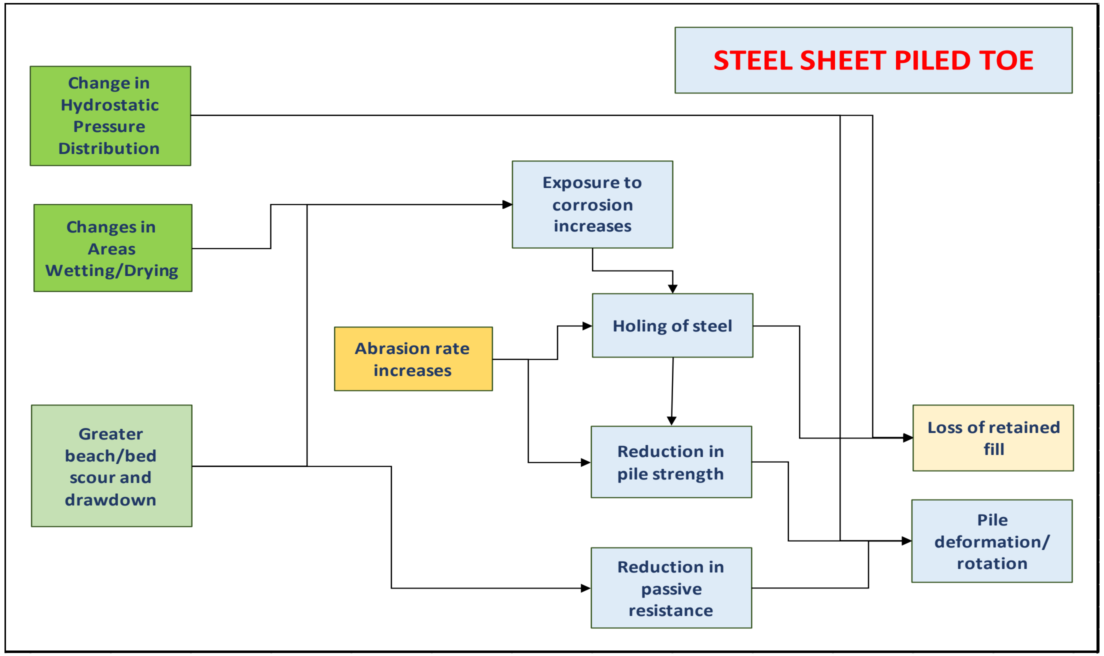
(3) CONCRETE REVETMENT DETAIL



ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(4) STEEL SHEET PILED TOE DETAIL



ASSET TYPE: Wall (Revetment)	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a revetment seawall providing coastal erosion protection include:

- Greater structure induced scouring of fronting beach leading to greater potential for damage to toe, undermining and ultimately collapse of the revetment.
- Higher wave forces leading to displacement of revetment cover layer and loss of retained fill or underlayers.
- Increased rate of deterioration of concrete and steel sheet piling (if present), leading to reduction in their integrity and deterioration of the structure.
- Higher rates of wave overtopping, with damage to adjacent assets (promenade or cliff face) which in turn could lead to damage to the seawall.

A coastal revetment will be highly vulnerable to these climate change factors in several ways. It will have exposure to high water levels and wave activity, both of which will increase further as a result of climate change – waves considerably as a result of depth limiting effects being significantly reduced. This will be exacerbated by reflections off the structure further reducing beach levels.

The consequences of this include greater instability and damage at the toe of the structure and to the revetment cover layer, whether that is rock or concrete or any other material. Changes in pressure distributions resulting from a change in water levels may also contribute to displacement of the revetment cover layer. One difference from other seawall types is the potential for suction/uplift and displacement of concrete panels or blocks due to reduction in mass and strength if these have deteriorated. Damage to and localised failure of the revetment will lead to overall loss and instability of the entire structure. Another difference is that any resulting failure of a rock seawall will be progressive, whereas for a concrete revetment this can be sudden.

Some of the maintenance actions required to address deterioration of concrete are going to be similar to those at present, i.e. patching and repairing damaged concrete. However, there will be an increasing probability that requirements could become difficult to address without more fundamental alterations to the structural elements or substantial repairs after events. That could involve altering the revetment protection type or size altogether, or provision of new toe structures. Without such alterations there is a high potential for a significant increase in the chance of failure.

General maintenance will not generally be able to address these issues and therefore the vulnerability is considered to be High.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

In addition to any structure induced scouring, beach level variability due to climate change could independently lead to levels falling below critical levels for stability of structures, leading to their undermining and collapse without major construction works to prevent this from occurring.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Beach	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"Beaches that are found along the coast can perform a flood defence and/or erosion protection function. Beaches are usually a natural feature, but may be managed to ensure that they continue to provide protection"

There are different beach materials to consider:

- Sand
- Shingle
- Cobble
- Mixed
- Composite

A beach could be considered in the context of a whole beach (in plan form) or part of a beach (e.g. in cross section). There is a need to consider both, but with considerable variation in the nature of a whole beach, attention is mainly focussed on cross-section and the potential for that to deteriorate and thus some reduction in function to occur.

There are two aspects of potential beach change; magnitude of change and frequency of change.

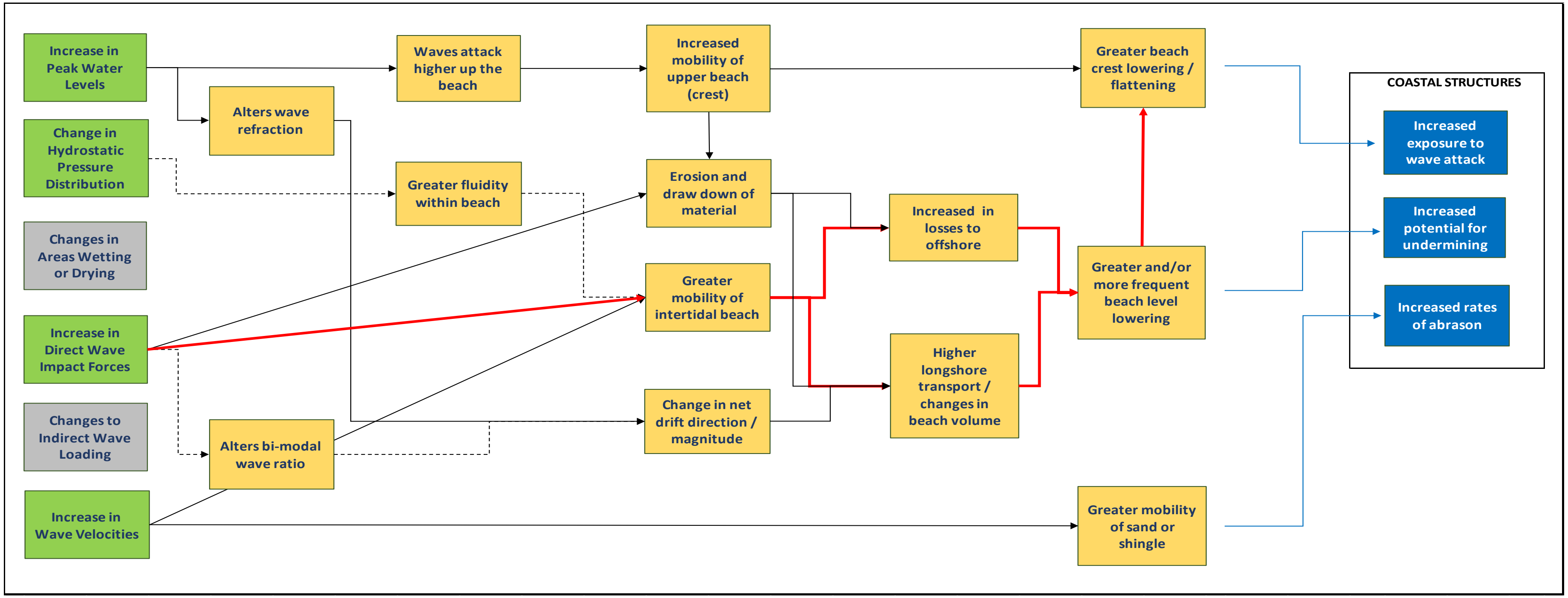
As well as being an asset in their own right, beaches also have a critical role to play in terms of the wider impact upon other assets, notably coastal structures, cliffs and dunes.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

*Change in ***wind direction*** could affect beach movement by altering wave direction and thus transport rates
*Change in ***storm frequency*** or ***storm sequencing*** could alter beach recovery and thus vulnerability.

ASSET TYPE: Beach	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Beach		ENVIRONMENT: Coastal	
QUALITATIVE ASSESSMENT			

Beaches are intertidal and dynamic, naturally adjusting to the hydrodynamic forces upon them. Therefore by definition changes in sea level, storm surge and waves must have an impact upon them.

The impacts of these climate change factors on deterioration of beaches include:

- Sea level rise alters the day-to-day area of exposure and response. The active zone will change and thus mobility of the beach will change. The impacts of any constrictions to beach movement, e.g. a backing seawall or control structures, will be more emphasised.
- Higher storm surges and larger waves will result in much greater and more sudden variations in beach levels during storm events. The rate and magnitude of changes on the beach would both be increased.

The magnitudes of changes are dependent upon beach material type (sand, shingle, cobbles), but all are highly vulnerable as the material that is there on the beach is generally in equilibrium to the incident conditions at that site. So all beaches are going to be affected considerably by climate change factors. Higher storm surges and larger waves will result in much greater and more sudden variations in beach levels during storm events, however even day-to-day sea level rise will alter the area of exposure and response.

The maintenance commitment will to some extent depend upon the function provided by the beach, but could be significantly increased where they are a critical part of the FCERM. That maintenance may include much greater or more frequent recycling or re-profiling campaigns. In some cases this could require renourishment or the introduction of beach control structures to address the impacts. There will be instances where no beach management measures are required at present but will now be required as a direct consequence of these climate change factors.

Therefore, beaches are considered to have High vulnerability.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

The vulnerability of beaches as an asset (defence) in their own right is important, but their behaviour and response to climate change also has a direct impact upon all other coastal assets on or behind beaches; affecting their exposure, e.g. to undermining, the levels of damage experienced, due to lesser wave attenuation and in some cases higher abrasion. In many cases it is this beach behaviour which will have the greatest impact upon those other coastal assets.

It should also be remembered that beaches are generally a recreational asset with associated economic benefits as well as a FCERM asset.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Dune	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Defence'

"Dunes that are found along the coast can perform a flood defence and/or erosion protection function. The stabilised zone is a combination of slacks, dune ridges, and dune pastures, which not only protect the hinterland from flooding but are multi-functional for ecology and recreational purpose. A wide dune system might be compromised by flow routes through the slack"

There are various types of dune systems which include:

- Foredunes
- Embryonic dunes
- Transgressive dunes
- Parabolic dunes
- Climbing dunes
- Relict dunes

However, for purposes of this analysis the focus is on simple foredunes that are providing the main FCERM defence at the back of a beach.

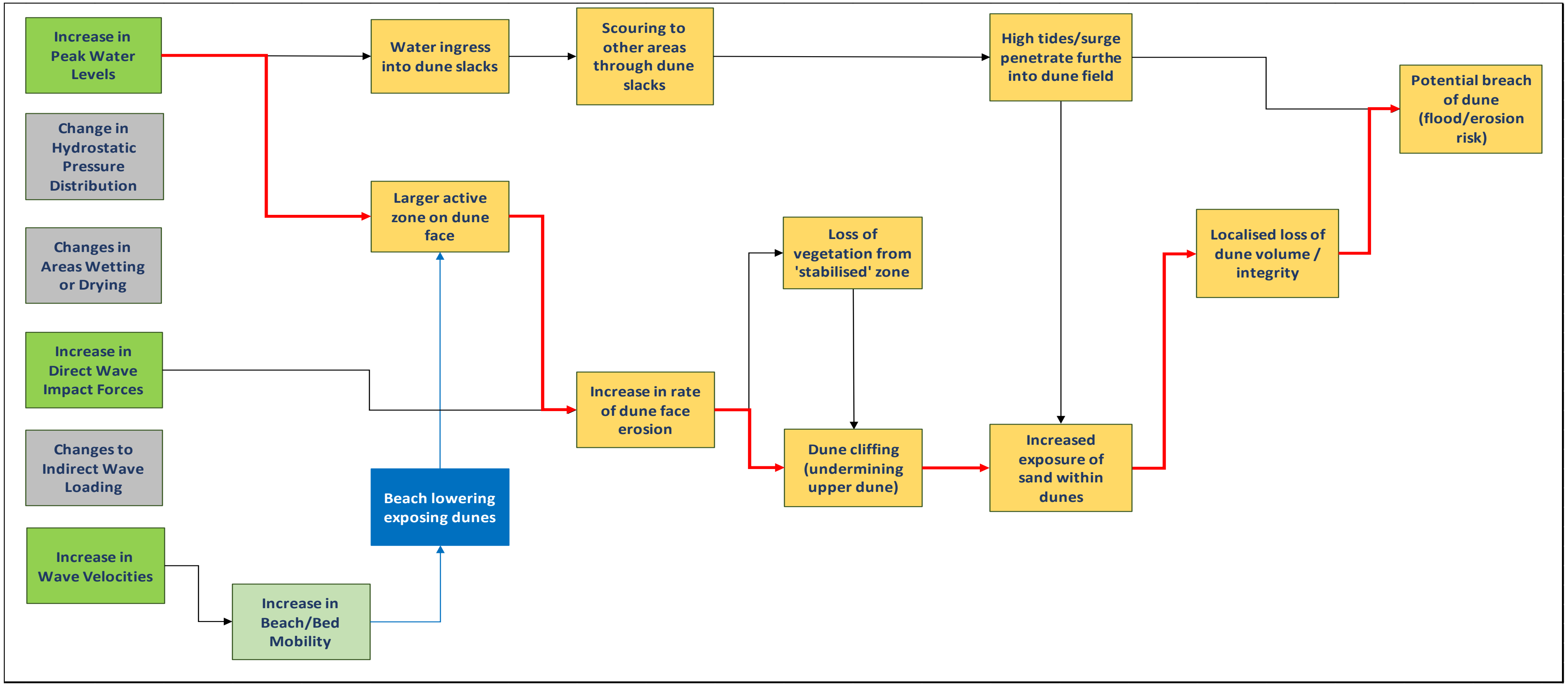
CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

**Wind* is a most significant factor – dunes are built by, and shaped by, winds therefore by definition any changes in wind must have an effect (unless the dune has already stabilised, i.e. relict)

*Change in ***temperature*** could perhaps affect dune vegetation

ASSET TYPE: Dune	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Dune		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of dunes include:

- Sea level rise, and storm surges increase the active zone of the dune face to erosion by wave action, removing vegetation, in turn leading to increased mobility of the sand (due to wind*) – reducing the volume and stability of the dune.
  **This is without any change in winds due to climate change.*
- High water levels can lead to more regular ingress of water through dune slacks, leading to cutting path(s) through dune field to cause flooding.

Dunes are highly sensitive to climate change but consequences are low unless (a) they are fully breached, leading to flood risk, or (b) there are built assets in the dunes which can be undermined and eroded/lost.

As assets in their own right they are dynamic structures so can usually move and reform, but this is not the same as deterioration; this mobility simply happens with greater magnitude and frequency. They will though definitely be affected and subject to some change as a consequence of these factors. Any remedial actions will depend upon the function provided by the dune field, and their overall health and size, and in exceptional circumstances they may need to be rebuilt, but more commonly there would be an increased commitment to maintaining/replacing or introducing dune stabilisation measures (fencing, planting etc). Vulnerability therefore is classed as Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

Like other coastal assets, the impacts upon the dunes will be directly affected by the impacts upon the beaches fronting them.

In the case of dunes, a change in wind climate as a result of climate change could alter the impact to 'high'. In extreme cases it is possible that climate change effects could compromise their ability to rebuild.

It should also be remembered that dunes are also a recreational asset with associated benefits, and an ecological asset, as well as a FCERM asset.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Barrier Beach	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"Barrier beaches found extending from the coast can perform a flood defence and/or erosion protection function"

Unlike regular beaches, the barrier beach is generally made up of coarser material, and although these can be purely of sand most of those we will be interested in are likely to be:

- Shingle/Pebble
- Cobble
- Mixed (shingle/sand matrix)

The barrier beach is often also only the upper part of a composite beach, i.e. with a flatter lower foreshore frequently found between MSL and LAT.

A barrier beach could be considered in the context of a whole beach (in plan form) or part of a beach (e.g. in cross section). There is a need to consider both, but with considerable variation in the nature of a whole beach, attention is mainly focussed on cross-section and the potential for that to deteriorate and thus some reduction in function to occur.

The mechanisms for beach deterioration and failure will be similar to regular beaches, but with greater emphasis on:

- Breach Potential
- Percolation / Seepage

There are two aspects of potential barrier beach change; magnitude of change and frequency of change.

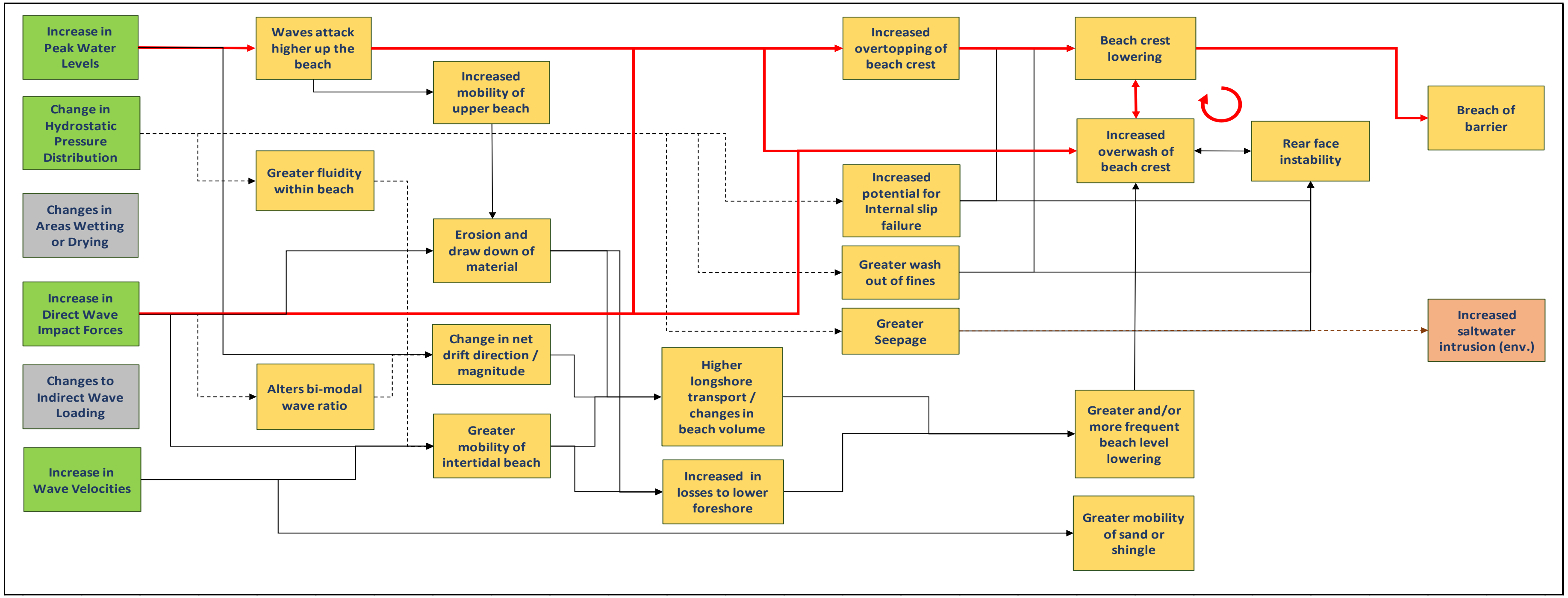
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	Potential*

*Change in ***wind direction*** could affect beach movement by altering wave direction and thus material transport rates
*Change in ***storm frequency*** or ***storm sequencing*** could alter beach recovery and thus vulnerability.

ASSET TYPE: Barrier Beach	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Barrier Beach	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

Barrier beaches, like regular beaches, are intertidal and dynamic, naturally adjusting to the hydrodynamic forces upon them. Therefore by definition changes in sea level, storm surge and waves must have an impact upon them.

The impacts of these climate change factors on deterioration of barrier beaches include:

- Sea level rise alters the day-to-day area of exposure and response. The active zone will change and thus mobility of the beach will change. This could result in higher rates of transgression, i.e. landward movement of the barrier.
- Higher storm surges and larger waves will result in much greater and more sudden variations in beach levels during storm events. The rate and magnitude of changes on the beach would both be increased.
- A key impact from climate change is the potential increase in overflow and overwash of the barrier resulting from higher water levels and waves, but further exacerbated by the two impacts described above, drawing it down and leading to breach, with consequential flooding.
- Other additional considerations include increase in seepage through the barrier and washout of material due to the change in the hydraulic gradient across the beach. That though will depend upon geometrical and geotechnical properties of the barrier (some are wide, others are narrow, some are well consolidated with high fines content within, others less so).

The magnitudes of changes are dependent upon beach material type (shingle, cobbles, mixed), associated permeability, and their geometry, but all are highly vulnerable as the material and shape of the barrier is generally in equilibrium to the incident conditions at that site. So all barrier beaches are going to be affected considerably by climate change factors. Higher storm surges and larger waves will result in much greater and more sudden variations in beach levels and risks of breach during storm events, however even day-to-day sea level rise will alter the area of exposure and response, leading to a potentially less robust barrier to withstand those storms.

The maintenance commitment will to some extent depend upon the area behind the barrier and thus tolerable risk, but would be significantly increased where they are a critical part of the FCERM. That maintenance may include much greater or more frequent recycling or re-profiling campaigns. In some cases this could require renourishment or the introduction of control structures to address the impacts. There will be instances where no beach management measures are required at present but will now be required as a direct consequence of these climate change factors.

The vulnerability of barrier beaches as an asset (defence) to climate change is therefore considered to be very High.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

Barrier beaches provide an important defence function in many locations, and their robustness is critical to providing the required standard of protection to hinterland. This will be reduced by these climate change factors.

Barrier beaches are generally one part of a wider dynamic and interacting system, so their response to climate change may have impacts beyond just their own function. This can include

interactions with the fronting beach, or the transport of beach material to adjacent frontages, e.g. in front of cliffs or defences. It should also be remembered that barrier beaches often form part of a coastal environment with recreational use, and/or support certain drift line habitats, so have associated economic and ecological benefits as well as a FCERM asset.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Promenade	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"Promenade found along the coast can perform a flood defence and/or erosion protection function"

Assume seawall is dealt with separately – damage to seawall is an initial process

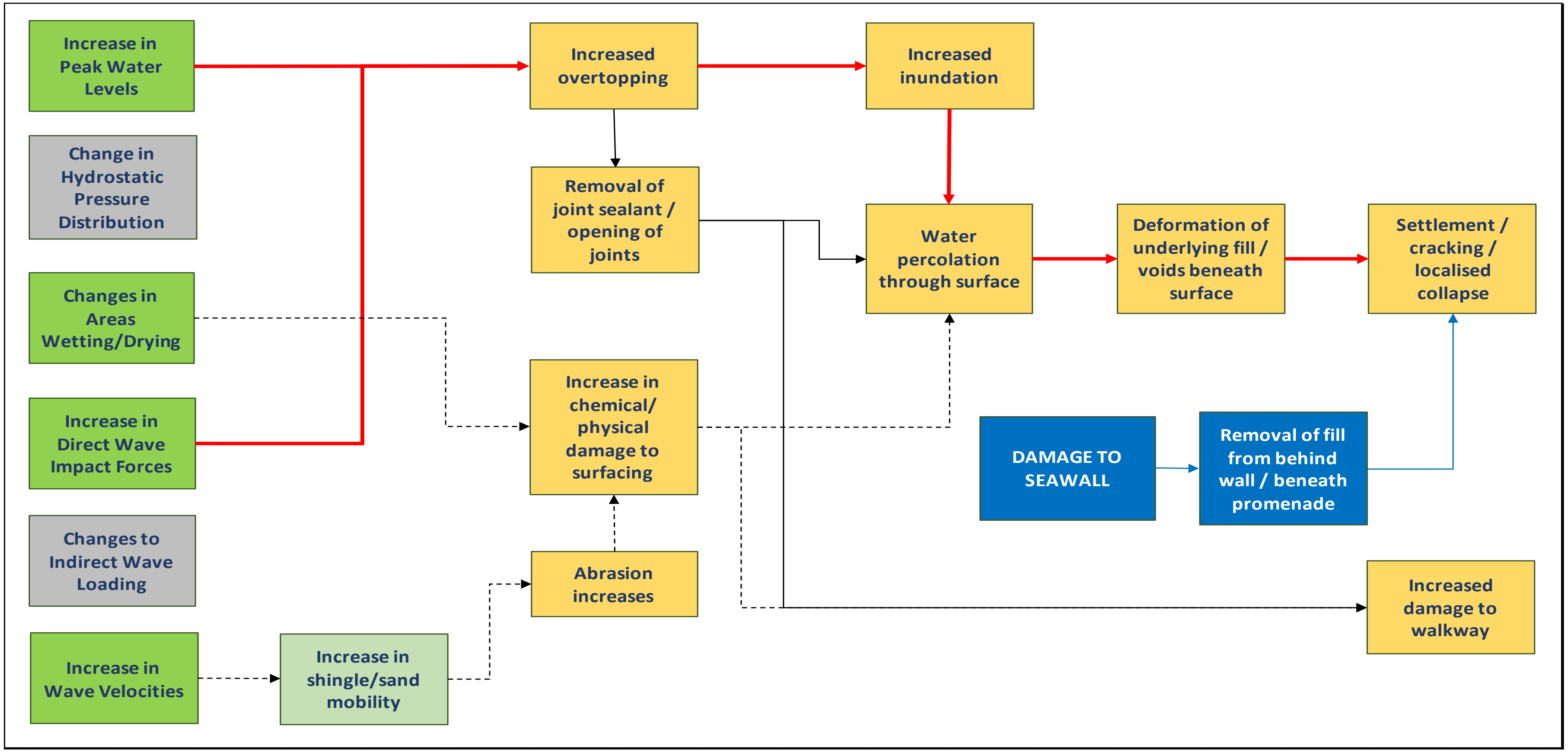
A promenade is not the main structural element in terms of sea defence – the seawall is the critical element. Seawalls are dealt with separately.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Promenade	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Promenade		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of promenades include:

- Water ingress/percolation due to higher frequency of overtopping from storms due to higher water levels
- Increased abrasion and frequency of exposure leading to greater damage to the walkway surface
- Indirect vulnerability (higher) would be via seawall damage, resulting in removal of fill from beneath the promenade, and its collapse.

High water levels (due to sea level rise and storm surge) will allow higher run up on beaches and increased overtopping of seawall, leading to greater volume and frequency of water on the promenade. This can result to increased percolation through the surface, or increased wear and tear to joints and seals allowing water penetration. Both could lead to carbonation of steel (if reinforced slabs) and spalling of concrete, or deformation of underlying fill leading to cracking and potentially localised collapse of the promenade. Abrasion of the surface may also result through higher sand or shingle mobility as a consequence of higher overtopping. . In this context the beach type (sand or shingle) is a consideration.

The nature of maintenance to address these issues is likely to be identical to that currently carried out, simply required a little more often to maintain as a serviceable walkway and restrict the ingress of water. The vulnerability to deterioration from climate change of these assets are therefore likely to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

It is possible that damage to the promenade could have a subsequent impact upon the seawall, allowing for the removal of fill from behind that wall.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Cliff (Unprotected)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"Cliffs that are found along the coast can perform a flood defence and/or erosion protection function"

Geology is a key/primary component affecting susceptibility to, and rate of, erosion. Examples of differences include:

- Solid rock
- Softer tills (sands and gravels)
- Chalk
- Mud/silts
- Cohesive/non-cohesive

Cliff/failure type is also important in terms of how much these assets might be impacts. Examples of such types include:

- Simple
- Complex/landsliding
- Composite

It is questionable whether a natural cliff can be termed to be an 'asset', it is by definition an erodible edge to a piece of land. The assets of concern here are the land, property and infrastructure that sit inland of the cliff line. In the case of natural cliffs, deterioration or failure can only therefore only really be defined as their erosion, which might also be considered to be a measure of their performance.

Some cliffs are [almost] fully protected, with a substantial toe structure such as a seawall or revetment. These are different assets however and dealt with separately. Some other cliffs are also stabilised, with measures which may include surface or in-slope drainage, ground anchors, or slope re-grading/re-profiling. Again however these are not however included here.

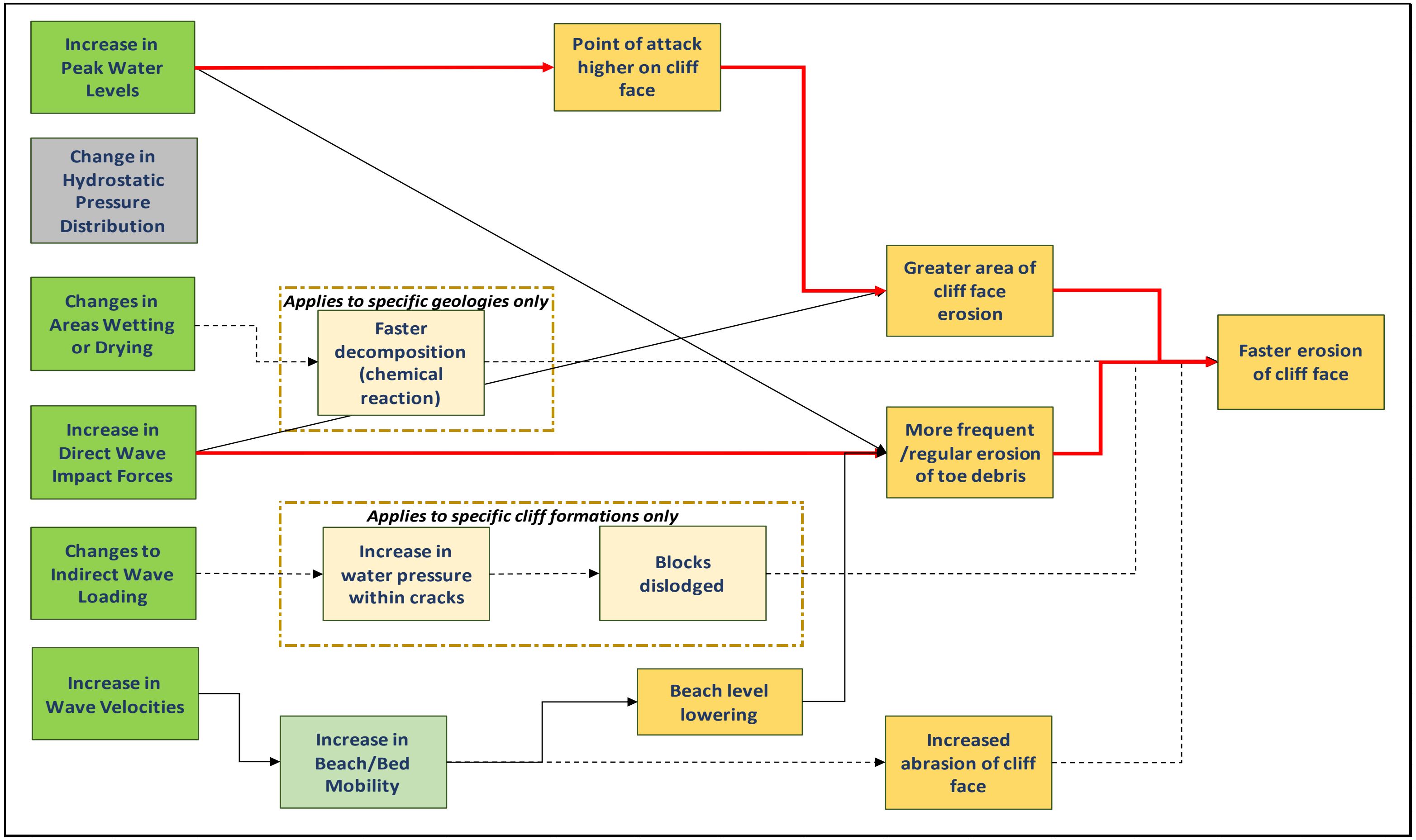
This assessment covers natural unprotected cliffs only. Separate assessments have been made for cliffs with slope stabilising measures, and for seawalls and revetments protecting cliffs.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

* ***Rainfall*** – can be primary driver of failure on landsliding – saturation/drainage etc
* Effect of changes in ***temperature*** and ***wind*** are however relatively negligible

ASSET TYPE: Cliff (Unprotected)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Cliff (Unprotected)	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of the climate change factors on deterioration of unprotected cliffs include:

- Higher water levels increase the area of cliff directly impacted by wave attack, which will increase the amount/speed of erosion.
- Larger waves due to higher water levels (as waves at cliff toe will almost always be depth limited) results in faster erosion of toe debris and this more rapid erosion of the cliff face.
- Other potential impacts are lesser and in some cases specific only to particular geologies or cliff type.

In all cases, the main cause of change in vulnerability is an increase in wave attack upon the cliff – primarily as a consequence of increased sea level rise enabling larger waves, and more frequent exposure to them, at the base of the cliff. Other impacts are secondary by comparison.

The rate of change however depends almost entirely on the cliff geology (hard, soft, cohesive, non-cohesive) and, associated with that, the type of cliff failure mechanism (simple, composite, complex). However, although this will directly affect the rate of erosion, the impact is just the change in rate *relative to* the underlying rate (i.e. a 0.5mm/yr increase in a cliff presently eroding at 1mm/year is just as significant as a 250mm/yr increase in a cliff presently eroding at 500mm/yr).

Although all cliffs will be highly sensitive to climate change, as this rate will always increase by comparison with the historic rate at those same sites, but they are not necessarily deteriorating significantly as an asset. The cliff may offer less protection to anything located on top and landward of the cliff line (a performance issue) but it will still exist, just in a more retreated position. There could be some change in form due to climate change, i.e. more erosion resulting in less vegetation and greater exposure of the bare cliff, which might be regarded as increased deterioration. Low key interventions might also be introduced at the back of the beach to reduce (rather than halt) that increase in the rate of erosion, so overall the magnitude of vulnerability is categorised as Moderate.

MAGNITUDE:

	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

In performance terms, the rate of retreat of cliffs will change the risks to people and property and the vulnerability to climate change would be regarded as High. The measures that would need to be taken to address such erosion depend upon what lies landward of them, but if this retreat puts those at risk, then significant interventions are required.

Although not included within the current assessments, it is worth noting again the impacts of increased rainfall on cliff instability, particularly landslips.

It should be remembered that cliffs can often provide a habitat for flora and fauna, so there are also potential ecological implications associated with their change and any management of that.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Cliff (Stabilised Slope)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"Cliffs that are found along the coast can perform a flood defence and/or erosion protection function"

Cliffs may be

- Unprotected
- Stabilised Slope/Face
- Defended (e.g. seawall or revetment at the base)

This assessment covers stabilised cliff slope/face only. Separate assessments are provided for works providing cliff toe protection (see Seawalls) and for non-stabilised cliffs (see Cliffs (Unprotected)).

Cliff stabilisation works are installed to control erosion of the cliff face surface and prevent slips or falls from occurring. Generally these will be put in place in conjunction with cliff toe protection works (else they would be undermined), and for the purposes of this assessment it is assumed that cliff toe protection exists.

Stabilisation works themselves may include:

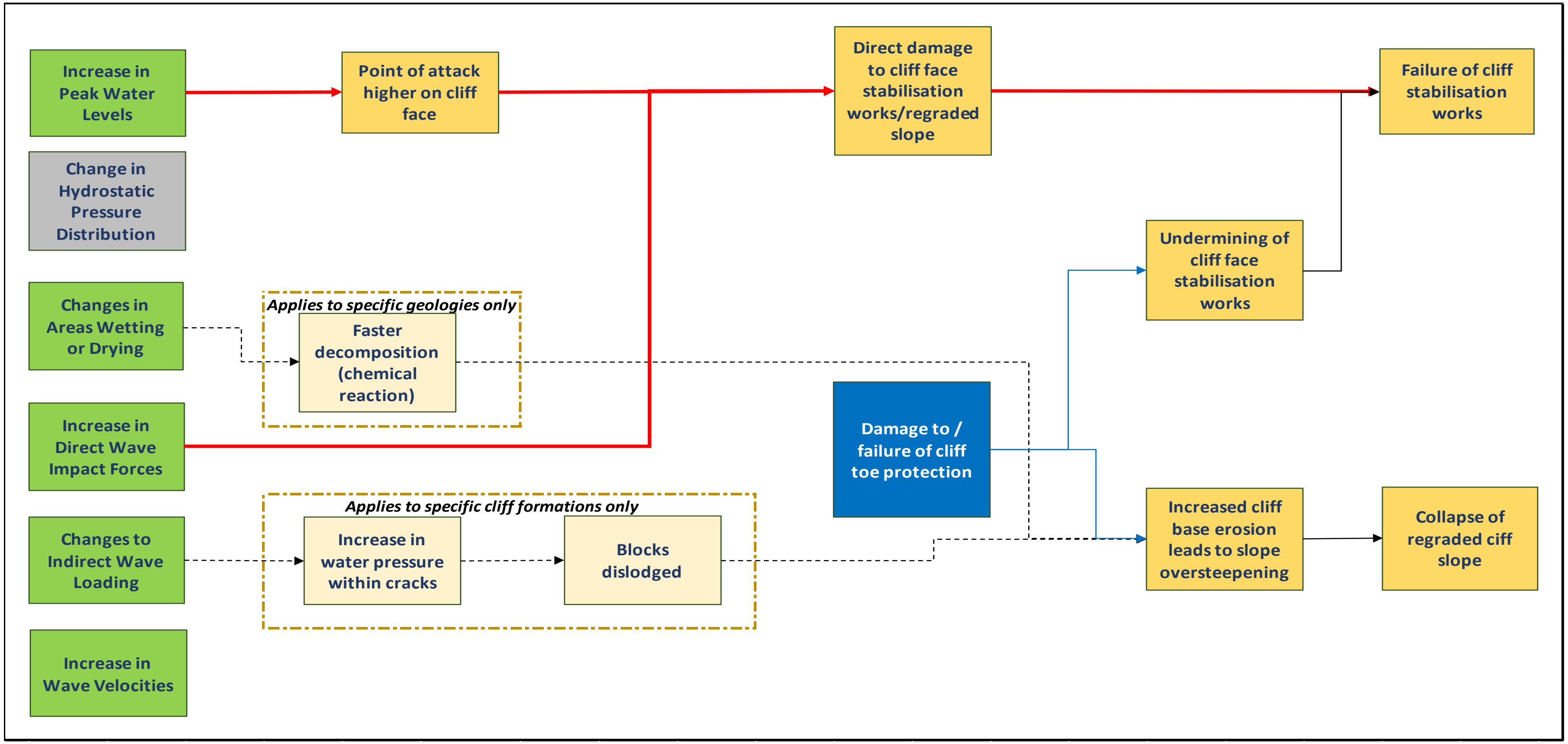
- in-slope drainage works,
- ground anchors/rock nailing,
- slope re-grading/re-profiling.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

* ***Rainfall*** – can be primary driver of failure on landsliding – saturation/drainage etc

ASSET TYPE: Cliff (Stabilised Slope)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Cliff (Stabilised Slope)		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of the climate change factors on deterioration of cliff stabilisation measures include:

- Higher water levels allowing large storm waves to reach and impact directly upon the re-graded slope or cliff face works.

However, if the toe protection works (revetment or seawall) were to be badly damaged or fail, then this could result in erosion at the base of the cliffs, leading to oversteepening and undermining of the upper cliffs, resulting in slope failure or destabilising any works thereon.

The impacts on the stabilisation works are indirect (it is the supporting ground that is impacted) but the consequences for these works could include:

- destabilisation of cliff drainage works would require reinstallation on a more frequent basis)
- the same for works to replace ground anchors
- greater frequency of operations to re-grade cliffs (where this is the only stabilisation measure)

Although these are all significant undertakings, the probability of any increase in requirements due to climate change effects are considered to be low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

In performance terms, the rate of retreat of cliffs will change the risks to people and property and the effects of climate change would be regarded as High.

Although not included within the current assessments, it is worth noting again the impacts of increased rainfall on cliff instability, particularly landslips, and especially if cliff drainage measures are damaged or fail.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Groyne (Timber)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"A groyne is a linear structure extending from the shore into the water that provides coastal erosion protection on beaches"

There are 3 main elements to consider, planks, piles and fixings:

- TIMBER PLANKS* – can be displaced, loosened, rot or split, or abraded – leading to loss of structural competence
- TIMBER PILES – can rot, split, abraded, be destabilised (lean, buckle, snap) – necking due to shingle abrasion is one of biggest issues, weakening section.
- METAL FIXINGS – come loose, broken/sheared, corroded or abraded

*Many groynes also have steel sheet piling as well as planking.

Timber structures on beaches have potentially more susceptibility to material deterioration than many other structure types. Shingle abrasion can be a big issue; so it is important to differentiate between sand beach and shingle beach settings.

Rotting of timbers will depends on timber type

As well as the elements, the wider impacts of other assets, in this case beaches, is also a key consideration; beach levels have a critical influence on these structures. Differential pressure due to beach levels either side can lead to extreme loading on planks leading to piles buckling/collapse

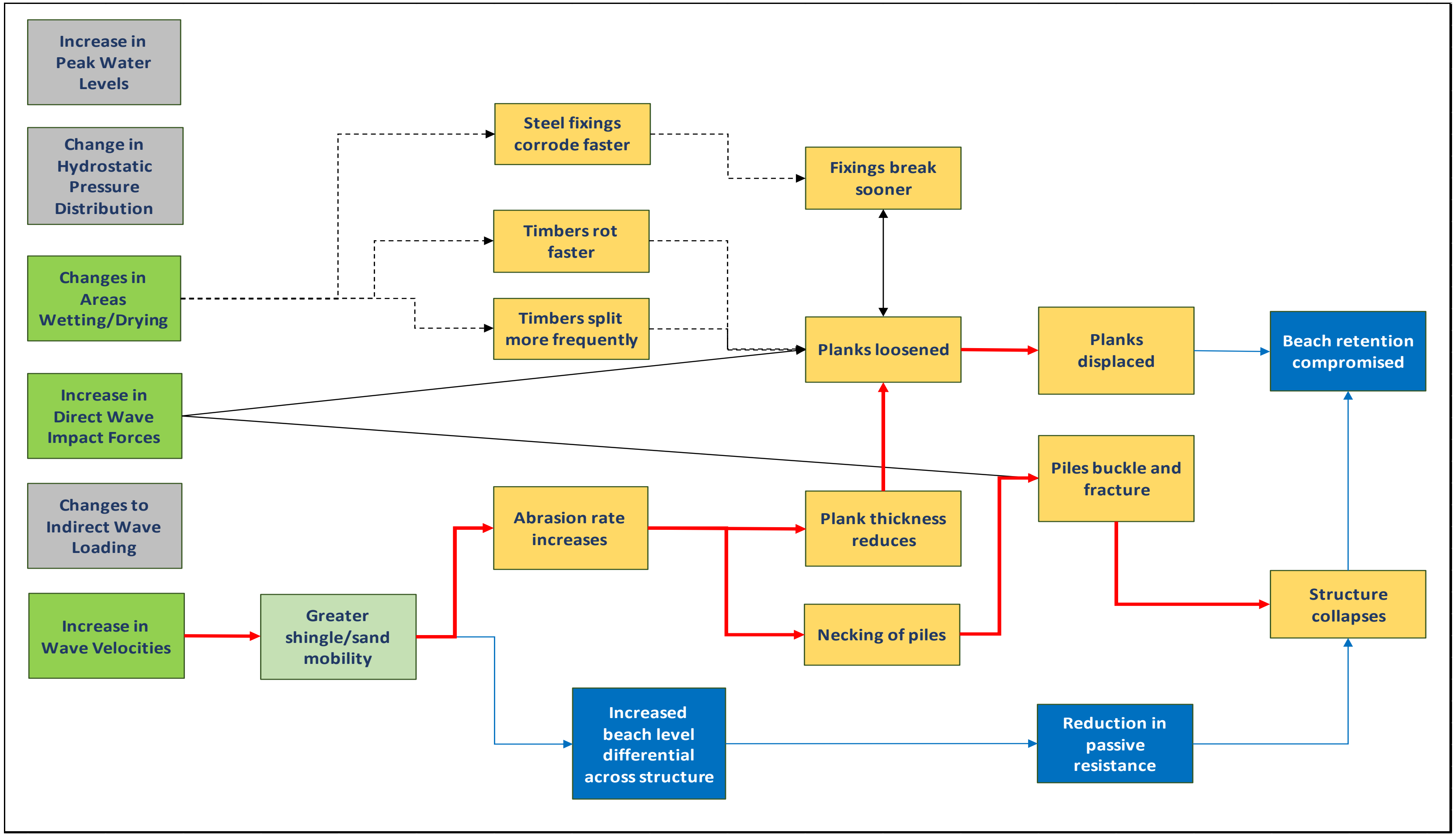
There is also a time dependency matter to consider. As well as wear and tear/condition deterioration over time, changes in design codes mean that structures built for example 30 years ago will not be to same standards as those in last 10 years.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

*Change in ***water temperate*** could alter ecology and biodiversity of marine organisms, including marine borers.
Changes in ***wind direction*** or ***storm frequency*** could affect beach movements and thus indirectly affect these structures, but this relates to the beach rather than the groyne.

ASSET TYPE: Groyne (Timber)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Groyne (Timber)	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of timber groynes include:

- Greater mobility of shingle leading to greater abrasion of timbers – e.g. necking of piles, which could ultimately leading to them snapping.
- Higher wave forces on the timber planks lead to then becoming loosened and/or displaced.
- Increased rates of rotting/splitting and corrosion due to changes in wetting and drying are possible but not considered to be key areas of vulnerability – these structures are designed to frequently be wet and the changes in this will be small.

Assuming that the beach level is not a factor (see other potential impacts below), abrasion due to the higher mobility of the beach material, particularly shingle is the primary issue for these structures. This leads to reduction in element section – loosening planks or necking of piles – which reduce structural competence.

The types of maintenance actions required to address these matters will be similar to that at present, e.g. replacing planks and fixings as required, but with increased frequency, or requiring more remedial actions, e.g. to brace/prop groynes to prevent collapse.

Overall, this increased maintenance commitment means that the vulnerability is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

Although not specifically an impact on asset deterioration, the effects of climate change on beach levels is perhaps the most significant issue for these structures. Changes in wave climate leading to differences in material retention either side of the structures, or beach downcutting, could significantly affect the overall stability of these structures. With less passive resistance to wave impact forces on the planks, the loading would transfer onto the piles and could lead to them buckling/snapping, with collapse of the groyne.

Overall, the vulnerability would be high if impacts of beach level variability on stability is taken into account.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Groyne (Rock)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Beach Structure'

"A groyne is a linear structure extending from the shore into the water that provides coastal erosion protection on beaches"

Groynes in this context will almost certainly be constructed from large armour rock with a roundhead of rock at the end – potentially of larger rock to provide stability.

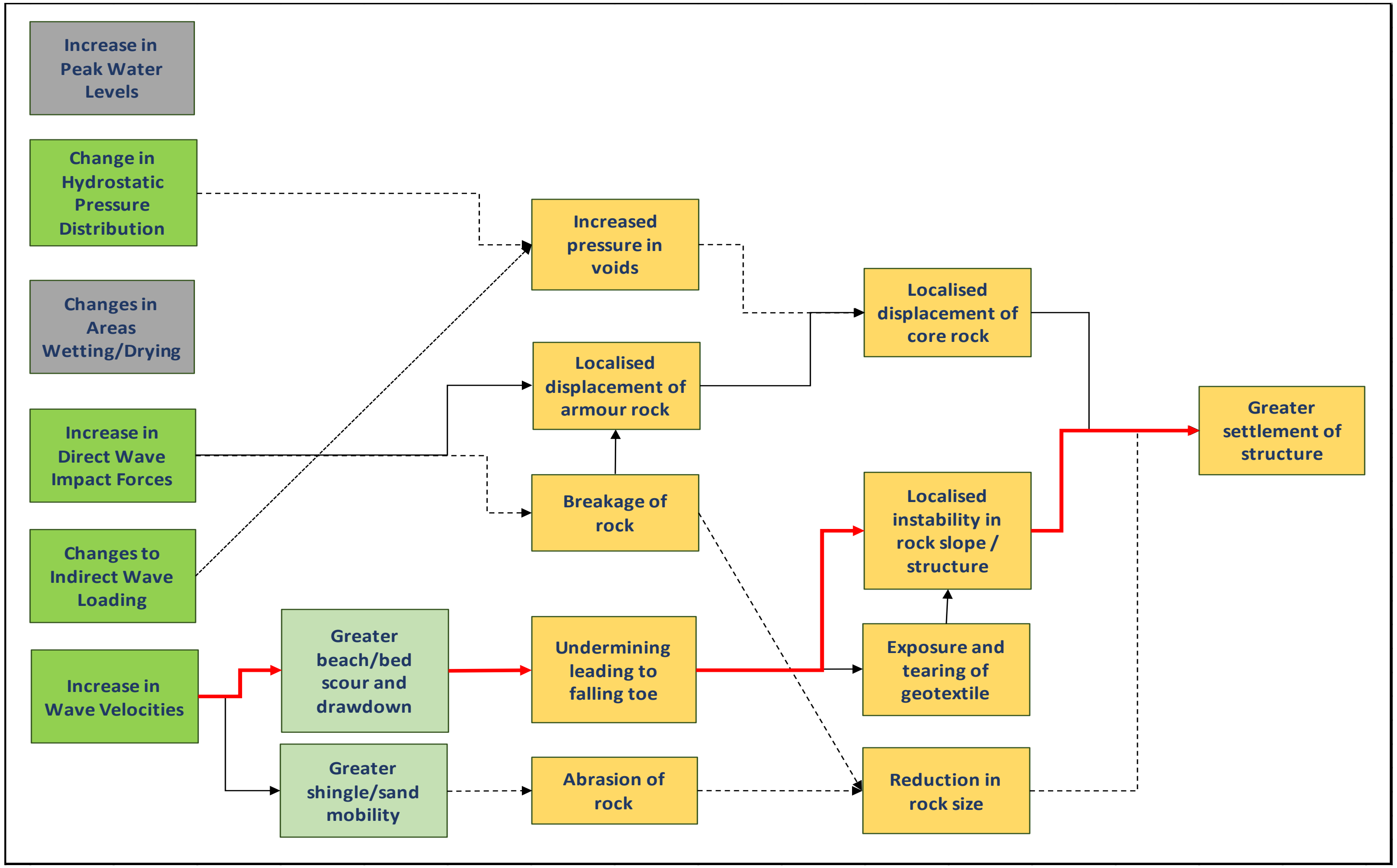
Most of these types of structures have been built in the last 25 years, so their design will almost certainly have taken account of climate change factors.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Groyne (Rock)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



<table>
<tr><td colspan="2">ASSET TYPE: Groyne (Rock)</td><td colspan="2">ENVIRONMENT: Coastal</td></tr>
<tr><td colspan="4">QUALITATIVE ASSESSMENT
The impacts of these climate change factors on deterioration of rock groynes include:
• Deeper water and larger waves impacts leading to greater potential for displacement of cover layer armour rocks, leading to localised loss (including core material).
• Greater variability and lowering of beach and bed levels along toe of the groyne, leading to toe falling and potential displacement of rocks.

The effects of climate change on structure deterioration are however generally likely to be Low. These structures are flexible and designed to adjust shape/deform to accommodate the hydrodynamic conditions, so other than some deformation should be able to accommodate the increase in waves being considered without catastrophic failure.

These structures are also designed to be relatively maintenance free – as and when anything is required, the action generally taken is to add some more rocks or rearrange those that are already there. Given most of these structures have been built within the past 25 years, it is also likely that allowance for a certain level of sea level rise was already built into their design.</td></tr>
<tr><td colspan="4">MAGNITUDE:</td></tr>
<tr><td>HIGH</td><td>MODERATE</td><td>LOW</td><td>NEGLIGIBLE</td></tr>
<tr><td></td><td></td><td>X</td><td></td></tr>
<tr><td colspan="4">OTHER POTENTIAL IMPACTS
It is highly unlikely that a rock groyne is going to fail to the point where beach retention is compromised.</td></tr>
</table>

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Breakwater	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"A breakwater provides coastal erosion protection and may provide a secondary function as a quay"

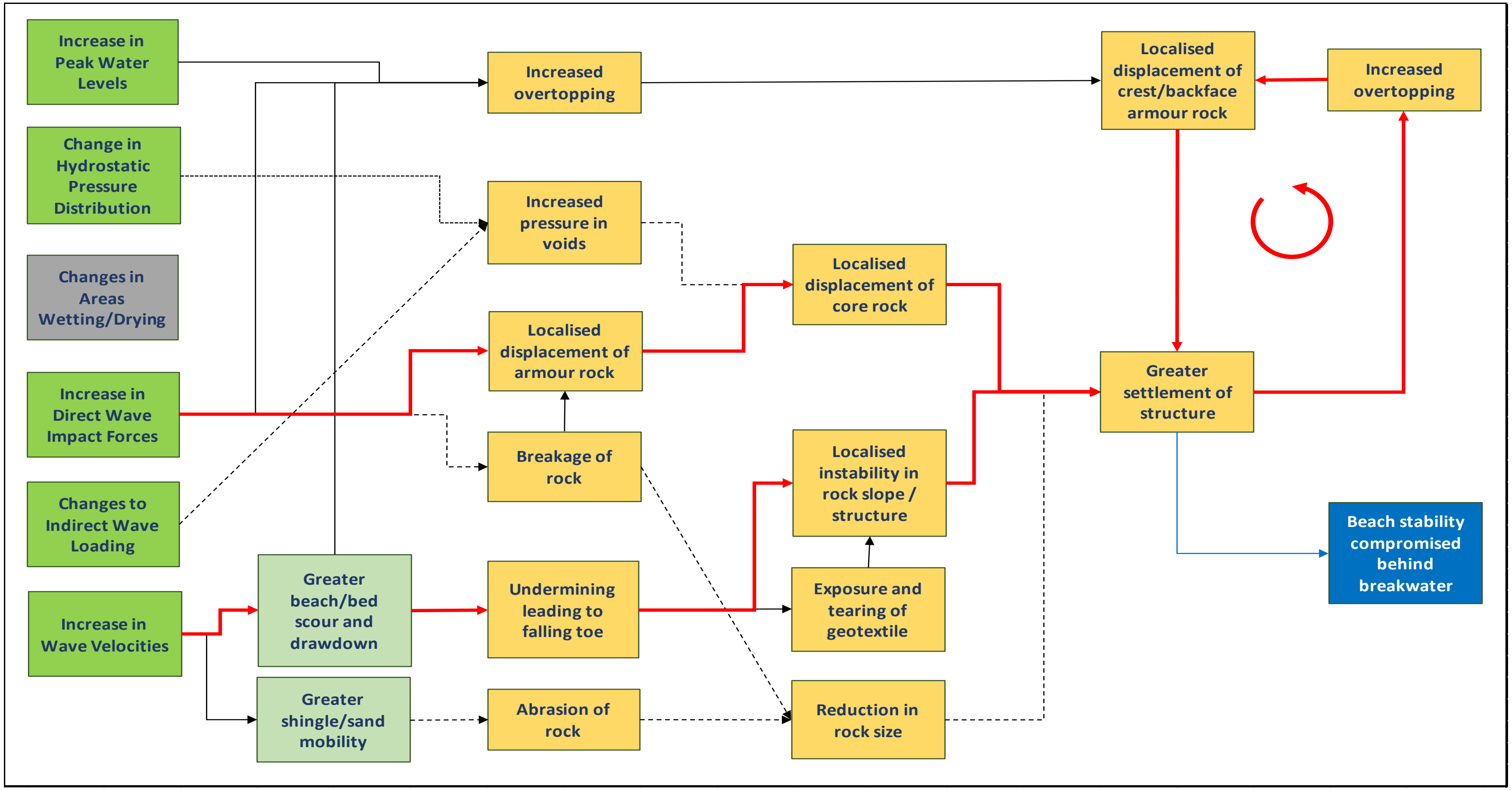
Coastal breakwaters in this context will almost certainly be constructed from large armour rock. Rock breakwaters are designed to deal with overtopping – rock on back face will generally be similar to or same as front.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Breakwater	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Breakwater	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of rock breakwaters include:

- Under extreme events: increased potential for displacement of rocks on front, crest or rear face, leading to localised loss (including core material) as a result of deeper water and larger waves
- Under day-to-day events: greater erosion of bed at toe of structure due to waves, leading to toe falling and potential displacement of rocks. This could be a result of greater wave run down reflections off the structure

The effects of climate change on structure deterioration are however generally likely to be Low. These structures are flexible and designed to adjust shape/deform to accommodate the hydrodynamic conditions, so other than some deformation should be able to accommodate the increase in waves being considered without catastrophic failure.

These structures are also designed to be relatively maintenance free – as and when anything is required, the action generally taken is to add some more rocks. Given most of these structures have been built within the past 25 years, it is also likely that allowance for a certain level of sea level rise was already built into their design.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The magnitude of impacts might be considered Moderate if the protection being provided by the asset, e.g. beach levels or wave attenuation to defences, has a high dependency upon the breakwater. This is though a standard of protection/performance issue rather than asset deterioration.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Slipway (Concrete)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"As slipway is a structure that allows access into the sea or other body of water from a beach or quayside"

Differences between timber and concrete slipways – ***this assessment covers concrete slipways***.

These are often mass concrete structures with no foundation, built directly over a beach/foreshore.

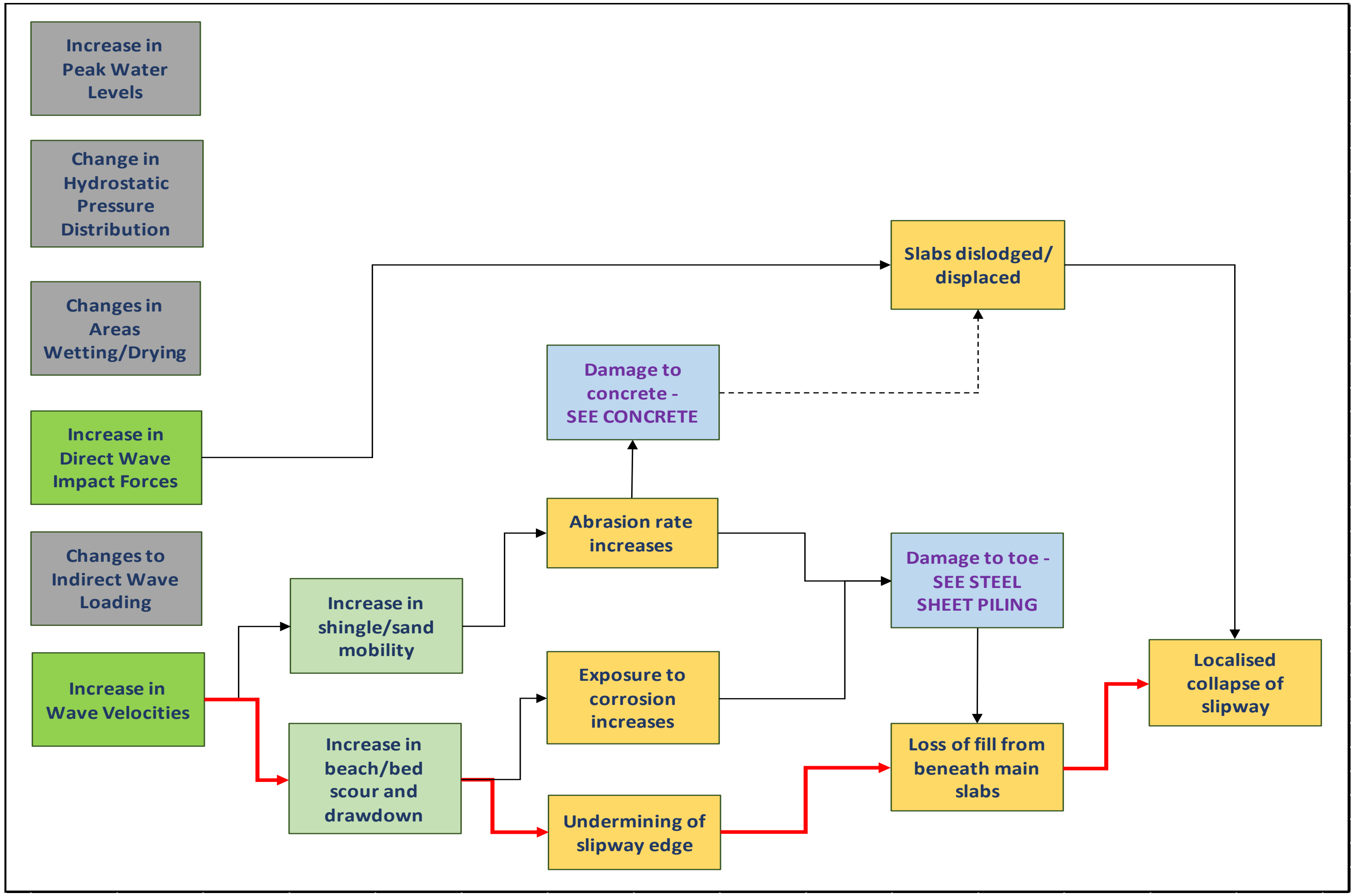
There will however be some which are reinforced concrete, and some which will have some foundation structure, e.g. steel sheet piling with concrete capping.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Slipway (Concrete)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Slipway (Concrete)		ENVIRONMENT: Coastal	
QUALITATIVE ASSESSMENT The impacts of these climate change factors on deterioration of concrete slipways include: • Lowering of beach/foreshore with edge scour leading to undermining and localised collapse of slipway. • Greater mobility of shingle leading to greater abrasion of concrete. • Corrosion/abrasion of steel sheet piling if present, leading to holing, and potential for loss of retained fill and localised collapse of slipway. These are often mass concrete structures with little foundation. Apart from concrete abrasion, which will generally be constricted by the exposed coarse aggregates so climate change factors will not alter significantly, there is little effect on these structures. The types of maintenance actions required to address deterioration of concrete are going to be similar to those at present, i.e. patching and repairing damaged concrete. These are likely to be of low consequence as these are structures that have been designed to be exposed to the sea, although any such activities may be required a little more frequently. The only other issue will be indirectly, through falling beach/bed levels. Often these structures have little in the way of formal foundations, so this will lead to undermining, cracking of the concrete and localised breakage/collapse. This could therefore require more repair activity than is currently undertaken. For this reason, the vulnerability is categorised as Moderate.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		
OTHER POTENTIAL IMPACTS There is a performance issue in that if maintenance actions are not increased to take account of higher rates of deterioration, then use of the slipway may be compromised.			

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Slipway (Timber)	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"As slipway is a structure that allows access into the sea or other body of water from a beach or quayside"

Differences between timber and concrete slipways – ***this assessment covers just timber slipways***.

There are 3 main elements to consider, planks, piles and fixings:

- TIMBER PILES/SUPPORTS – can rot, split, abraded, be destabilised (lean, buckle, snap) – shingle abrasion is one of biggest issues, weakening section.
- TIMBER SURFACE/DECK – planks can be displaced, loosened, rot or split, or abraded – leading to loss of structural competence
- METAL FIXINGS AND CROSS MEMBERS – come loose, broken/sheared, corroded or abraded

Timber structures on beaches have potentially more susceptibility to material deterioration than many other structure types. Shingle abrasion can be a big issue; so it is important to differentiate between sand beach and shingle beach settings.

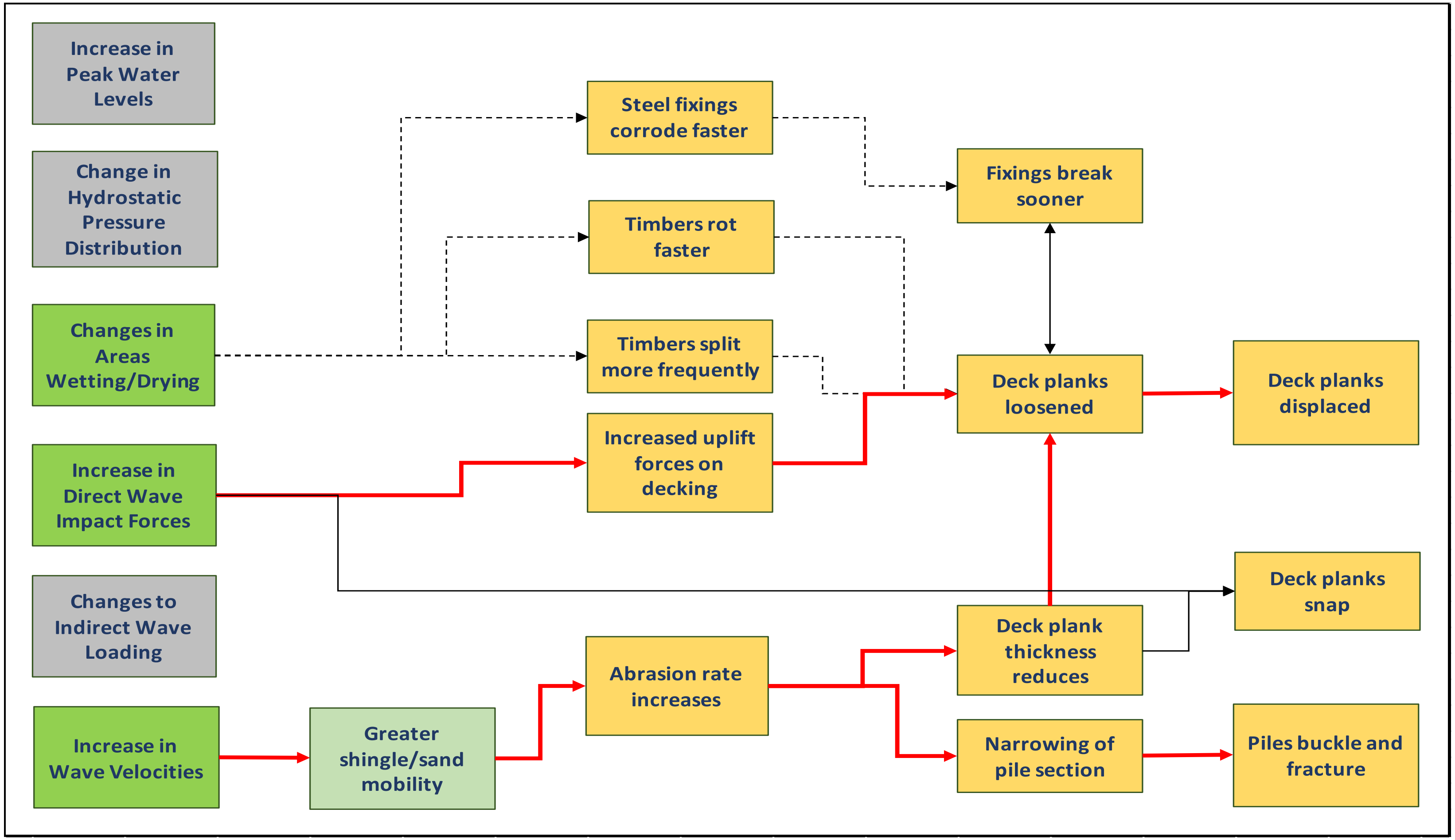
Rotting of timbers will depends on timber type.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	Potential*

*Change in ***water temperate*** could alter ecology and biodiversity of marine organisms, including marine borers.

ASSET TYPE: Slipway (Timber)	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Slipway (Timber)		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of timber slipways include:

- Greater mobility of shingle leading to greater abrasion of timbers – e.g. necking of piles, which could ultimately leading to them snapping.
- Higher wave forces on the underside of timber decking lead to planks becoming loosened and/or displaced.
- Increased rates of rotting/splitting and corrosion due to changes in wetting and drying are possible but not considered to be key areas of vulnerability – these structures are designed to frequently be wet and the changes in this will be small.

Abrasion due to the higher mobility of the beach material, particularly shingle is a primary issue for these structures. This leads to reduction in element section – loosening planks or necking of piles – which reduces structural competence. Also to consider is the increased loading on these structures from larger waves, in particular uplift forces increasing the potential displacement of the deck elements.

The types of maintenance actions required to address these matters will be similar to that at present, e.g. replacing planks and fixings as required, but with increased frequency, or requiring more remedial actions.

Overall, this increased maintenance commitment means that the vulnerability is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

There is a performance issue in that if maintenance actions are not increased to take account of higher rates of deterioration, then use of the slipway may be compromised.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Steps	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"Steps are a means of access to a beach"

This asset types refers to access steps, not stepped seawalls – keep separate.

These steps could be:

- As part of the seawall (often little more than mass concrete attached to the seawall)
- Over a structure (for example timber steps across the face of a revetment)
- Stainless steel either attached to a wall or over a structure.

The key components of a set of steps to consider include:

- Goings and risings
- Any support structure/fixings
- Handrailing

An additional factor for steps is potential for drop off the end due to falling beach levels.

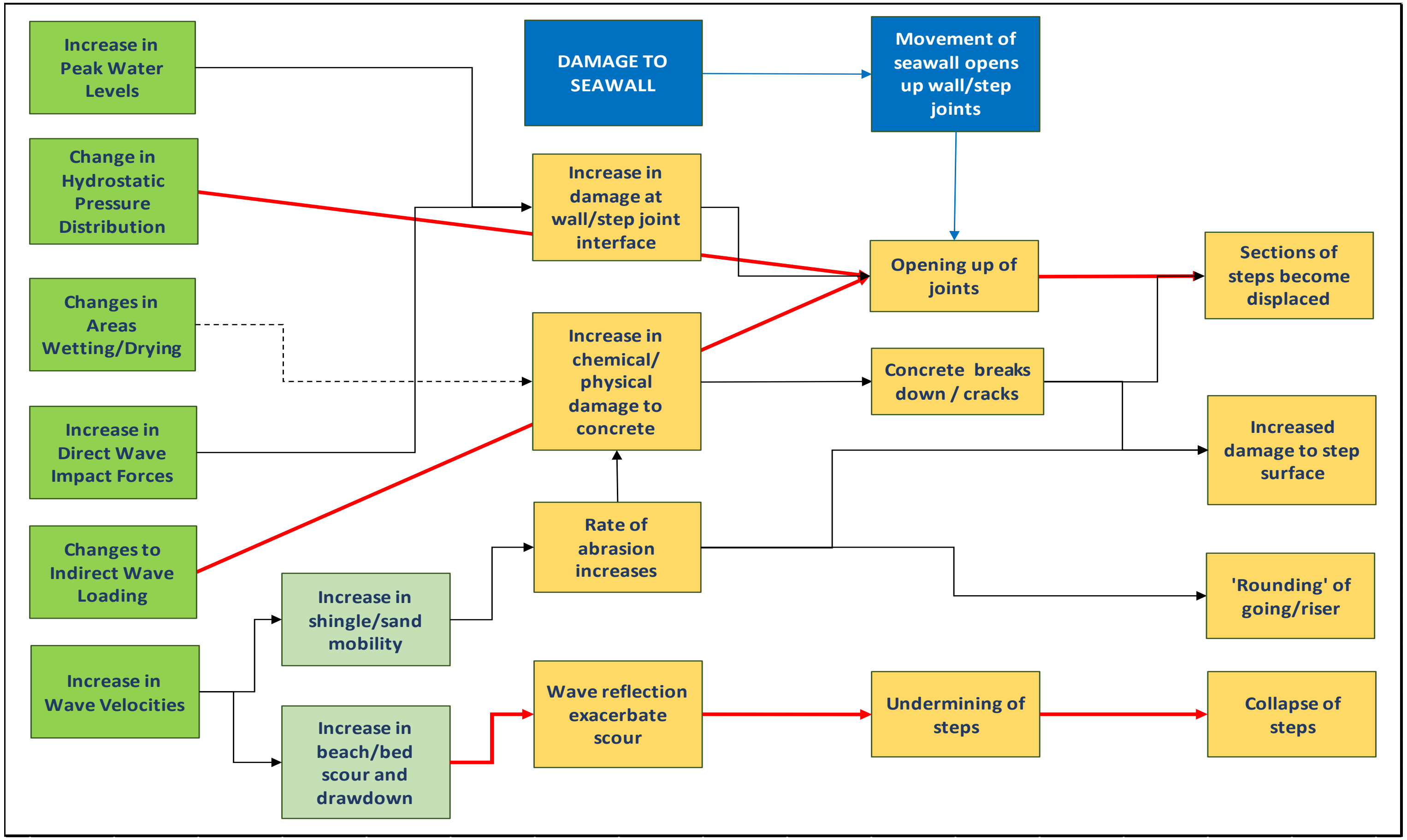
This assessment primarily covers concrete steps, forming part of a seawall, together with handrails. The mechanisms for deterioration of timber, will be very similar to that of other timber structures (e.g. slipways). The primary deterioration process for stainless steel structures attached to a wall will be very similar to that for hand railing.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	No

ASSET TYPE: Steps	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

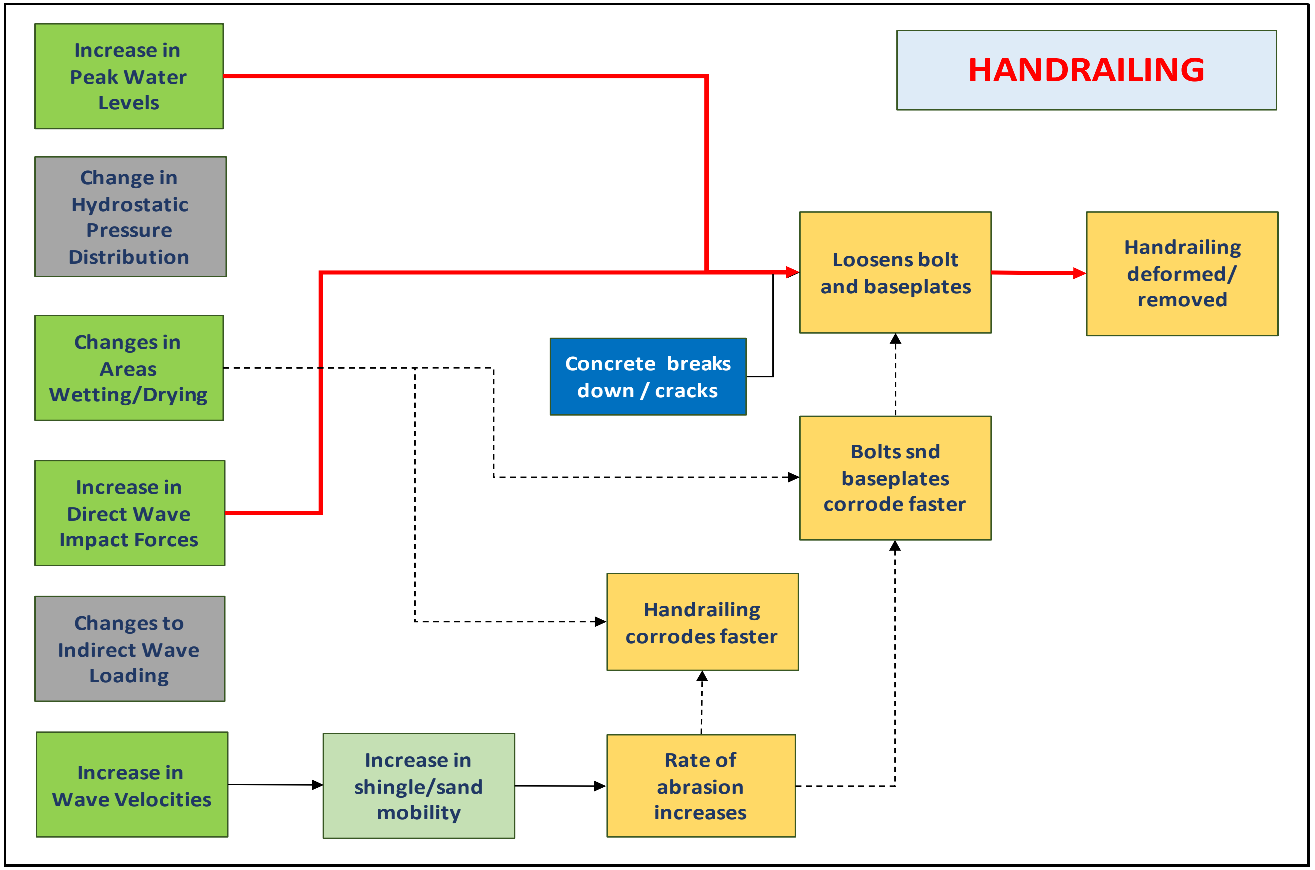
(1) CONCRETE



ASSET TYPE: Steps	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

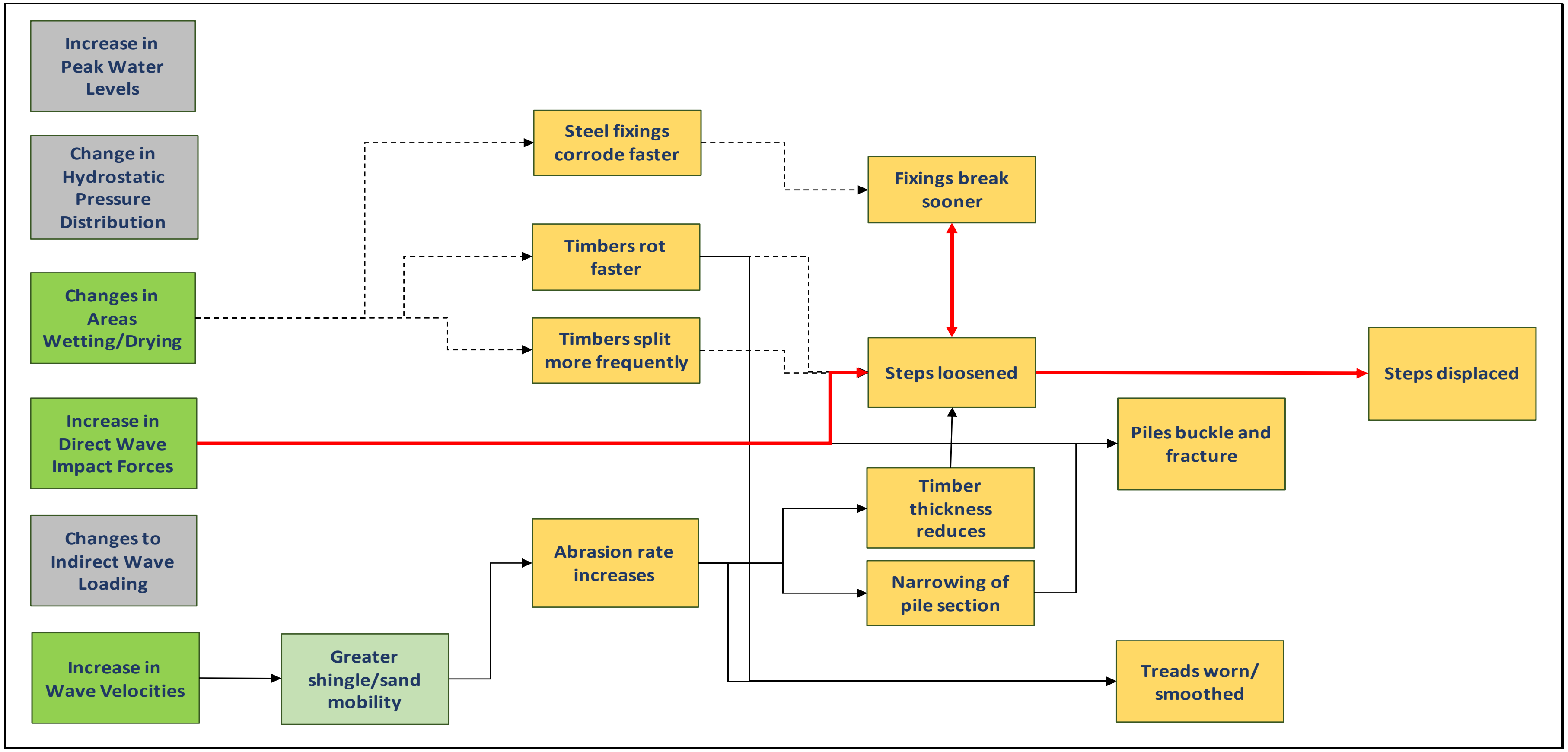
(2) STEEL HANDRAILING



ASSET TYPE: Steps	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(3) TIMBER



ASSET TYPE: Steps	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of concrete steps include:

- Increased exposure to higher water levels and wave forces opens up joints between main seawall and steps, leading to displacement of sections.
- Increased wave reflections producing greater scour of the beach and undermining of the steps, leading to collapse.
- Increased frequency/level of resurfacing of concrete steps to maintain their safe use.
- Damage or destabilisation of steel handrails.

For timber steps these would also include:

- Greater mobility of shingle leading to greater abrasion of timbers.
- Higher wave forces lead to timber elements becoming loosened and/or displaced.
- Increased rates of rotting/splitting due to changes in wetting and drying.

For stainless steel steps, the deterioration impacts would be similar to those for handrails.

Concrete steps are often concrete structures of considerable mass attached to a seawall, and often without any formal toe structure. They will not themselves be unduly affected by climate change effects in terms of structural integrity. Abrasion of the surface concrete may result through higher sand or shingle mobility as a consequence of higher run up and overtopping, which could require more frequent maintenance to maintain in a safe condition. In this context the beach type (sand or shingle) will be a consideration. Otherwise, this concrete abrasion will generally be constricted by the exposed coarse aggregates so there is limited additional effect on these structures from climate change. The bigger issue is the abrasion leading to 'rounding' of the edges of the steps, which reduces the tread area and becomes a safety issue.

With increased exposure and abrasion due to climate change factors, deterioration of concrete around bolts and baseplates could occur. Coupled with greater wave forces on these elements, the potential for damage to handrails will be increased.

The types of maintenance actions required to address deterioration of concrete are going to be similar to those at present, i.e. patching and repairing damaged concrete, or repairing handrails. These activities may be required more frequently, and replacement requirements may increase.

The greatest increased risk to these structures however is whole structure failure either from displacement of sections due to their detachment from the seawall/each other, or undermining beneath their base and collapse due to scour. Because of their shape and size, this would affect the entire steps (unlike a ramp or slipway where only part might be affected). Should this occur then more substantial repair works may be required to underpin/extend the steps. The vulnerability is therefore considered to be Moderate.

For timber steps, the abrasion of the supporting pile structure is less of an issue than for other beach structures, as these will generally be embedded in the revetment, not in the beach so have less direct exposure to this process. This can still leads to reduction in element section and reduce structural competence. An increase in abrasion may more commonly lead to wearing out of the tread, leaving the steps more dangerous to use. Another issue will be the increased loading on these structures from larger waves, in particular uplift forces increasing the potential displacement of the step elements. The types of maintenance actions required to address these

matters will be similar to that at present, e.g. replacing steps, treads, and fixings as required, but with increased frequency, or requiring more remedial actions.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		

OTHER POTENTIAL IMPACTS

There are associated performance/health and safety issues with beach levels falling leaving an unsafe drop from the bottom of the steps onto the beach.

Also, if maintenance actions are not increased to take account of higher rates of deterioration, then safe use of the steps may be compromised. One of those additional actions could be the more regular cleaning of the steps if they are more regularly underwater and become more slippery due to being wetter and greater deposition of seaweed, or replacement of the timber treads (e.g. gritting them) to make them safe for use. Similar H&S issues exist with timber steps, where rounding of the edge between the going and riser can occur, compromising their safe use.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Ramp	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Beach Structure'
"A ramp is a means of access to the top of the beach"

A ramp is similar to concrete slipways, but not into water (from above definition it extends onto the upper beach).

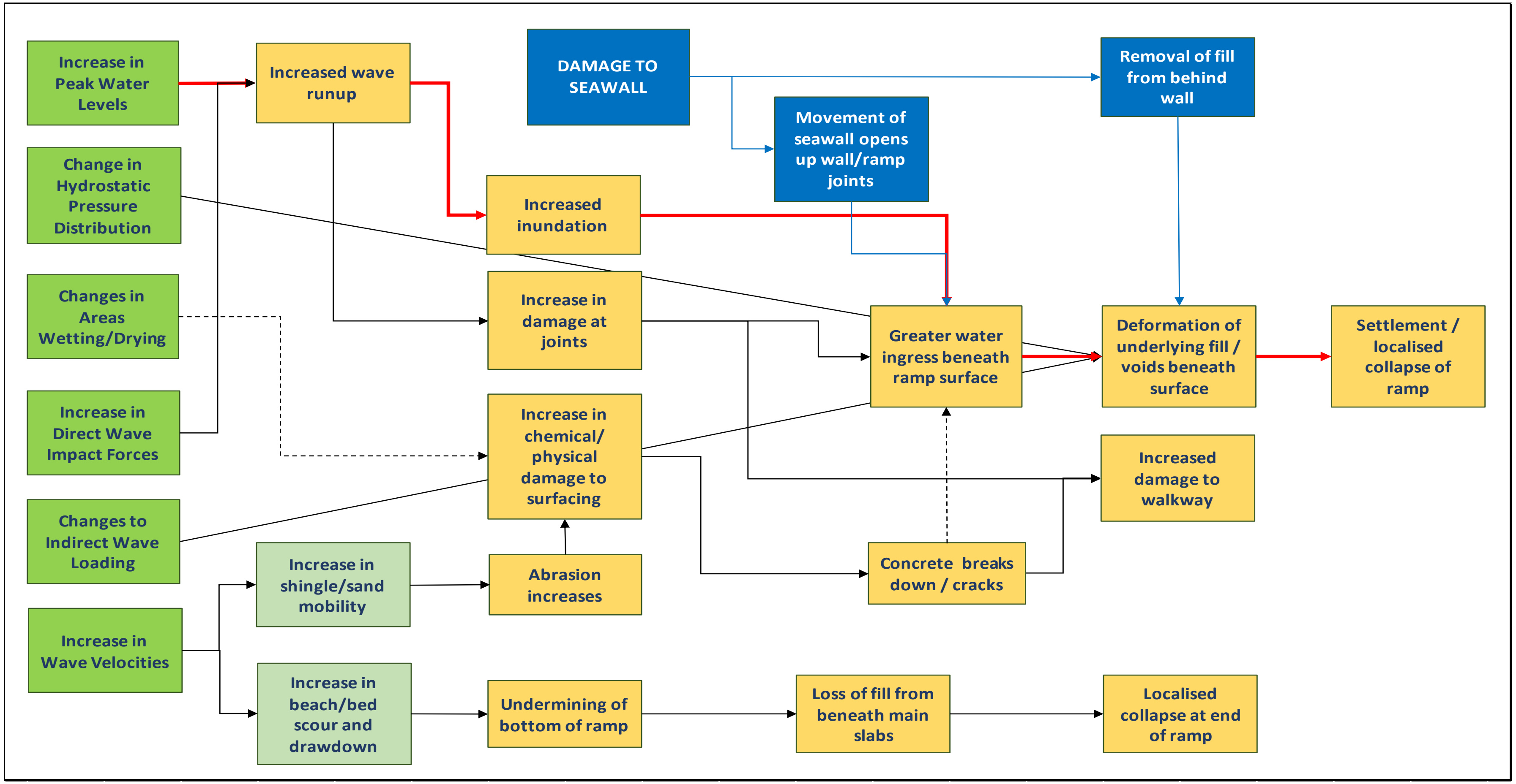
In many instances a ramp is effectively a sloping surface between two wall sections – the walls supporting the ramp is not included here – *see Seawalls for those details*.

An additional factor for ramps is potential for drop off the end due to falling beach levels, which is a health and safety issue.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	No

ASSET TYPE: Ramp	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Ramp	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of ramps include:

- Abrasion of concrete from increased mobility of shingle requiring greater maintenance to retain in safe useable condition.
- If there is no foundation structure, indirect process is beach/bed drawdown leading to undermining, cracking and breaking away
- Water ingress/percolation due to higher frequency of exposure to wave run up from storms due to higher water levels, leading to deformation of underlying fill

High water levels (SLR and storm surge) will allow higher run up on beaches and increased overtopping of seawall, leading to greater volume and frequency of water on the ramp, which could lead to increased percolation through the surface, or increased wear and tear to joints and seals allowing water penetration. Both could lead to spalling of concrete (if reinforced structure), and/or deformation of underlying fill leading to cracking and potentially localised collapse of the ramp.

Abrasion of the surface concrete may result through higher sand or shingle mobility as a consequence of higher run up and overtopping, which could require more frequent maintenance to maintain as a serviceable walkway. In this context the beach type (sand or shingle) will be a consideration. Otherwise, this concrete abrasion will generally be constricted by the exposed coarse aggregates so there is limited additional effect on these structures from climate change.

The types of maintenance actions required to address deterioration of concrete are going to be similar to those at present, i.e. patching and repairing damaged concrete. These are likely to be of low consequence as these are structures that have been designed to be exposed to sea conditions, although any such activities may be required a little more frequently.

The other potential issue will be indirectly, if lowering of the beach at the bottom of the ramp leads to it being undermined and collapsing. Often ramps are mass concrete and have little in the way of formal foundations, so this will lead to cracking of the concrete and localised breakage/collapse. This could therefore require some repairs to be carried out.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

Beach level variability due to climate change could independently lead to levels falling below critical levels, leading to the undermining and collapse of the supporting section of seawall. This is a more substantial impact than any of the deterioration processes.

There is also an associated performance/health and safety issue with beach levels falling leaving an unsafe drop from end of ramp onto beach. Furthermore, if maintenance actions are not increased to take account of higher rates of deterioration, then safe use of the ramp may be compromised.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Beacon	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"A beacon is attached directly to the bed of the sea or a river and may be lighted or unlighted. Some can also be found on land"

A beacon will most likely comprise a steel pile, driven into the seabed, with a topmark or light atop.

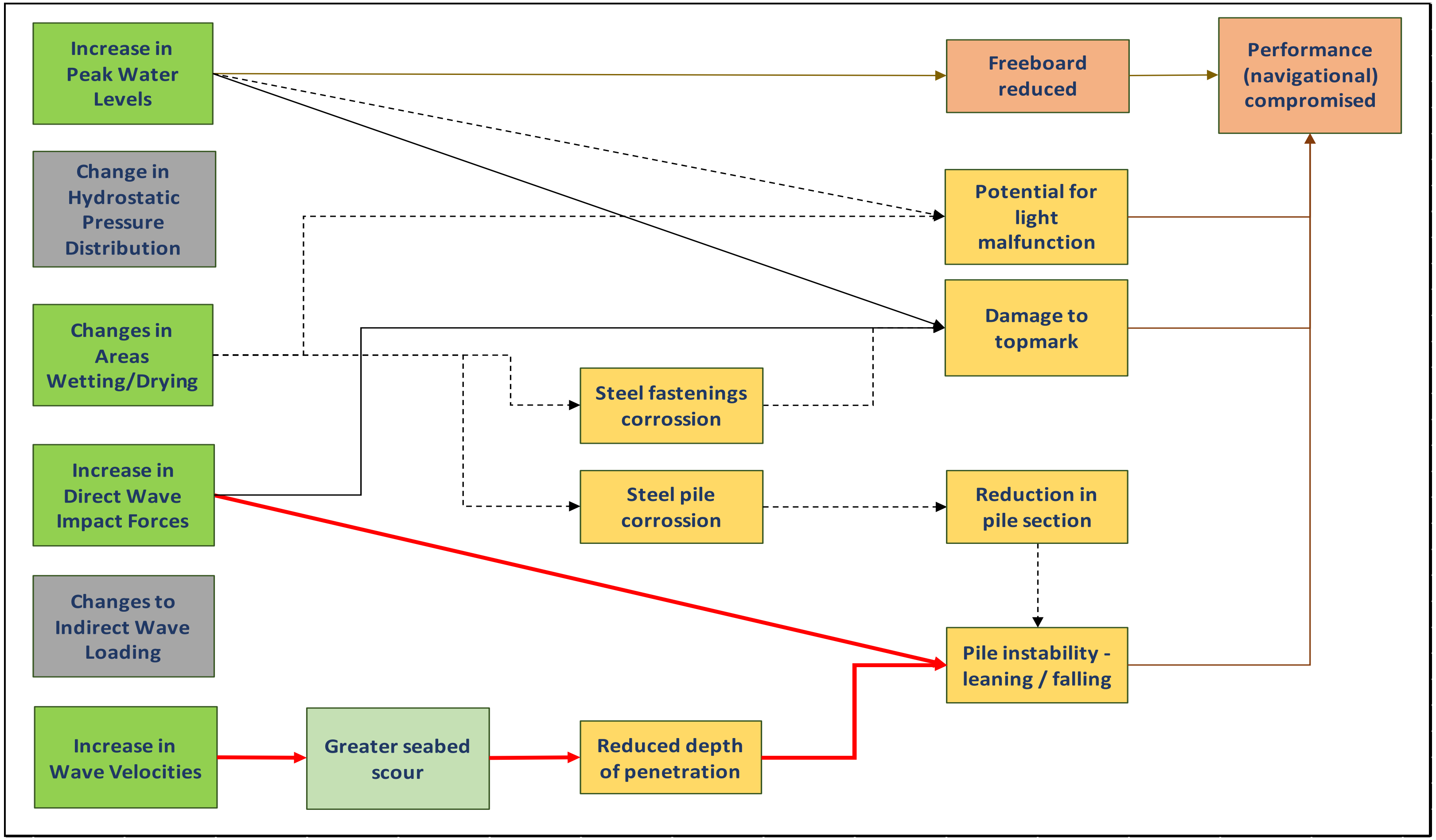
The distinction between a signal and the topmark of a beacon is however unclear (within the AIMS definitions).

This assessment covers beacons in the open sea. Those located in other environments, e.g. estuaries, are dealt with separately.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	Yes	No	No

ASSET TYPE: Beacon	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Beacon		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of beacons in the coastal environment include:

- Increased velocities at the sea bed could increase scour and reduce passive resistance to pile/post toppling. However, this would only be likely in shallow water – in deeper water there will be no discerable increase in wave velocities at the seabed.
- Piles could be destabilised through changes in wave loading.
- Higher water levels, allowing higher wave forces upon more elevated parts of the structure could lead to more damage of the topmark.
- Changes in areas vulnerable to corrosion would occur, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.

The main area of potential change would be an increase in loading on the supporting pile, which could result from higher wave impacts. This instability could be further increased by seabed lowering due to waves and currents, although the increase in wave heights is unlikely to significantly alter bed scour at depth. These piles are though expected to have been designed to take loadings under extreme conditions, and it is likely to be only in exceptional circumstances where the change in the climate factor is the reason for damage and repair. Damage and/or a requirement for maintenance to the topmark/light could possibly increase as a consequence of increased wave forces or malfunction resulting from higher water levels. The rate of corrosion is however unlikely to alter measurably.

The maintenance commitment to these assets is not expected to alter significantly as a consequence of climate change; the requirement for such activities may be a little more frequent only.

These vulnerability from a deterioration perspective is therefore Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

There is a performance issue to consider. Beacons should be designed to have at least a 2m freeboard, and with sea level rise this freeboard will be reduced. A reduction in freeboard due to higher water levels could therefore compromise navigation requirements and could require these structures to be extended vertically, or replaced.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Buoy	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type ‘Aids to Navigation’
“A buoy floats on the surface of the water and is anchored to the bed of the sea or river. It may be lighted or unlighted.”

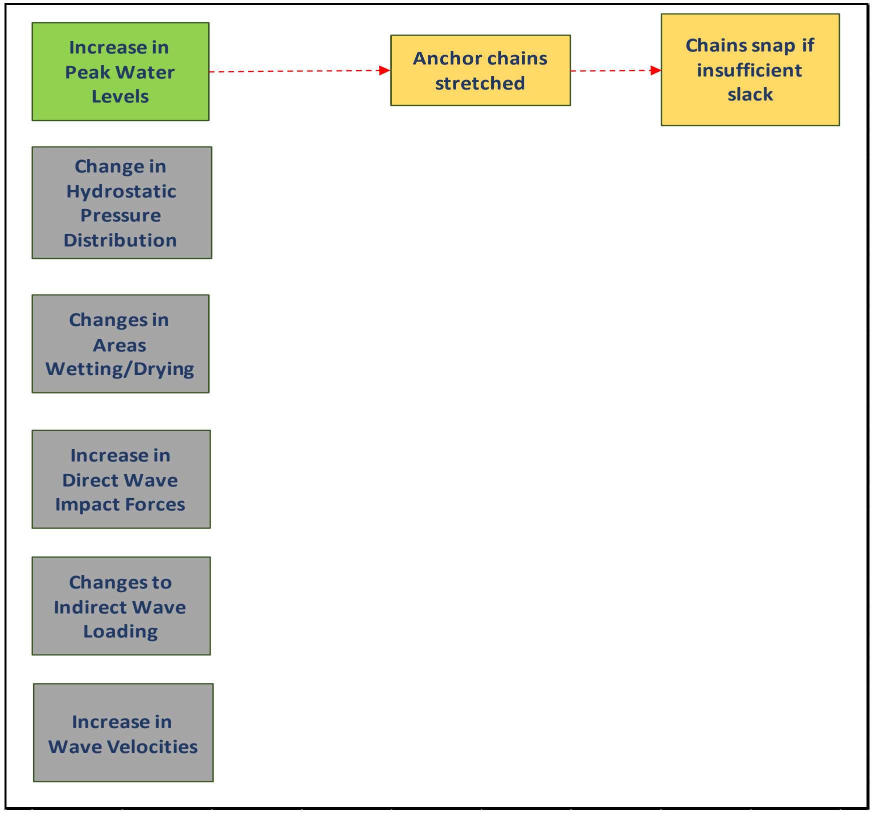
Buoy is generally made of plastic. Could be damaged/cracked, but not a climate change consideration. Moorings are usually a steel chain, but always submerged and corrosion/abrasion will be no different with climate change. Anchor block is often no more than a large lump of concrete on the seabed – not usually ‘designed’ as such. No difference in vulnerability with climate change.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Buoy	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Buoy		ENVIRONMENT: Coastal	
QUALITATIVE ASSESSMENT The impacts of these climate change factors on deterioration of buoys in the coastal environment include: • Anchor chains snapping as a result of being of insufficient length to accommodate deeper water resulting from higher water levels. The only impact climate change will have on these assets will be if the anchor chains do not have sufficient slack to accommodate greater wave depths resulting from higher water levels. Buoys sometimes have a 2 or 3 point mooring – in which case higher water levels and swells could stretch chains beyond their length, leading to them snapping. This may already be accommodated by the existing designs. If not, this can be simply remedied by installing longer chains to accommodate this as part of routine maintenance. The vulnerability to climate change impacts is therefore Negligible.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
			X
OTHER POTENTIAL IMPACTS None identified.			

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Signal	ENVIRONMENT: Coastal

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"A signal in the marine and fluvial environment provides traffic control or fog warnings"

The distinction between a signal and a beacon is unclear (within the CAMC definitions).

It is possible that a signal also includes audio signals (e.g. foghorns) as well as lighted signals.

For the purpose of this assessment, the signal is considered to be only the top part of the structure and assumed to be mounted upon a pile or other supporting structure.

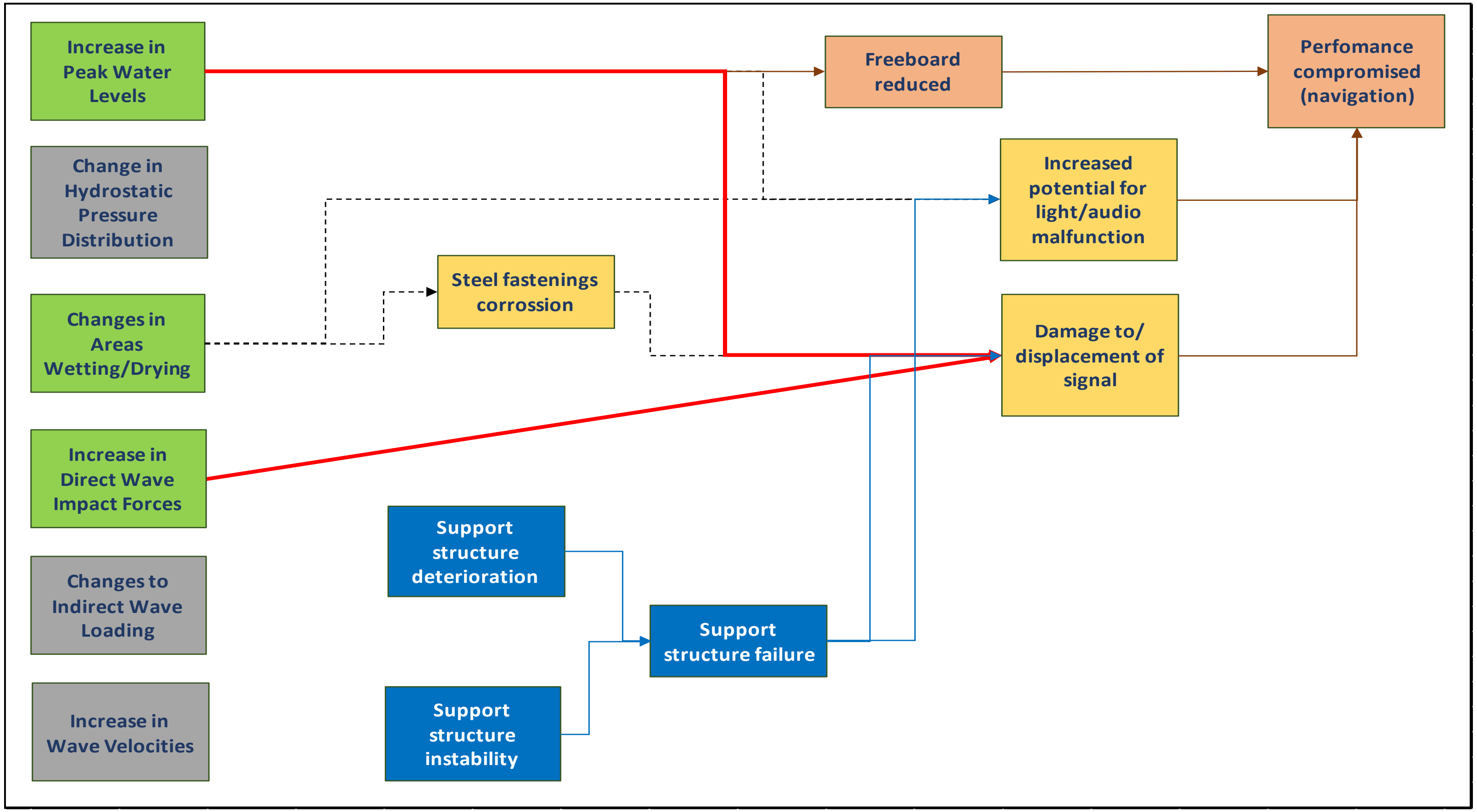
This assessment covers signals in the coastal environment only. A separate assessment is made for those in other environments, e.g. estuaries.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	Yes	No	No

ASSET TYPE: Signal	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Signal		ENVIRONMENT: Coastal	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a signal in the coastal environment include:

- Higher water levels and higher wave forces impacting upon more elevated parts of the structure could lead to more damage of the signal.
- Higher water levels and more frequent wetting/drying could potentially lead to more regular malfunction of light or audio equipment providing the signal.
- Mountings and fixings in areas susceptible to corrosion would experience faster rates of deterioration, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.

In terms of malfunction or corrosion issues, these structures are designed for exposure to frequent wetting and drying, so the impact of climate change on these and thus any change to maintenance requirements is likely to be very slight.

Damage and/or a requirement for maintenance to the signal could possibly increase as a consequence of larger waves and higher water levels, increasing the forces that the asset is exposed to. Again however, these assets are designed to withstand and perform under severe storm conditions, so the effects of climate change upon their deterioration or any increase in maintenance commitment are likely to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

The main area of impact to these assets are to the structure that they are mounted upon. Damage to that could lead to instability and thus damage of the signal.

Another issue is reduction/loss of performance function. These signals will be designed to have a certain amount of freeboard; with sea level rise this will be reduced and navigational control could be compromised. To counter this, these signals may need to be raised or replaced.

4 Fluvial Assets

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Open Channel	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Channel'
"An open channel is any channel that is not culverted."

The identification of Open Channel in AIMS is to mark the alignment of the water course; it does not include for any attributable assets, such as bank protection which is included under High Ground. In fact, Open Channel does not include channel sides at all, nor other assets found along such channels (e.g. Weirs).

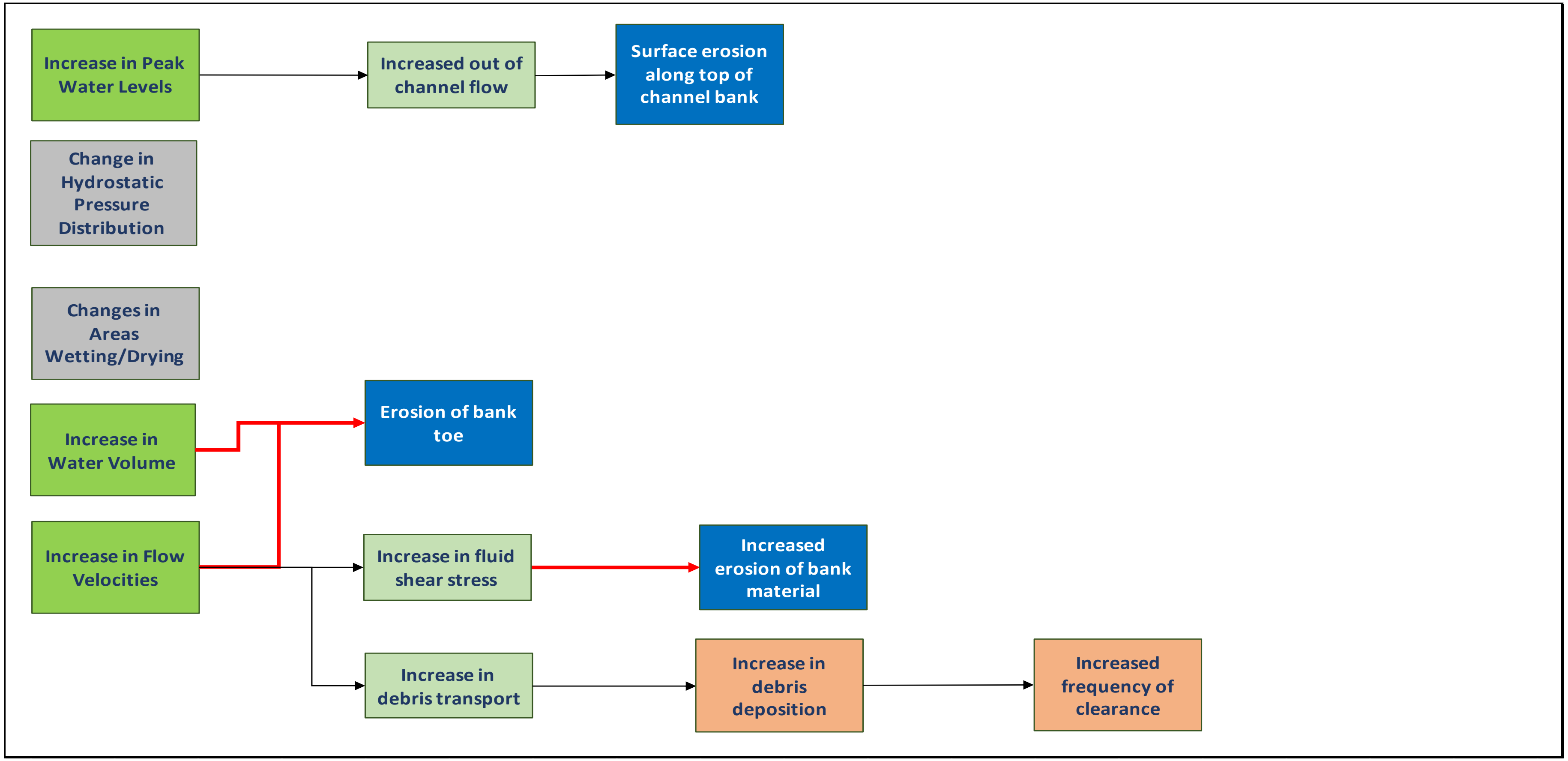
Climate change increases in velocities could increase bed mobility. Increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport within the watercourse.

It is questionable though whether Open Channel can be termed to be an 'asset', in relation to deterioration in the context of this study. The assets of real concern here would be any structures found within the river/channel system, which may in turn be affected by changes in the channel, rather than the channel itself.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Open Channel	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Open Channel		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of unprotected open channels include:

- Increase in water volume and flow velocity causing erosion of the channel bed, leading to potential undercutting along the toe of the channel bank (high ground or embankment), leading to slope failure.
- Increased debris deposition from higher flows requiring increased clearance.

The potential for erosion/undercutting along the bank toe is the primary issue, but this is of concern for those assets (bankside high ground or embankments) rather than the open channel itself. The outside bends of unprotected open channels will be the most vulnerable to increased flows and flow velocities.
Although watercourses have a maintenance commitment to ensure conveyance is not compromised, in the context of this study examining deterioration, these are not considered to be an asset in that context and there will not be any change in maintenance commitment other than for performance related concerns. So overall the magnitude of vulnerability is categorised as Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels and volumes will also reduce the capacity of the channel. Where this results in the target conveyance no longer being achieved, then works to increase the channel capacity would be required. Depending upon the changed geometry of the channel the geotechnical stability of the channel banks may require checking and redesigning.

Resultant changes in channel geometry will affect the interaction with in channel assets, which may have to be redesigned to prevent negative impacts on stability, performance, deterioration. For example outfalls may have to be repositioned or the erosion protection around will need to be increased if the channel is widened by the effects of climate change.
Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Simple Culvert	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Channel'.
"A simple culvert is a covered channel or large pipe to convey water below ground level, whose cross section is made of the same material throughout."

The CAMC definition goes on to note that culverts are distinguished from outfalls because they form part of the main watercourse, whereas outfalls discharge surface water drainage or water from a small watercourse into the main watercourse. Note also that some bridges are constructed from large rectangular concrete box sections, but these should not be considered a culvert if they can be visually inspected from the channel bank.

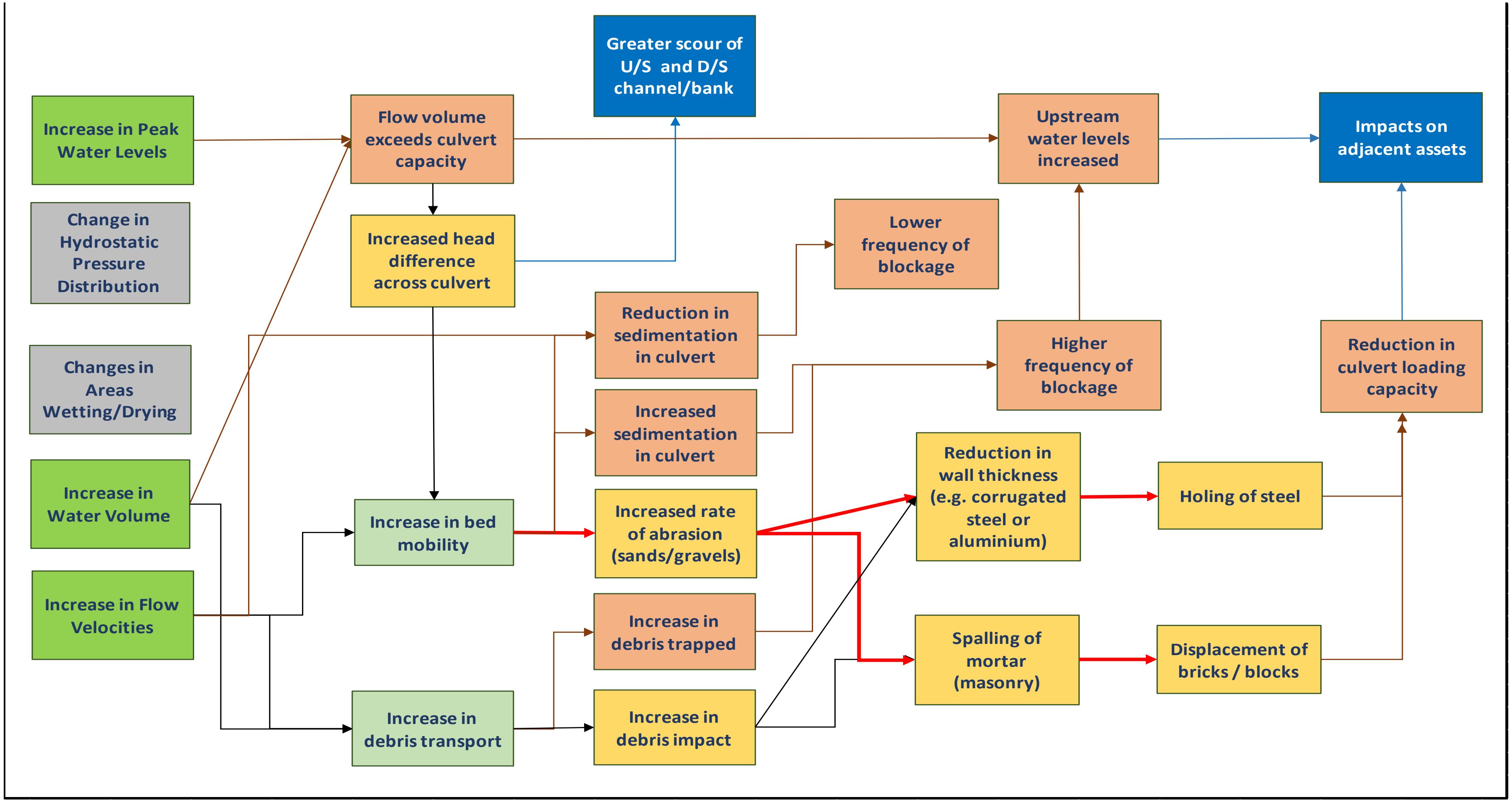
Simple culverts can be constructed from concrete, steel, masonry and plastic. As defined in CAMC this assessment covers only the deterioration of culverts composed of a single construction material.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Simple Culvert | ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Simple Culvert		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on the deterioration of culverts include:

- Increased bed mobility of sand and gravels causing increased abrasion of culvert materials
- Increased debris impact and damage as a result of greater flows and volumes

The main factors are the increases in flow velocities, volumes and levels. As culverts are in-channel assets the impact of increased wetting/drying and change in hydrostatic pressures are negligible.

Culverts made from corrugated steel or corrugated aluminium would experience increased erosion by abrasion; as would masonry culverts already in a damaged condition, thereby reducing the design life of these structures. Conversely, the impact of increased abrasion on culverts composed of concrete, plastic, vitrified clay and cast iron is likely to be negligible.

Culverts made from materials at higher risk from abrasion could require relining by specialist techniques to repair/prevent deterioration caused by climate change increases. Culverts generally could require more frequent condition inspection by CCTV survey to assess condition and potential deterioration.

The overall impacts on deterioration of culverts would depend upon the proportion of culverts made up from the more susceptible materials, but overall the vulnerability to deterioration from climate change increase is considered Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of a culvert is to convey a design flow of water. A culvert design capacity 20% higher than the current design flow is normally recommended. Therefore a 15% climate change flow increase would reduce this margin while a 30% climate change flow increase could result in culvert capacity being exceeded and a larger replacement culvert being required. If the required replacement was extensive, and / or located such that construction is difficult, then the impact could be much greater.

Climate change increases in peak water levels and flow volumes could also result in capacity problems for open channels located upstream and downstream of the culvert. These factors are covered under the ‘open channel’ asset type, but if climate change increases result in the culvert having inadequate capacity, then out of bank flow upstream of the culvert could result.

Culverts can cause channel bank erosion upstream and downstream and sediment deposition. These effects would be amplified by climate change increases if the culvert remained unchanged and potentially could cause instability of associated culvert structures i.e. headwalls.

There may also be increased scour and undermining of the channel upstream and downstream of the culvert due to increased bed mobility, which could then impact upon the stability of the culvert itself.

There will be an increase in maintenance commitments to clear blockages resulting from increased debris and sediment deposition.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Complex Culvert	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Structure'

"A complex culvert is a covered channel to convey water below ground level, whose cross section is made of different material throughout (for example: masonry sides covered with a concrete soffit)."

The CAMC definition goes on to note that culverts are distinguished from outfalls because they form part of the main watercourse, whereas outfalls discharge surface water drainage or water from a small watercourse into the main watercourse. Note also that some bridges are constructed from large rectangular concrete box sections, but these should not be considered a culvert if they can be visually inspected from the channel bank.

Complex culverts can be constructed from a combination of a variety of different materials including concrete, steel, masonry and plastic. As defined in CAMC this assessment covers only the deterioration of culverts composed of more than one material.

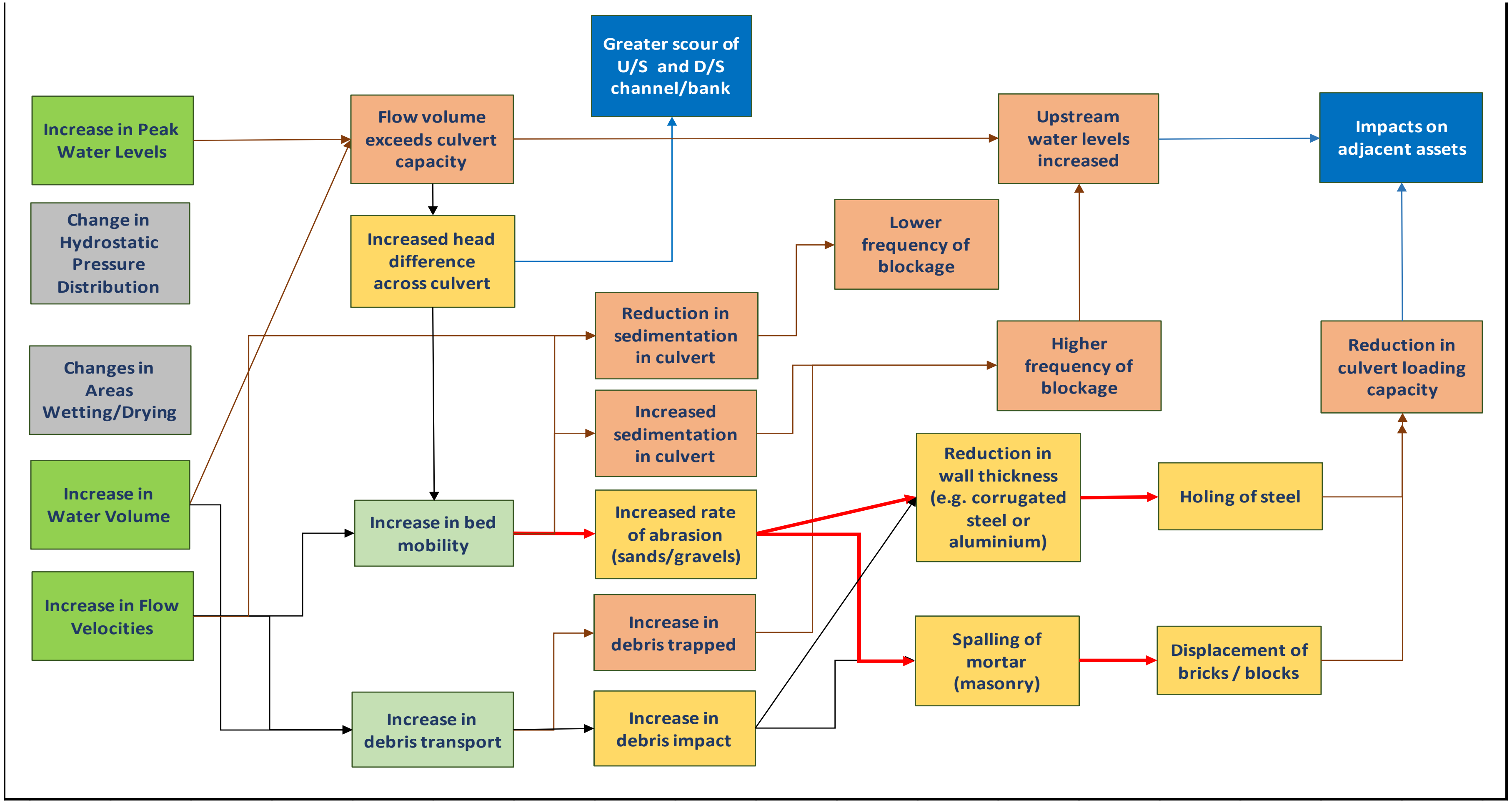
This could include a culvert length where culverts of different materials are used within that length, e.g. a length of masonry culvert joining onto a length of concrete culvert either side of an inspection chamber.

However, the purpose and function of simple and complex culverts is identical.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Complex Culvert	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Complex Culvert	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on the deterioration of culverts include:

- Increased bed mobility of sand and gravels causing increased abrasion of culvert materials
- Increased debris impact and damage as a result of greater flows and volumes

The main factors are the increases in flow velocities, volumes and levels. As culverts are in-channel assets the impact of increased wetting/drying and change in hydrostatic pressures are negligible.

Culverts made from corrugated steel or corrugated aluminium would experience increased erosion by abrasion; as would masonry culverts already in a damaged condition, thereby reducing the design life of these structures. Conversely, the impact of increased abrasion on culverts composed of concrete, plastic, vitrified clay and cast iron is likely to be negligible.

Culverts made from materials at higher risk from abrasion could require relining by specialist techniques to repair/prevent deterioration caused by climate change increases. Culverts generally could require more frequent condition inspection by CCTV survey to assess condition and potential deterioration.

The overall impacts on deterioration of culverts would depend upon the proportion of culverts made up from the more susceptible materials, but overall the vulnerability to deterioration from climate change increase is considered Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of a culvert is to convey a design flow of water. A culvert design capacity 20% higher than the current design flow is normally recommended. Therefore a 15% climate change flow increase would reduce this margin while a 30% climate change flow increase could result in culvert capacity being exceeded and a larger replacement culvert being required. If the required replacement was extensive, and / or located such that construction is difficult, then the impact could be much greater.

Climate change increases in peak water levels and flow volumes could also result in capacity problems for open channels located upstream and downstream of the culvert. These factors are covered under the ‘open channel’ asset type, but if climate change increases result in the culvert having inadequate capacity, then out of bank flow upstream of the culvert could result.

Culverts can cause channel bank erosion upstream and downstream and sediment deposition. These effects would be amplified by climate change increases if the culvert remained unchanged and potentially could cause instability of associated culvert structures i.e. headwalls.

There may also be increased scour and undermining of the channel upstream and downstream of the culvert due to increased bed mobility, which could then impact upon the stability of the culvert itself.

There will be an increase in maintenance commitments to clear blockages resulting from increased debris and sediment deposition.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Bridge	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Channel Crossing'
"A bridge is any structure that allows road, rail, pedestrian or farm access over a channel. This also includes aqueducts."

A bridge can be constructed from a wide range of materials including masonry, timber, concrete, metals, etc. Their composition can also be quite varied. This template considers the bridges from a high level with no specific form and includes for the major components of a bridge, i.e

- Deck
- Abutments
- Support Piers (if any)

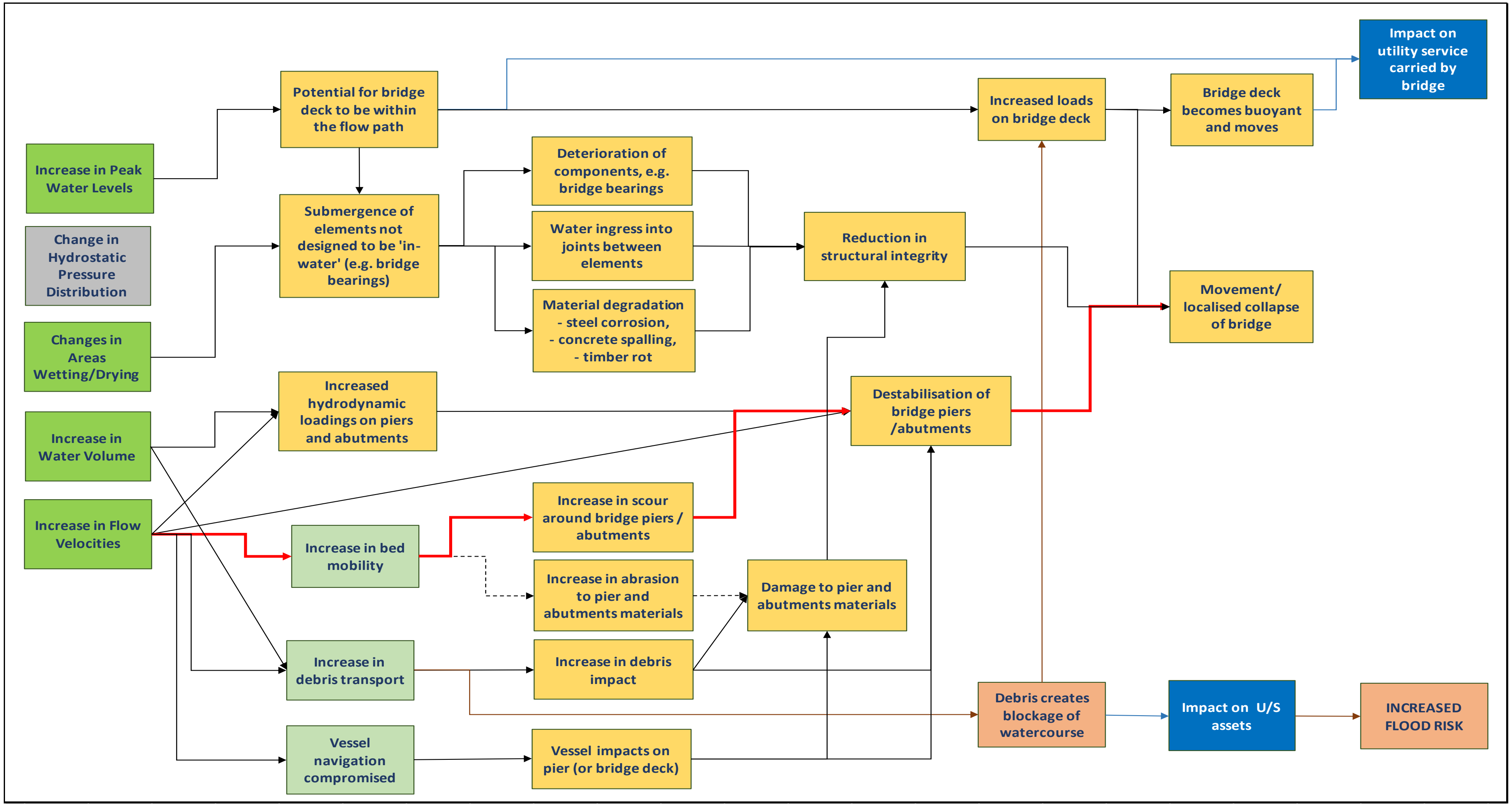
Abutment and Central Pier in the context of 'Major Civils' asset types are covered in separate assessments. Likewise Bridge Abutment in the specific context of forming part of a 'Defence' asset type is also covered in a separate assessment. Consequently, the conclusions of this assessment will relate specifically and only to the crossing (i.e. deck) element of the bridge, which is not in itself usually providing an FCERM function.

Climate change increases in peak water levels and flows could result in increased and/or new forces on the bridge and a change of which elements of the bridge become exposed to a water environment. Increases could also cause increases in debris transport and bed mobility.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Bridge	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Bridge	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of bridges potentially include:

- Increases in peak water levels, flows and flow velocities would cause increased loads onto the bridge if the increased water level resulted in the bridge being within the flow path.
- Impact damage to the bridge deck and support piers resulting from large items of debris hitting the bridge either more frequently and/or with higher forces due to increased flow velocities and water levels.
- Increases in peak water levels, flows and flow velocities have potential for increased impact damage from vessels which may find navigation more difficult in these conditions.
- Changes in Areas Wetting/Drying could have potentially adverse effect on bridge bearings and deterioration at supports and joints between bridge components or other elements of the bridge which are not designed for a water environment.

If higher water levels result in the bridge being within the flow path, there would be potential for lighter bridge decks to fail (sliding failure) through high flows transferring loads to the bridge. A large and important bridge would have a deck soffit level designed to be above any reasonable foreseeable channel water level, although the susceptibility to damage depends entirely on the freeboard that exists.

Impact damage to the supporting piers and abutments is however a potential issue, with more and possibly larger items of debris carried along the watercourse with more force during high flow events.

Increases in flow velocities could potentially result in erosion to the channel banks and bed adjacent the bridge, and cause reduced stability of piers and abutments. Erosion would increase to already damaged areas of scour protection, resulting in increased maintenance. A large and important bridge would have been designed with scour (erosion) protection against any reasonably foreseeable flow velocities, but this will vary from structure to structure.

Likely requirements would be increased condition inspection resulting from greater frequency of high flow events, and potentially more regular repair activities if damage has occurred, and to ensure scour protection remains adequate.

Therefore the impact of climate change increase will vary from bridge to bridge with smaller, less strategic, bridges potentially being more vulnerable than larger structures, although it is notable that some severe damage has occurred to older bridges under high flow conditions even without climate change effects. There is a risk to bridges from much greater river flows, and the potential works required could vary from modest to significant. However, the bridge overall does not usually provide an FCERM function, therefore in that context the potential impact of climate change should be considered Low at worst.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Increases in peak water levels and the potential for increased blockages that resulted in the bridge deck being within the channel flow would cause a reduction in channel capacity (performance issue), and potential for upstream out of channel flow (performance issue).

Increases in peak water levels, flows and flow velocities could potentially result in more debris becoming trapped by the bridge deck, especially if the increased water levels resulted in the bridge deck being within the flow path. This would require an increase in inspection and maintenance (clearance).

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Utility Services	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Channel Crossing'.
"A utility service is any structure that allows a utility service to cross a channel. This can be either above or below the channel."

Utility service assets can be found in three main configurations within a watercourse:-

- Below channel bed
- Above channel bed fixed to another watercourse spanning asset (e.g. bridge)
- Above channel bed and self-spanning watercourse

The materials used to form the Utility Service crossing will affect how the asset degrades, although most crossings are robust, e.g. steel pipe.

The relative position of the asset within the watercourse will also influence how they will be affected by the impacts of Climate Change on fluvial flow characteristics.

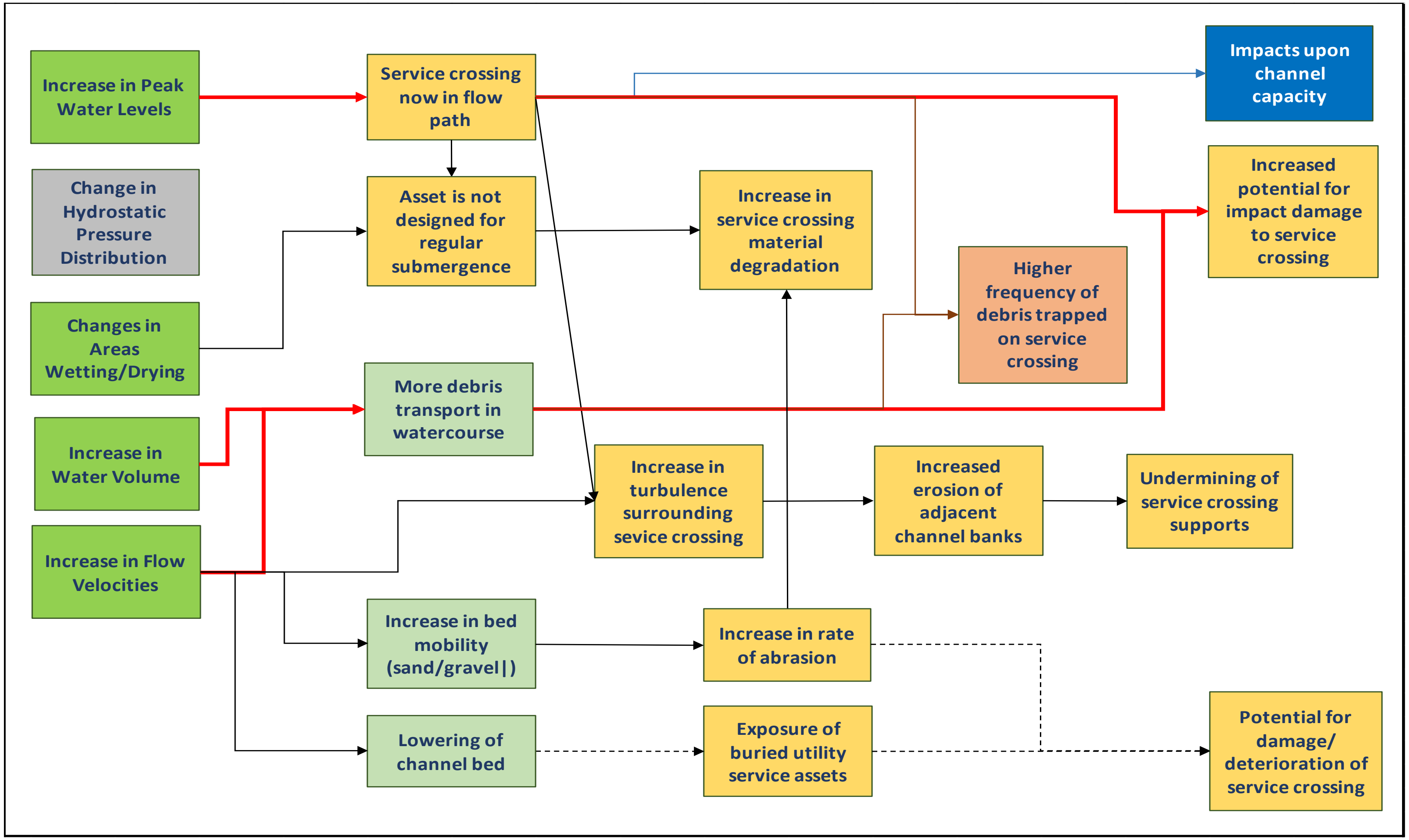
Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility. Increases in peak water levels and flows could expose elements of the utility services not previously exposed to a water environment.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Utility Services	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Utility Services	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of utility services include:

- Increases in peak water levels, water volume and flow velocity could cause increases in channel debris transport.
- Increases in flow velocities could cause channel bed erosion with exposure and potential damage to a service crossing below channel bed level.
- Increase in erosion at the supports to the service crossing, resulting from higher flows.

Increases in the potential for large debris items causing impact damage and increased abrasion respectively to a service crossing above channel bed level would be the main issue with respect to these assets.

Bed mobility would also be a potential issue for buried utility services, although it might be assumed that such services are buried to a substantial depth or designed to resist and exposure if they lay beneath and erodible bed.

Climate change increased flow velocities may cause an above bed level service crossing to create increased turbulence that may result in channel bank erosion. This erosion and undermining along the adjacent banks could lead to potential failure of the support.

The maintenance requirements necessary to address these matters will not be different from those at present, but inspections and any necessary actions may be required more frequently as a result of climate change.

If the utility service crossing has been adequately designed, the overall climate change vulnerability is considered as Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The presence of the utility crossing may result in out of channel flow caused by climate change increases in peak water levels and water volume to. If it is not possible to relocate the utility crossing, channel widening and increased support to the crossing may be necessary. In order to achieve increased channel flow capacity in locations it may be necessary to relocate the utility crossing.

Increases in peak water levels, water volume and flow velocity could cause increases in channel debris transport resulting in increased frequency of debris being trapped onto service crossings e.g. pipe crossings, above channel bed level. This would cause increased frequency of inspection and clearance to preserve channel capacity.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Embankment (Turfed - Unprotected)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"An embankment is an earthen structure used in the fluvial, tidal and coastal environments for flood defence and/or erosion protection."

Embankments may be protected or unprotected.

Protected embankments can include:

- PERMEABLE REVETMENTS – open cell (e.g. plastic geotextile grids, concrete open cell); toe rolls; toe geotextile plant pallets; grassed composites; concrete bag-work; stone; gabion mattress; concrete unit with toe protection.
- IMPERMEABLE REVETMENTS – grouted stone; concrete slabs; concrete sprayed gabion mattress.

This assessment covers unprotected, i.e. turfed only embankments. A separate assessment has been made for protected embankments.

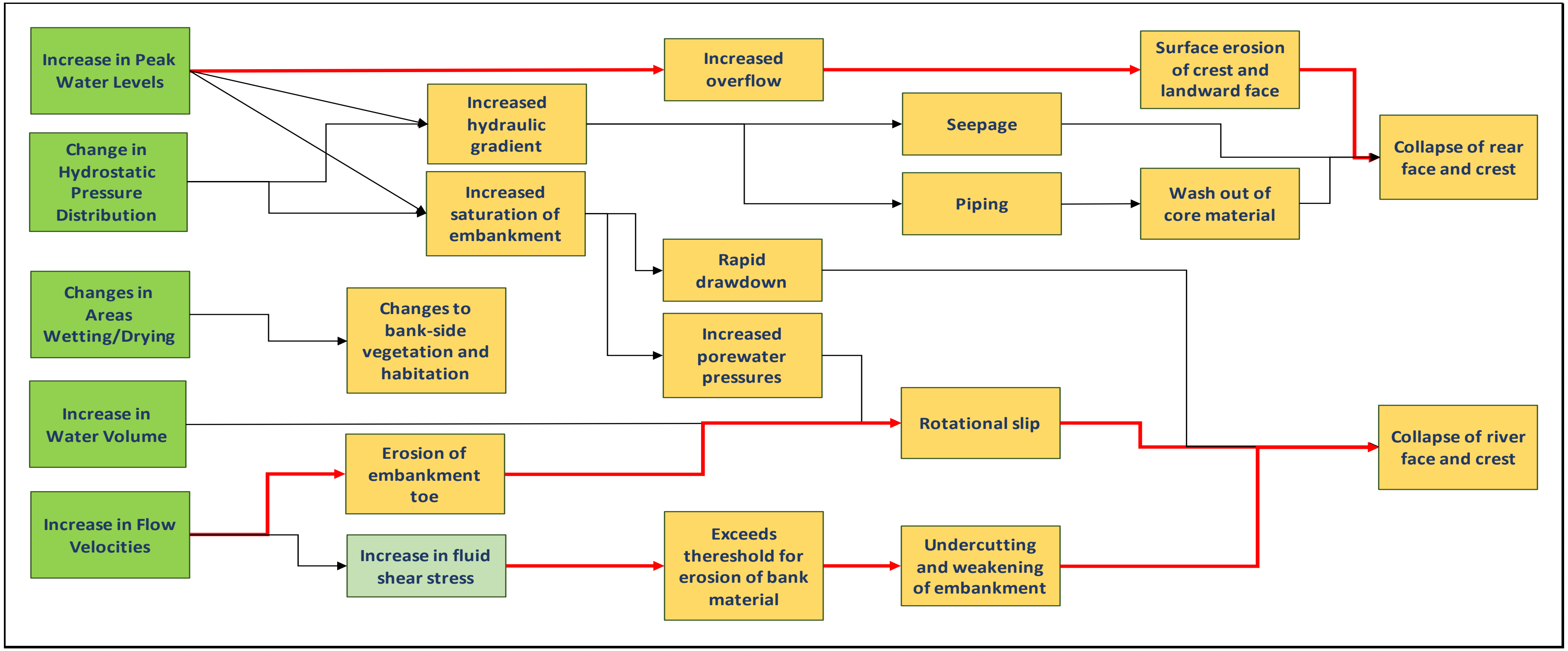
Unprotected embankments are those that are covered just by vegetation (turfed). To note, turf is suitable up to 1.8m/s flow velocity.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	Potential*

*Increased ***rainfall*** could result in greater saturation of embankments, exacerbating the instability issues described here, whilst lesser rainfall (droughts) could result in more drying out of embankments leading to cracking and fissuring.
* Changes to ***rainfall*** and ***temperature*** could impact upon vegetation growth on embankments, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.
*Changes to ***temperature*** (and ***rainfall***) could impact upon fauna and thus habitats, resulting in more burrowing or activity on embankments that requires more intervention to overcome.

ASSET TYPE: Embankment (Turfed - Unprotected)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Embankment (Turfed - Unprotected)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of unprotected embankments potentially include:

- Increase in peak water levels resulting in greater and/or more frequent overflow, causing erosion of soft exposed faces on crest and landward face
- Increase in water volume and flow velocity causing erosion of front face and/or undercutting, leading to slope failure
- An increase hydrostatic pressure causing increased seepage and potential piping through the embankment, leading to potential erosion and failure on landward face.
- Changes to vegetation cover and habitation, requiring increased inspection and actions

The potential for overflow causing crest and rear face erosion, and the potential for erosion/undercutting of the river face are the primary issues for these structures. The outside bends of channel embankments will be the most vulnerable to increased flows and flow velocities if protection is absent or insufficient. In terms of the potential instabilities caused by changes in hydrostatic pressure differences, poorly maintained embankments, e.g. with animal burrows, will be the most vulnerable.

Some of the maintenance actions required to address these matters will be similar to that at present, but will be required with greater frequency. However, in addition there could be a much increased requirement to repair damage to prevent breaches caused by erosion, or indeed having to repair breached embankments from time to time where these do occur. In some instances it may be necessary to modify these embankments and introduce protection in the form of revetments and anti-scour protection.

Overall, therefore, this increase in maintenance commitments and the increase in the chance of failure of these unprotected embankments, mean that the vulnerability is considered to be High.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels will also reduce the standard of protection provided by the embankments. Where this results in the target standard no longer being achieved, then works to increase the height of the embankment crest would be required. Depending upon the geotechnical stability of that higher embankment, this could also necessitate a corresponding widening of the structure.

Although not included in the current assessment, it is worth noting the potential impacts of increases in temperature making banks more susceptible to erosion through fissuring and cracking, and increases in rainfall increasing pore pressures in banks making them more susceptible to seepage and piping failure during and post flood events. Other impacts of these factors are the change in vegetation growth or burrowing activity, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.

Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Embankment (Permeable Revetment)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"An embankment is an earthen structure used in the fluvial, tidal and coastal environments for flood defence and/or erosion protection."

Embankments may be protected or unprotected.

Protected embankments can include:

- PERMEABLE REVETMENTS – open cell (e.g. plastic geotextile grids, concrete open cell); toe rolls; toe geotextile plant pallets; grassed composites; concrete bag-work; stone; gabion mattress; concrete unit with toe protection.
- IMPERMEABLE REVETMENTS – grouted stone; concrete slabs; concrete sprayed gabion mattress.

This assessment covers embankments protected by permeable revetments. Separate assessments have been made for embankments protected by impermeable revetments and unprotected embankments.

Depending upon the revetment material, some are suitable only for low flow velocities, some for low and medium flow velocity, with stone rip rap potentially suitable for high flow velocity.

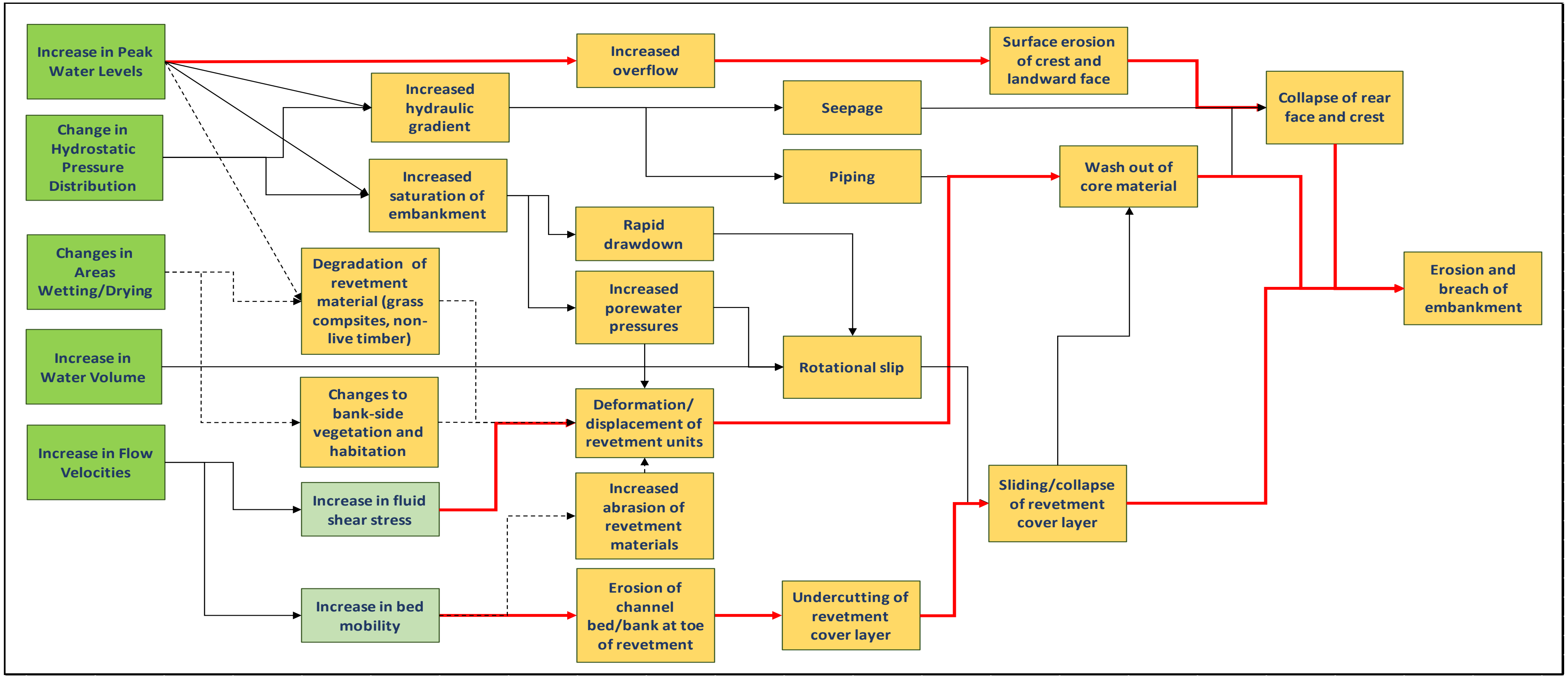
For the purpose of these assessments, it is assumed that the protection is applied only to the exposed face.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	Potential*

*Increased ***rainfall*** could result in greater saturation of embankments, exacerbating the instability issues described here, whilst lesser rainfall (droughts) could result in more drying out of embankments leading to cracking and fissuring.
* Changes to ***rainfall*** and ***temperature*** could impact upon vegetation growth on embankments, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.
*Changes to ***temperature*** (and ***rainfall***) could impact upon fauna and thus habitats, resulting in more burrowing or activity on embankments that requires more intervention to overcome.

ASSET TYPE: Embankment (Permeable Revetment)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Embankment (Permeable Revetment)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of embankments protected by permeable revetments potentially include:

- Increase in peak water levels resulting in greater and/or more frequent out of channel flow, causing erosion of unprotected crest and landward face.
- Increase in destabilisation of revetment layer due to higher flows or degradation, reducing protection and increasing wash out of material
- Increase in water volume and flow velocity causing erosion of front face and/or undercutting, leading to slope failure.
- An increase in hydrostatic pressure causing increased seepage and potential piping through the embankment, leading to potential erosion and failure on landward face.
- Changes to vegetation cover and habitation, requiring increased inspection and actions for the landward face. The potential for overflow causing rear face erosion and animal burrows into the rear face are also issues for these structures.

The vulnerability of embankments protected by permeable revetments to climate change increases will depend upon the nature of the protection. For some types of permeable revetment, the risks will also depend upon whether there is a suitable protective under-layer.

Grassed composites, toe geotextiles, low level timber piling and toe protection, and non-live timber revetment are suitable for low velocity or static channels. Therefore these types of permeable revetment are expected to be most vulnerable to any increase in peak flow velocities, requiring a more regular maintenance commitment and potentially the protection system replaced with a more robust revetment type. The durability of non-live timber revetment is also considerably reduced by increased wetting and drying, and is therefore very vulnerable to climate change increases peak water levels.

Concrete bag-work, toe rolls, pocket fabric, live willow (mattress of willow fascines tied together), and gabions are suitable for low to medium flow velocities. Some of these types, e.g. concrete bag-work will be vulnerable to undermining; others, e.g. gabions, are vulnerable to abrasion and wash out of material from the bank behind. Pocket fabric is vulnerable to wash out of ballast and uplift from hydrostatic pressure increases. Toe rolls are vulnerable to scour. Live willow mattress is vulnerable to gravel erosion, herbivore damage, and increases in peak water levels resulting in submergence exceeding 8 days.

Concrete unit revetment, open cell revetment, and stone rip-rap are suitable for medium to high flow velocities. Concrete unit revetment is vulnerable to erosion of sub-soil and displacement of the blocks, which can also result from pressure differences caused by increases in hydrostatic pressure. Open cell revetment is vulnerable to wash out of material from the cells, and stone rip-rap is vulnerable to flow velocities exceeding the design velocity. Therefore these types of permeable revetment are considered to be at moderate risk from climate change increases.

The maintenance actions required to address many of these matters will be similar to that at present, but could be required with much greater frequency. However, in addition there could be a much increased requirement to repair damage to prevent breaches caused by erosion, or indeed having to repair breached embankments from time to time where these do occur. In some instances it may be necessary to modify these embankments and introduce enhanced protection in the form of harder revetments and anti-scour protection.

Overall therefore, the vulnerability to these climate change factors on these assets is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X	X	X	

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels will also reduce the standard of protection provided by the embankments. Where this results in the target standard no longer being achieved, then works to increase the height of the embankment crest would be required. Depending upon the geotechnical stability of that higher embankment, this could also necessitate a corresponding widening of the structure.

Where there is a need to alter the nature of the revetment, the introduction of harder impermeable revetments can result in climate change impacts exacerbating scour downstream of the revetment, potentially requiring extension of the revetment.

Although not included in the current assessment, it is worth noting the potential impacts of increases in temperature making banks more susceptible to erosion through fissuring and cracking, and increases in rainfall increasing pore pressures in banks making them more susceptible to seepage and piping failure during and post flood events. Other impacts of these factors are the change in vegetation growth or burrowing activity, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.

Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Embankment (Impermeable Revetment)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"An embankment is an earthen structure used in the fluvial, tidal and coastal environments for flood defence and/or erosion protection."

Embankments may be protected or unprotected.

Protected embankments can include:

- PERMEABLE REVETMENTS – open cell (e.g. plastic geotextile grids, concrete open cell); toe rolls; toe geotextile plant pallets; grassed composites; concrete bag-work; stone; gabion mattress; concrete unit with toe protection.
- IMPERMEABLE REVETMENTS – grouted stone; concrete slabs; concrete sprayed gabion mattress.

This assessment covers embankments protected by impermeable revetments. Separate assessments have been made for embankments protected by permeable revetments and unprotected embankments.

Impermeable revetments are suitable for use in high flow velocity and heavy erosion situations.

For the purpose of these assessments, it is assumed that the protection is applied only to the exposed face.

CLIMATE CHANGE FACTORS CONSIDERED

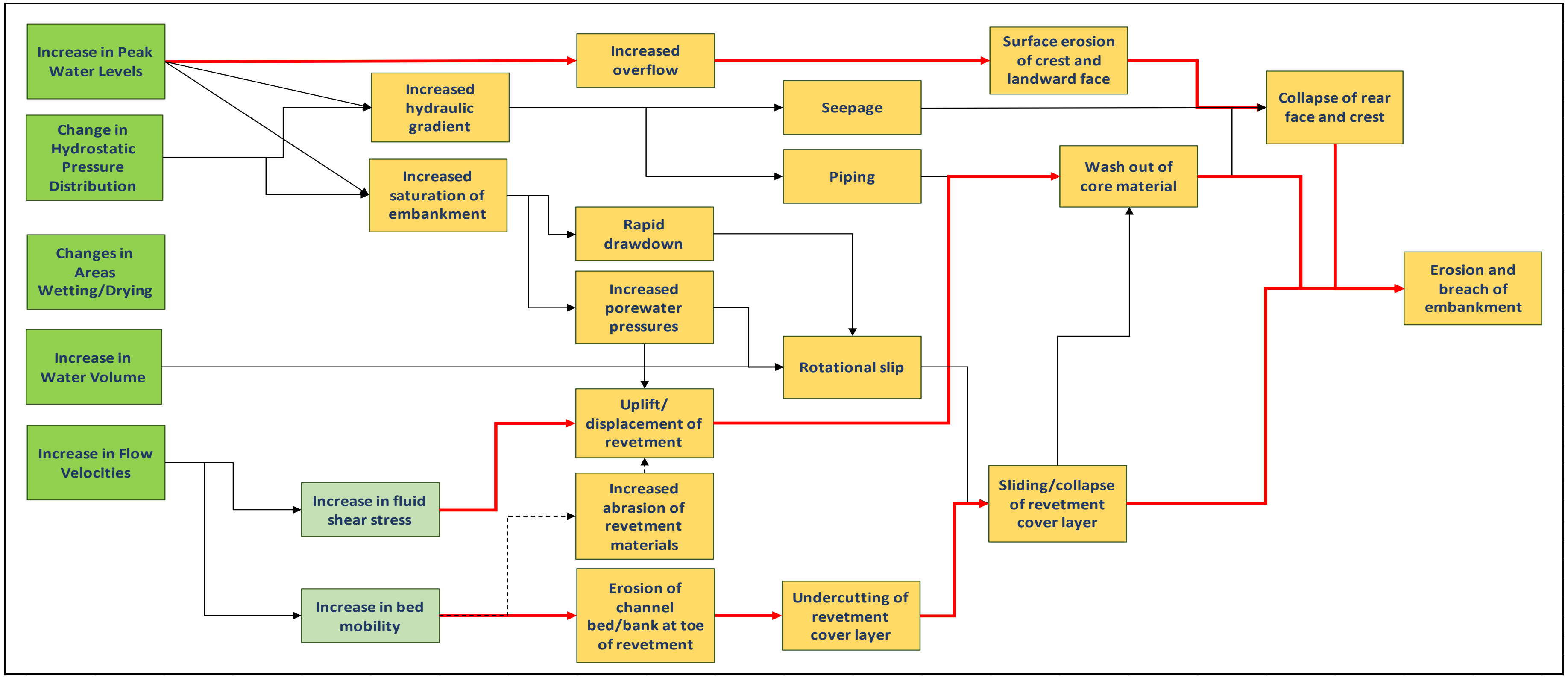
Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	Potential*

*Increased ***rainfall*** could result in greater saturation of embankments, exacerbating the instability issues described here, whilst lesser rainfall (droughts) could result in more drying out of embankments leading to cracking and fissuring.
* Changes to ***rainfall*** and ***temperature*** could impact upon vegetation growth on embankments, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.
*Changes to ***temperature*** (and ***rainfall***) could impact upon fauna and thus habitats, resulting in more burrowing or activity on embankments that requires more intervention to overcome.

ASSET TYPE: Embankment (Impermeable Revetment)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

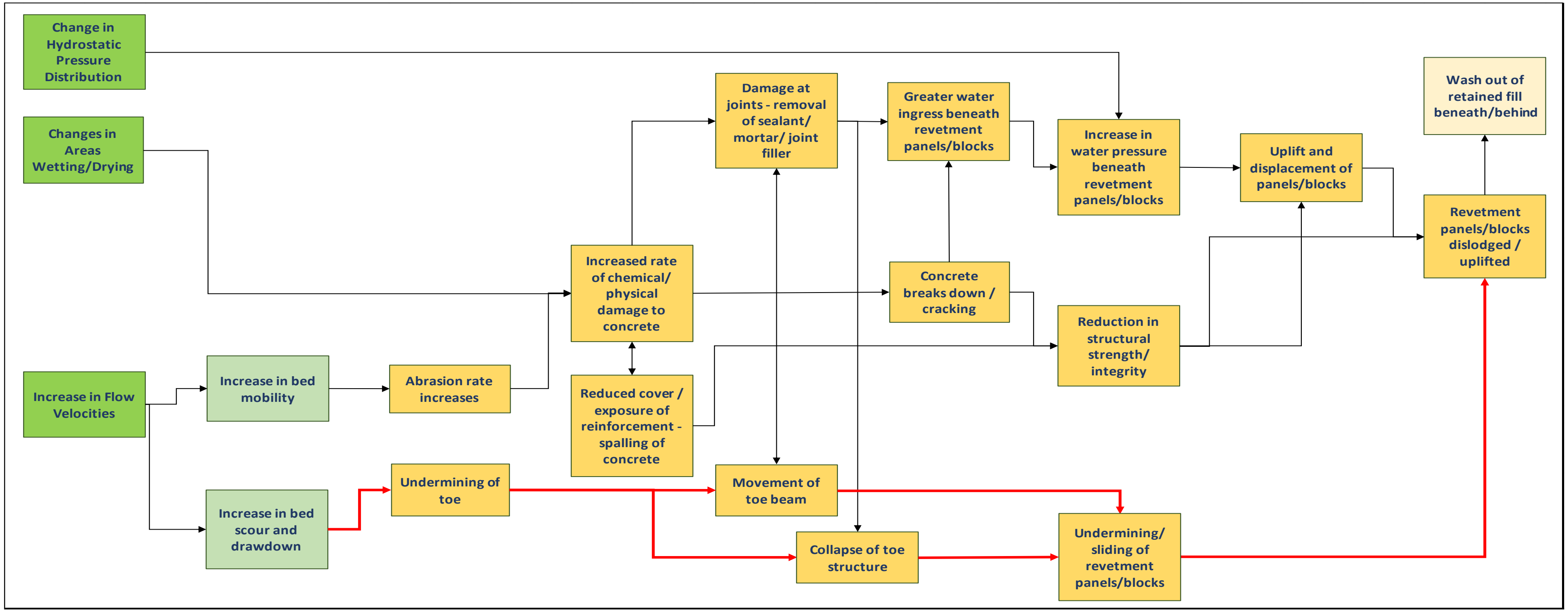
(1) OVERALL



ASSET TYPE: Embankment (Impermeable Revetment)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) CONCRETE REVETMENT



ASSET TYPE: Embankment (Impermeable Revetment)		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of embankments protected by impermeable revetments potentially include:

- Increase in peak water levels resulting in greater and/or more frequent out of channel flow, causing erosion of soft exposed faces on the landward face.
- Increase in destabilisation of revetment layer due to higher flows or degradation, exposing core of embankment to erosion and wash out of fill.
- Increase in water volume and flow velocity causing erosion of undercutting of revetment, leading to slope failure.
- An increase in hydrostatic pressure causing uplift and displacement of the revetment cover layer
- Increase in hydrostatic pressure producing geotechnical instabilities within the embankment
- Changes to vegetation cover and habitation due to changes in wet/dry areas and erosion, requiring increased inspection and actions for the landward face.

The primary issues for these structures are the potential for erosion caused by the overflow of the rear face, the potential for undermining and thus failure of the revetment, and the potential for increased pore pressure reducing the stability of the embankment/revetment.

The maintenance actions required to address some of these climate change impacts will be similar to that at present, but will be required with greater frequency. If properly designed, these revetments will have been provided with adequate toe protection and drainage weep holes, which may address some of these issues. However, in addition there could be an increased requirement to repair damage or replace revetment units that are displaced by the various causes outlined above. There could also be a much greater level of repair activity required to address overflow damage, and potentially a requirement to add protective layers to address this problem. For these reasons, the vulnerability to climate change effects on deterioration of these assets is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels will also reduce the standard of protection provided by the embankments. Where this results in the target standard no longer being achieved, then works to increase the height of the embankment crest would be required. Depending upon the geotechnical stability of that higher embankment, this could also necessitate a corresponding widening of the structure.

Where there is a need to alter the nature of the revetment, the introduction of harder impermeable revetments can result in climate change impacts exacerbating scour downstream of the revetment, potentially requiring extension of the revetment.

Although not included in the current assessment, it is worth noting the potential impacts of increases in temperature making banks more susceptible to erosion through fissuring and cracking, and increases in rainfall increasing pore pressures in banks making them more susceptible to seepage and piping failure during and post flood events. Other impacts of these factors are the change in vegetation growth or burrowing activity, necessitating more (or less)

frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation. Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Wall	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"A wall is a raised structure used in the fluvial, tidal and costal environments for flood defence and/or erosion protection. Also covers walls used in dam structures. Small wall structures found along channels that offer no flood defence or questionable erosion protection should be defined as High ground."

In line with the definition in CAMC (above) ***this assessment covers raised river walls only***, i.e. above channel side, not walls lining open channels for which separate assessments have been made.

Walls in a fluvial environment can be constructed from:

- Masonry
- Steel
- Plastic
- Concrete
- Timber
- A combination of these materials.

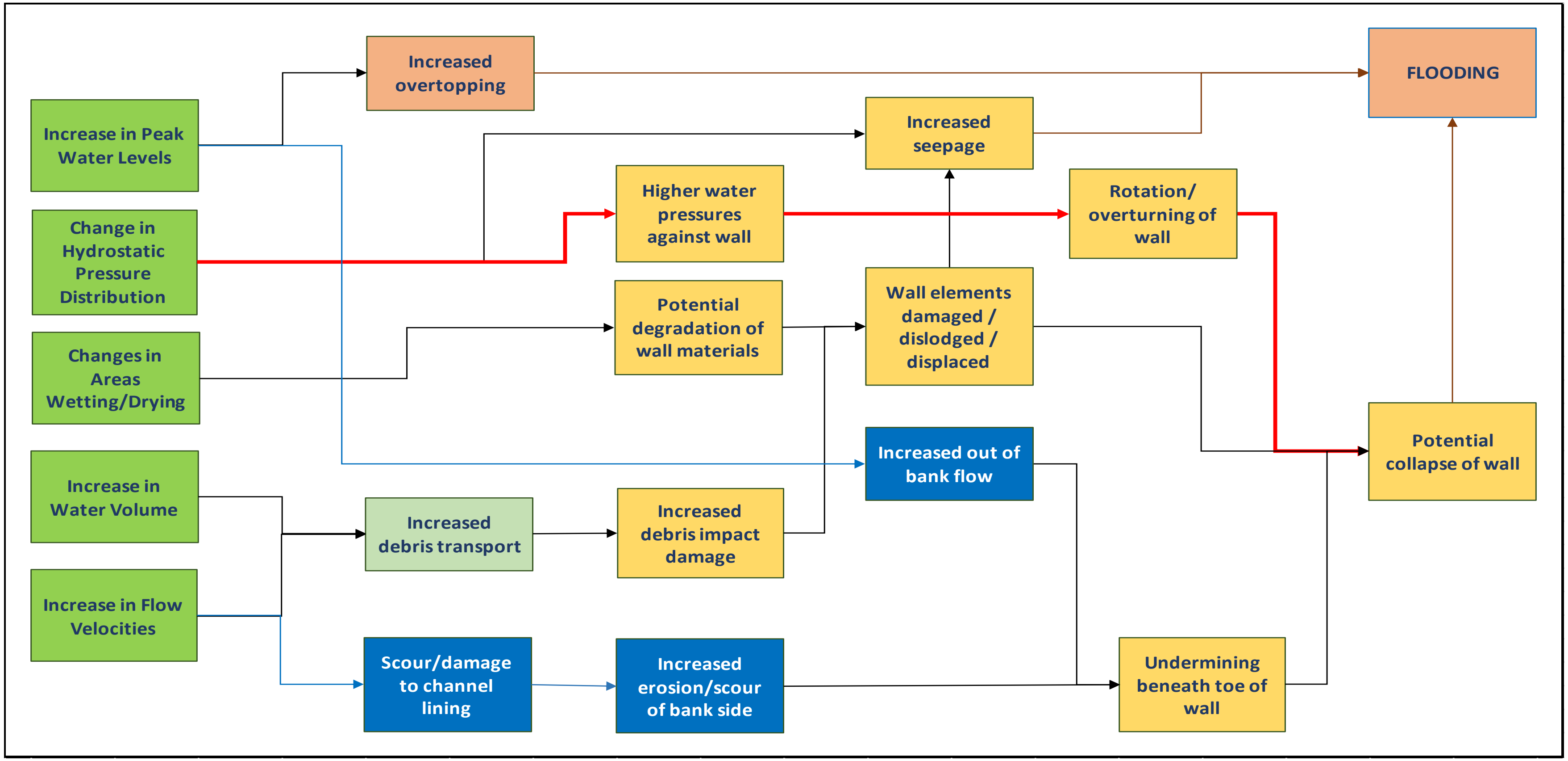
Walls can deliver both flood protection through preventing water movement above and/or below ground level through the use of cut off structures. Traditionally piling is used for cutting off flow paths through the ground and can be constructed from plastic or steel. Piling can often form above ground defences as well, whereas concrete and masonry walls are predominantly used for above ground defences.

The result of all these factors is that there will be considerable variability in the range of walls and the potential for their deterioration (and failure). Despite this, some generalities can be assumed for the purpose of considering those deterioration and failure processes.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Wall	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Wall		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of wall structures include:

- Potential for reduced stability resulting from increased flow velocities causing erosion of the channel side leading to and undermining along the toe of the wall.
- Potential for reduced stability resulting from increased hydrostatic pressure causing increased rotational/overturning forces on the wall, as well as potential for uplift, seepage and sliding.
- Potential for impact damage from large floating items of debris resulting from increased flows and flow velocities.
- The impacts of climate change increases on deterioration of the materials forming the walls

The main difference for these assets resulting from climate change is the increase in the level of exposure to higher water levels and associated higher flows, which walls above channel side would only experience on an infrequent basis.

One consequence of this will be more regular and potentially increased active pressures upon the wall leading to greater potential for overturning or damage to the wall from debris impacts or from higher rates of material degradation. The wall will have most likely have been designed for the full range of hydrostatic pressures that can be experienced, so should remain stable, but there could be instances where buttressing is required. The increase in any material degradation is likely to be more of an issue in the case of masonry and concrete in an already damaged condition, where more regular exposure to higher flows could exacerbate the level and rate of damage. Potentially there is increased need to inspect and maintain the wall for greater damage resulting from climate change impacts, particularly if the location of the wall is considered vulnerable to impact from large items of floating debris. Maintenance activities would likely be similar to that at present, albeit may be required more frequently, although there may be circumstances where the wall design needs to be improved to that more similar to the channel side lining due to the higher frequency of exposure.

Another consequence is the higher potential for damage to the channel side in front or beneath the wall, leading scouring and undermining of the wall. The potential for undermining will depend upon the nature of the channel side and its protection, and the nature of the foundation to the wall, so any need to underpin the wall or construct a new toe is going to be asset-specific.

Although the impact of climate change on deterioration will be very specific to each individual asset, in all cases a raised river wall will be experiencing exposure on a much more regular basis. This could lead to increases in repairs to address this, therefore the overall vulnerability to climate change on the deterioration of this asset type is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

There is the potential for increased water levels to result in more regular flooding and thus the need to increase wall height, which could require construction of a redesigned wall. Therefore these impacts could potentially be significant. There is also potential for increased flow volumes to cause outflanking of the wall; resulting in the need to extend the wall.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Flood Gate	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type "Defence"

"A flood gate forms part of a flood defence, usually to provide access through the defences. This is not to be used for assets that control the flow of water which are found in the Structure Type"

Flood gates can be formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change.

The flood gate will usually consist of:

- Frame
- Gate
- Fastenings
- Seals
- Hinges (side hinged flood gates only)
- Actuation mechanism (sliding flood gates only)

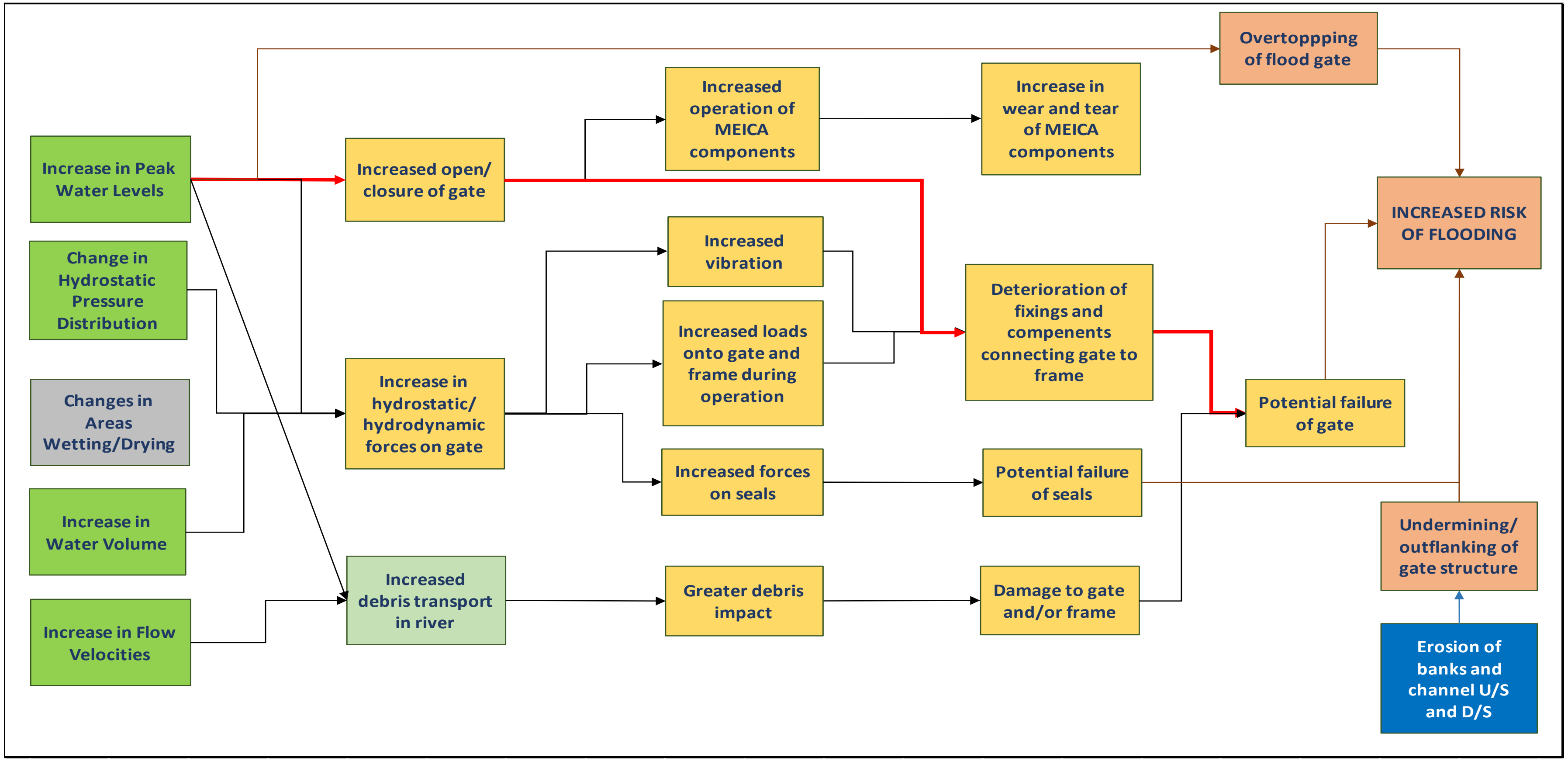
It will be designed to normally be above and out of water, but with water against it when closed in high flow events.

Increases in peak water levels and flows could also result in increased and/or new forces on the flood gate. Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could also cause increases in debris transport.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Flood Gate	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Flood Gate		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a floodgate include:

- Increase in peak water levels would increase load onto the gate, gate fastenings, and seals
- Increase in debris carriage by the flow with potential for damage and abrasion
- Increase in frequency of operation due to peak water levels leading to higher wear and tear on gate fastenings, seals and any operating mechanisms

The likelihood of structural failure from reduced load safety margins, and failure of seals leading to increased seepage, is considered negligible to low. Increased abrasion from debris transport/impact could slightly increase the deterioration of the structure. The deterioration would most obvious where assets are painted. The impact on the actual structure however is considered low if maintained appropriately and because a flood gate as defined in CAMCS would be located parallel to the flow.

Increased frequency of operation is most likely to affect the assets deterioration, with wear and tear on moving components and replacement of seals on a more frequent basis. Overall, the impact of climate change on deterioration may require a modest increase in the frequency of replacement of some of these components, and/or keeping them in operational condition, but as part of regular maintenance regimes which will not differ too much from present. Therefore the vulnerability is considered no greater than Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Climate change increased water levels could result in functional failure of the defence from overtopping due to it being of insufficient height, which would require redesign and re-fabrication. Increased peak river flows could also require a significant increase in operation to open and close the gates, or even functional failure if there is reduced flood warning time resulting in an inability to close all gates in time to prevent flooding.

An increase in the volume of debris flowing down a watercourse as a result of higher flows, could see more frequent deposition of material adjacent to the gate and hence require more regular inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Demountable	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"A demountable is a temporary defence that is brought to, or stored on, site and erected when necessary to form a flood defence."

Demountable defence structures can be constructed from a number of different materials including steel, aluminium, timber and plastics. Their composition is often is very specific to the defence required. Unlike many other defence assets these are principally only installed and operated during high flows. They are normally stored on site to allow ease and speed of installation prior to operation.

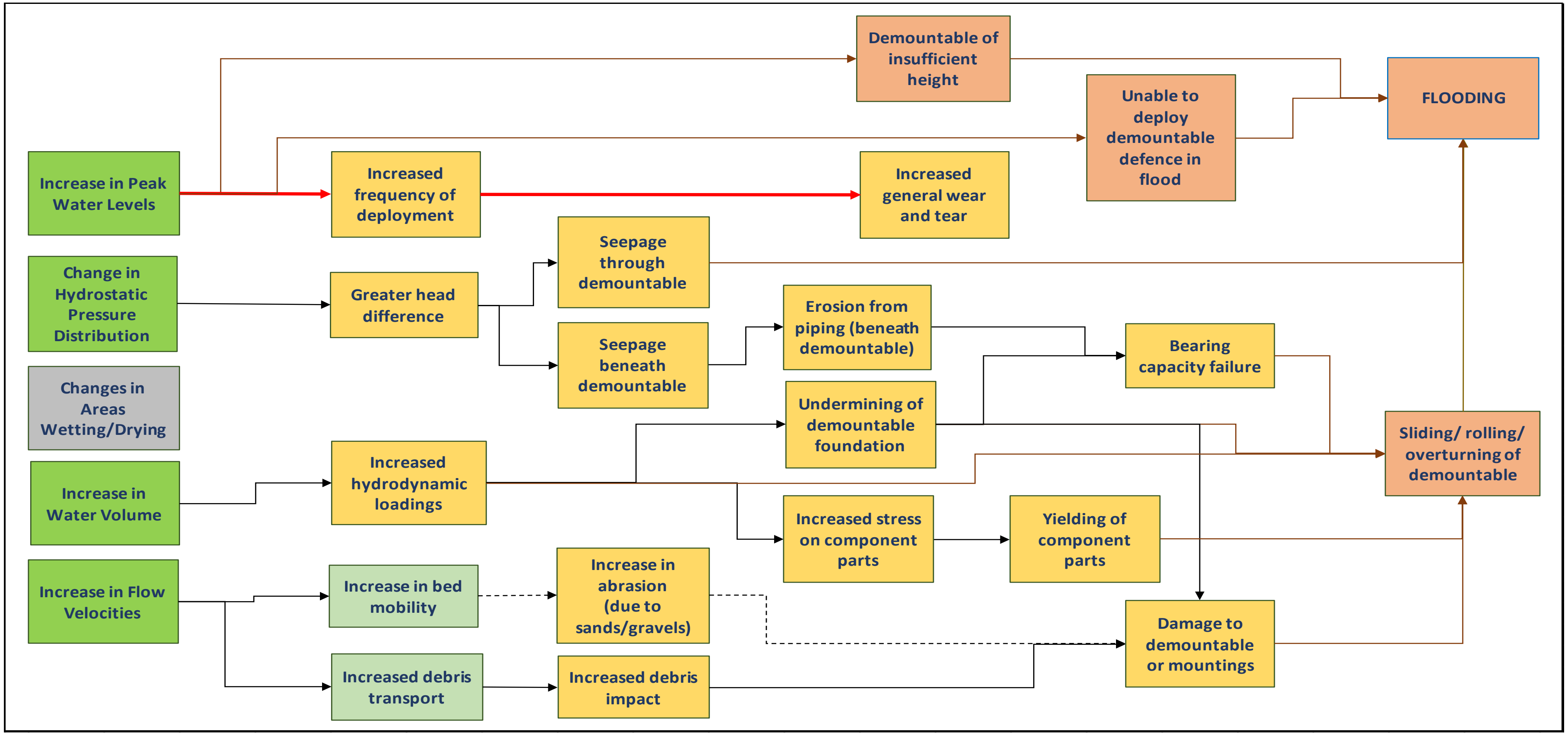
Climate change increases in peak water levels and flows could also result in increased forces on the demountable. Higher flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport along the watercourse.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Demountable	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Demountable	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of demountable defences include:

- Climate change increased peak water levels, hydrostatic pressures and flow velocities would result in increased load onto the demountable defence that may result in sliding or rolling or overturning, or yielding of component parts.
- Increases in hydrostatic pressures may also increase seepage through a demountable defence or its subsoil resulting in internal erosion from piping and causing bearing capacity failure.
- Increased flow velocities could also cause erosion of the demountable foundation. This would be dependent on the location of foundation in relation to the flow.
- Increased flow velocities and volumes could increase debris transport within watercourses thereby increasing the risk of impacts and thus damage to the demountable.
- More frequent deployment of them due to higher river flows/flood potential, leading to more wear and tear.

Increased usage of demountables could result in in increased repairs and/or replacement frequency. The may also be an increased need to inspect and potentially repair the ground onto which the demountable is seated may also be required, depending on the nature of the ground.

Although the overall deterioration vulnerability due to climate change impact is considered as Low, this could be outweighed by a reduction in performance from functional or operational failure.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Climate change increased water levels, hydrostatic pressures and water volume could result in functional failure of the defence from overtopping, excessive seepage or outflanking; and having potentially The overtopping/outflanking of the demountable defence could impact on other assets, causing flooding or erosion behind the structure. Potentially redesign and re-fabrication are required.

Climate change increased water volume and flow velocities could result in operational failure due to reduced flood warning time resulting in failure to erect defences in time to prevent flooding.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Bridge Abutment	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type “Defence”
A bridge abutment that ties into a flood defence to act as a defence. If the bridge that the abutment belongs to crosses a watercourse it will also have to be defined as a channel crossing.

As this defence otherwise forms part of a normal bridge, the abutment would normally be constructed from concrete or masonry, with probably a concrete pad foundation that may incorporate a steel sheet pile toe line alongside the watercourse, depending upon the underlying strata.

Increases in peak water levels and flows could result in increased and/or new forces on the abutment and a change of which elements of the abutment become exposed to a water environment. Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility.

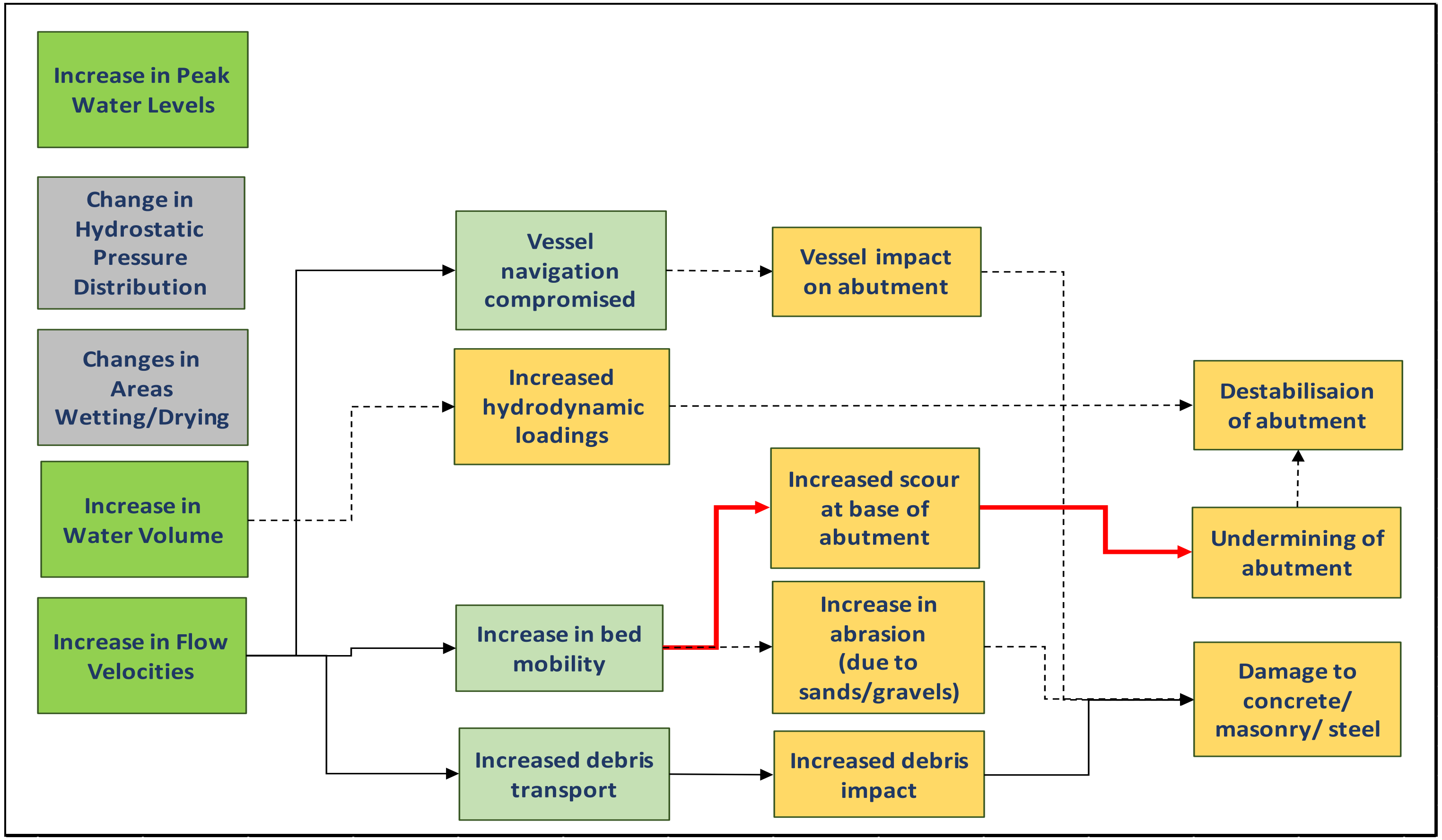
Climate change impacts that potentially affect a bridge deck have been considered under asset type ‘Bridges’.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Bridge Abutment	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Bridge Abutment		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of bridge abutments include:

- Increases in flow velocities will change bed mobility and have a potential to cause erosion/undermining to the sides and toe of the abutment.
- Increases in peak water levels, flows and flow velocities have potential for increased impact damage from vessels which may find navigation more difficult in these conditions.
- Degradation of materials as a consequence of abrasion or debris impact damage.

Vulnerability to impact damage would depend upon the design of abutment and presence/ absence of an upstream protective barrier. As the bridge abutment is intended to form part of a defence, it may well be flush with the adjacent parts of the defence, e.g. a floodwall, so the potential for impact damage is probably low.

A bridge abutment forming part of a flood defence along a watercourse will probably have been designed to meet foreseeable water levels, flows and flow velocities. The main impact of climate change increases is potential scour and undermining along the toe of the abutment if bed levels fall.

Increased inspection of the bridge including the abutment following high flow events, and potential repairs to any scour protection along the toe are the likely extent of any additional maintenance requirements resulting from these climate change factors. Therefore the overall vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Increases in peak water levels and water volumes could potentially exceed the design flood flow capacity beneath a bridge located along a watercourse; requiring an enlargement to avoid flow out of banks upstream. These increases could also result in a need for raising of abutments if walkways etc. also have to be raised.

Climate change increases in peak water levels and water volumes could also potentially impact the supported bridge, which transfer loads and rely on stability from abutments. This would consequently require the abutments to be modified.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: High Ground (Natural/Unlined)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"High ground covers all other extents along water courses that are not defined as any other Defence Asset Type. It covers situations where the only defence is the ground itself. Examples include the top of a river bank or a cliff adjacent to a water course"

Although the CAMC definitions and illustrative examples suggest that High Ground does not include channel sides or lining of such channels, the use of it within AIMS does in fact include attributes for those and this is how AIMS has actually been populated.

So, for the purposes of this assessment High Ground is interpreted to be the channel side or river banks, which may be natural or may be lined (i.e. with walls providing retention of that ground or providing erosion protection, but noting also that CAMC defines walls in a fluvial situation as only 'raised' walls, i.e. providing flood protection over and above the top of the channel side).

Unprotected (unlined) open channels are those that are covered just by vegetation. (To note, turf is suitable up to 1.8m/s flow velocity.)

This assessment covers unprotected (unlined) i.e. vegetated high ground (river banks) only. A separate assessment has been made for protected (lined) banks and channels.

Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport within the watercourse. Increases in peak water levels could expose some areas of the channel to river flows and wetting/drying on a more regular basis.

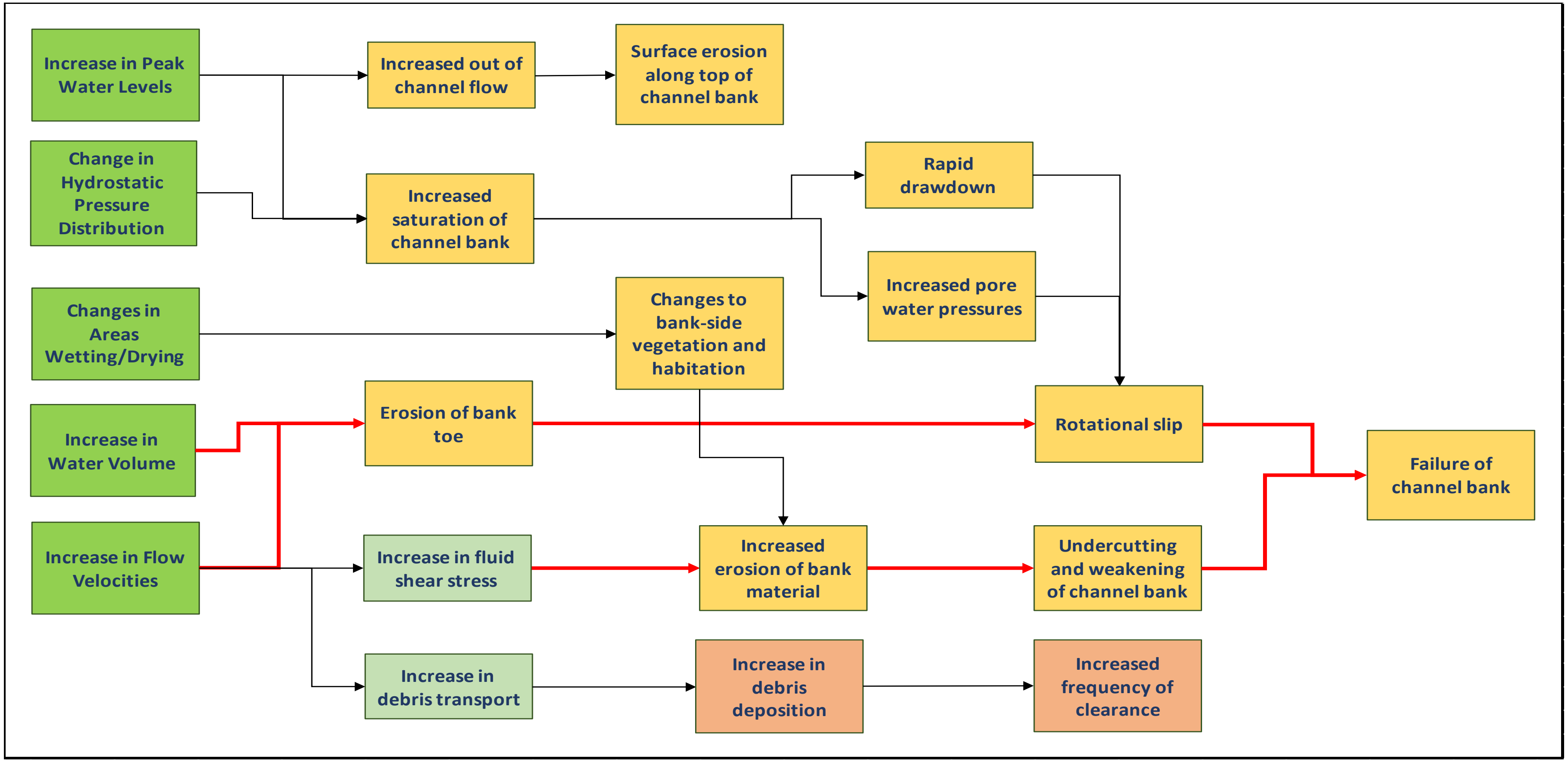
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	Potential*

* Increased ***rainfall*** could result in greater saturation of banks, whilst reduced rainfall (droughts) could result in more drying out of soil structures.
* Changes to ***rainfall*** and ***temperature*** could impact upon vegetation growth on banks
* Changes to ***temperature*** (and ***rainfall***) could impact upon fauna and thus habitats, resulting in more burrowing or activity on banks.

ASSET TYPE: High Ground (Natural/Unlined)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: High Ground (Natural/Unlined)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of unprotected high ground (river bank) potentially include:

- Increase in peak water levels resulting in greater and/or more frequent overflow, causing erosion of the river bank crest.
- Increase in water volume and flow velocity causing erosion of the channel bed, leading to potential undercutting along the toe of the bank, leading to slope failure and cut back.
- Increase in water levels increasing the area of bank directly impacted by river flows, which will increase the amount/speed of erosion

The potential for erosion/undercutting along the edge of the high ground is the primary issue. The outside bends of a river channel will be the most vulnerable to increased flows and flow velocities. In terms of the potential instabilities caused by changes in hydrostatic pressure differences, poorly maintained banks, e.g. with animal burrows, will be the most vulnerable.

Although unprotected bank sides will be highly sensitive to climate change, as they are the naturally eroded faces created by the flow regime which is subject to that change, it is questionable whether this further change in response to higher flows can be categorised as deterioration. As a result they may offer less protection to anything located on top and landward of the erodible edge (a performance issue) but the ‘asset’ will still exist, just in a more retreated position. There could be a much increased requirement to repair damage caused by erosion, or indeed having to repair collapsed banks from time to time where these do occur, but otherwise these assets are not maintained from a deterioration perspective unless there are receptors at risk. As key locations where this is the case will likely already have protection (see lined high ground), there will not be significant change in maintenance commitment other than for performance related concerns. So overall the magnitude of vulnerability is categorised as Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

In performance terms, the rate of erosion of high ground will change the risks to anything present upon or behind it, and the impacts of climate change may not become considerable. The measures that would need to be taken to address such erosion depend upon what ‘receptors’ lie landward of them, but if this retreat puts those at risk, then interventions are required, which will be a change in asset type.

These assets may also provide a habitat for flora and fauna, so there are also potential ecological implications associated with their change and any management of that.

Although not included in the current assessments, it is worth noting again the potential impacts of increases in temperature making banks more susceptible to erosion through fissuring and cracking, and increases in rainfall increasing pore pressures in banks making them more susceptible to failure during and post flood events. Other impacts of these factors are the change in vegetation growth or burrowing activity, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: High Ground (Lined - Permeable)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"High ground covers all other extents along water courses that are not defined as any other Defence Asset Type. It covers situations where the only defence is the ground itself. Examples include the top of a river bank or a cliff adjacent to a water course"

Although the CAMC definitions and illustrative examples suggest that High Ground does not include channel sides or lining of such channels, the use of it within AIMS does in fact include attributes for those and this is how AIMS has actually been populated.

So, for the purposes of this assessment High Ground is interpreted to be the channel side or river banks, which may be natural or may be lined (i.e. with walls providing retention of that ground or providing erosion protection, but noting also that CAMC defines walls in a fluvial situation as only 'raised' walls, i.e. providing flood protection over and above the top of the channel side).

Protection can include:

- PERMEABLE LINING – open cell (e.g. plastic geotextile grids, concrete open cell); toe rolls; toe geotextile plant pallets; grassed composites; concrete bag-work; stone; gabion mattress; concrete unit with toe protection.
- IMPERMEABLE LINING – grouted stone; concrete slabs and walls; masonry walls; gravity walls; concrete sprayed gabion mattress; steel sheet piles (cantilever and tied back).

This assessment covers channel sides with permeable lined protection. Depending upon the lining material, some are suitable only for low flow velocities, some for low and medium flow velocity, with stone rip rap potentially suitable for high flow velocity. Separate assessments have been made for high ground protected by impermeable linings and unprotected (natural) river banks.

Increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport within the watercourse. Increases in peak water levels could expose some areas of the channel to river flows and wetting/drying on a more regular basis.

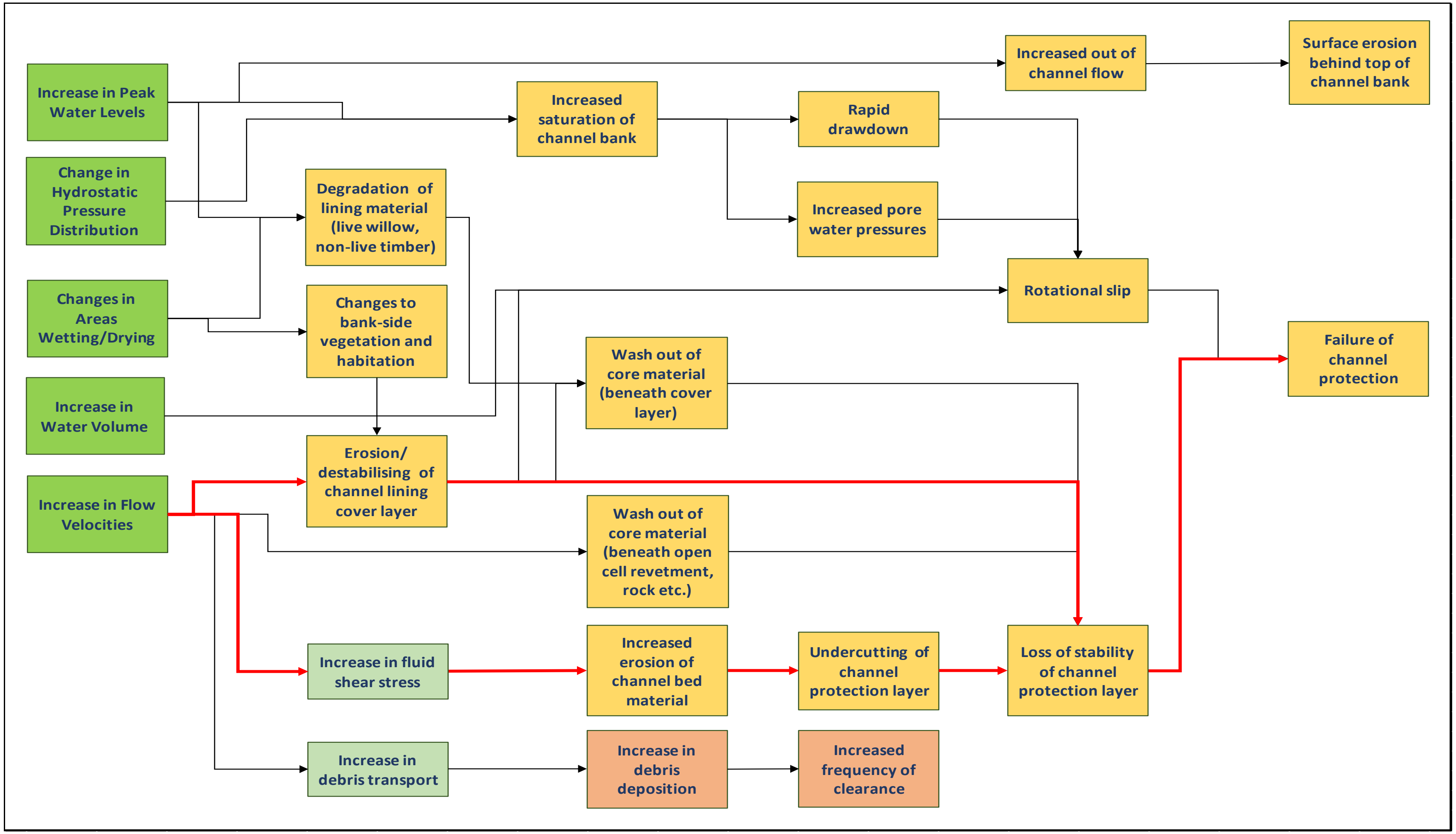
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	Potential*

* Increased ***rainfall*** could result in greater saturation of banks, whilst reduced rainfall (droughts) could result in more drying out of soil structures.
* Changes to ***rainfall*** and ***temperature*** could impact upon vegetation growth on banks (in situations where the lining is an open cell system intended to contain/include vegetation.

ASSET TYPE: High Ground (Lined - Permeable)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: High Ground (Lined - Permeable)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of high ground (river banks and channel sides) with permeable lined protections include:

- Increase in peak water levels resulting in greater and/or more frequent overflow, causing erosion of soft exposed faces above the level of existing toe protection such as concrete bag work
- Increase in water volume and flow velocity causing erosion and lowering of the bed level along the toe of the protection lining, leading to localised collapse if adequate toe protection is not present.
- Potential for increased abrasion of the permeable protection causing wash out of material and requiring increased inspection and maintenance.
- Changes to vegetation cover and habitation above the level of existing toe protection, reducing erosion protection and requiring increased inspection and actions.

The vulnerability of banks and channel sides protected by permeable linings to climate change increases will depend upon the nature of the protection.

Grassed composites, toe geotextiles, low level timber piling and toe protection, and non-live timber are suitable for low velocity or static channels. Therefore these types of permeable linings are expected to be most vulnerable to any increase in peak flow velocities, requiring a more regular maintenance commitment and potentially the protection system replaced with a more robust lining type. The durability of non-live timber is also considerably reduced by increased wetting and drying, and is therefore very vulnerable to climate change increases peak water levels. These type of linings are considered to be the most vulnerable to climate change impacts

Concrete bag-work, toe rolls, pocket fabric, live willow (mattress of willow fascines tied together), and gabions are suitable for low to medium flow velocities. Some of these types, e.g. concrete bag-work will be vulnerable to undermining; others, e.g. gabions, are vulnerable to abrasion and wash out of material from the bank behind. Pocket fabric is vulnerable to wash out of ballast and uplift from hydrostatic pressure increases. Toe rolls are vulnerable to scour. Live willow mattress is vulnerable to gravel erosion, herbivore damage, and increases in peak water levels resulting in submergence exceeding 8 days.

Concrete unit linings, including open cell, are suitable for medium to high flow velocities. Concrete unit lined channels are vulnerable to erosion of sub-soil and displacement of the blocks, which can also result from pressure differences caused by increases in hydrostatic pressure. Open cell is vulnerable to wash out of material from the cells. However, these types of permeable linings are considered to be at lower risk from climate change increases.

The maintenance actions required to address many of these matters will be similar to that at present, but could be required with much greater frequency. However, in addition there could be a much increased requirement to repair damage to prevent localised failures caused by erosion, or indeed having to reconstruct from time to time where these do occur, repairing the area behind too which will most likely have suffered damage and collapse as a consequence. In some instances it may be necessary to modify these protective systems and introduce enhanced protection in the form of harder linings and anti-scour protection.

The effect of these climate change factors on the deterioration of these assets depends entirely upon the nature of the lining material, but with a notable increase in maintenance likely to be required for some of these, the overall vulnerability is considered to be Moderate.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels and volumes will also reduce the capacity of the channel. Where this results in the target conveyance no longer being achieved, then works to increase the channel capacity would be required. Depending upon the changed geometry of the channel the geotechnical stability of the channel banks may require checking and redesigning.

The use of hard permeable lined protections can also result in climate change increases causing increased scour downstream of the channel, potentially requiring extension of the protection.

Resultant changes in channel geometry will affect the interaction with in channel assets, which may have to be redesigned to prevent negative impacts on stability, performance, deterioration. For example outfalls may have to be repositioned or the erosion protection around will need to be increased if the channel is widened by the effects of climate change.

Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

Although not included in the current assessments, it is worth noting again the potential impacts of increases in temperature making banks more susceptible to erosion through fissuring and cracking, and increases in rainfall increasing pore pressures in banks making them more susceptible to seepage and piping failure during and post flood events, reducing stability of the protection.

Other impacts of these factors are the change in vegetation growth or burrowing activity, necessitating more (or less) frequent grass cutting, or result in different vegetation growth requiring more frequent clearance of vegetation.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: High Ground (Lined - Impermeable)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"High ground covers all other extents along water courses that are not defined as any other Defence Asset Type. It covers situations where the only defence is the ground itself. Examples include the top of a river bank or a cliff adjacent to a water course"

Although the CAMC definitions and illustrative examples suggest that High Ground does not include channel sides or lining of such channels, the use of it within AIMS does in fact include attributes for those and this is how AIMS has actually been populated. .

So, for the purposes of this assessment High Ground is interpreted to be the channel side or river banks, which may be natural or may be lined (i.e. with walls providing retention of that ground or providing erosion protection, but noting also that CAMC defines walls in a fluvial situation as only 'raised' walls, i.e. providing flood protection over and above the top of the channel side).

Protection can include:

- PERMEABLE LINING – open cell (e.g. plastic geotextile grids, concrete open cell); toe rolls; toe geotextile plant pallets; grassed composites; concrete bag-work; stone; gabion mattress; concrete unit with toe protection.
- IMPERMEABLE LINING – grouted stone; concrete slabs and walls; masonry walls; gravity walls; concrete sprayed gabion mattress; steel sheet piles (cantilever and tied back).

This assessment covers channel sides with impermeable lined protection (which includes sloped revetments and vertical walls lining channels). These are suitable for use in high flow velocity and heavy erosion situations. Separate assessments have been made for high ground protected by permeable revetments and unprotected (natural) river banks.

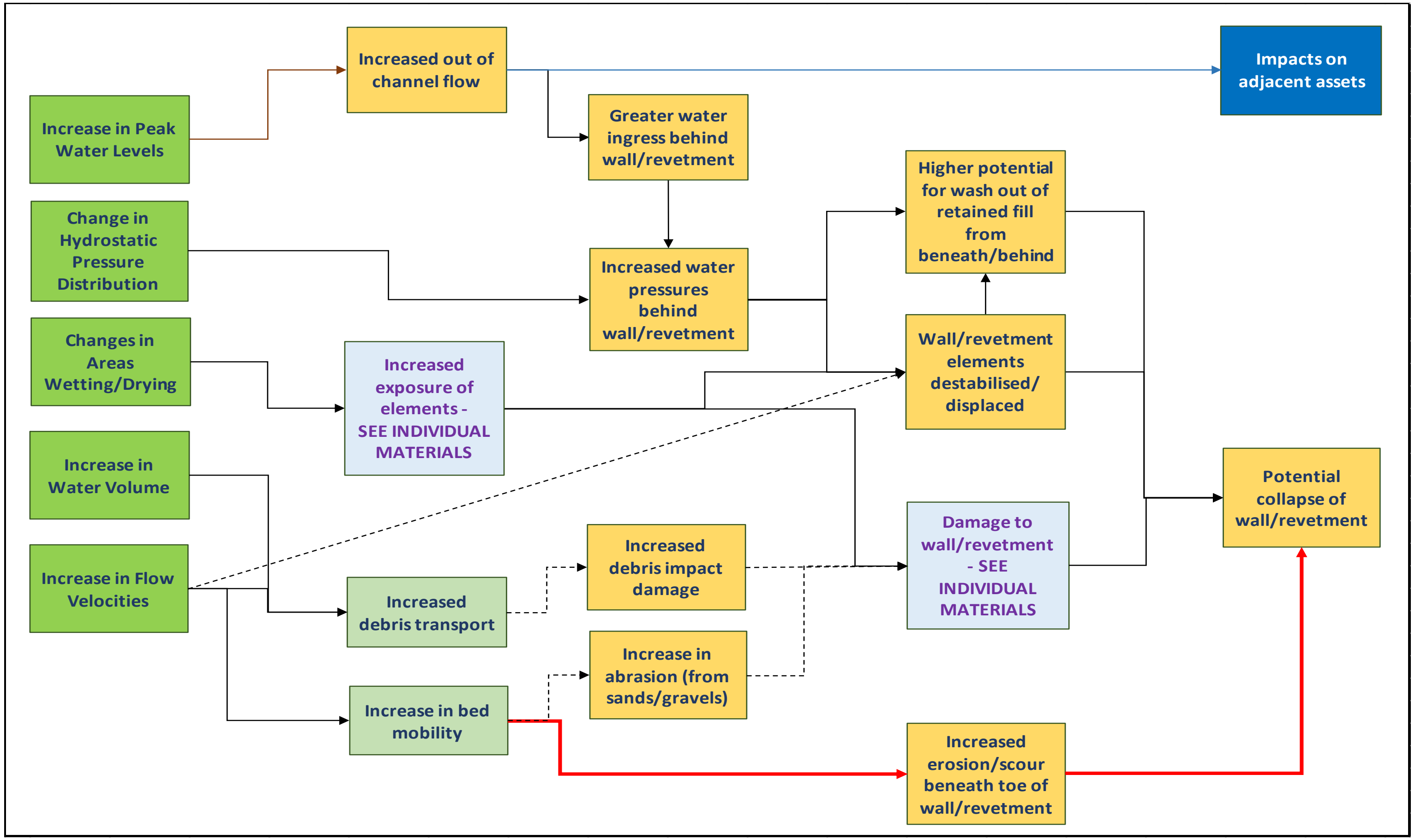
Increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport within the watercourse. Increases in peak water levels could expose some areas of the channel to river flows and wetting/drying on a more regular basis.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: High Ground (Lined - Impermeable)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

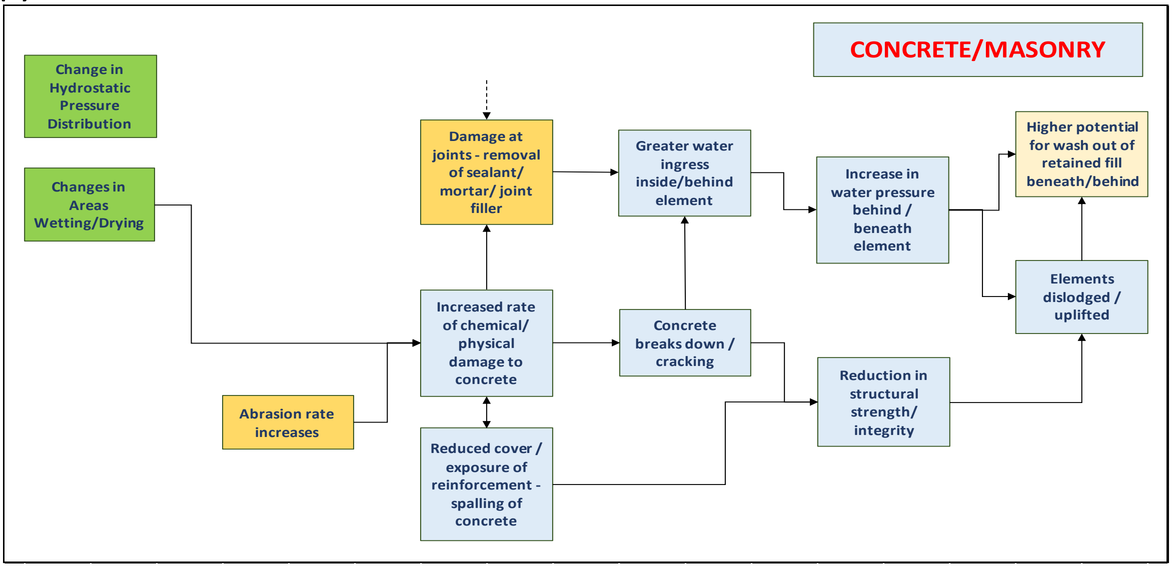
(1) OVERALL

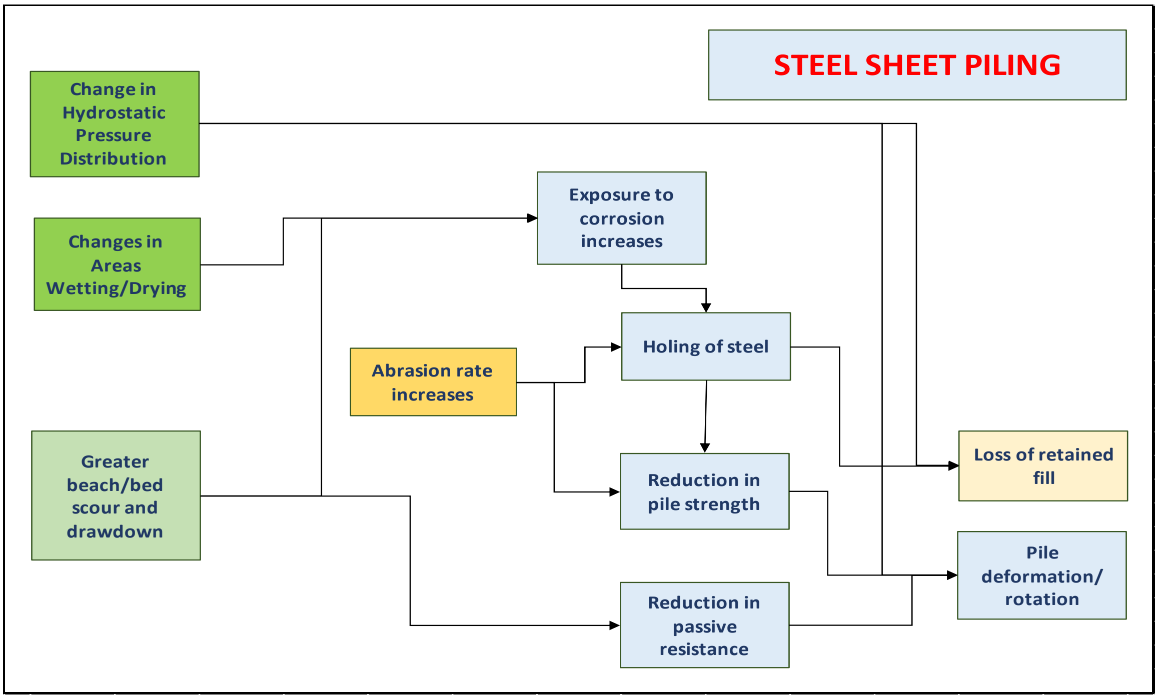


ASSET TYPE: High Ground (Lined - Impermeable)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) SUPPLEMENTARY DETAILS





ASSET TYPE: High Ground (Lined - Impermeable)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of high ground (river banks and channel sides) protected by impermeable linings include:

- Increase in water volume and flow velocity causing erosion of softer channel bed material, leading to potential lowering of bed level adjacent to sheet piles, gravity walls and sloping revetment; and reducing stability if adequate toe protection is not present.
- An increase in abrasion damage to concrete and masonry walls in already damaged condition.
- Potential for increased abrasion of grouted stone and concrete sprayed gabion mattresses.
- Displacement of the protective lining and erosion behind due to higher hydrostatic pressures

These types of wall/revetment linings are intended for high flow velocities, so should be designed for and capable of withstanding these peak flows even if they are greater and more regular. As such, the potential for higher flows displacing units or part of the system are not expected to be significant. Likewise, deterioration due to abrasion or impact damage are not expected to be significant, although there could be some modest increased requirement to repair damage.

If the impermeable lined protection system (wall or revetment) and accompanying toe protection have been properly designed, the increase in maintenance commitments and likelihood of failure of these impermeable revetments, mean that the climate change impact will be low. Some of the maintenance actions required to address these matters will be similar to that at present, but will be required with greater frequency.

The primary risk to these structures will be from potential scour at their base, although it is usual for a scour (bed level) allowance of 10% of the retained height, up to 0.5m, to be included in the design of retaining structures such as steel sheet piled walls. Therefore the lowering of the bed would have to exceed this amount before the safety factors are reduced, however this presents a risk and if scour does exceed this depth then works would be required to either extend or introduce a new toe or scour protection. For this reason, the overall vulnerability of these assets is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

In addition to the deterioration aspects and potential failure mechanisms, the increase in water levels and volumes will also reduce the capacity of the channel. Where this results in the target conveyance no longer being achieved, then works to increase the channel capacity would be required. Depending upon the changed geometry of the channel the geotechnical stability of the channel banks may require checking and redesigning.

The use of hard impermeable protections can also result in climate change increases causing increased scour downstream of the lined channel, potentially requiring extension of the protection.

Resultant changes in channel geometry will affect the interaction with in channel assets, which may have to be redesigned to prevent negative impacts on stability, performance, deterioration. For example outfalls may have to be repositioned or the erosion protection around will need to be increased if the channel is widened by the effects of climate change.

Increased debris transport and deposition onto the channel bank and bed may also require increased inspection and clearance. The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Washland	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Land'
"Washland is an area of land that is used for flood storage including reservoirs and lakes"

The distinction between Washland and High Ground is not entirely clear, so for the purposes of this assessment, it is assumed that High Ground is land that is not floodable, but Washland is (i.e. floodplain alongside a river).

Based upon the CAMC definitions Washland ***does not*** include channel sides (see Open Channel (unprotected) for details), but refers to the land above the bank of the river/watercourse.

It is questionable whether Washland can be termed to be an 'asset', in relation to deterioration or maintenance requirements, as it is defined as an area of land that can accommodate flood water. The assets of real concern here would be any receptors such as land use, property and infrastructure that sit within that washland, or other asset types that allow or control flood waters to flow onto the washland. Impacts on these will also be primarily their capacity to store flood water in times of excessive flood waters, so it is not immediately apparent how they might deteriorate, either as a consequence of climate change factors or otherwise.

Although the definition also includes reservoirs and lakes, it is not entirely clear to what extent such features are captured within AIMS under the 'Washland' category, nor how higher river flows will affect their deterioration either. Therefore, this assessment has focussed only on the riverside floodplain definition of a washland.

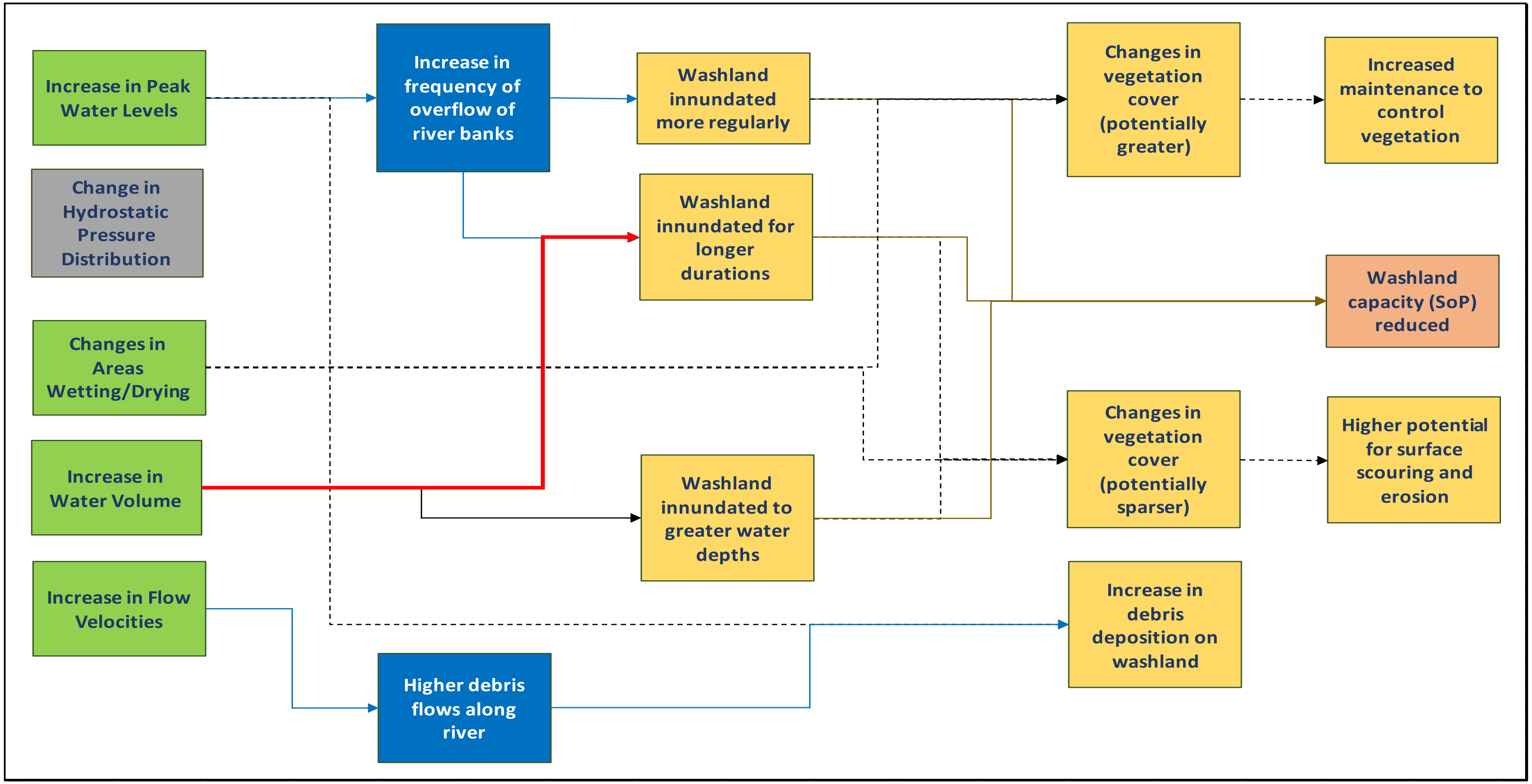
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	Potential*

* Changes to ***temperature*** or ***rainfall*** could affect the vegetation and habitats on the washland, altering its characteristics.
* Increased ***rainfall*** could result in greater saturation of washland, reducing capacity to drain and result in reducing capacity to accommodate out of bank overflow

ASSET TYPE: Washland	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Washland	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of washland potentially include:

- Increase in peak water levels resulting in greater and/or more frequent inundation from overflow of the banks).
- Increase in water volume causing greater or longer duration of inundation of the washland
- Increased debris deposition from higher flows requiring increased clearance.
- Changes to vegetation cover and habitation, potentially greater or lesser.

Although vegetation cover and habitation could result in an increased maintenance to control, or preserve, this change is expected to be negligible as a consequence of the climate change factors being examined here. Likewise, an increase in debris deposition is likely to be a minor issue relative to other performance related issues.

An increase in peak water levels is likely to be the main factor, as it is only through this that they will become exposed to these impacts. Although washlands will be sensitive to this, they are not necessarily deteriorating significantly as an asset. The issue is primarily one of capacity to accommodate higher water volumes (which is a performance issue) but the 'asset' will still exist, largely in its current form. These assets are unlikely to have any FCERM maintenance commitment to them (they are an area of land managed often for other purposes, such as grazing), therefore by definition there will not be any change in maintenance commitment other than for performance related concerns. So overall the magnitude of vulnerability is categorised as Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

The primary consequence of these climate change factors for washlands will be the relative reduction in capacity (expressed in terms of 'event' probability) to accommodate higher water volumes resulting from the greater river flows. This could lead to increased flood levels elsewhere along the river, or further inland of the washland.

Attenuation of flood water across the washland may reduce with higher water levels, so areas landward of this might experience water reaching them faster and with greater flow speeds.

These assets will also provide a habitat for flora and fauna, so there are also potential ecological implications associated with their change and any management of that.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Screen	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A screen or grid is used to collect debris and/or prevent access to culverts, outfall, channels etc."

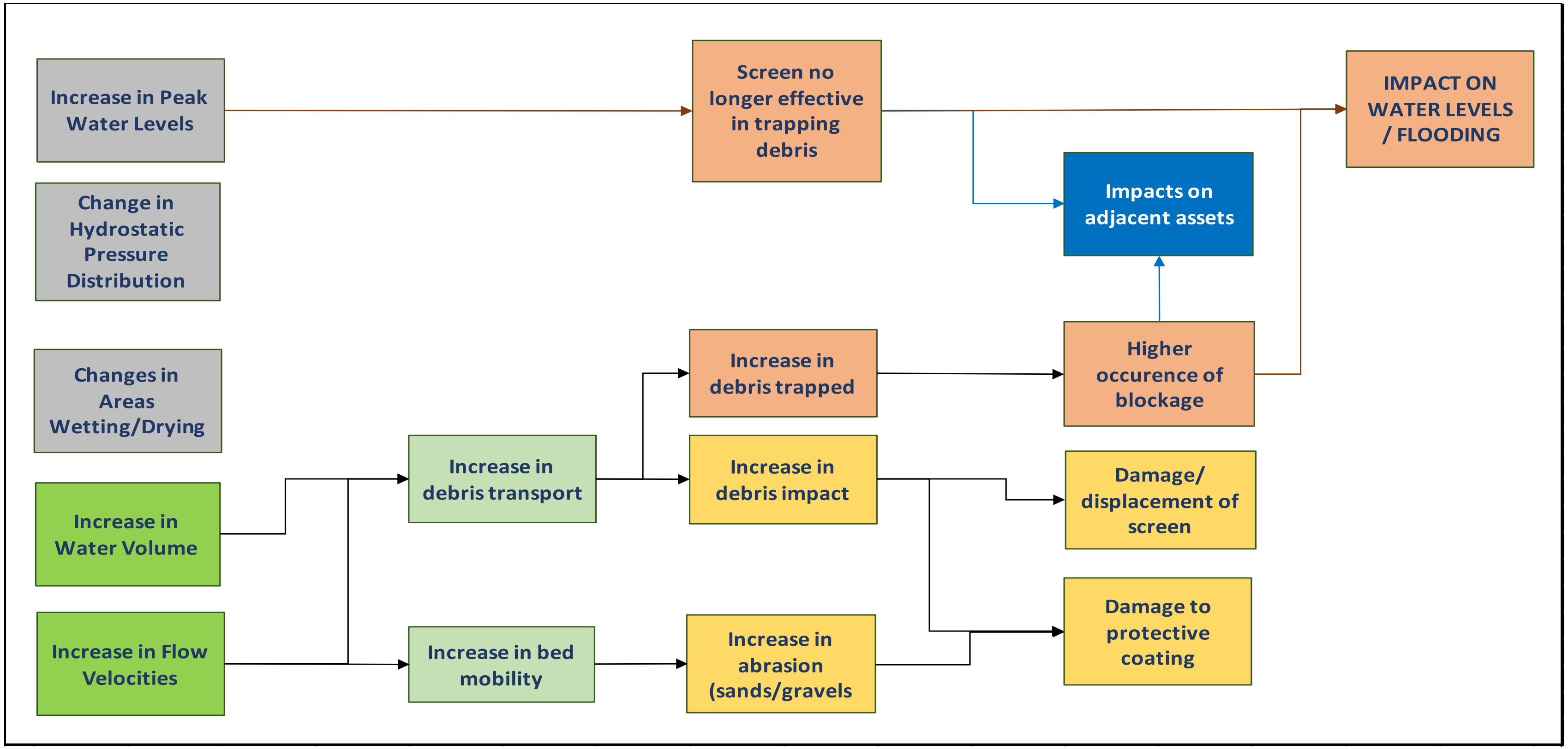
A screen would typically be secured to concrete/masonry wing walls, headwall and apron immediately upstream of the culvert entrance and be provided with access for debris removal. The screen would typically be constructed from steel and suitably protected to work in a water environment. Screens may also be placed across the outlet to prevent unwanted access into the culvert

Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport, which the screen is designed to trap.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Screen | **ENVIRONMENT: Fluvial**

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Screen	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of screen structures include:

- Increased debris transport resulting from higher river flows leading to greater impacts upon it and potential for damage
- Greater abrasion of the screen material (steel) as a consequence of more attrition from sand and gravel transported by higher flows

The types of maintenance and repair actions required to address these impacts would not be very different from present, but there may some slight increase in them. For example, the potential for increased damage to the screen could require more frequent inspection and maintenance; greater abrasion or impact damage could result in more frequent repairs to the protective coating on the steel.

However, assuming that screens have been designed in accordance with approved guidelines, the change in these requirements are expected to be alter very little, so the climate change vulnerability is considered as Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

Increased debris transport resulting from higher river flows could also leading to increased blockage at the screen and an increased maintenance requirement to clear it. Larger increases in peak water levels could result in difficulty of access to clear debris during period of high flows until these subside. The resultant increases in water volumes could also result in the design screen area becoming inadequate; resulting in redesign and replacement being required.

Increases in peak water levels may also result in the screen becoming ineffective as material simply is transported over the screen and thus may affect downstream assets. The increase in blockages of screens could also impact upstream and downstream assets as it causes a potential temporary dam across the watercourse.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: **In channel stop-logs**	**ENVIRONMENT:** **Fluvial**

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Structure'

"In channel stop logs are used to control the flow in a channel by means of adjustable barriers (stop-logs). In channel stop-logs are not to be used for flood defences – despite the physical similarities, these are classified as Demountable under the Defence Asset Type"

Stop-logs can be used to isolate an asset such as a flow control gate to enable maintenance or debris clearance to be undertaken.

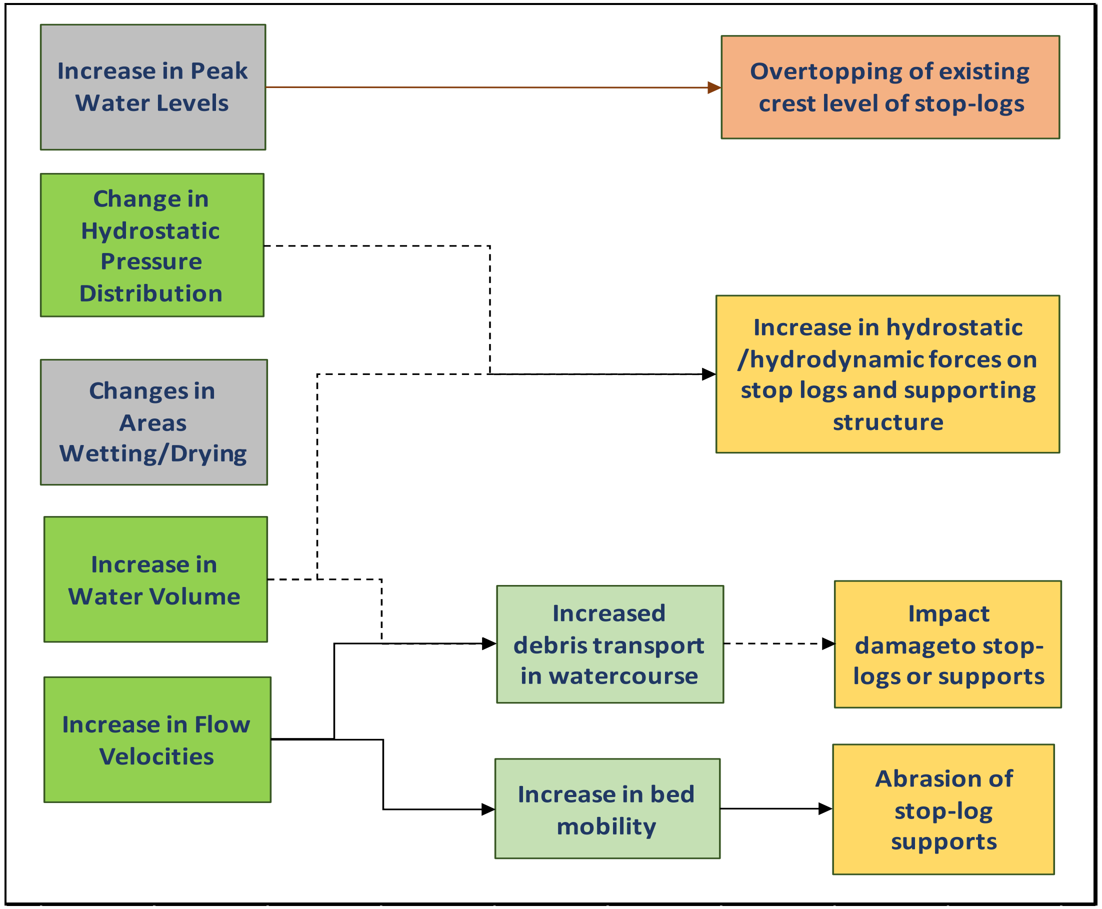
In-channel stop logs can be used for both the control of flows in a channel, for example to control water levels into and from a SSSI, but additionally for the isolation of in-channel assets for inspection and maintenance. This function creates further scenarios to consider in terms of potential deterioration and failure modes e.g. lock refurbishments which require full drawdown of water on one side of the stop logs with the potential full height retained water on the other side.

In channel stop logs can be fabricated using a variety of materials including steel, aluminium, timber, HDPE and concrete. These are assets which are particularly affected by flow volumes, velocities and water levels. The impacts of changes in hydrostatic and hydrodynamic forces on the deterioration of the asset are important to consider when reviewing the assets structural stability. The impact of increased wetting/drying on stop logs as in channel assets are negligible.

CLIMATE CHANGE FACTORS TO CONSIDER				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: In channel stop-logs	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN CLIMATE CHANGE LOADING AND ASSET DETERIORATION



ASSET TYPE: In channel stop-logs		ENVIRONMENT: Fluvial	
QUALITATIVE ASSESSMENT The impacts of these climate change factors on the deterioration of in channel stop logs include: • Abrasion to stop-log supports from higher bed mobility • Impact damage to stop-logs from higher debris flows Otherwise, the stop-log is intended to work in a water environment; therefore climate change increases in water flows etc will have little impact on deterioration The impacts of these climate change factors on asset failure is small because of the high factor on hydrostatic action included in the design and because the stop-logs would not be installed into higher water flows. The impacts of these climate change factors on deterioration of stop-logs is also considered to be negligible because they would not be installed into higher water flows due to creation of flood risk, and would therefore not be subject to increased abrasion. Stop-logs are low maintenance assets provided the manufacturer's recommendations are followed. Climate change increases could result in more frequent use of stop-logs, for example to clear debris from control gates, but the effects on stop-log deterioration and maintenance is going to be Negligible.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
			X
OTHER POTENTIAL IMPACTS Climate change increases in peak water levels would result in overtopping if there is no or insufficient design freeboard; and replacement could be required because stop-logs are normally designed for hydrostatic pressure only to the top of the stop-logs. Climate change increases in peak water levels would result in overtopping if there is no or insufficient design freeboard; and replacement could be required because stop-logs are normally designed for hydrostatic pressure only to the top of the stop-logs. An increase in retained water height would require a check and possible redesign of new stop-logs with different section sizes, which would in turn require the stop log supports to be modified. An increased stop-log height requirement would require new stop-logs and supports to be designed. The design and construction of the supports could cost more than replacing the stop logs if the supports form part of another complex asset, which is hard to modify. The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.			

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Control Gate (Mitre Gate)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A control gate can be adjusted to alter the flow of water in a channel. This includes penstocks, sluice gates, mitre gates, sector gates and radial gates."

Control gates are predominantly formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change. The materials normally used in the construction of control gates include steel, timber and plastics. The type of control gate will also influence how the asset will be affected by the influence of the climate change.

There are several types of control gate to consider. ***This assessment covers only mitre type control gates*** – separate assessments are made for other types of control gate.

Mitre gates, also known as pointing doors, consist of a pair of vertically hinged doors which close in a V formation such that they are held closed by hydrostatic pressure of water on one side. This ensures that significant flow along a channel is only allowed in one direction. Mitre gates are only operated manually when there is little or no head difference between the upstream and downstream sides. They generally range in size from 5 sqm to 80 sqm or larger. They generally consist of the following components:

- Doors - may be steel, wooden with steel frames, or composite material
- Sealing faces
- Cill
- Quoins
- Pintles
- Gearboxes

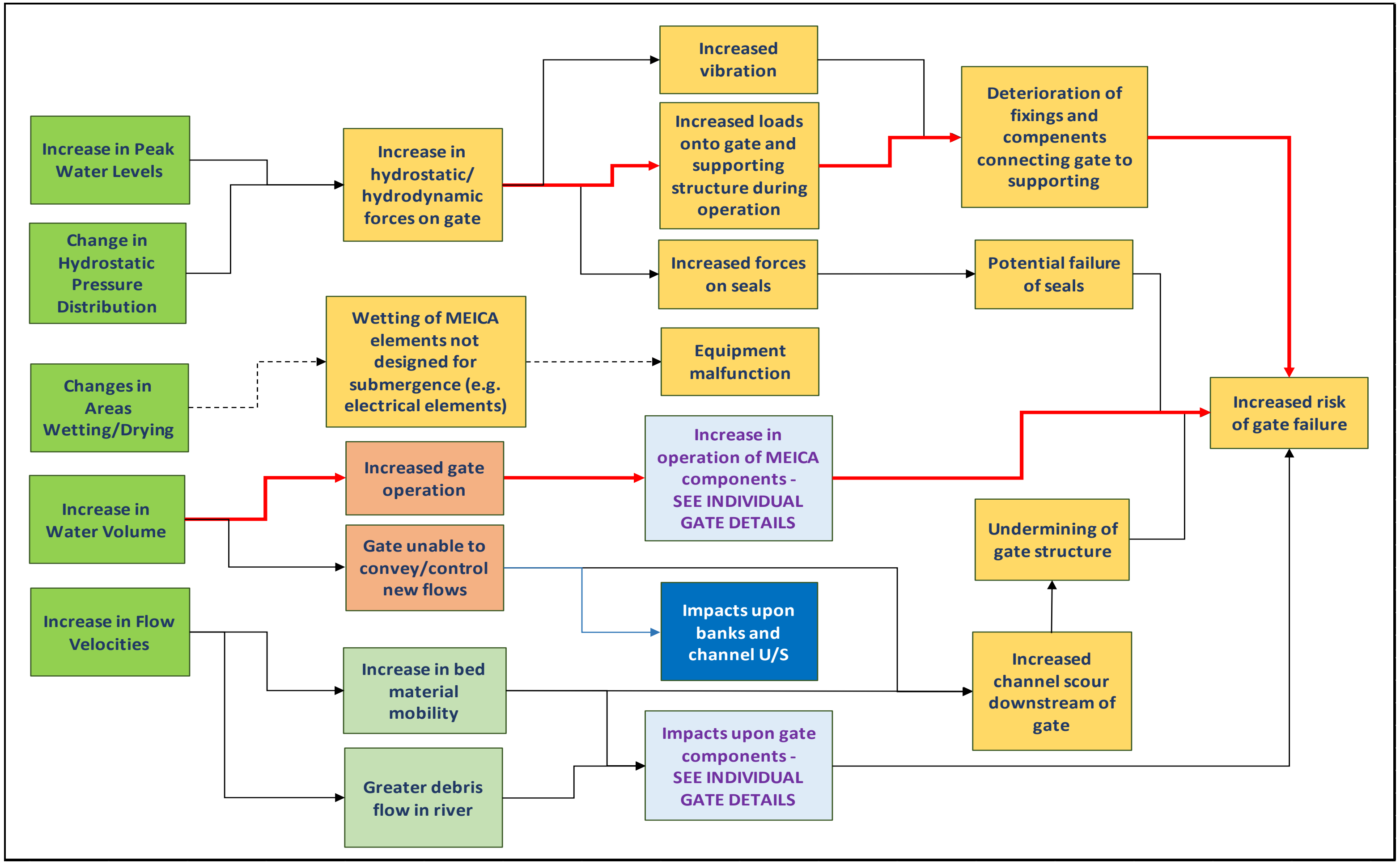
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors
No	No	No	Yes	No

ASSET TYPE: Control Gate (Mitre Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

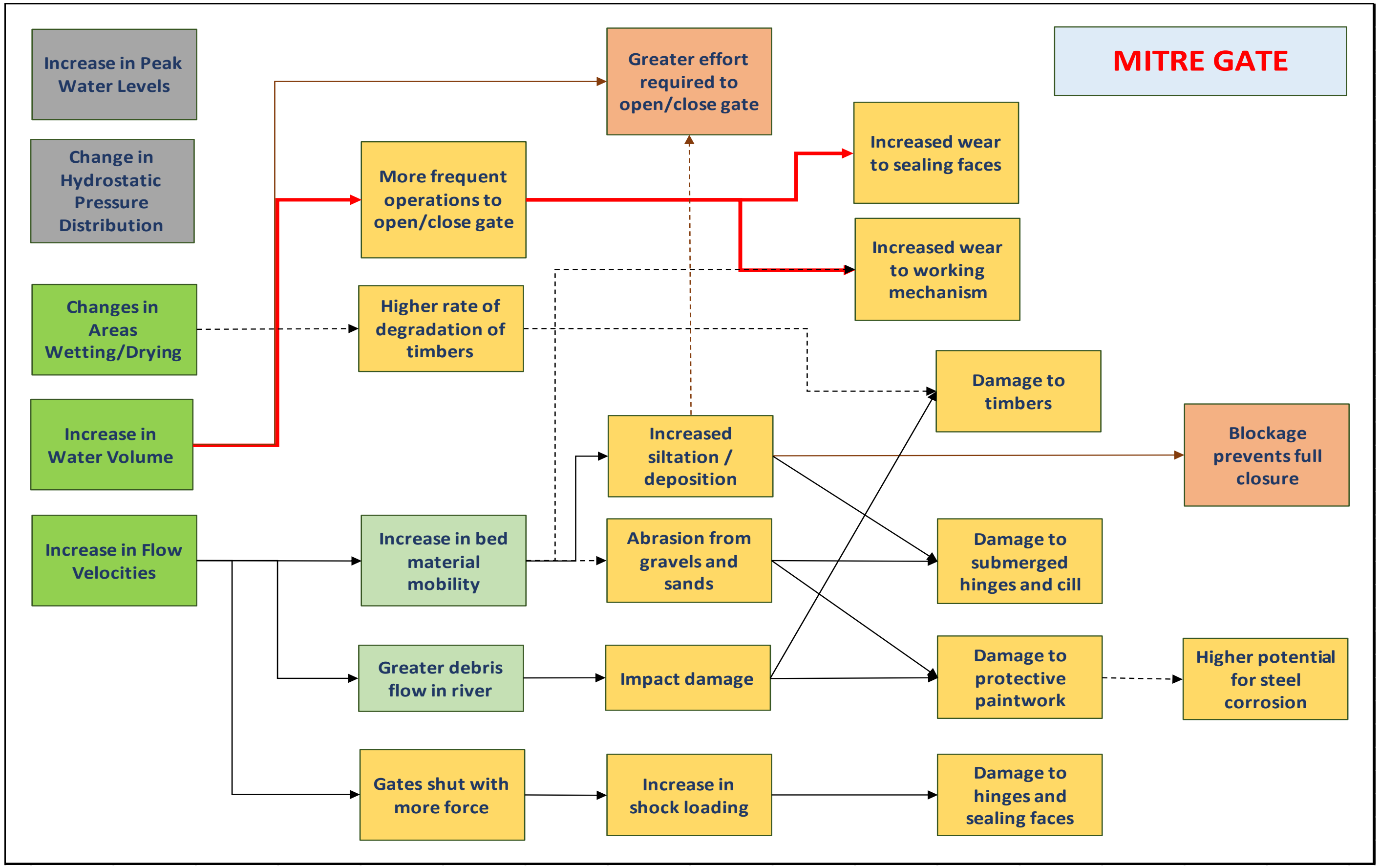
(1) OVERALL



ASSET TYPE: Control Gate (Mitre Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) MITRE GATE DETAILS



ASSET TYPE: Control Gate (Mitre Gate)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of mitre gates include:

- Greater hydrodynamic and hydrostatic loads onto the gate supports resulting from increased water levels and flow velocities during operation.
- Increased or introduced gate vibration resulting from increased water levels and flow velocities during operation.
- Higher possibility of impact damage to the gate from large items of floating debris, e.g. logs, caused by increased flow velocities.
- Increase in water volume requiring more frequent operation of the gate, resulting in increased wear to components.
- Increase in flow velocities, resulting in greater transport of bed materials. If deposited around the gate's cill, silt could cause damage.
- Increase in flow velocities, resulting in the gates being opened and closed with greater force and experiencing greater shock loading. This may result in an increase in maintenance requirements, or else may necessitate design modifications to absorb the energy of the gates as they are opened or closed by the flow.

Mitre gates are constructed from steel or timber and designed to be in the water. Therefore the overall climate change impact on the main gate material is considered to be negligible except for where major impact damage could occur.

Assuming the gate has been correctly designed for loading under extreme flows, it is expected the impact on deterioration of the asset from the level of increased flows and water levels being considered here will also be small. This could however have a bearing on the rate of deterioration of fixings and components connecting the gate to the supporting structure, e.g. from shock loading.

The main issue for mitre gates will be the increase in wear and tear resulting from the more frequent and forceful operation that may be required. Many maintenance tasks for this type of control gate require the gates to be dewatered and removed from the channel. This is a substantial task with significant associated expense. For the larger mitre gates, it would typically be carried out circa every 30 years. In the future, major refurbishments like this may have to become more frequent.

As a result, the anticipated increase in maintenance commitment due to climate change is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

In a fluvial context, mitre gates are typically in locks to prevent flow through the channel when there is a difference in water level either side of the gates, whereas the purpose of mitre gates in a tidal river is typically to limit backflow of water along channels when downstream levels rise. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation. An increase in flow volumes and water levels could therefore result in the need to increase the height of the gates. Raising the height of mitre gates is a relatively simple task, for example additional beams may be stacked on top of the doors to provide additional height to cope with increased peak water levels.

Even without replacement, the need for increased operation of the control gate may result in a considerable increase in human input, for inspection, maintenance, and operation.

If an increase in flow velocities results in greater transport and deposition of river bed materials around the gate's cill, silt could prevent full closing of the gate and cause deterioration. This would necessitate a higher commitment to clearing the siltation.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Control Gate (Radial Gate)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Structure'

"A control gate can be adjusted to alter the flow of water in a channel. This includes penstocks, sluice gates, mitre gates, sector gates and radial gates."

Control gates are predominantly formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change. The materials normally used in the construction of control gates include steel, timber and plastics. The type of control gate will also influence how the asset will be affected by the influence of the climate change.

There are several types of control gate to consider. ***This assessment covers only radial type control gates*** – separate assessments are made for different types of control gate.

Radial gates are horizontally pivoted, and may be designed for both undershot and overtopping operation. They generally consist of the following components:

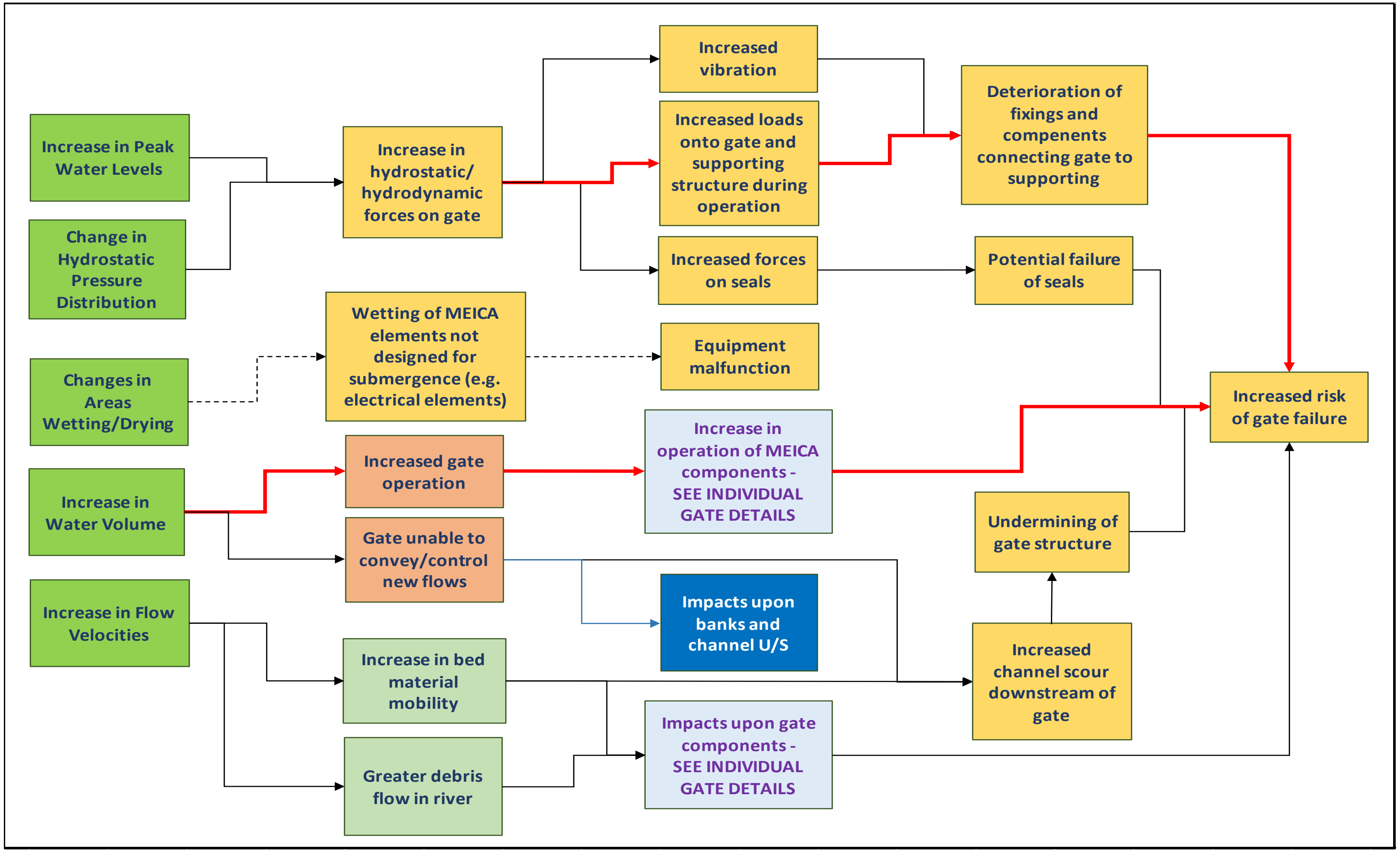
- Skin plate
- Frame
- Counterweight
- Seals
- Cill
- Bearings
- Actuation mechanism
- Civil structure

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Control Gate (Radial Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

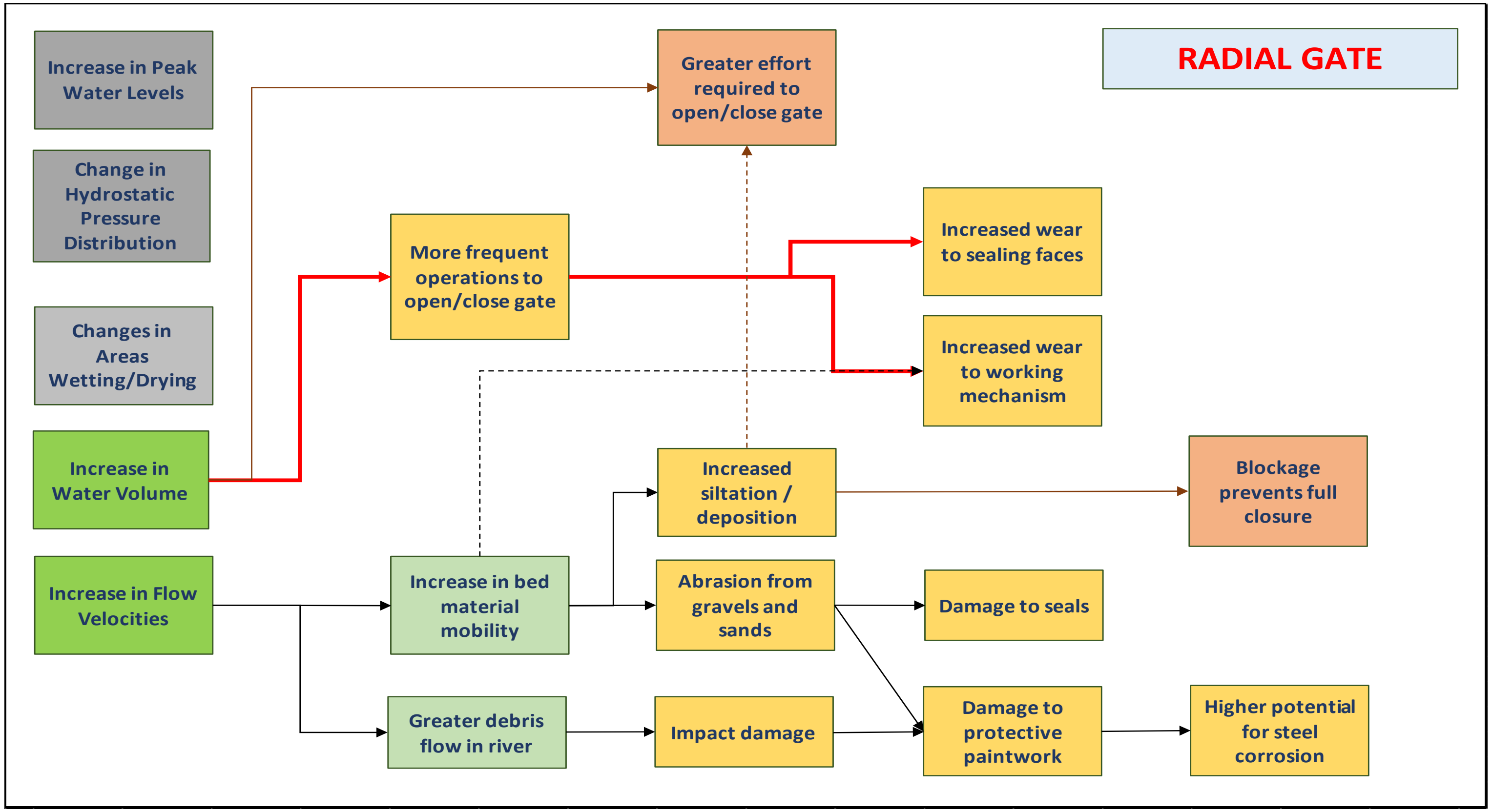
(1) OVERALL



ASSET TYPE: Control Gate (Radial Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) RADIAL GATE DETAILS



ASSET TYPE: Control Gate (Radial Gate)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of radial gates include:

- Greater hydrodynamic and hydrostatic loads onto the gate supports resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be raised fully clear of the flow.
- Increased or introduced gate vibration resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be opened fully clear of the flow.
- Increase in water volume requiring more frequent operation of the gate. This would result in increased wear to components, and therefore an increase in maintenance requirements.
- An increase in flow velocities could also lead to impact damage from logs and other heavy debris carried by the river. This would result in an increase in maintenance requirements.
- Greater scour immediately downstream of gates with short apron lengths, causing potential undermining and reduced stability.
- Increase in water volume requiring more frequent operation of the gate, resulting in increased wear to components.
- Higher flow velocities, resulting in greater transport of bed materials, leading to higher abrasion and damage to components.
- Components relating to gate operating mechanisms (especially electrical) designed to be out of the water but immersed due to higher levels.

Assuming the gate has been correctly designed for loading under extreme flows, it is expected the impact on deterioration of the asset from the level of increased flows and water levels being considered here will be small. This could however have a bearing on the rate of deterioration of fixings and components connecting the gate to the supporting structure. The maintenance (replacement) of these may therefore be required more often as a result of the climate change factors, but is not expected to result in a substantial change to currently expected requirements.

Most control gates are constructed from steel and with suitable protective coatings for working within water; therefore the overall climate change impact on the main gate material is considered to be negligible except for where major impact damage could occur.

The main issue for these gates will be the increase in wear and tear resulting from the increased level of operation that may be required. The types of maintenance would be the same as currently required, e.g. replacing seals, but could be required more frequently in line with their more regular use.
Increased frequency of submergence is unlikely to significantly affect the deterioration of these assets, unless it results in the exposure of components which have not been designed for being occasionally immersed e.g. Electrical or other MEICA elements.

Overall, however, the increase in maintenance commitments are not expected to be significant, and therefore the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of radial gates is to manage water levels. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation. Increases in peak water levels could result in overtopping of the gate even when fully raised, and thus a reduction in the gate's effectiveness.

An increase in flow volumes and water levels could therefore result in the need for significant modifications to, or even redesign and replacement of, the gate, lifting gear and support structure could all be needed. Even without replacement, the need for increased operation of the radial gate may result in a considerable increase in human input, for inspection, maintenance, and operation.

If an increase in flow velocities results in greater transport and deposition of river bed materials in the gate's floor recess of a radial gate, silt could prevent full opening or closing of the gate. This would necessitate a higher commitment to clearing the siltation.

Changes in flows and levels could impact telemetry equipment which may have to be repositioned and/or replaced to accurately assess hydrology associated with the asset.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Control Gate (Guillotine Gate)	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A control gate can be adjusted to alter the flow of water in a channel. This includes penstocks, sluice gates, mitre gates, sector gates and radial gates."

Control gates are predominantly formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change. The materials normally used in the construction of control gates include steel, timber and plastics. The type of control gate will also influence how the asset will be affected by the influence of the climate change.

There are several types of control gate to consider. ***This assessment covers only guillotine type control gates*** – separate assessments are made for different types of control gate.

Guillotine gates are vertically lifting gates placed in a channel to provide flow control. They generally range in size from 2 sqm to 40 sqm. Flow is generally intended to undershoot the gate, but may overtop in some circumstances. They generally consist of the following components:

- Gate
- Gantry
- Seals
- Cill
- Wheels
- Running tracks
- Ropes or chains
- Winding drums or sprockets
- Counterweight
- Gearboxes
- Actuator
- Civil structure

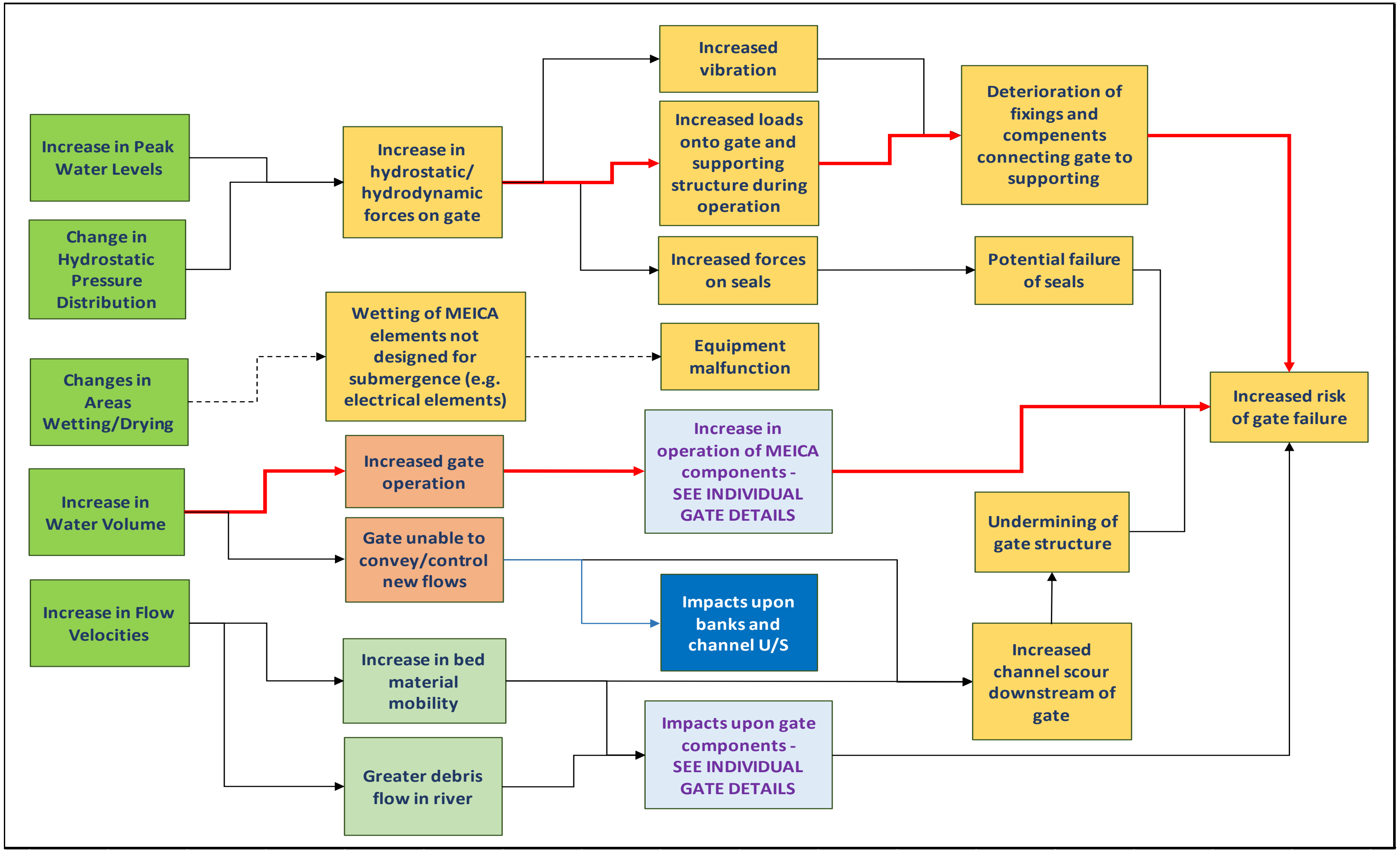
CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	Potential*

*Increased ***rainfall*** could contribute to higher volumes of flood water to be discharged via the guillotine gate, or more frequent operations, which could increase wear and tear.

ASSET TYPE: Control Gate (Guillotine Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

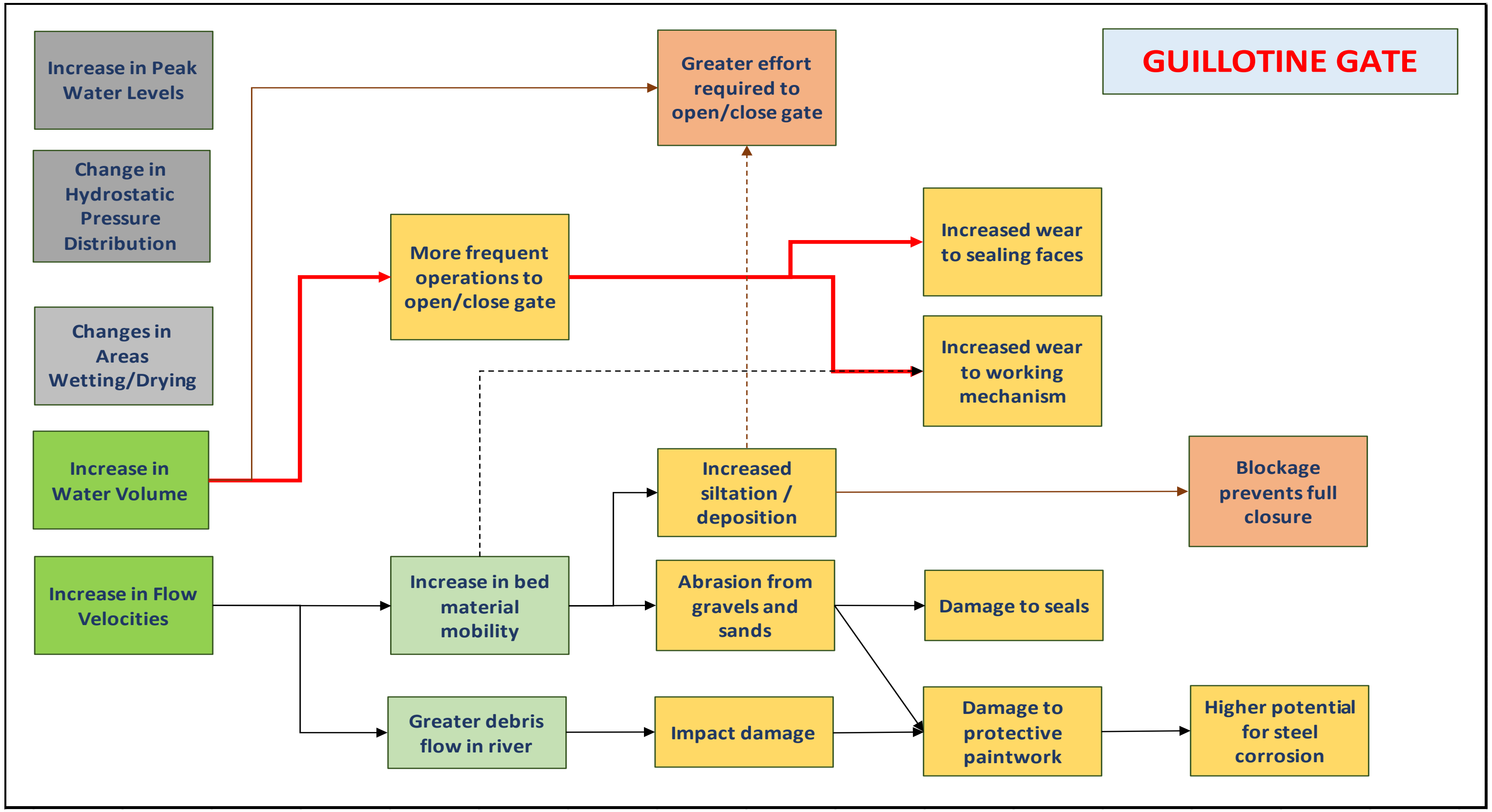
(1) OVERALL



ASSET TYPE: Control Gate (Guillotine Gate)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) GUILLOTINE GATE DETAILS



ASSET TYPE: Control Gate (Guillotine Gate)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of guillotine gates include:

- Greater hydrodynamic and hydrostatic loads onto the gate supports resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be raised fully clear of the flow.
- Increased or introduced gate vibration resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be raised fully clear of the flow.
- Increase in water volume requiring more frequent operation of the gate. This would result in increased wear to components, and therefore an increase in maintenance requirements.
- Increase in flow velocities, resulting in greater transport of bed materials. If deposited around the gate's cill and running tracks, silt could prevent full closing of the gate. This would necessitate a higher commitment to clearing the siltation.
- An increase in flow velocities could also lead to impact damage from logs and other heavy debris carried by the river. This would result in an increase in maintenance requirements.
- Greater scour immediately downstream of gates with short apron lengths, causing potential undermining and reduced stability.
- Higher flow velocities, resulting in greater transport of bed materials, leading to higher abrasion and damage to components.
- Components relating to gate operating mechanisms (especially electrical) designed to be out of the water but immersed due to higher levels.

Assuming the gate has been correctly designed for loading under extreme flows, it is expected the impact on deterioration of the asset from the level of increased flows and water levels being considered here will be small. This could however have a bearing on the rate of deterioration of fixings and components connecting the gate to the supporting structure. The maintenance (replacement) of these may therefore be required more often as a result of the climate change factors, but is not expected to result in a substantial change to currently expected requirements.

Most control gates are constructed from steel and with suitable protective coatings for working within water; therefore the overall climate change impact on the main gate material is considered to be negligible except for where major impact damage could occur.

The main issue for guillotine gates will be the increase in wear and tear resulting from the increased level of operation that may be required. The types of maintenance would be the same as currently required, e.g. greasing spindles to maintain in good working order, but could be required more frequently in line with their more regular use. In extreme cases there may be a requirement to upgrade working mechanisms, e.g. introducing a higher rated actuator or gearbox to enable continued operation.

Increased frequency of submergence is unlikely to significantly affect the deterioration of these assets, unless it results in the exposure of components which have not been designed for being occasionally immersed e.g. Electrical or other MEICA elements.

Overall, however, the increase in maintenance commitments are not expected to be significant, and therefore the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of guillotine gates is to manage water levels. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation.

An increase in flow volumes and water levels could therefore result in the need to increase the height to which the gate must be raised to prevent obstruction to higher flows; and potentially to increase the height and width of the gate orifice to pass increased flood flows. Significant modifications to, or even redesign and replacement of, the gate, lifting gear and support structure could all be needed. Even without replacement, the need for increased operation of the guillotine gate may result in a considerable increase in human input, for inspection, maintenance, and operation.

If an increase in flow velocities results in greater transport and deposition of river bed materials in the gate's floor recess of a guillotine gate, silt could prevent full opening or closing of the gate. This would necessitate a higher commitment to clearing the siltation.

Changes in flows and levels could impact telemetry equipment which may have to be repositioned and/or replaced to accurately assess hydrology associated with the asset.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Control Gate (Penstock)	**ENVIRONMENT: Fluvial**

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A control gate can be adjusted to alter the flow of water in a channel. This includes penstocks, sluice gates, mitre gates, sector gates and radial gates."

There are several types of control gate to consider which may be divided into two broad categories:

- IN-CHANNEL CONTROL GATES - e.g. Mitre Gates, Radial Gates, Rising Sector Gates, Guillotine Gates.
- OUT-OF-CHANNEL CONTROL GATES – e.g. Penstocks on outfalls or as part of a sluice gate providing regulated exchange

This assessment covers only Penstock type control gates – separate assessments are made for in-channel control gates.

The main components of a Penstock are:

- Frame
- Gate/door
- Seals
- Spindle
- Actuating mechanism/ gearbox

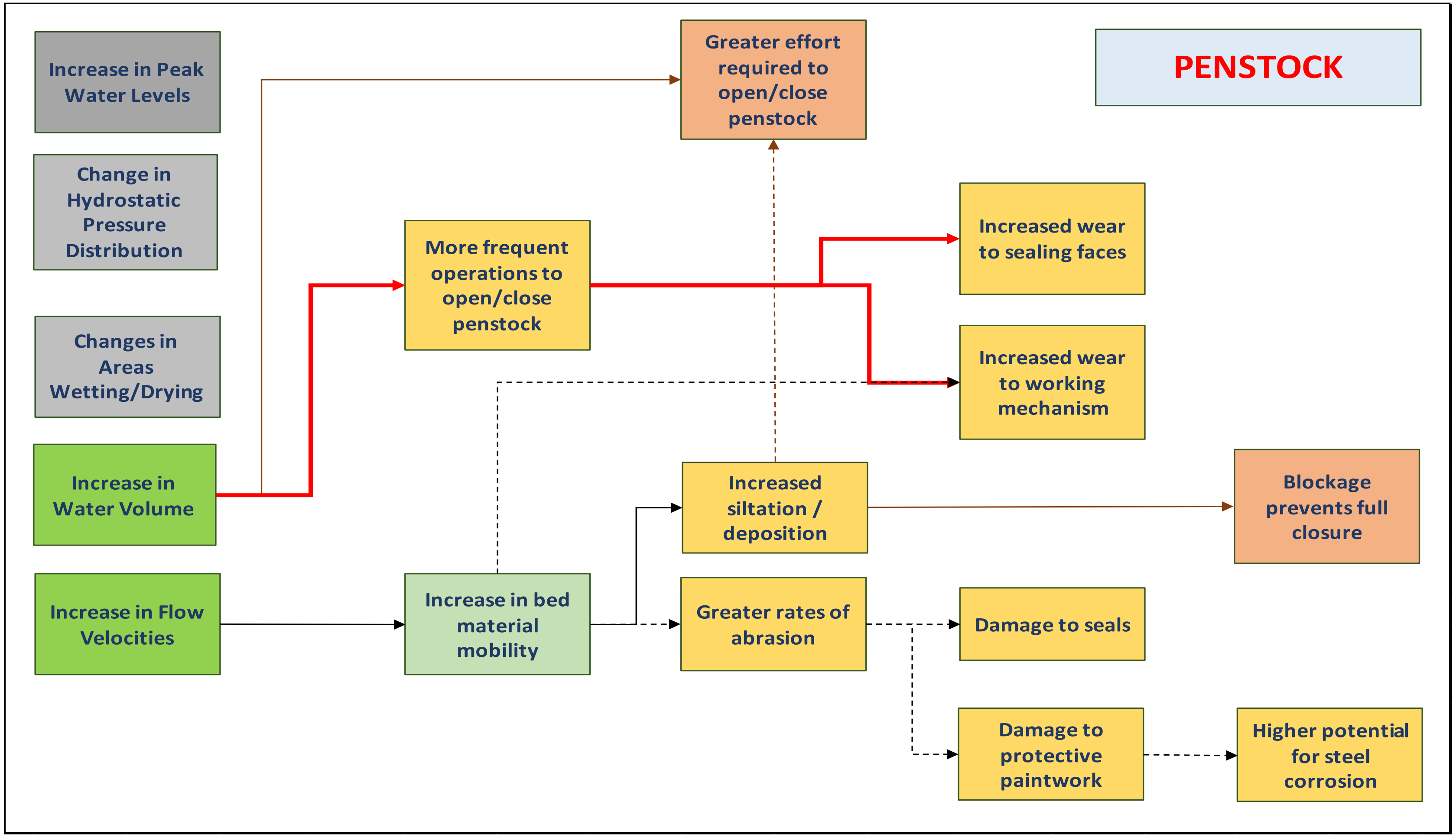
There are two types of Penstock: on-sealing and off-sealing, depending on the water pressure. Penstocks are rated for different pressures. Penstocks are often pre-fabricated units.

CLIMATE CHANGE FACTORS CONSIDERED				
Storm Surge Increase	**Storm Surge Increase**	**Storm Surge Increase**	**Storm Surge Increase**	**Storm Surge Increase**
No	No	No	No	Potential*

*Increased ***rainfall*** could contribute to higher volumes of flood water to be discharged via the penstock, or more frequent operations, which could increase wear and tear.

ASSET TYPE: Control Gate (Penstock)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Control Gate (Penstock)	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of penstocks include:

- Increases in water volume, including the unpredictability of flows (magnitude and duration), requiring more frequent operation of the penstock
- Increased operation required, leading to greater wear and tear
- Higher river flows resulting in greater transport of bed materials, and debris, damaging or compromising the operation of the penstock

Although factors such as river bed material transport and debris impact could also affect the deterioration of these assets, their impacts are expected to be negligible in comparison with other consequences which impact upon the operation itself.

The main issue for penstocks will be the increase in wear and tear resulting from the increased level of operation that would potentially be required. The types of maintenance would be the same, e.g. greasing spindles to maintain in good working order, but could be required more frequently in line with their more regular use, although in extreme cases there may be a requirement to upgrade working mechanisms, e.g. introducing a higher rated actuator or gearbox to enable continued operation.

However, overall the increase in maintenance commitments are not expected to be significant, and therefore the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of a penstock is to manage water levels. If the operation of these is compromised, then that could increase flood levels/flood risk to areas reliant upon its operation.

Although the increase in maintenance commitment required to deal with deterioration aspects is not expected to be significant, there will be a sizeable increase in frequency of operation and manpower required due to the climate change factors. These factors could also result in greater effort being required to operate the penstock.

Another potential issue is the greater potential for blockage of the penstock due to increased debris carriage or siltation resulting from higher flows, requiring more regular inspection and maintenance to clear.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Outfall	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"An outfall is a small surface water drain that discharges into a watercourse or the sea. It can also include larger flapped outfalls where a small watercourse flows under a defence and thence into a larger watercourse or the sea."

Outfalls can take various forms and sizes, but may typically consists of an outfall pipe, usually fitted with a flap valve at the downstream discharge end of a pipe or culvert, enclosed within a concrete/masonry structure consisting of a head wall, side walls and apron; with the flap valve secured to the headwall. Alternatively the outfall may be little more than an aperture through a continuous wall, such as a concrete, masonry or steel sheet pile, with a flap valve secured to it.

Deterioration of a penstock gate which may form an outfall control is considered under 'Control Gates' asset type. Deterioration of an embankment defence through which the watercourse flows is considered under 'Embankments' asset type.

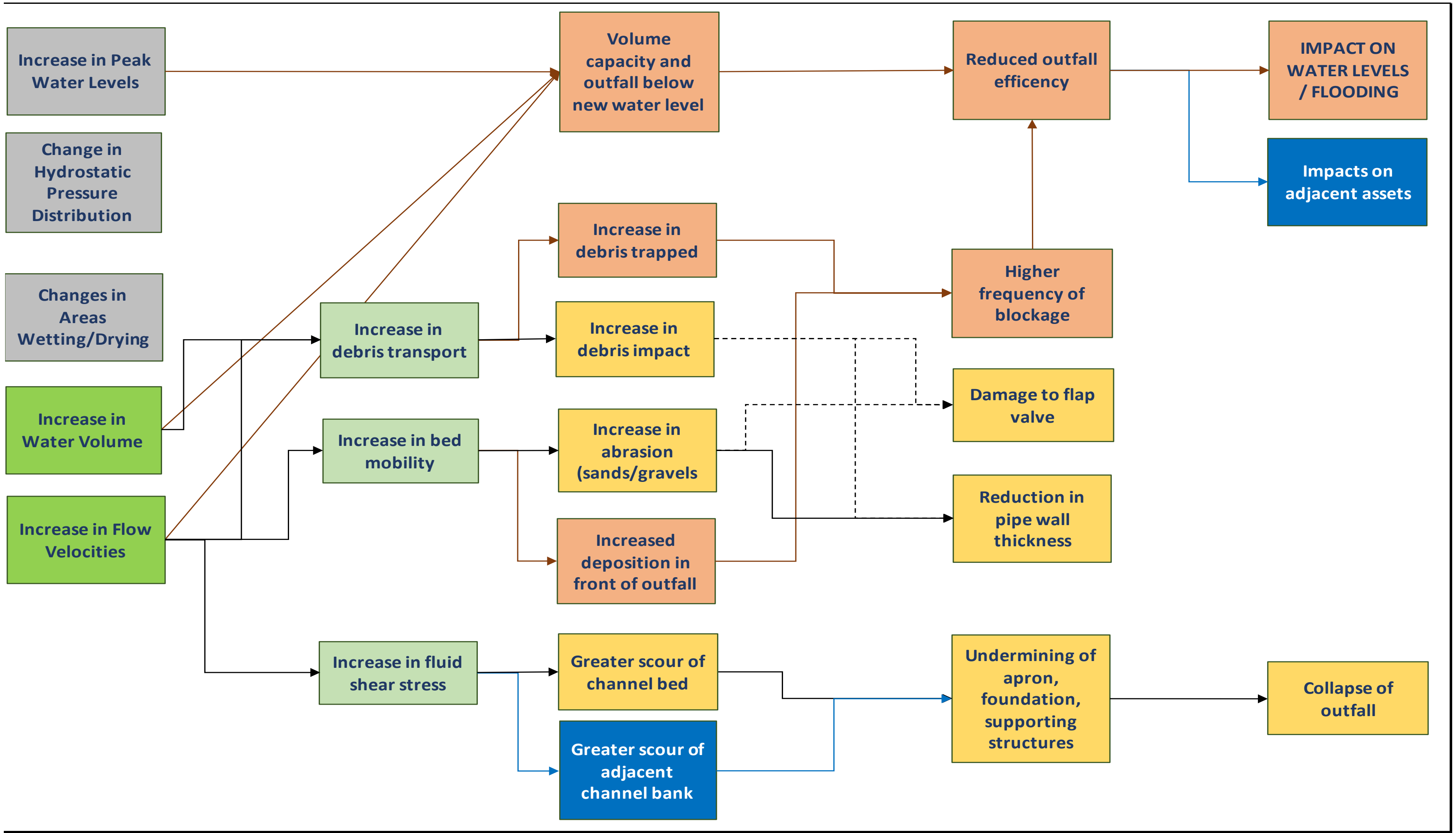
Changes in peak flow levels and volumes could alter the hydraulics associated with the outfall. Increases in velocities could also increase bed mobility, whilst climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Outfall

ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Outfall	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of outfalls include:

- Increase in flow velocities would increase the amounts of grit and debris flowing through the outfall with increased abrasion and impact.
- Increase in debris flowing through the outfall could result in damage or abrasion.
- Increased flows through the outfall resulting in increased erosion to outfalls having downstream aprons, and erosion immediately downstream resulting in undermining of the apron.

Abrasion on the outfall pipe itself (assuming material usually concrete/masonry, plastic, vitrified clay or cast iron/steel) would increase as a consequence of more bedload and suspended material washing through the outfall, or potentially through greater debris transport. This also depends on material; a concrete pipe would for example be more susceptible than one formed from HDPE. However, the increase in this rate is unlikely to have much impact upon the maintenance requirements for any of these structures.

Although abrasion could increase, HDPE and ductile iron flap valves both have good impact resistance, and bronze sealing faces have good resistance to erosion by grit. Therefore climate change increases in flow velocities are considered to have little impact on deterioration of the flap valve materials.

If and where present, increased flows through the outfall could increase scour of any apron provided immediately downstream of the outfall, requiring repairs or enhanced protection to prevent undermining.

The overall maintenance regime for outfalls is not expected to alter significantly as a consequence of the above; the primary issue being the potential need for more regular inspection and unblocking these structures (a performance issue). Maintenance actions with respect to deterioration could include increased inspection to ensure against undermining of the downstream apron, and concrete repairs to abrasion damage if required. Consequently the vulnerability to climate change on deterioration of these assets are considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

An increase in water volumes could result in the outfall having insufficient capacity; requiring enlargement with potentially high impact for a substantial outfall system. This could also negatively impact assets upstream of the outfall as the increased volume backs up at this asset.

An increase in the volume of debris flowing down a watercourse as a result of higher flows, could see more frequent trapping of this at or in the outfall and require more regular maintenance to inspect and unblock these structures, and to ensure that the flap disc remains free to swing open and to close. Conversely, higher flows could help to clear blockages, depending upon the nature of the debris.
An increase in downstream water levels could reduce the effectiveness of the outfall system; requiring replacement with a more suitable design.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Weir	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A weir crosses a channel to increase the upstream water level. This includes fixed weirs, manual weirs and mechanical weirs."

There are 3 main types of weir to consider:

- FIXED CREST OVERFLOW WEIRS – usually constructed from concrete, occasionally masonry
- TILTING WEIRS – usually steel or HDPE moving weir between concrete support wing walls and with concrete apron, usually with head and tail cut offs. Tilting weirs may be manually operated or electrically actuated, using either wire ropes or screw threads.
- WIERS INCORPORATING FLOW/WATER LEVEL CONTROL GATES* – gates normally supported by concrete piers or steel A-frames and with concrete apron; usually with head and tail cut offs. The gates may be manually or mechanically operated

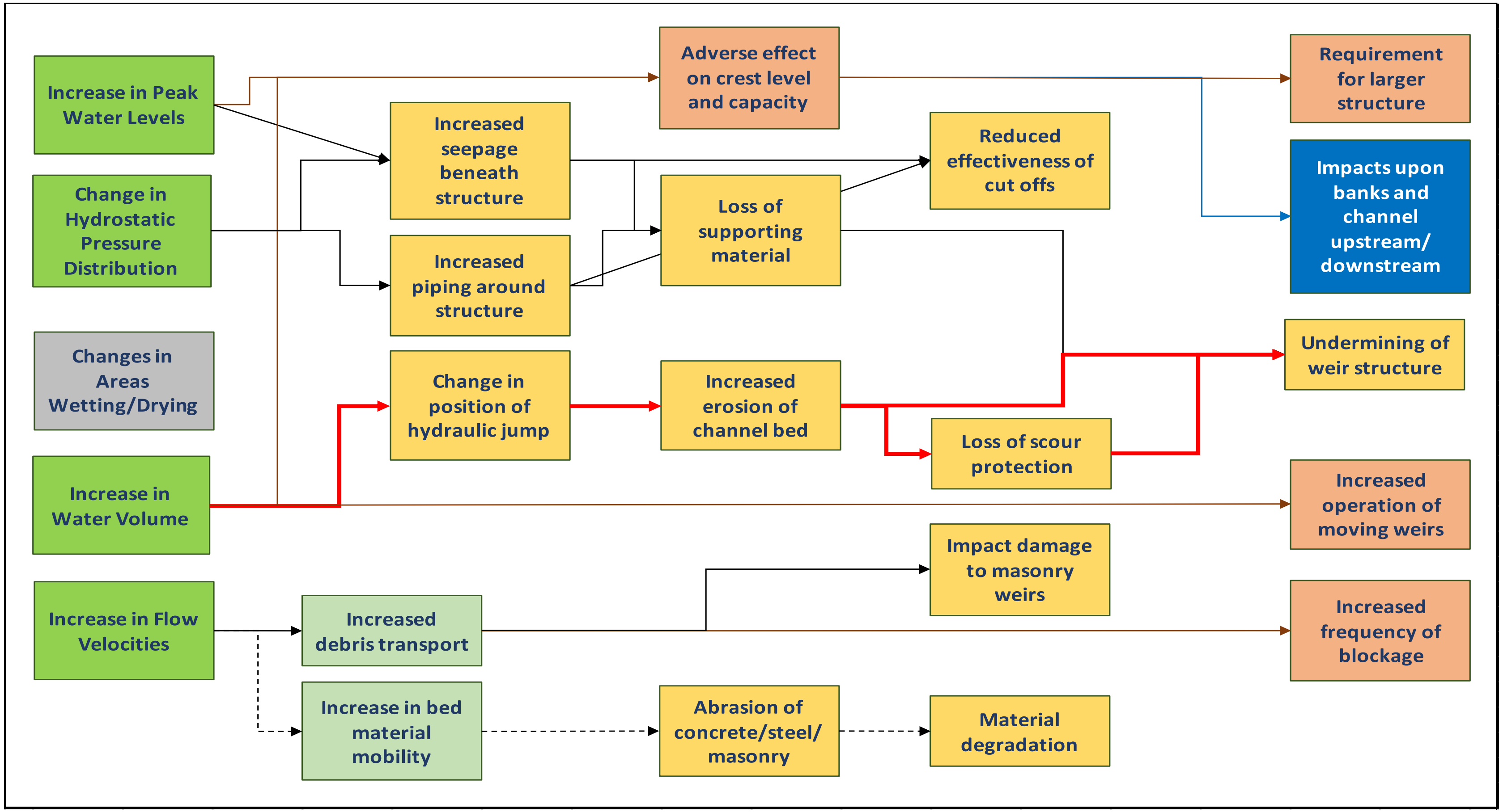
**To note, is that the deterioration processes specifically relating to the control gates are dealt with under that asset type, and not here.*

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Weir	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Weir	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of weirs include:

- Bed (weir pool) downstream of weir may be subject to increased erosion and deepening resulting from increased water levels, velocities and turbulence, leading to undermining of the weir structure and/or destabilising of scour protection
- Potential for increased seepage beneath and around structures, with those built in fine materials being most vulnerable.

These assets are specified for use in water, therefore any climate change increases in water levels and flows should not by themselves decrease the design life, e.g. for steel A-frames the splash zone would move to a higher level, but the effects would be the same.

To prevent channel bank and bed erosion, with potential bank collapse and undermining of weir structure; enhanced bank and downstream bed protection may be required.

Masonry fixed crest overflow weirs are considered to be more vulnerable that more substantial weirs constructed of concrete and steel sheet piling.

Maintenance actions would include increased inspection to ensure against undermining of the downstream cut off, and repairs to weirs of masonry construction. There may be an increased requirement to review and perhaps extend the cut offs at the sides of the weir to prevent piping.

This level of increase in maintenance commitments would indicate a Moderate vulnerability.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

The purpose of a weir is to retain upstream water levels. However if a tilting weir or weir incorporating control gates also has a flood prevention (i.e. flow passage) purpose, or if a fixed crest weir would cause increased flows to flow out of banks then to prevent unacceptable out of channel banks flow; increased flow volumes may require weir enlargement. The reconstruction required to provide increased flow capacity by enlargement of a gated weir or conversion of fixed crest to a gated weir would be a ‘high’ impact.

Other consequence of this for adjacently located assets are that:

- Crest levels of channel banks upstream of weir may be exceeded with subsequent out of banks flow, so would require raising.
- Banks of channel may be subject to increased erosion resulting from increased water levels, velocities and turbulence, increasing their vulnerability to failure.

To prevent reduced weir operability, increased debris clearance or debris prevention measures may also be required. This may not alter annual maintenance requirements but will require more human input to clear these structures, and to operate tilting weirs and weirs with control gates. Similarly, there may also be a requirement for increased operation of tilting weirs and weirs with control gates.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Spillway	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'.
"A spillway provides an overflow in a reservoir, flood storage area, or along defences. This includes overflow spillways, side spillways and shaft spillways."

Spillways can be constructed from reinforced/unreinforced concrete, masonry and earth (although in the case of the latter the spillway area would also normally be hardened up, e.g. reinforced with grasscrete).

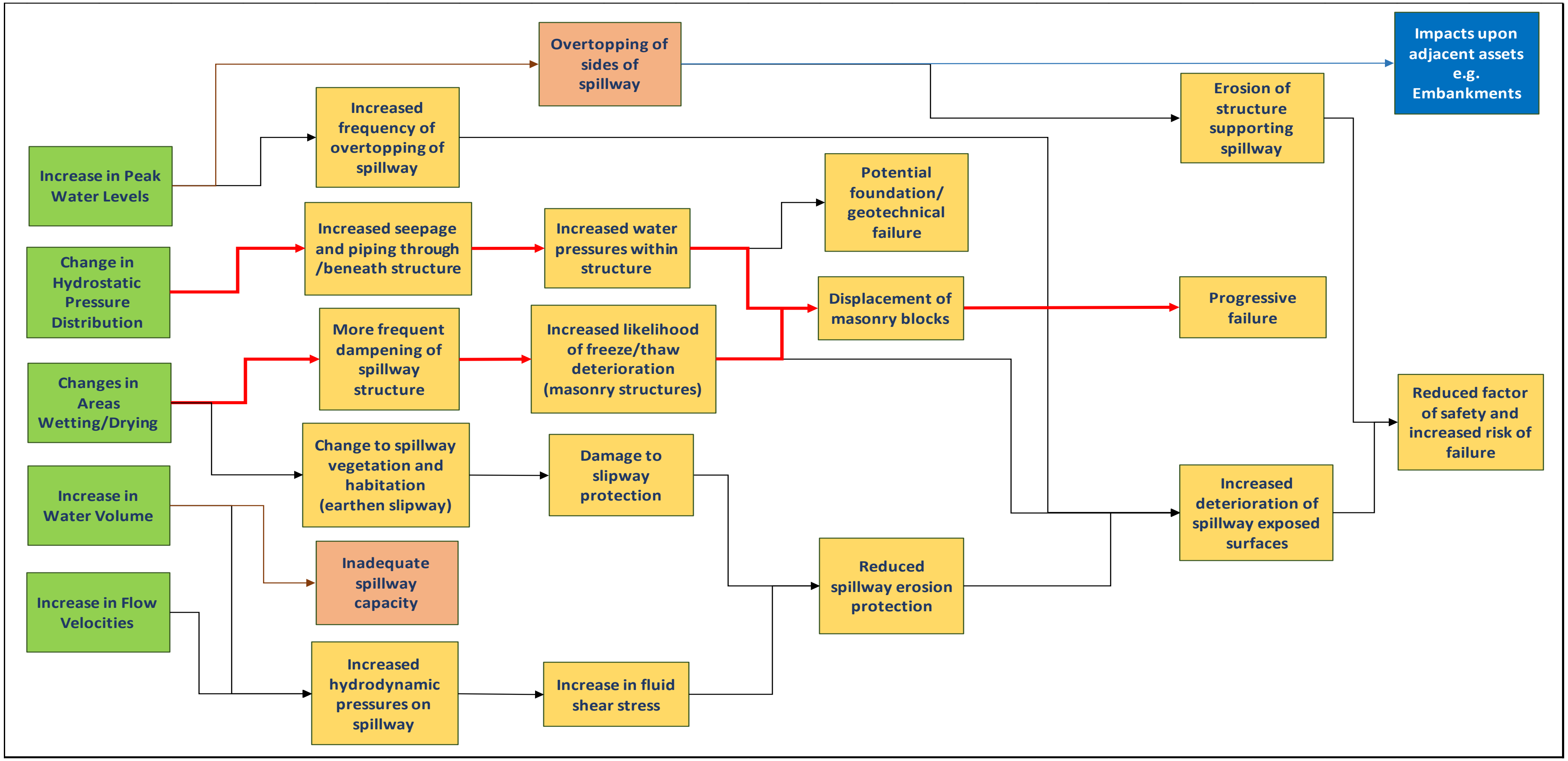
As defined in CAMC spillways can be associated with a number of different functions (flood storage, reservoirs and flood defence) and can be formed in a number of different configurations.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Spillway | ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Spillway	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of spillway structures include:

- Increased deterioration of spillway exposed surfaces resulting from increased peak water levels, changes in areas wetting/drying, and increased flow velocities.
- Increased deterioration of masonry spillways resulting from changes in areas wetting/drying.
- Increased erosion resulting from greater seepage and piping caused by higher hydrostatic pressure.
- Increases in duration of events would expose spillways to flows for longer durations which will in turn cause an increased potential for erosion of the spillway.

Stepped masonry spillways can degrade due to internal hydrodynamic pressure fluctuations from the spillway flow; which can dislodge both masonry elements and/or the mortar pointing between them. Masonry spillways are therefore the most vulnerable to climate change increases in water volume and flow velocities. Concrete and concrete open cell (e.g. grasscrete) protected spillways are less vulnerable.

Failure of spillways can be caused by foundation failure; external flow erosion; and masonry deterioration. Foundation failures are typically associated with the spillway foundations being undermined by water leaking through the bed, or invert of the spillway and washing material away as it does so. External flow erosion is associated with rainfall runoff flowing down the area immediately behind the sidewalls, leading to the removal of soil from this location. Where the wall has been designed to assume such support, this can leave the sidewall vulnerable to collapse under high discharge flow. Another possible reason for the loss of such support soil can be overtopping of the spillway walls during spillway discharge. In some cases flow erosion can also apply to the erosion of the soil or foundations at the downstream end of the spillway, resulting in regressive undermining. Spillways are therefore vulnerable to climate change increases in peak water levels, hydrostatic pressure, water volume and flow velocities that can lead to foundation failure and failure from external flow erosion.

A factor which acts to degrade masonry is dampness. Without inherent dampness, masonry is much less susceptible to either frost damage or chemical attack. Therefore, if a wall is kept dry and excludes water, it is likely to remain in good condition. Masonry spillway walls are therefore vulnerable to increase in peak water level and changes in areas, wetting/drying. The maintenance requirement of keeping the tops of walls adequately waterproofed will therefore increase.

Climate change increases will result in increased maintenance to ensure the spillway is retained in good condition. Overall, the effect of climate change increases on spillways is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

A spillway design should include the largest flood it is designed to handle. Therefore climate change increases could have high impact on performance and create the need for an enlarged or replacement spillway having increased capacity.

Failure to dissipate the water energy on the spillway can lead to scouring and erosion at the base of the associated reservoir, flood storage area, or defence. Therefore climate change increases reducing the effectiveness or integrity of spillway can also reduce the performance of the associated asset. The overtopping of spillway sides and hence increased out of channel flow could also negatively impact adjacent assets.

Changes in flows and levels will also impact telemetry equipment which may have to be repositioned and/or replaced to accurately assess hydrology associated with the asset.

Climate change increases may also require an increased frequency of debris clearance.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Stilling Basin	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Structure'.
"A stilling basin is a structure that reduces the water velocity before it passes further downstream. It is usually found at the outfall of a reservoir or flood storage area."

Being subject to both high flow velocities and turbulent flow, stilling basins are normally constructed from reinforced concrete aprons and sidewalls, with steel sheet piing across the downstream end of the basis, depending upon the soil strata.

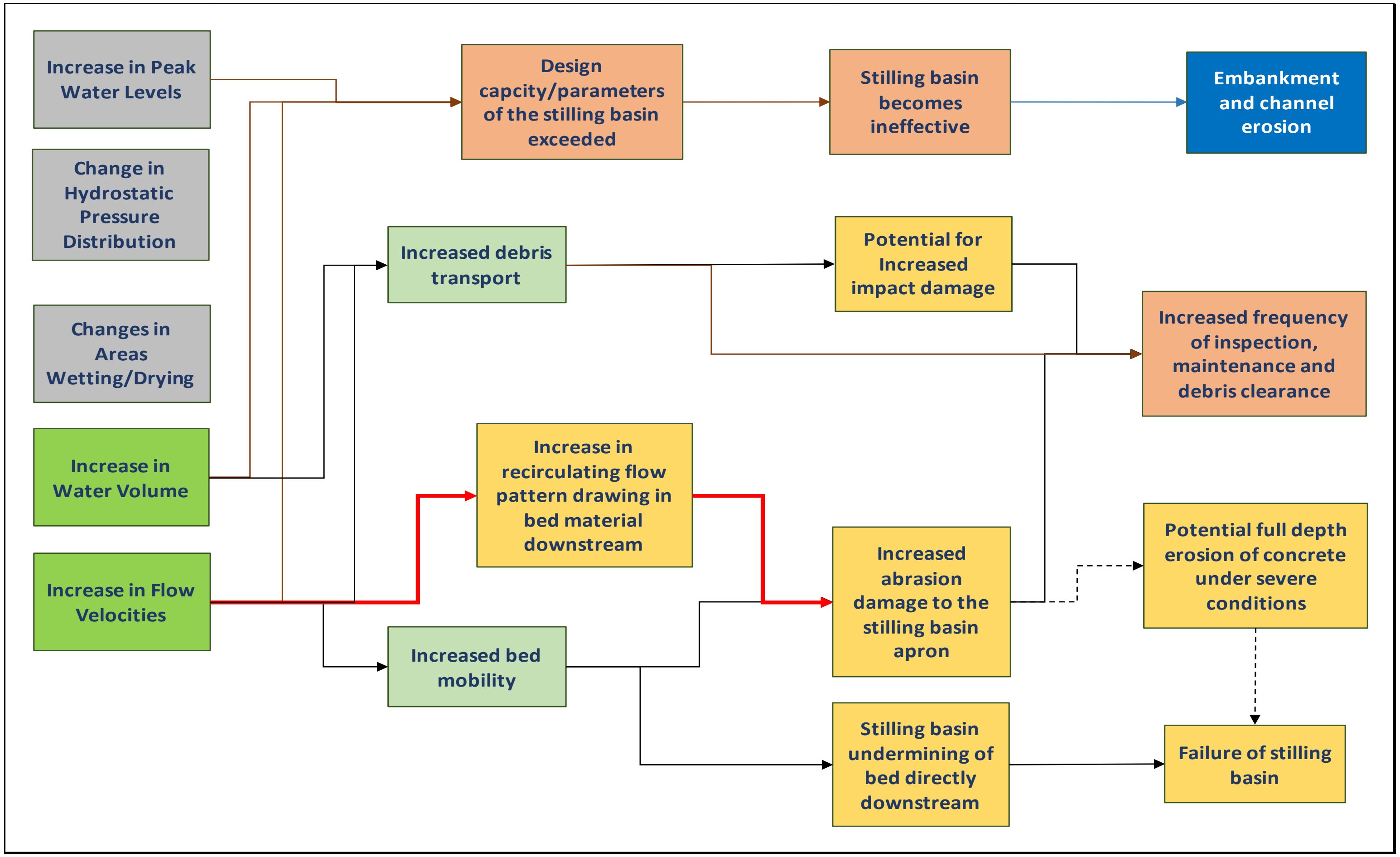
The area immediately downstream of the flow control gate within a gated weir structure is also often designed as a stilling basin to contain the hydrodynamic jump.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Stilling Basin	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Stilling Basin	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of stilling basin structures include:

- An increase in bed load carried by greater flow velocities resulting in abrasion of spillway materials.
- A change in flow patterns created by the stilling basin exacerbating abrasion potential.
- Greater water volumes and flow velocities leading to greater carriage of debris within the watercourse, leading to the potential for damage.

Stilling basin abrasion damage occurs when a recirculating flow pattern draws abrasive materials (sand, gravel, rock etc) into the stilling basin from the streambed downstream and turbulent flow continues to move them against the concrete stilling basin surface causing severe abrasion damage. A stilling basin can therefore be vulnerable to climate change increases in water volume and flow velocities, resulting in reduced design life and/or increased maintenance. Failure would occur if the abrasion continued through the full depth of the stilling basin apron concrete.

Depending upon the design of the stilling basin (e.g. thickness and strength of apron) and nature of the downstream streambed; increased maintenance could be necessary to prevent failure could result from climate change increases in water volume and flow velocities. Typically however these aprons can be of considerable thickness (e.g. >0.5m); not to resist abrasion but to provide weight against flotation. Appropriate fitment of flow deflectors across the downstream portion of a stilling basin can beneficially change the flow pattern within the basin to reduce or eliminate abrasion damage.

Overall, the vulnerability to climate change increases is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Climate change increases in water volume could exceed the design capacity of the stilling basin; requiring enlargement or replacement and having high impact.

The poor performance of the stilling basin to reduce flow velocities under new flow regime could see increased erosion of the channel bed and banks downstream of the asset.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Draw-off tower	ENVIRONMENT: Fluvial (Reservoir)

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type "Structure"
"A draw-off tower removes water from a reservoir and diverts it elsewhere."

A draw-off tower is located within a reservoir, not a river. The reservoir will be affected by inflowing rivers.

Draw-off towers can be formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change.

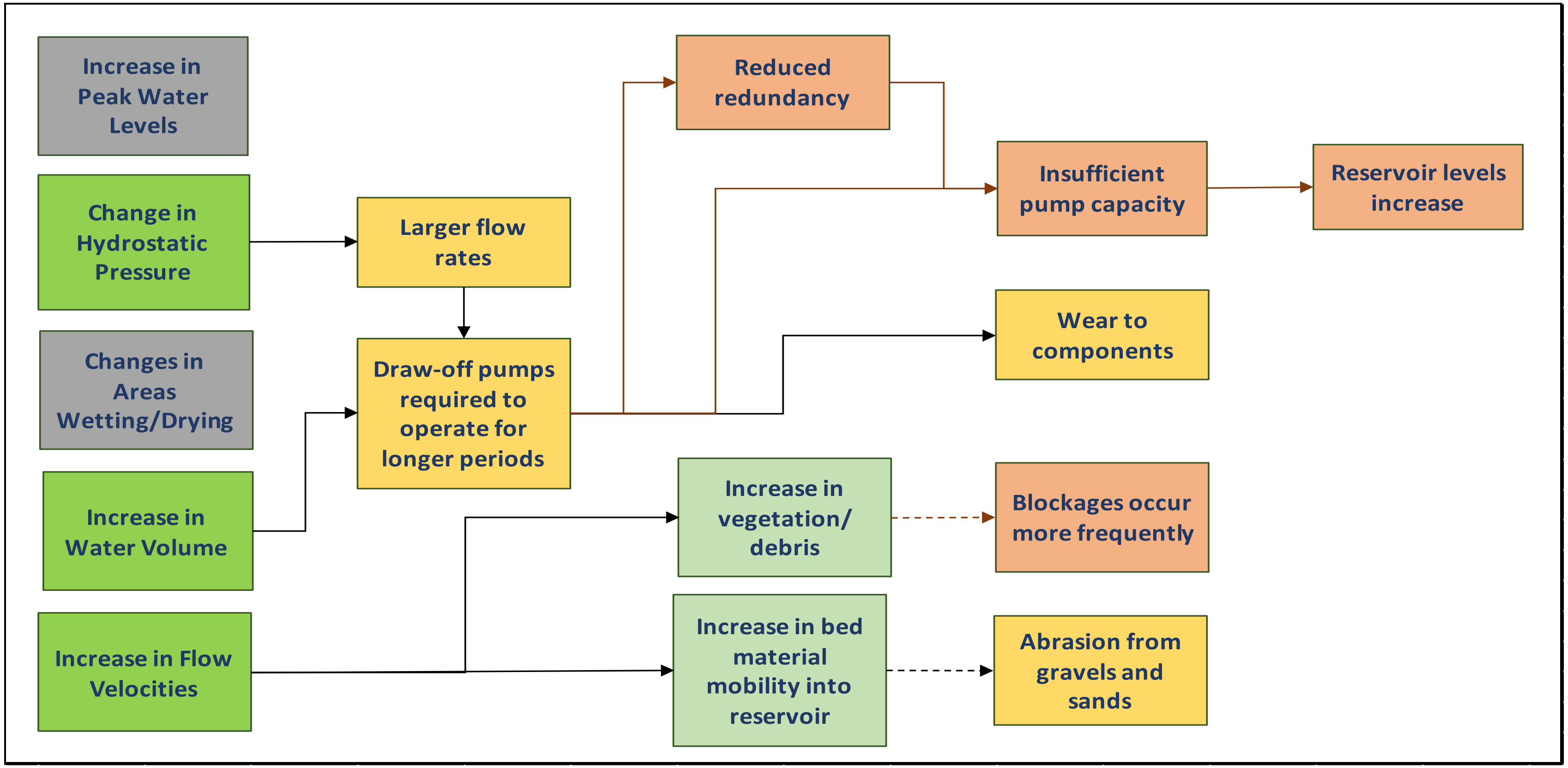
When considering the deterioration of a draw off tower from the impacts of climate change it is important to assess how the reservoir itself will be impacted. Climate change increases in fluvial flow velocities and volumes, frequency of events, duration of events could all cause increases in volumes which are held in reservoirs.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Draw-off tower	ENVIRONMENT: Fluvial (Reservoir)

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Draw-off tower		ENVIRONMENT: Fluvial (Reservoir)	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a draw-off tower include:

- Increase in levels could result in more frequent use and thus wear and tear of outlet valves and pipes to control water levels in reservoir

The increased volumes which may be experienced within the reservoir are likely to have a negligible impact as valves are more likely to suffer from absence of use so these impacts may actually be beneficial to condition.

The lower valve and the outlet pipe would be specifically designed for sediment transport so the risk of actual failure would be low. Changes in areas wetting/drying will have no impact as components are designed for use in water.

The overall vulnerability to climate change increases is therefore considered Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

Increases in water volume resulting from increased inflow into reservoir could potentially exceed the design capacity of the outlet valves and pipes. This could have a high impact on the control of water levels in reservoir and thus impact the performance of other assets associated with reservoirs e.g. spillways.

Increase in flow velocities into the reservoir has the potential for increased sediment carriage and deposition in the reservoir. The increased sediment retained in the reservoir can change the balance of watercourses downstream of the reservoir and at the same time reduce the capacity of the reservoir.

Increased usage of lower outlet valve and pipe to remove sediment from reservoir resulting in increased risk of blockage and hence requiring increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Fish-pass	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A fish pass is found at weirs and control gates to enable fish to get past these obstructions."

A fish pass can be constructed from a wide range of materials including masonry, timber, concrete, metals, plastics, rock etc. Their composition can also be quite varied depending on the target fish species, structures they provide passage over, etc. Most fish pass structures will be fitted with some form of debris deflector at the upstream end; a stainless steel plate across the end being quite typical.

This template considers the fish passes from a high level with no specific form.

Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility.

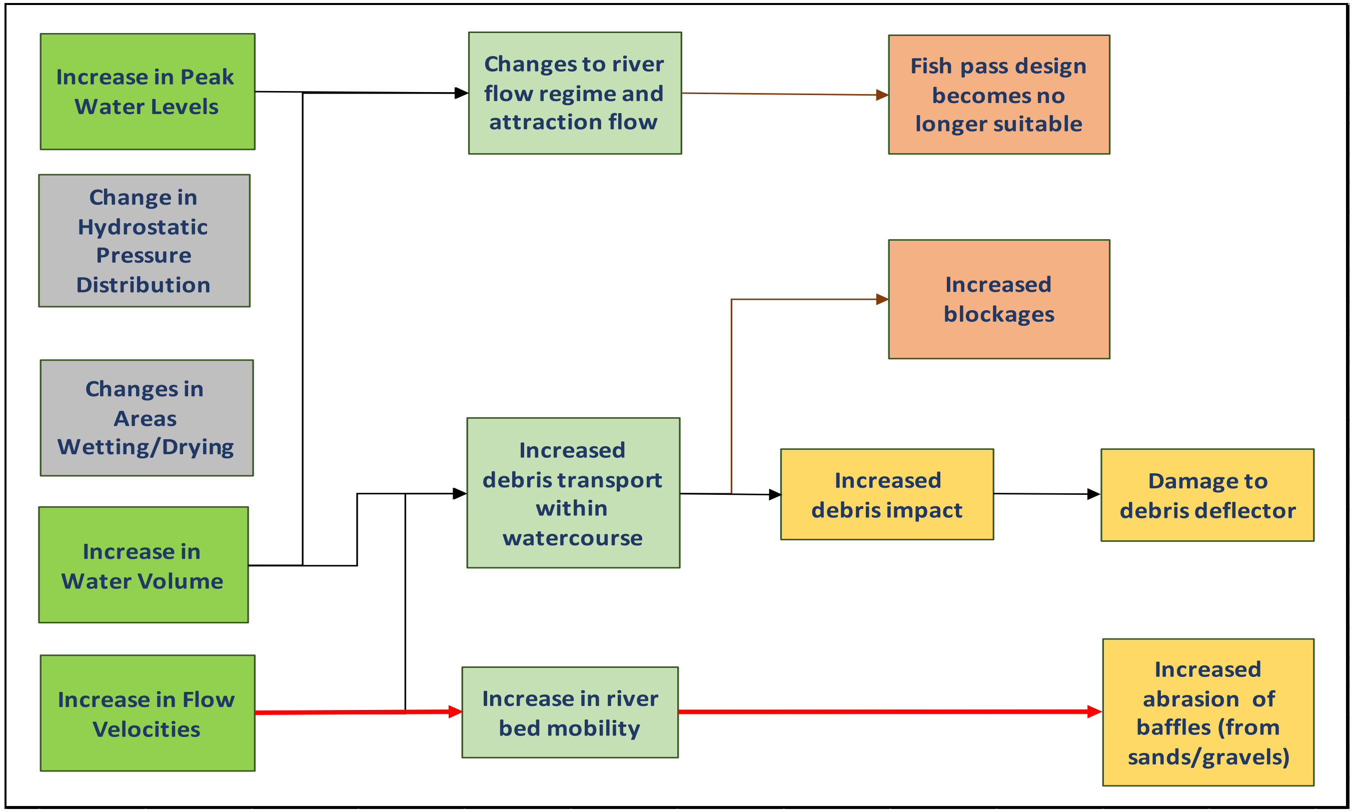
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No*

*Changes in ***temperate*** (and flow rates) could result in change in habitat for target species, in which case the fish pass design may no longer be suitable without modification. This is however a performance issue rather than a deterioration issue, so not assessed further.

ASSET TYPE: Fish-pass	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Fish-pass		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of fish pass structures include:

- Increases in flow velocities resulting in increased bed load sediment causing amplified damage to less durable fish pass fixture and fittings e.g. baffles.
- Increases in flow velocities and volumes could result in increased transport of debris, resulting in increased impact damage.

Although the potential exists for impact damage resulting from higher debris flows, a properly designed fish pass will though include a suitable debris deflector at the upstream end of the fish pass. Undermining or other structural failure as a result of deterioration is unlikely to be a serious issue for fish passes incorporated into major structures because the whole structure will be protected by head and tail aprons. Fish passes made in the form of natural channels will be most susceptible to increased frequency of repairs.

The types of maintenance requirements to otherwise address the above impacts will be similar to that at present, just required more frequently. For example fish pass baffles may need to be replaced more frequently due to increased abrasion resulting from higher bed load sediment transport (e.g. baffles require to be replaced when then become less than 8mm thick).

Therefore the overall effect of the climate change factors on deterioration of these assets is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Increases in peak water levels and flows within a river due to climate change could result in the design of a fish pass being no longer suitable. This could include the envisaged attraction flow to fish being altered, i.e. the flow speeds (or water temperatures) are no longer conducive to the target species which reduce or disappear from these locations.

Changes in flows and levels will also impact telemetry equipment which may have to be repositioned and/or replaced to accurately assess hydrology associated with the asset.

Increases in flow velocities and volumes could result in increased transport of debris if the deflector is overtopped, resulting in increased frequency of blockages. The increase in potential blockages could result in more frequent out of channel flow caused by the fish pass being unable to convey sufficient volumes. Therefore more inspection and maintenance would be required.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Hydro-brake	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type "Structure"
A hydro-brake is fixed structure that controls the flow of water using a vortex.

A hydro-brake typically consists of steel hydro-brake control unit attached within a concrete chamber. The hydro-brake and chamber can come in numerous configurations to suit the flow environment.

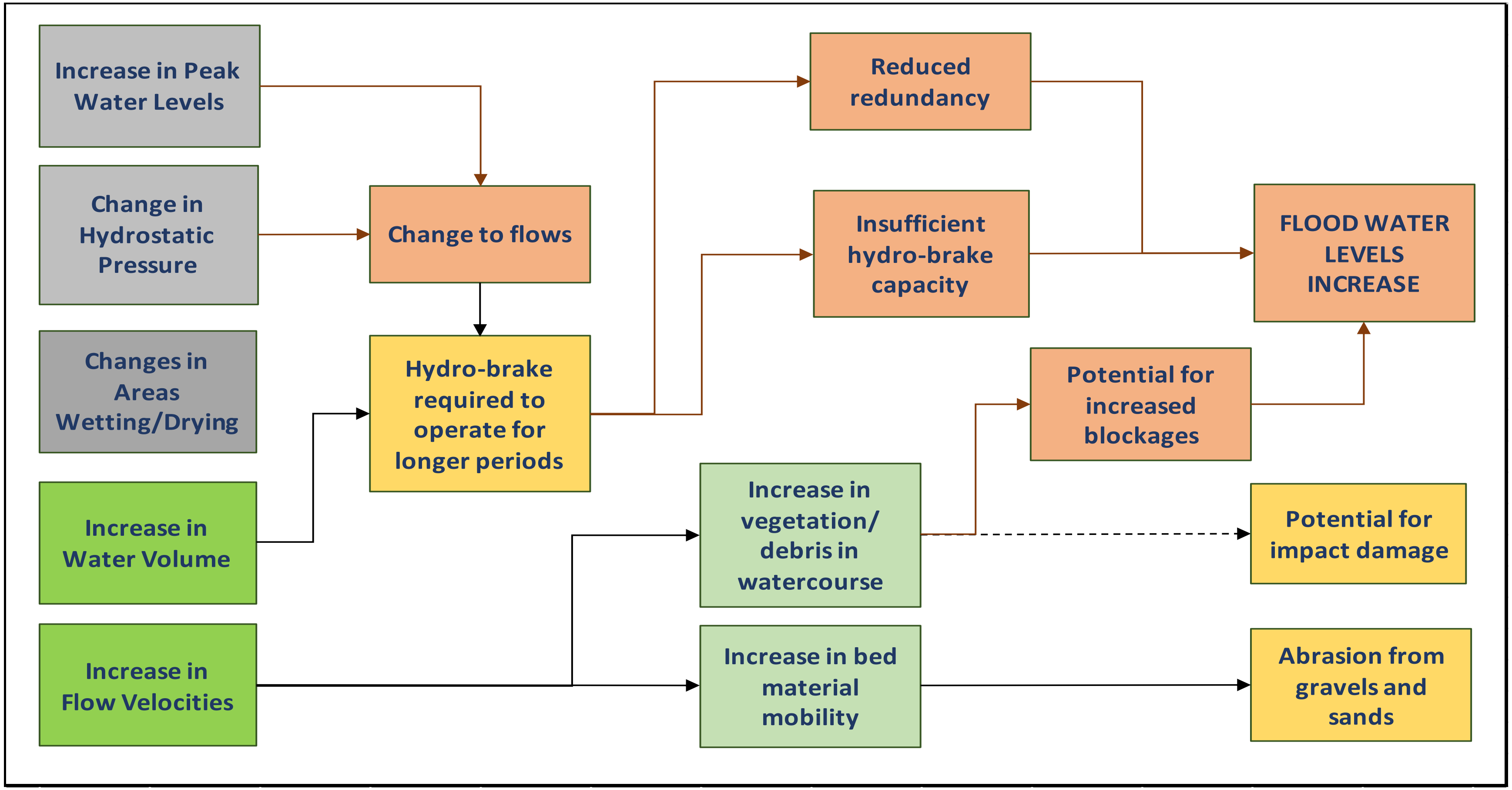
Deterioration of the pipe or culvert leading to the hydro-brake is considered under 'Simple Culverts' asset type.

Changes in peak flow levels and volumes could alter the hydraulics associated with the hydro-brake. Increases in velocities could increase mobility of bed material. Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all also cause increases in debris transport within the watercourse.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Hydro-brake	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Hydro-brake		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of hydro-brakes include:

- Increase in flow velocities would increase the amounts of grit and debris flowing through the hydro-brake with increased abrasion of the component materials.
- Increase in debris flowing into the hydro-brake could result in damage or abrasion.

The overall maintenance regime for hydro-brakes is not expected to alter very much as a consequence of the above; the main issue being the potential need for more regular inspection and clearing of these structures (performance issues). Consequently, in terms of the effects of climate change on deterioration of these assets, the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Hydro-brakes are designed to be self-cleansing and have reduced risk of blockage due to having cross-sectional area larger than a simple orifice of equivalent flow capacity and therefore are easier to rod/jet. Therefore, the increase in debris and bedload is unlikely to have only a small impact upon the maintenance requirements for these structures.

An increase in water levels, velocities and volumes could result in the hydro-brake having insufficient capacity; requiring replacement with potentially high impact. This could also negatively impact assets upstream of the hydro-brake as the increased volume backs up at this asset.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Inspection Chamber	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type ‘Structure’.

“An inspection chamber is a means of inspecting a structure, and this asset sub-type is to be used for all types of inspection chambers (manholes).”

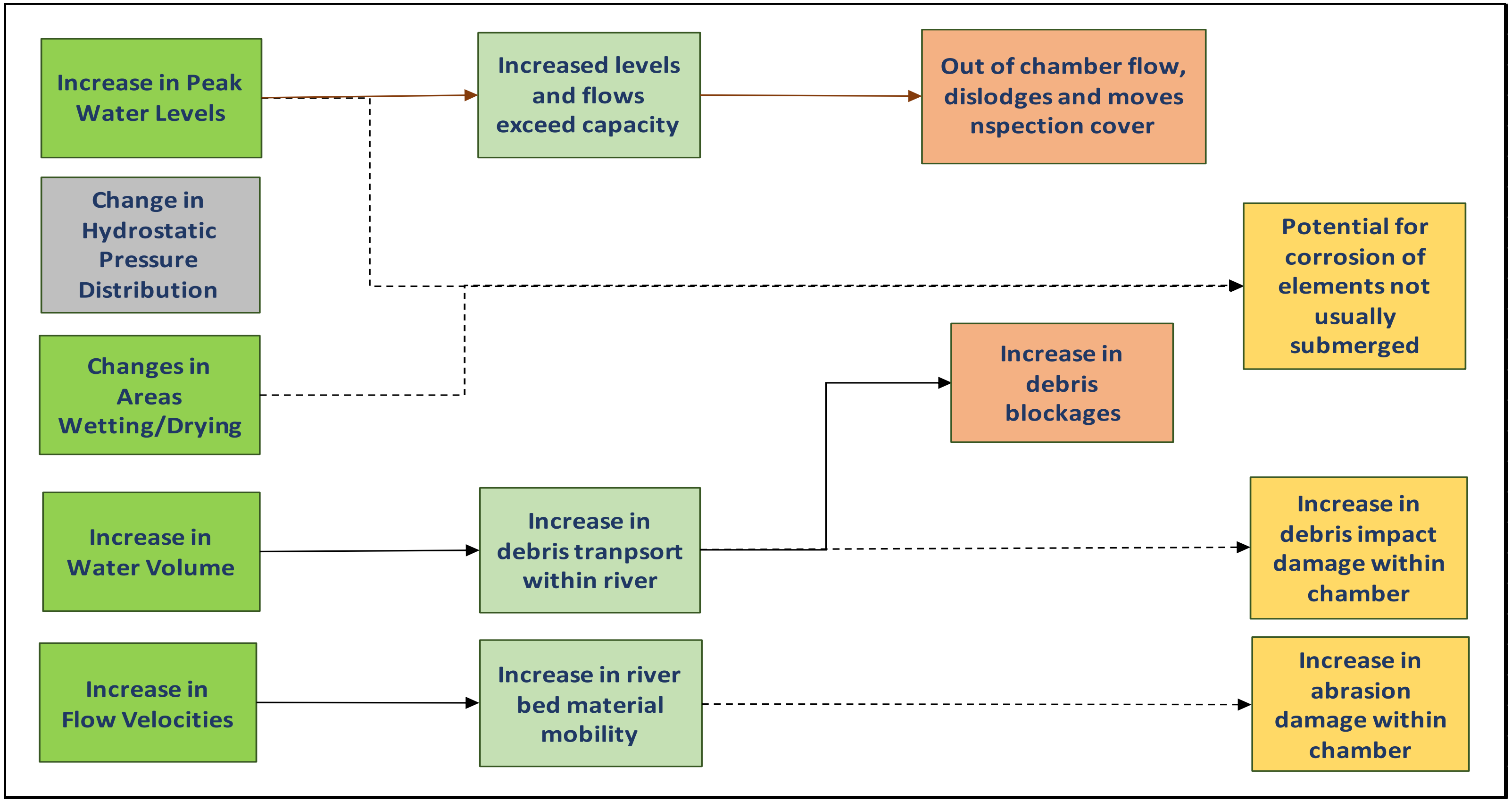
Inspection chambers are usually constructed from concrete or masonry, and with access covers made from cast iron or steel. Inspection chambers can vary greatly in size from below 1m to several metres in diameter. Inspection chambers are generally installed where pipes and/or culverts will form a junction; also where there is a change in direction, or change in size, along a pipeline/culvert.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Inspection Chamber	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Inspection Chamber	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of inspection chambers include:

- Increases in peak water levels and flows could expose elements of the inspection chamber not previously exposed to a water environment and cause these abrade or corrode e.g. inspection hatch hinges.

The construction materials within inspection chambers will have resistance to erosion and abrasion, and low exposure to these will mean that there is little chance that these will increase in any noticeable way and thus little change in maintenance due to deterioration is likely.

The vulnerability to climate change of these assets is therefore considered to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

There is potential for increases in water volumes to exceed system design capacity resulting in surcharge flow lifting and/or displacing covers and causing flooding. This may increase the level of inspections and replacement.

Climate change increases in water volume and flow velocities can increases transport of debris and bed load sediment that could increase risk of blockage and thus a need for more frequent clearance if upstream protective screens are absent or inadequate. Therefore there is potential for increased maintenance to clear blockages. Most culvert entrances are provided with properly designed screens however.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Instruments - Active Monitoring	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Instruments'
"Active monitoring instruments provide functions such as the sensing of water levels at a gauging station."

Active instruments include a variety of sensors which provide electronic information on river flow. They include the following:

- Ultrasonic level sensors
- Hydrostatic (i.e. pressure-based) level sensors
- Shaft encoder/float based level sensors
- Flow meters

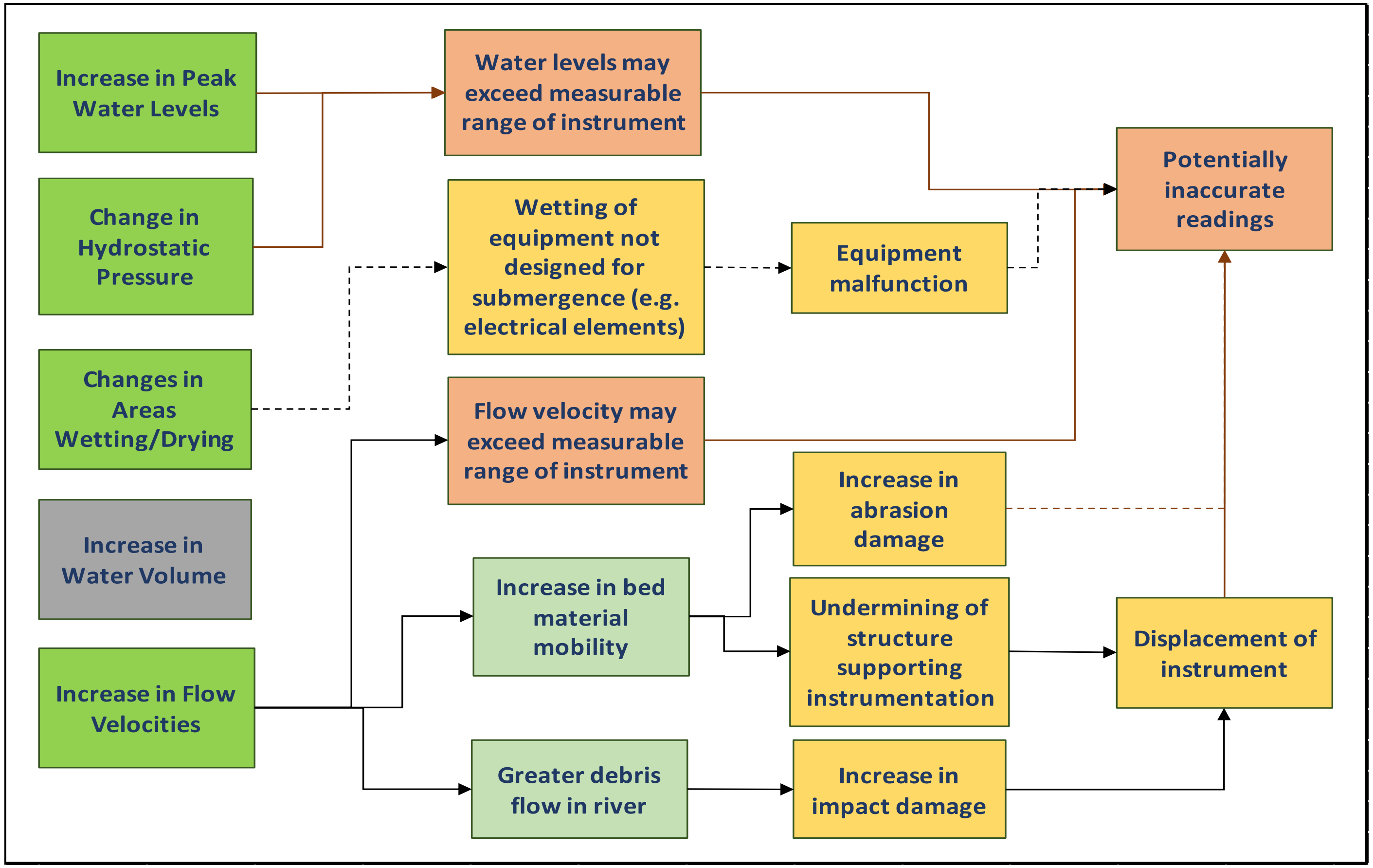
Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could change the degree to which components of the asset is submerged, as well as causing increases in bed mobility and debris transport.

CLIMATE CHANGE FACTORS TO CONSIDER

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Instruments - Active Monitoring | ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Instruments - Active Monitoring		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of Active Monitoring Instruments include:

- Increases in flows leading to potential for increased risk of impact damage or abrasion from large debris items.
- High flow velocities leading to channel scour around the instruments support and its destabilisation.

If the instrumentation is mounted, then increased flows and bed mobility could necessitate a need to provide additional bed protection around the support post or to reset the instrumentation following scour. This is though entirely dependent upon the depth to which the instrument has been set and the nature of the bed material. Instrumentation secured to lock walls or bridge abutments would be less vulnerable.

Overall, there is the potential for climate change to have some minor effect upon deterioration of these assets, but the extent and probability of this in terms of additional maintenance requirements is considered Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

The result in increased flows and levels may exceed the existing measurable range of the instruments. This would result in inaccurate readings being taken, which would cause problems when this data is used for further analysis. However, it is considered unlikely that climate change would have a substantial enough impact on flows to cause this to happen.

Increases in peak water levels, flows and flow velocities would increase debris carriage that could become trapped by the instruments and support resulting in the need for increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Instruments – Passive Monitoring	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type "Instruments"

"Passive monitoring instruments provide functions such as a water level gauge board or maximum level recorder."

Passive monitoring instruments are normally composed in relatively simple configurations and of simple materials within the watercourse, for example a steel, wooden or plastic painted post either set in the bank/bed or fixed to a permanent structure with fixings such as steel brackets.

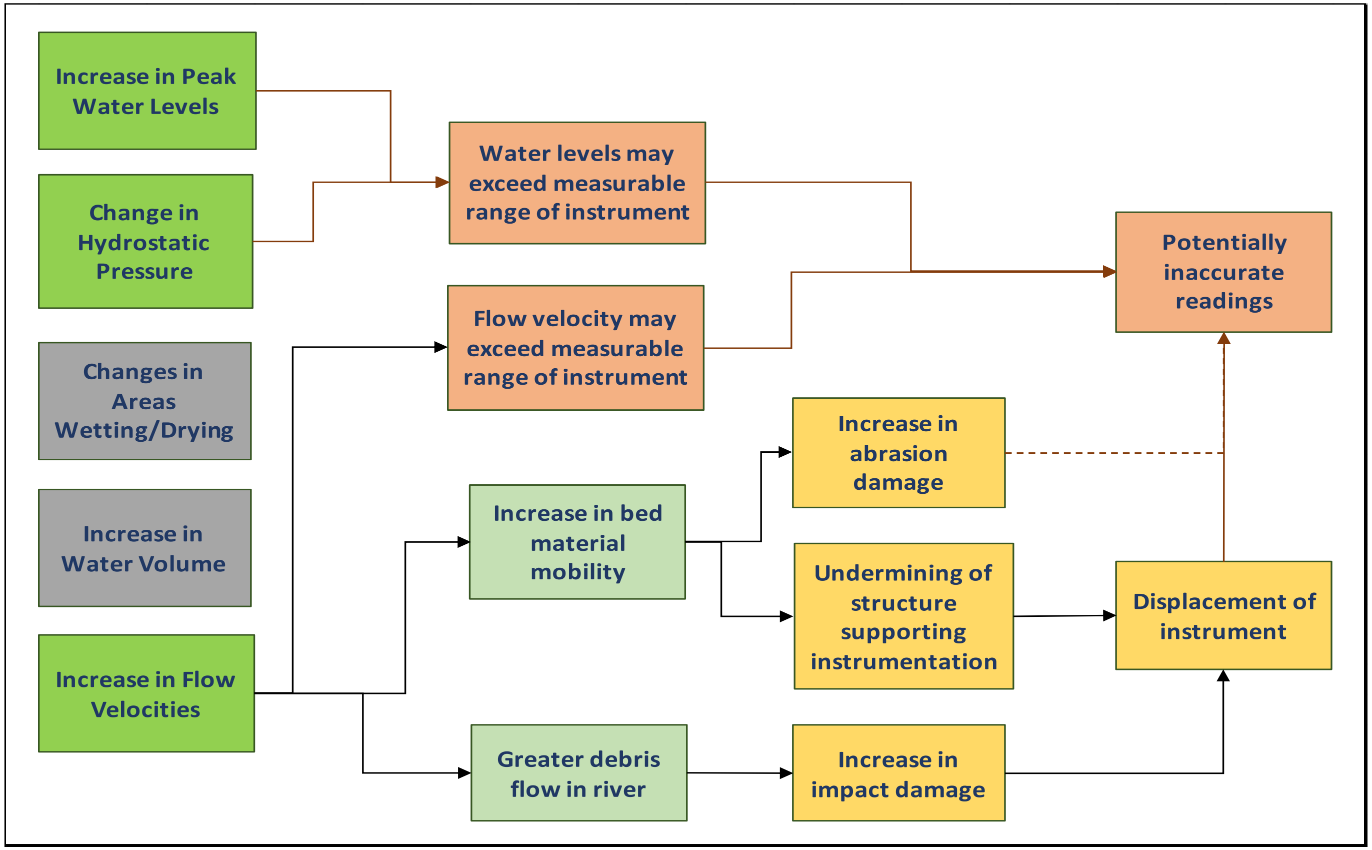
Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Instruments – Passive Monitoring	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Instruments – Passive Monitoring		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of Passive Monitoring Instruments include:

- Increases in flows leading to potential for increased risk of impact damage or abrasion from large debris items.
- High flow velocities leading to channel scour around the instruments support and its destabilisation.

Increases in debris carriage that could break or lead to abrasion (of the painted surface) of the instruments, would require additional maintenance to repair or replace them.

Increased flows and bed mobility could necessitate a need to provide additional bed protection around the support post or to reset the instrumentation following scour. This is though entirely dependent upon the depth to which the instrument has been set and the nature of the bed material. Gauge boards secured to lock walls or bridge abutments would be less vulnerable

Overall, there is the potential for climate change to have some effect upon deterioration of these assets, but the extent and probability of this in terms of additional maintenance requirements is considered Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

Increases in peak water levels may exceed the existing measuring range of the instrumentation and cause performance issues.

Increases in peak water levels, flows and flow velocities would increase debris carriage that could become trapped by the instruments and support resulting in the need for increased inspection and clearance.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Pump House	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Buildings'
"A pump house is a building that houses pumps and the facilities necessary to support their operation"

Under the CAMC definition, this asset refers to the building itself and not the equipment that this houses. These buildings will as a rule not generally be located within the watercourse itself, so not directly subjected to the climate change factors being assessed here. The buildings will instead usually sit elsewhere within the floodplain, often elevated, so their deterioration will only be as a consequence of other assets (e.g. flood banks or channel sides) being overflowed, therefore the impacts of climate change upon the pump house itself would be considered to be negligible.

However, for the benefit of this study, the potential impacts of the climate change factors on the operational (MEICA) elements of the pump station have been considered here as increases in peak water levels and flows could result in changes in operational requirements and increased and/or new forces on the pumping station components.

Pumping stations are used to transfer water from one location to another. The two main factors describing a pumping station's performance are flow rate and head (i.e. pressure increase). Often a pumping station will have more than one pump, and be designed to operate in a duty/assist or duty/standby configuration.

A pumping station would typically consist of the following components:

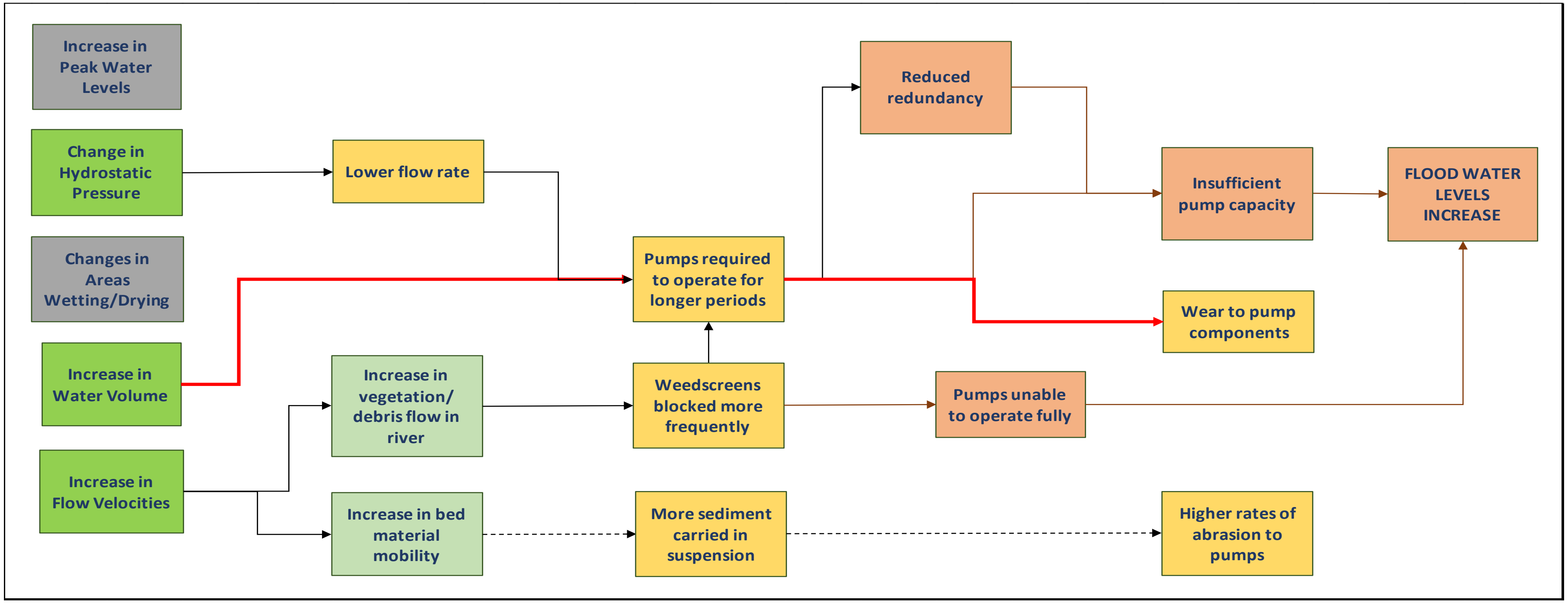
- Pumps
- Pipework
- Valves
- Gearboxes
- Motors
- Electrical equipment
- Weedscreens
- Civil structure

CLIMATE CHANGE FACTORS TO CONSIDER

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Pump House | ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Pump House	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

Climate change factors may potentially impact on pumping stations in the following ways:

- Increase in water volume requiring more frequent and longer operation of the pumping station. This could result in increased wear to components.
- An increase in flow velocities could also lead to increased bed mobility and thus result in more material passing through the pumps leading to more abrasion.
- An increase in flow velocities could increase debris transport which could either block the pumps or damage pumping station components.

Due to the way pumps operate, when there is an increase in the head of water to be overcome (for example because of a water level rise on the outlet side of the pumps), the flow rate that can be achieved decreases. This will result in the pumps having to operate for longer periods of time to move the same volume of water. If the amount of water to be pumped increases, this will also have a proportional increase on the amount of time required to do so. With pumps being required to operate for longer periods, more wear will be experienced by motors, bearings and the like. This will lead to an increased maintenance requirement. Similarly, if more debris/vegetation is transported by the flow, the weedscreens at the inlet of the pumping station will become blocked, resulting in an interruption of flow to the pumps' inlets which may lead to entrainment of air and cavitation, significantly shortening the life of the pumps.

An increase in flow velocities upstream of the pumps will not directly affect pumping operations - the flow rate through the pumping station will be determined by the pumps' ability to draw in water. However, more bed material may be present in the flow as a result of the increased upstream velocities. This would result in increased abrasive wear to the impellers and other internal parts of the pumps, reducing pumping performance and necessitating more frequent overhauls of the pumps.

Overall, there is the potential for some increase in maintenance to maintain pumps which could deteriorate more quickly as a result of climate change factors in a fluvial environment, so the vulnerability is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

The purpose of pumping stations is to manage water levels. The main issue for pumping stations is that their capacity may become insufficient and that flood water levels may increase as a result. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation. Substantial upgrades, or even complete replacement, may be necessary to address this. For this reason the potential impact in performance terms would be high.

There is also a potential increase in inspection and maintenance activities not related to deterioration. If more debris/vegetation is transported by the flow, the weedscreens at the inlet of the pumping station will also become blocked more frequently and will need to be cleared more often.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Abutment	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Major Civils'
"An abutment used for a major structure such as those at the Thames Barrier or other larger than usual structures."

The abutment of a major civils structure within a watercourse is that part of the structure adjacent to the watercourses, as opposed to central piers which are within the watercourse. As the abutment forms a part of a major civils structure it would probably be constructed from reinforced concrete, perhaps with masonry cladding.

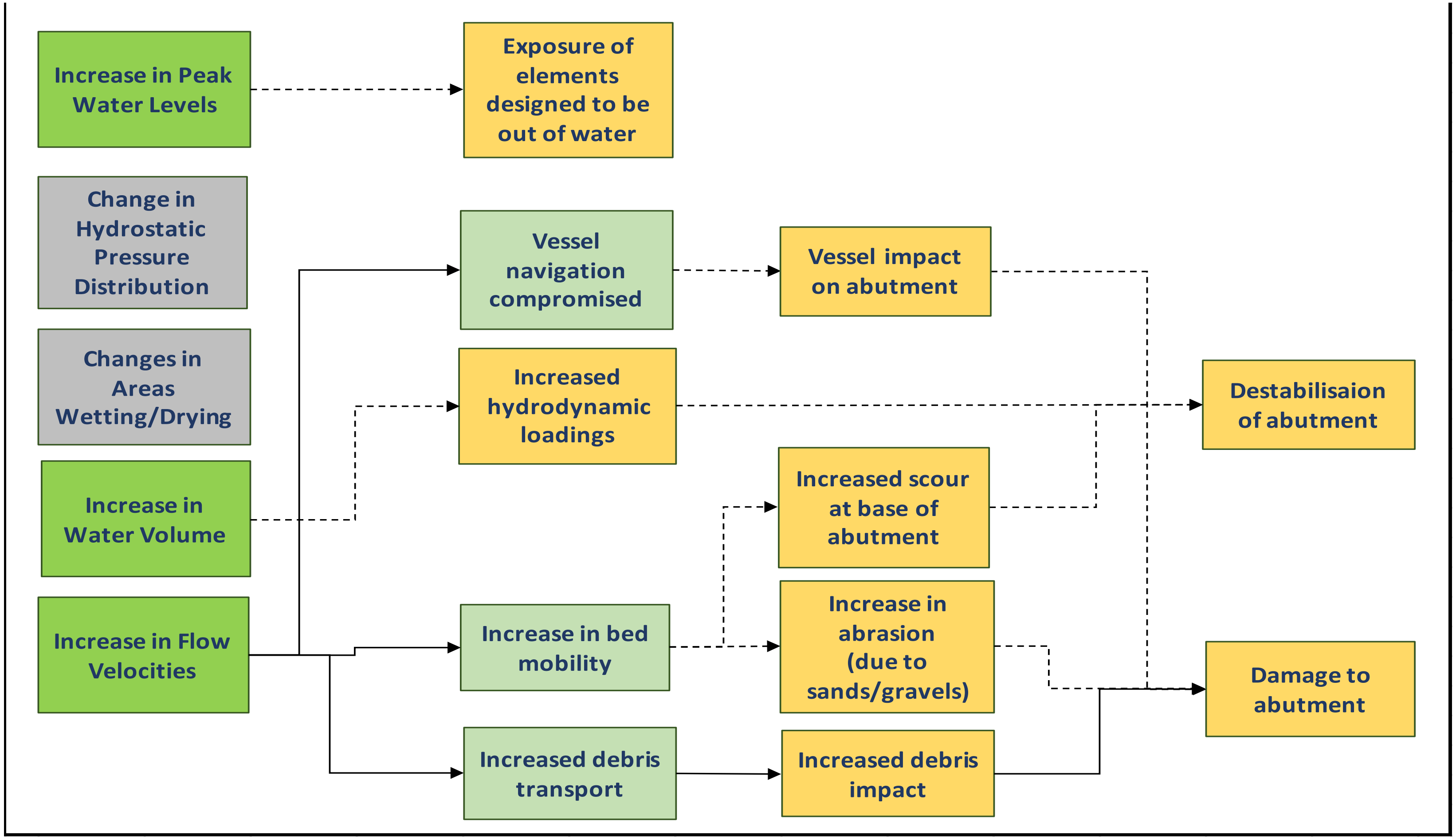
The foundation could be in the form of a concrete pad, perhaps supported by bearing piles, depending upon the underlying strata, and perhaps with steel sheet piles along the toe. Or, the foundation could be in the form of an apron, continuous beneath the structure and extending across the watercourse. This again could rest upon bearing piles and would most probably have upstream and downstream steel sheet pile lines. In all cases, for a major structure this foundation arrangement will have been designed to provide suitable protection under extreme flow speeds.

Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
No	No	No	Yes	No

ASSET TYPE: Abutment	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Abutment		ENVIRONMENT: Fluvial	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of bridge abutments include:

- Increases in flow velocities will change bed mobility and have a potential to cause erosion/undermining to the sides and toe of the abutment.
- Increases in peak water levels, flows and flow velocities have potential for increased impact damage from vessels which may find navigation more difficult in these conditions.

The abutments to a major civils structure within a river will almost certainly have been structurally designed to meet all foreseeable water levels, flows and flow velocities; together with consideration of potential impact damage from vessels. Similarly, their foundation design should have accounted for extreme flows and scour scenarios, such that instability issues should not arise. The abutment foundation design and bed protection will have taken the local geology into account.

Where practicable, the abutments will have been located away from a navigation channel, and a protective floating barrier installed upstream. Vulnerability to impact damage would depend upon the design of abutment and presence/absence of an upstream protective barrier to prevent accidental impact from large vessels. However, navigation would probably be discouraged in many cases in high flow events (so called “Red Board Days”, so this risk would perhaps have low probability of being significantly different from present day risk.

Increased frequency of condition inspection may result from increased high flow events, together with any repairs resulting from the unlikely event of a major impact. Otherwise, given the expected level of robustness built into the design of these structures, the change in deterioration of this type of major civils asset to climate change increases is likely to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

Increases in peak water levels and water volumes could potentially exceed the design flood flow capacity beneath a bridge located along a watercourse; requiring an enlargement to avoid flow out of banks upstream. These increases could also result in a need for raising of abutments if walkways etc. also have to be raised.

Climate change increases in peak water levels and water volumes could also potentially impact in channel structures which transfer loads to the abutments for stability. This would consequently require the abutments to be modified.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Central Pier	ENVIRONMENT: Fluvial

DESCRIPTION

DEFINITION IN CAMC:

Listed under asset type 'Major Civils'
"A central pier used for a major structure such as those at the Thames Barrier or other larger than usual structures."

The central pier of a major civils structure is that part of the structure providing support with a watercourse, having flow on both sides.

If the central pier forms part of a major civils structure, it would probably be constructed from reinforced concrete, maybe with masonry cladding.

The foundation could be in the form of a concrete pad, perhaps supported by bearing piles, depending upon the underlying strata. Or, the foundation could be in the form of a continuous apron between the sides of the watercourse, and having upstream and downstream steel sheet pile lines. In all cases, for a major structure this foundation arrangement will have been designed to provide suitable protection under extreme flow speeds.

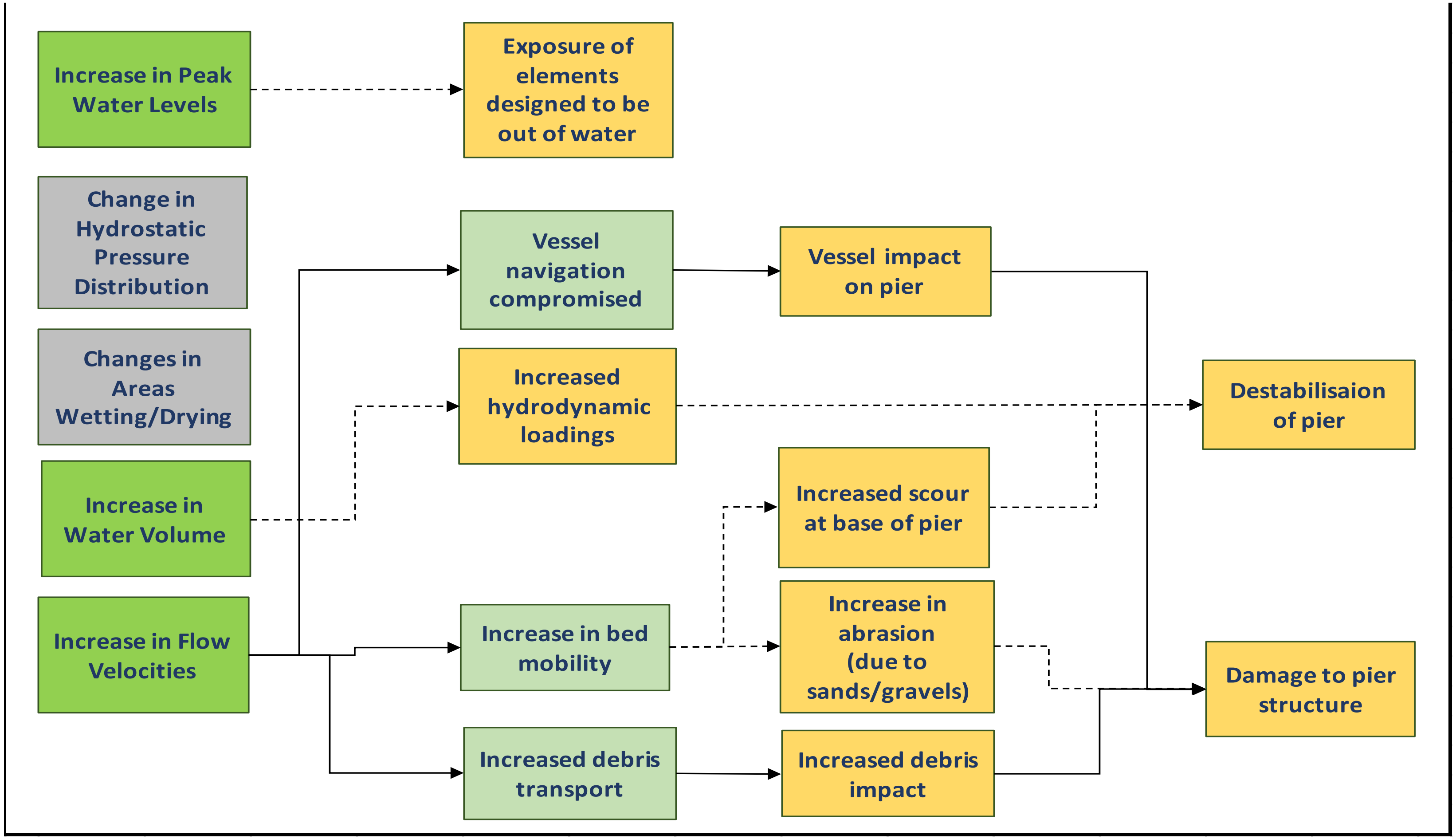
Climate change increases in flow velocities, peak water levels and volumes, frequency of events, duration of events could all cause increases in debris transport. Increases in velocities could also increase bed mobility.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
No	No	No	Yes	No

ASSET TYPE: Central Pier	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Central Pier	ENVIRONMENT: Fluvial

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a central pier include:

- Increases in peak water levels, flows and flow velocities have potential for increased impact damage from vessels which may find navigation more difficult in these conditions.
- Increases in flow velocities have potential to cause erosion to the toe of the pier, causing reduced stability margins. It is possible that erosion protection would need enhancement.
- Increases in peak water levels and flows could also result in increased and/or new forces on the pier and a change of which elements of the pier become exposed to a water environment.

The central piers of a major civils structure within a river will almost certainly have been structurally designed to meet all foreseeable water levels, flows and flow velocities; together with consideration of potential impact damage from vessels. Similarly, their foundation design should have accounted for extreme flows and scour scenarios, such that instability issues should not arise. The central pier foundation design and bed protection upstream and downstream will have taken the local geology into account.

Where practicable, a major civil structure will have been located away from a navigation channel, and a protective floating barrier installed upstream. Vulnerability to impact damage would depend upon the design of the pier and presence/absence of an upstream protective barrier to prevent accidental impact from large vessels. However, navigation would probably be discouraged in many cases in high flow events (so called “Red Board Days”, so this risk would perhaps have low probability of being significantly different from present day risk.

Increased frequency of condition inspection may result from increased high flow events, together with any repairs resulting from the unlikely event of a major impact. Otherwise, given the expected level of robustness built into the design of these structures, the change in deterioration of this type of major civils asset to climate change increases is likely to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

Increases in peak water levels and water volumes could potentially exceed the design flood flow capacity beneath a bridge located along a watercourse; requiring an enlargement to avoid flow out of banks upstream. These increases could also result in a need for raising of abutments if walkways etc. also have to be raised.

Climate change increases in peak water levels and water volumes could also potentially impact in channel structures which transfer loads to piers for stability. This would consequently require the abutments to be modified.

5 Estuary/Tidal River Assets

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Quay	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Defence'
"A quay has a primary function as a landing place for shipping, but it also provides a line of defence."

The distinction between Jetty and Quay is not entirely obvious. For the purposes of these assessments, define Jetty as an open-piled structure (as shown by the photograph in CAMC guidelines) and define Quay as a closed/solid structure. (*so therefore any 'closed' jetty structure will have the vulnerability characteristics defined for Quay, and vice-versa*).

Primarily considering Quay for Estuary settings on the basis that it is unlikely that there would be many if any of these as FCERM structures in the open sea. As such, the increase in wave heights factor is not included: the change in locally generated (within estuary) wave loading would be only due to higher water levels at the structure.

In other respects a quay will be similar in its construction and therefore vulnerability to climate change factors as a vertical seawall with concrete promenade except it also has berthing loads on it.

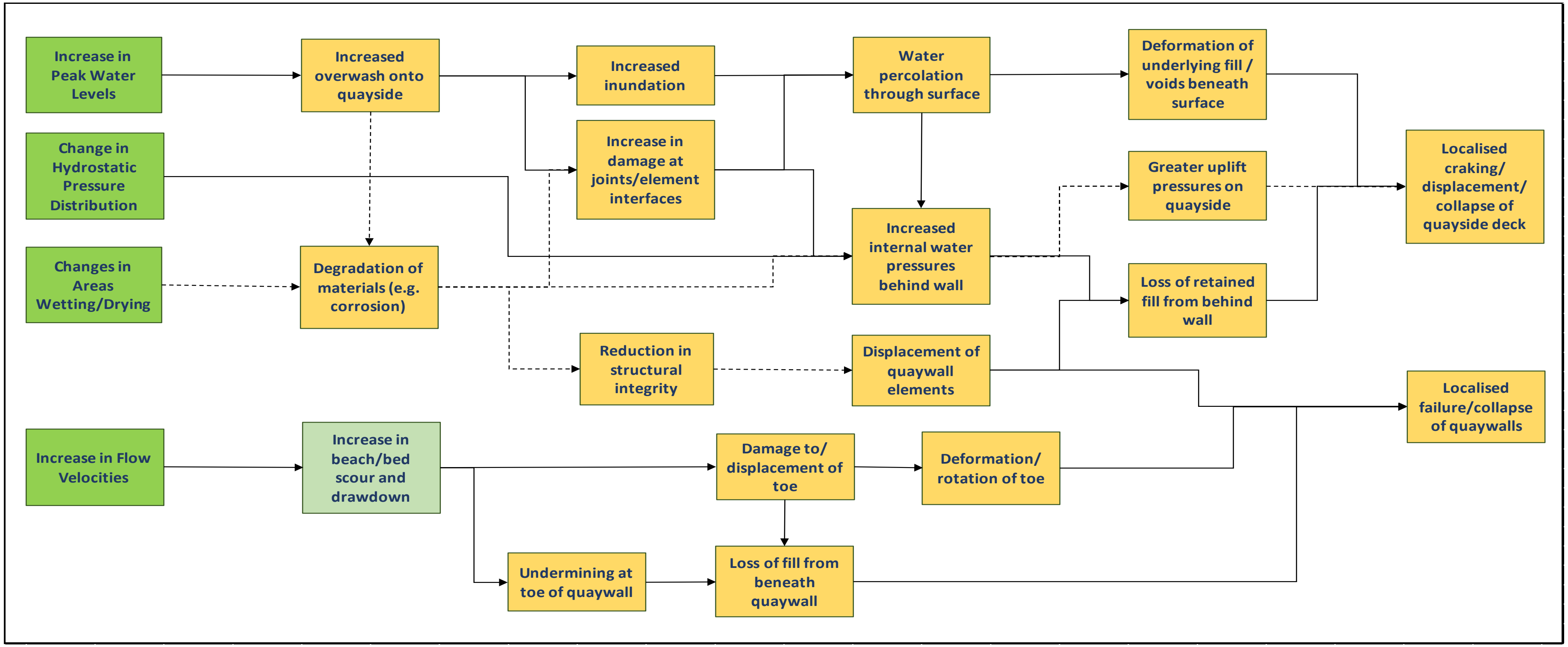
There may be differences in deterioration between steel sheet piled and concrete/masonry quays.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
Yes	Yes	No	Yes	No

ASSET TYPE: Quay | ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Quay	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a quay include:

- Water ingress/percolation through the quay surface due to higher frequency of overwashing from storms due to higher water levels
- Greater uplift forces on quay deck due to increased water pressures which are a consequence of higher water levels
- Increased flows leading to scour of bed along toe of structure leading to potential for undermining and loss of retained fill/localised collapse
- Increased rates of rotting/splitting of timber, corrosion and degradation of steel and concrete, due to changes in wetting and drying.
- Damage to quay walls, or higher water pressures, leading to loss of retained fill and collapse of deck of quay.

High water levels may result in a greater volume and frequency of water on the quay surface. This can result to increased percolation through the surface, or increased wear and tear at interfaces and joints allowing water penetration. Both could lead to carbonation of steel (if reinforced slabs) and spalling of concrete, or deformation of underlying fill leading to cracking and potentially localised collapse of the quay. The nature of maintenance to address these issues is likely to be identical to that currently carried out, simply required a little more often to maintain as a serviceable working surface and restrict the ingress of water. The impacts of climate change on deterioration in this regard are therefore likely to be low.

Although more of an issue for tidal river settings, scour of the bed around the base of the quay walls in the intertidal zones could increase in areas of higher river flows and higher tidal flows, but would be entirely dependent upon the nature of the toe construction or driven pile depths, and is most likely very low probability.

The types of maintenance actions required to address deterioration of the quay walls are going to be similar to those at present, i.e. patching and repairing damaged concrete. These are likely to be of low consequence as these are structures that have been designed to be exposed to this environment, although such activities may be required a little more frequently.

Overall, this level of change in the maintenance commitment means that the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

A much greater impact of climate change on these structures will be the changes in loading due to mooring forces. Higher day to day water levels (due to sea level rise) will alter the loading from vessel moorings. Likewise and during storm surge events periods of higher river flows, both mooring forces and impact forces from vessels berthed or berthing could be much greater. In all of these cases there is the potential for greater damage to the structure.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Saltmarsh	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Land'
"Salt marshes are a natural part of the coastal environment that have an effect on water management. Salt marshes lie just above the usual high tide line, although may be covered by exceptionally high tides"

Saltmarsh is generally (mainly) found in estuary environments, or along tidal rivers

They are only subject to locally generated waves (so any increase in wave climate is not relevant here), but could also be affected by fluvial flows in narrower channels, i.e. tidal river.

Saltmarshes are intertidal and dynamic, naturally adjusting to the hydrodynamic forces upon them and sediment in the system. One question therefore is whether there is enough to keep pace / accrete vertically with sea level rise? Their health or deterioration also depends on landward constrictions/squeeze that might prevent transgression.

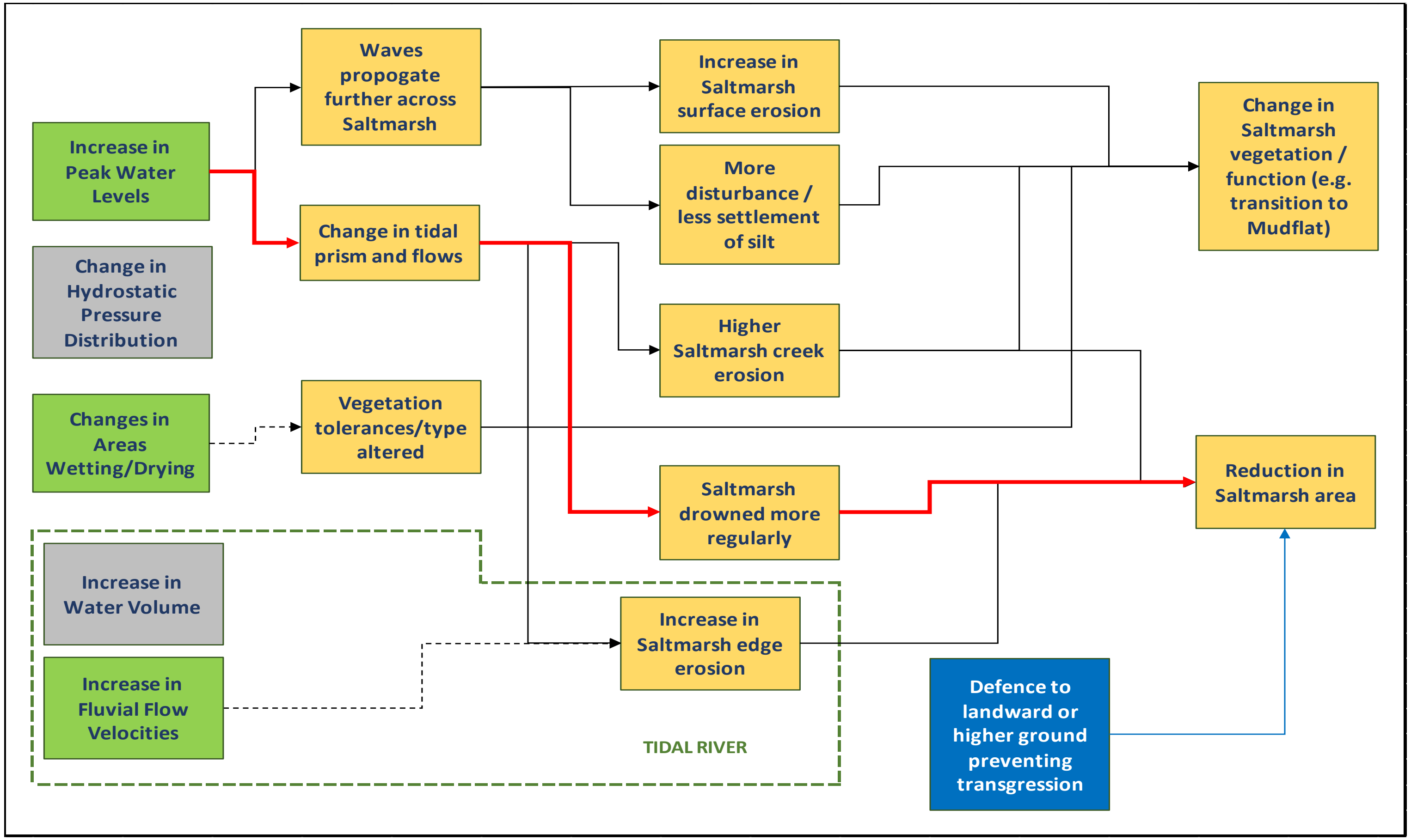
CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	No	Yes	Potential*

* ***wind direction and speed*** could affect locally generated waves in estuary environment (waves will be larger if fetch distance increased or winds are stronger)
* ***temperature*** could affect marsh vegetation
* ***rainfall*** could result in higher volume of freshwater affecting salinity of the marsh

ASSET TYPE: Saltmarsh	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Saltmarsh	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of saltmarshes include:

- Sea level rise can affect the saltmarsh by drowning (inability to vertically accrete), coastal squeeze (unable to transgress landward), as well as potentially producing higher flows through the creeks and channels increasing erosive forces.
- Along narrower channels, i.e. the outer stretches of tidal rivers where saltmarsh can exist, increased river flows could produce erosion of the outer edge of the saltmarsh.

Sea level rise is likely to be the key impact of all the climate change factors. They will be highly sensitive to this because all saltmarshes are critically dependent upon and exist where they are, due to tidal levels. So by definition, if those change (as they will with sea level rise) then the form, function and position of the saltmarsh must also change.

There are limits on what can be done to maintain saltmarshes other than provide more accommodation space for their transgression. This is a significant change, without which they will diminish, therefore the vulnerability of saltmarsh to the effects of climate change on its deterioration is considered to be High.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
X			

OTHER POTENTIAL IMPACTS

Wave attenuation across the saltmarsh will reduce with higher water levels unless the marsh can accrete at a rate to keep pace with climate change. Therefore larger waves may impact upon assets behind the marsh, e.g. flood embankments.

Saltmarshes are also an important ecological resource as well as a FCERM asset, so their deterioration has much wider implications.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Mudflat	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Land'
"Mudflats are a natural part of the coastal environment that have an effect on water management. Mudflats are usually covered at high tide"

Mudflats are a similar geomorphological form to saltmarshes, but lower in the tidal column and not supporting vegetation.

Mudflats are generally (mainly) found in estuary environments or along tidal rivers

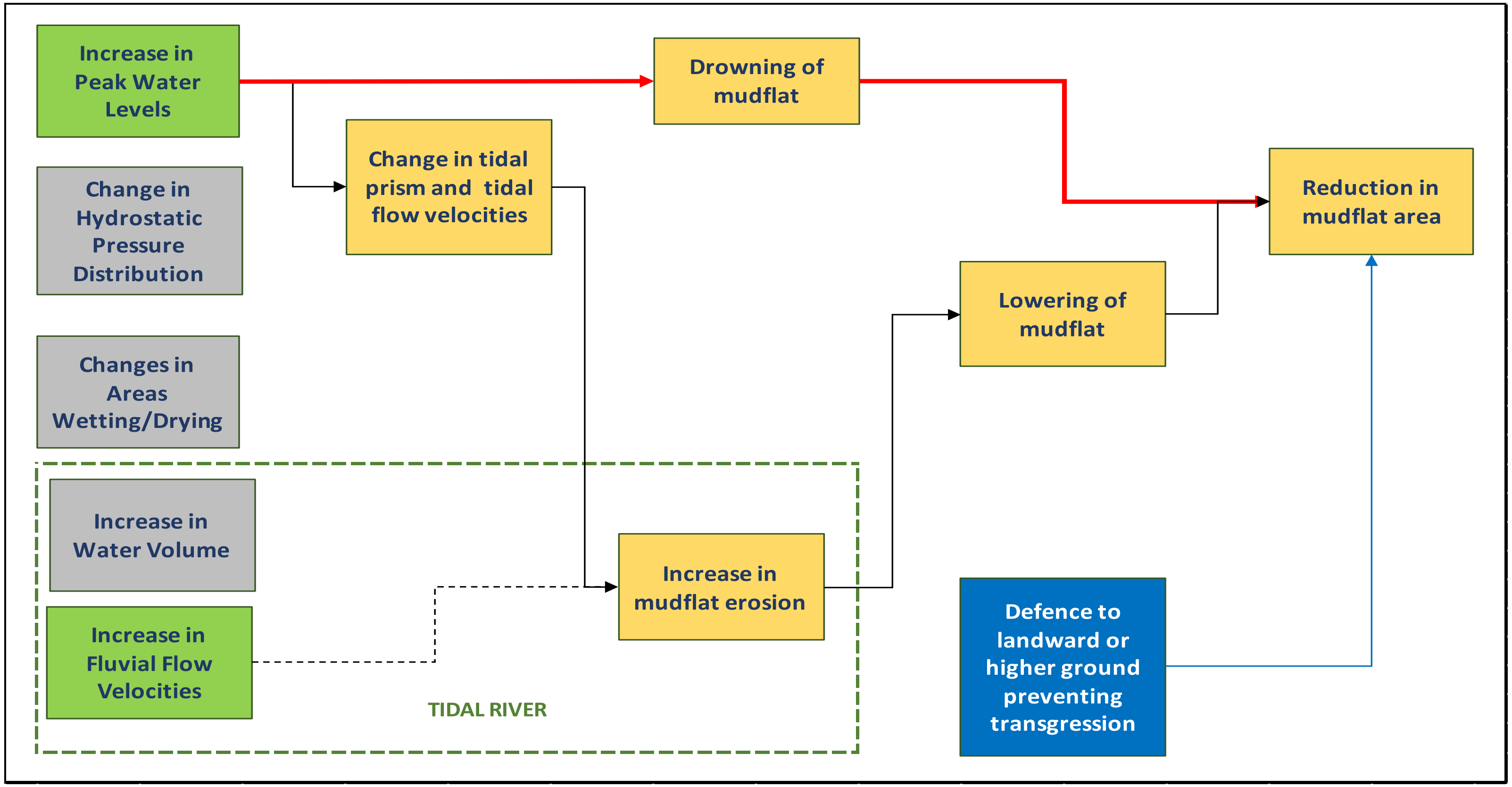
Like saltmarshes, one question is whether there is enough to keep pace / accrete with sea level rise? Their health or deterioration also depends on back constrictions/squeeze that might prevent transgression.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	No	Yes	No

ASSET TYPE: Mudflat	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Mudflat		ENVIRONMENT: Estuary	

QUALITATIVE ASSESSMENT

The impacts of climate change on mudflats include:

- An increase in peak water levels will produce higher flow velocities and potentially increased erosion. However, the higher water levels in an estuary setting could see a reduction in the wave orbital velocities at depth, i.e. at the mudflat surface, potentially reducing scouring forces.
- Likewise, increases in river flows could induce greater erosive forces, although only locally within the low water channel.
- The main impact is the drowning of the mudflat due to higher day-to-day water levels meaning it will become increasing subtidal rather than intertidal, and most probably squeezed, i.e. reduction in area, if there is no space for its natural transgression.

Although mudflats will be highly affected/sensitive to climate change, they are not necessarily deteriorating. The mudflat may offer less protection to front of other assets (a performance issue) but it will still exist, simply in a more regularly submerged state. The magnitude of impact is perhaps specific to what else is there, i.e. other assets, but in terms of mudflat deterioration itself the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

Estuary waves are generally smaller than those on the open coast and not depth limited, therefore the influence of the mudflat on wave attenuation under extreme conditions is likely to be very small. Consequently, further drowning or lowering of the mudflat would have limited impact on the performance of those assets.

Mudflats are though an important ecological resource as well as a FCERM asset, so the reduction in their size/extent of wetting and drying, does have wider implications.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Control Gate (Rising Sector Gate)	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A control gate can be adjusted to alter the flow of water in a channel. This includes penstocks, sluice gates, mitre gates, sector gates and radial gates."

Control gates are predominantly formed of a number of different constituent parts and materials, which will all influence the ways in which the asset will deteriorate in response to climate change. The materials normally used in the construction of control gates include steel, timber and plastics. The type of control gate will also influence how the asset will be affected by the influence of the climate change.

There are several types of control gate to consider. ***This assessment covers only rising sector type control gates*** – separate assessments are made for different types of control gate.

Generally very large gates, often used as barriers in navigable channels. Horizontally pivoted, when lowered they allow full flow and navigation through the channel. When raised they limit flow and prevent backflow up the channel, for example caused by a tidal surge. In some cases the gate can be further raised out of the water for inspection and maintenance. Rising sector gates generally consist of the following components:

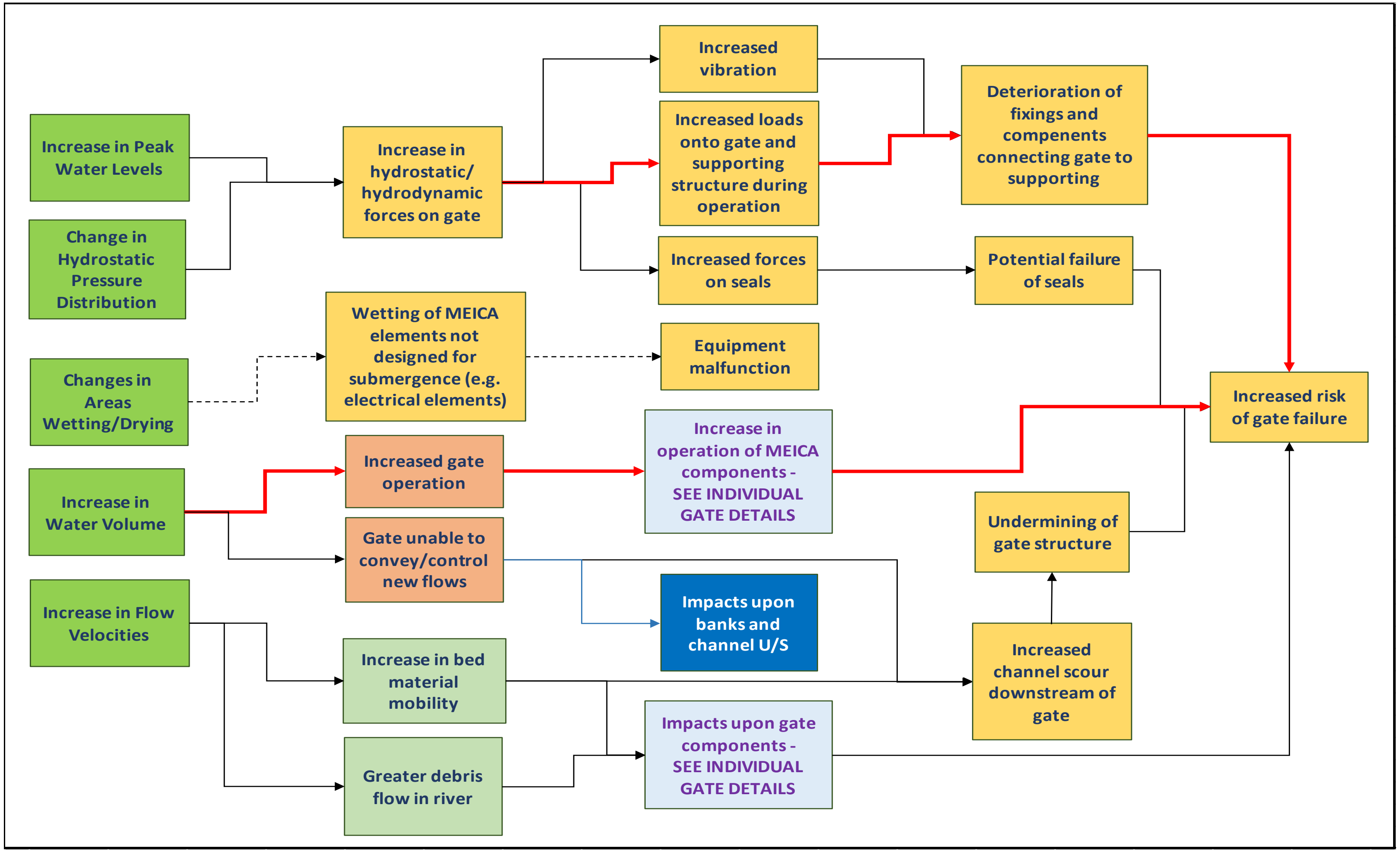
- Gate
- Seals
- Cill
- Bearings
- Actuation mechanism
- Civil structure

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
Yes	Yes	No	Yes	No

ASSET TYPE: Control Gate (Rising Sector Gate) | ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

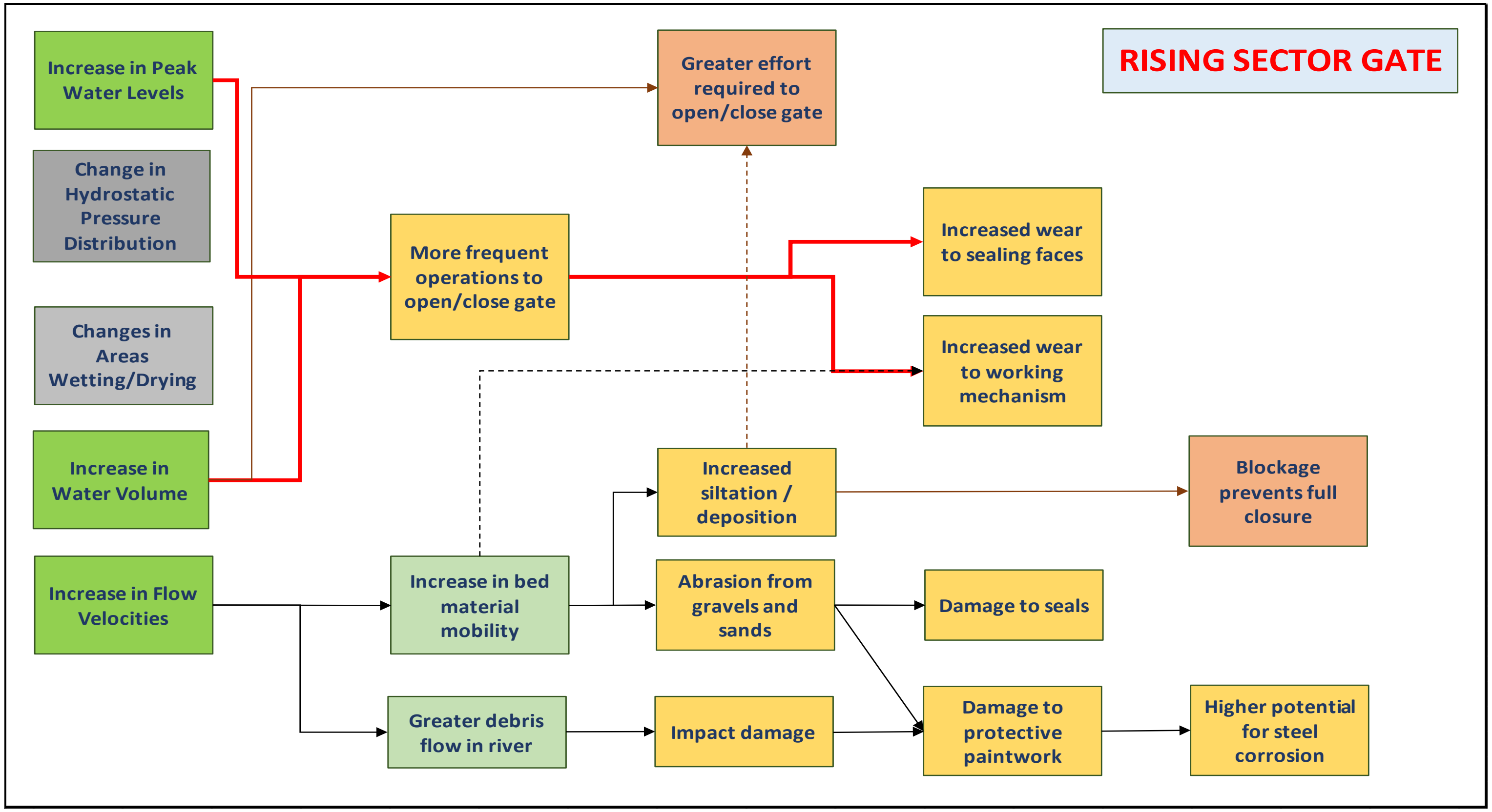
(1) OVERALL



ASSET TYPE: Control Gate (Rising Sector Gate) | ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(2) RISING SECTOR GATE DETAILS



ASSET TYPE: Control Gate (Rising Sector Gate)	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of rising sector gates include:

- Greater hydrodynamic and hydrostatic loads onto the gate supports resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be raised fully clear of the flow.
- Increased or introduced gate vibration resulting from increased water levels and flow velocities during operation and in situations where the gate cannot be raised fully clear of the flow.
- Increase in water volume requiring more frequent operation of the gate. This would result in increased wear to components, and therefore an increase in maintenance requirements.
- Increase in flow velocities, resulting in greater transport of bed materials. If deposited in the gate's floor recess, silt could prevent full opening of the gate. This would necessitate a higher commitment to clearing the siltation.
- Higher possibility of impact damage to the gate from large items of floating debris, e.g. logs, caused by increased flow velocities.
- Greater scour immediately downstream of gates with short apron lengths, causing potential undermining and reduced stability.
- Higher flow velocities, resulting in greater transport of bed materials, leading to higher abrasion and damage to components.
- Components relating to gate operating mechanisms (especially electrical) designed to be out of the water but immersed due to higher levels.

Assuming the gate has been correctly designed for loading under extreme flows, it is expected the impact on deterioration of the asset from the level of increased flows and water levels being considered here will be small. This could however have a bearing on the rate of deterioration of fixings and components connecting the gate to the supporting structure. The maintenance (replacement) of these may therefore be required more often as a result of the climate change factors, but is not expected to result in a substantial change to currently expected requirements.

Most control gates are constructed from steel and with suitable protective coatings for working within water; therefore the overall climate change impact on the main gate material is considered to be negligible except for where major impact damage could occur.

Increased frequency of submergence is unlikely to significantly affect the deterioration of these assets, unless it results in the exposure of components which have not been designed for being occasionally immersed e.g. Electrical or other MEICA elements.

Overall, however, the increase in maintenance commitments are not expected to be significant, and therefore the vulnerability is considered to be Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

The purpose of rising sector gates is to limit backflow of water along channels when downstream levels rise. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation.

Increase in peak water levels could result in overtopping of the gate even when fully raised, and thus a reduction in the gate's effectiveness. Because of the nature of their design, the height of rising sector gates cannot easily be increased.

An increase in flow volumes and water levels could therefore result in the need for significant modifications to, or even redesign and replacement of, the gate, lifting gear and support structure could all be needed. Even without replacement, the need for increased operation of the rising sector gate may result in a considerable increase in human input, for inspection, maintenance, and operation.

If an increase in flow velocities results in greater transport and deposition of river bed materials in the gate's floor recess of a rising sector gate, silt could prevent full opening or closing of the gate. This would necessitate a higher commitment to clearing the siltation.

Changes in flows and levels could impact telemetry equipment which may have to be repositioned and/or replaced to accurately assess hydrology associated with the asset.

The increase in peak water levels, if sustained for a period of time, may also impact on any emergency maintenance operations required to clear or repair these assets suffering damage or blockage at the time of the event.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Jetty	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Structure'
"A jetty is a structure that projects into the water in fluvial and coastal environments. This Asset Subtype is only to be used for structures that do not provide a primary defence function."

The distinction between Jetty and Quay is not entirely obvious. For the purposes of these assessments, define Jetty as an open-piled structure (as shown by the photograph in CAMC guidelines) and define Quay as a closed/solid structure. (*so therefore any 'closed' jetty structure will have the vulnerability characteristics defined for Quay, and vice-versa*).

Primarily considering Jetty for Estuary and Tidal River settings on the basis that it is unlikely that there would be many if any of these as FCERM structures in the open sea. As such, the increase in wave heights factor is not included: the change in locally generated (within estuary) wave loading would be only due to higher water levels at the structure.

In considering Jetty for Estuary or Tidal River setting, there will be some differences in terms of the forces upon them. Local wave forces would not be a consideration, and salt water would be less of an issue in a tidal river, whereas they will within an estuary. River flows, and higher water levels resulting from those, could however be a much greater change and impact in a tidal river, and could also result in higher debris flows within the river.

Consider the Jetty as having two primary components: the Supporting Structure and the Deck.

- SUPPORTING STRUCTURE: Comprised of piles and cross members. These are most likely to be timber or steel (maybe concrete in very old structures, but not included here)
- DECK STRUCTURE: Generally going to be either timber or reinforced concrete planking, or reinforced concrete panels supported on steel beams

There will be differences in deterioration between timber and steel/concrete jettys.

In a tidal river setting, just timber jetty structures have been considered.

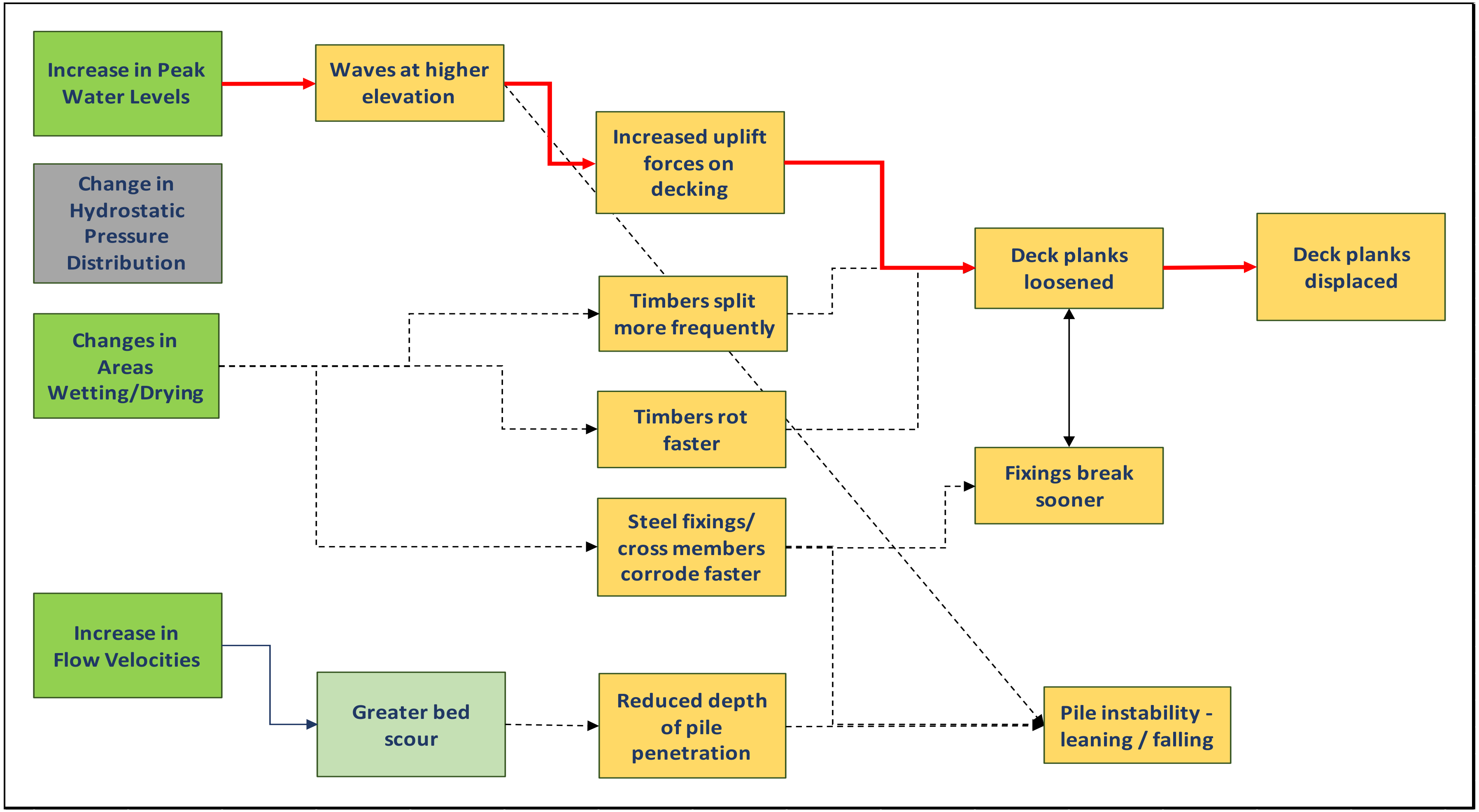
CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge Increase**	**Wave Height Increase**	**Higher Peak River Flows**	**Other CC Factors?**
Yes	Yes	No	Yes	Potential*

*Change in ***water temperate*** could alter ecology and biodiversity of marine organisms, including marine borers, which may impact upon timber structures.

ASSET TYPE: Jetty	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

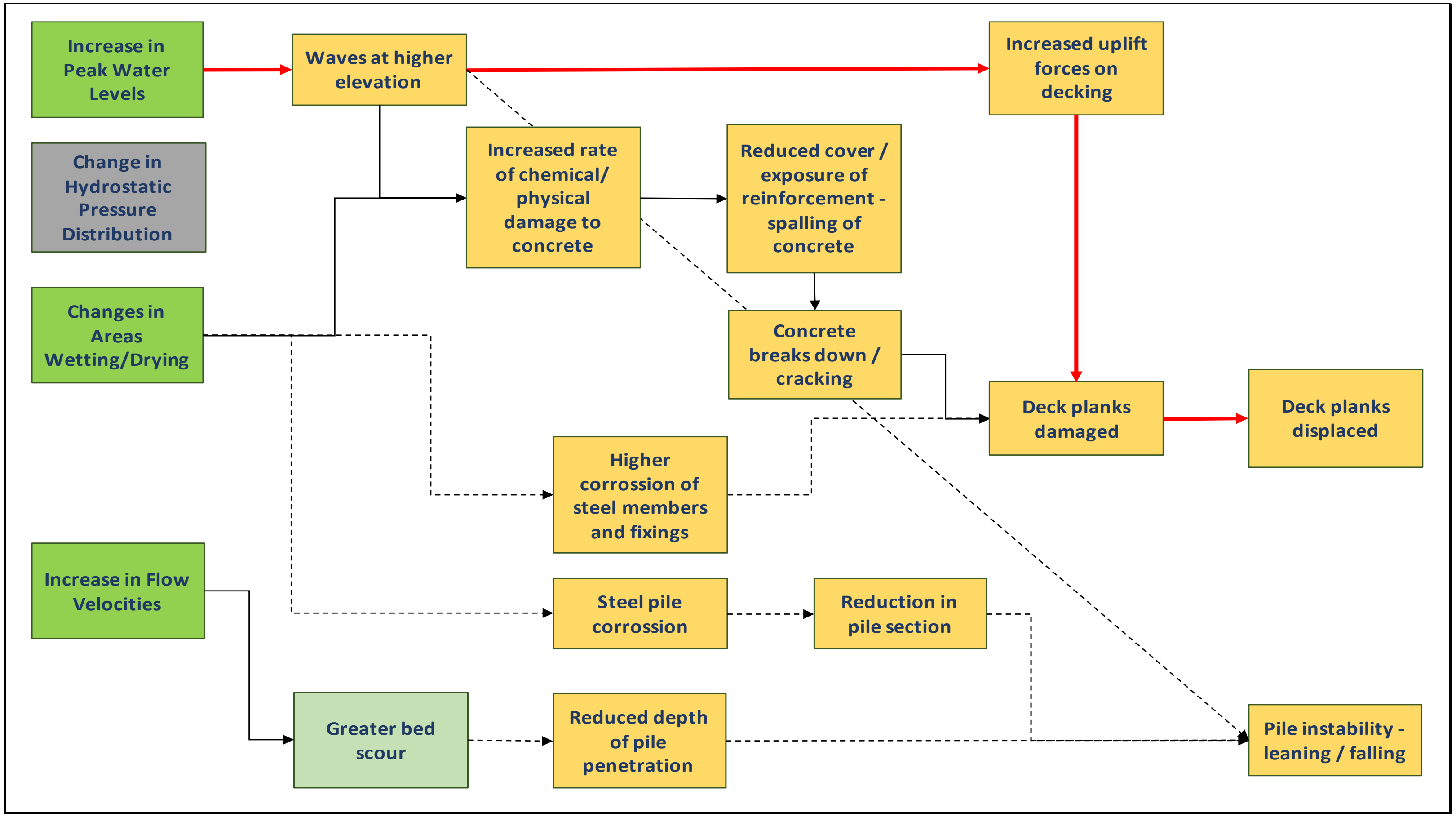
(1) OPEN ESTUARY - TIMBER STRUCTURES



ASSET TYPE: Jetty	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

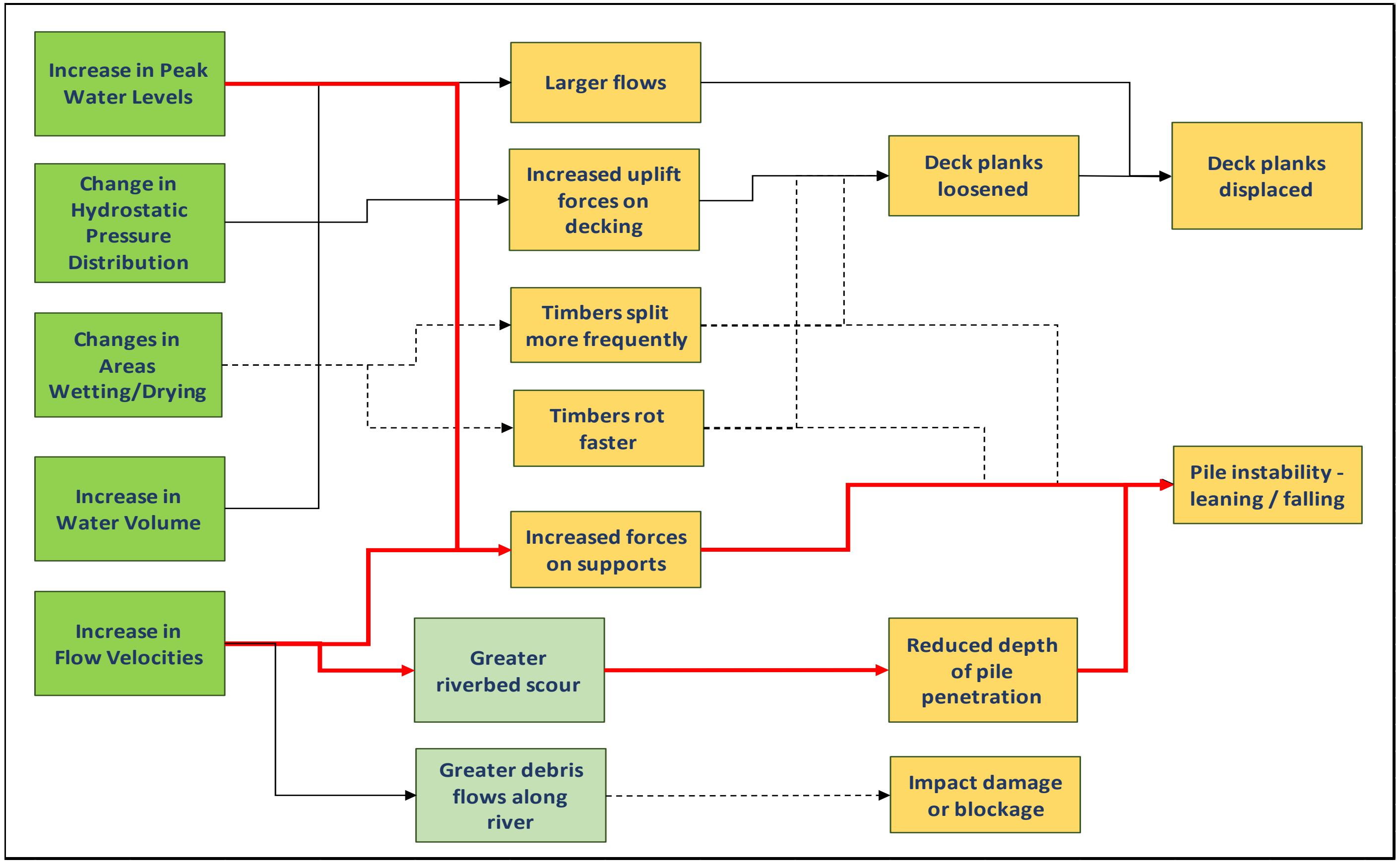
(2) OPEN ESTUARY - STEEL AND CONCRETE STRUCTURES



ASSET TYPE: Jetty	ENVIRONMENT: Tidal River

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS

(3) TIDAL RIVER – TIMBER STRUCTURES



ASSET TYPE: Jetty	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a jetty include:

- Greater uplift forces on deck structure due to waves impacts which are a consequence of higher water levels
- Impact forces from waves higher up on the supporting structure due to higher water levels in open estuary (although potential to destabilise pile is negligible as mooring forces would be greater force than this)
- Scour of bed around piles due to higher flow velocities
- Increased rates of rotting/splitting of timber, corrosion and degradation of steel and concrete, due to changes in wetting and drying are possible but not considered to be key areas of vulnerability – these structures are designed to frequently be wet and the changes in this will be small.

A key area of impact is potentially the loading resulting from higher water levels, primarily on the deck structure. Higher water levels will increase the potential for any locally generated waves to create uplift on the deck, although the size of these waves are generally small so this impact is probably going to be low but depends upon the freeboard (noting it would be a high vulnerability if the jetty were in open sea however). In a tidal river setting too, the change is the loading on the deck structure resulting from higher water levels, depends entirely on the freeboard between the deck and water level; if water levels remain below the deck at all times, then this vulnerability becomes negligible.

Increased debris flows from upstream as a consequence of higher river flows may also lead to the potential for more impact damage or a requirement for more regular clearing.

A more likely area of impact in tidal river/narrower estuary settings would be potential for scour of the channel bed around the supporting piles, created by increased river flows and higher tidal flows in areas where these are presently less common but will become more frequent with higher tidal levels and storm surges. In addition to this, the higher water levels and flows from both tidal and fluvial sources as a result of climate changes would increase the forces upon the supporting structures. In combination with scouring of the piles this could lead to destabilisation of these structures.

The types of maintenance actions required to address these matters will be similar to that at present, e.g. replacing planks and fixings, patching up and repairing concrete as required, but with perhaps increased frequency, or requiring more remedial actions. Should instability of the supporting structure occur, for example due to scour around the piles, it would require considerable additional strengthening of the structure to prevent collapse, in which case the impact would be high. But this is very site specific and dependent upon a number of coincident factors, so the overall magnitude of vulnerability for these assets in this setting is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

A potentially greater impact of climate change on these structures will be the changes in loading due to mooring forces. Higher day to day water levels (due to sea level rise) will alter the loading from vessel moorings. Likewise during storm surge events and periods of higher river flows, both mooring forces and impact forces from vessels berthed or berthing could be much greater. In all of these cases there is the potential for greater damage to the structure, or even failure of some components, e.g. breaking of the support structures.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Beacon	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"A beacon is attached directly to the bed of the sea or a river and may be lighted or unlighted. Some can also be found on land"

A beacon will most likely comprise a steel pile, driven into the seabed, with a topmark or light atop.

The distinction between a signal and the topmark of a beacon is however unclear (within the CAMC definitions).

This assessment covers beacons in an estuary only.

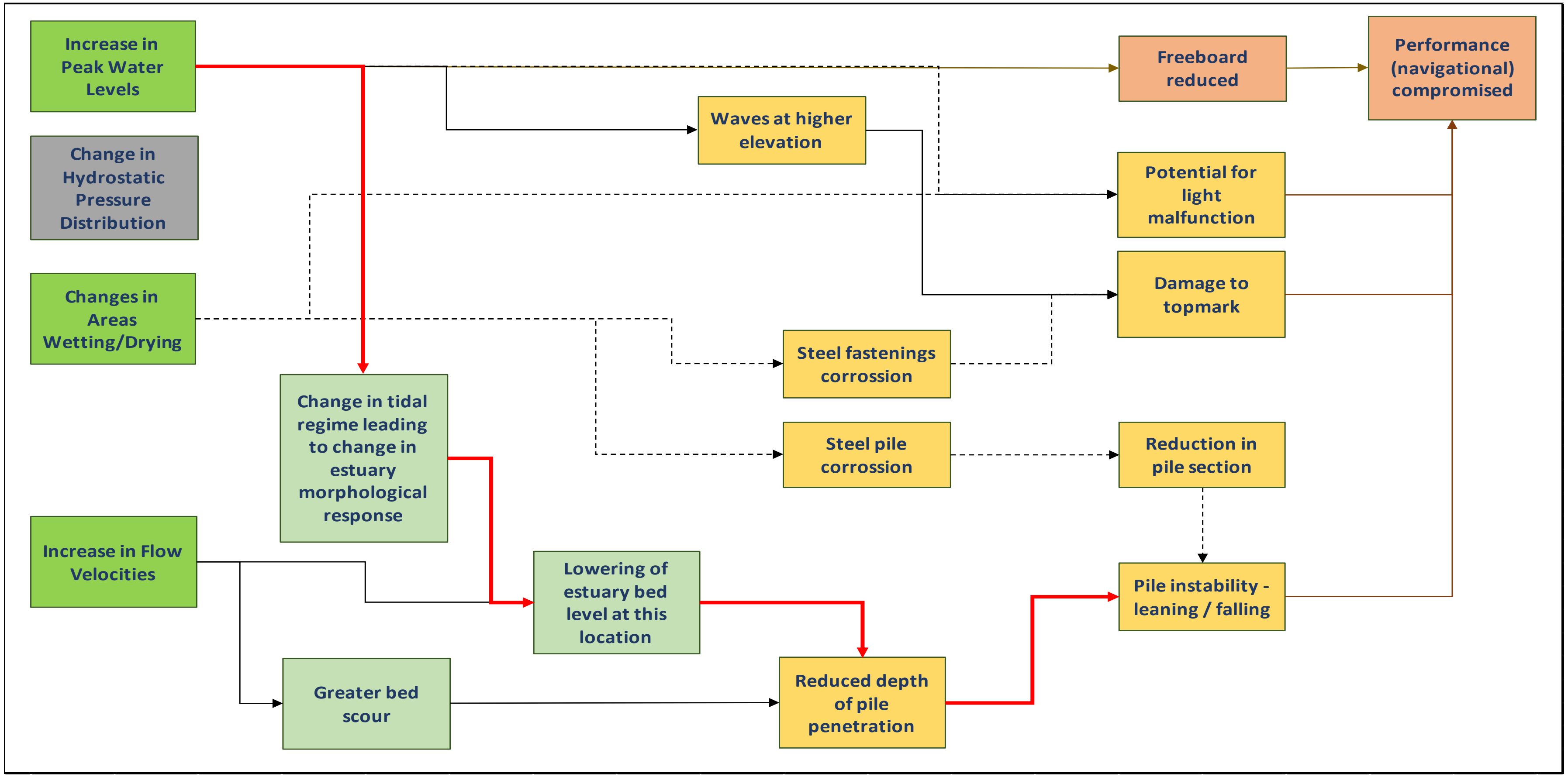
These will be subjected to locally generated waves (so climate change increase not relevant here), but might also be affected by higher river flows in the low water channel.

CLIMATE CHANGE FACTORS CONSIDERED

Sea Level Rise	Storm Surge	Wave Height	River Flows	Other
Yes	Yes	No	Yes	No

ASSET TYPE: Beacon	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Beacon	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a beacon in an estuary environment include:

- Increased river flow velocities at the bed could increase scour and reduce passive resistance to pile/post toppling. However, this would only be likely in the low water channel.
- Higher water levels, allowing estuary waves to impact upon more elevated parts of the structure could lead to more damage of the topmark.
- Changes in areas vulnerable to corrosion would occur, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.
- Sea level rise will produce a changes in tidal prism which will lead to morphological adjustment of the estuary with movement of shoals and channels. This may result in significant lowering of channel bed and destabilising of the pile/post structure.

Damage and/or a requirement for maintenance to the top light could possibly increase as a consequence of increased wave exposure resulting from higher water levels. However, these will not be large waves and these assets are designed to withstand storm conditions, so the impacts of climate change upon their deterioration or any increase in maintenance commitment are likely to be negligible. In terms of malfunction or corrosion issues, these structures are designed for exposure to frequent wetting and drying, so the impact of climate change on these and thus any change to maintenance requirements is also likely to be very slight.

The most damaging change would be the possible destabilising of the supporting pile, which could result from wider morphological change within the estuary due to sea level rise, or from local movement in the low water channel through higher river flows. Although these piles are likely to have been designed to deal with fluctuations under extreme conditions, the magnitude of these morphological changes could be much greater. However, the impact depends entirely upon the nature of change at that precise location. Should any work be required, then it is It is unlikely that repairs would be adequate and more likely that works to stabilise the existing structure such as bracing or scour protection would be required. A new structure may however be required for performance reasons, as the position of the beacon may now require relocating.

Although the impacts are potentially high, they are also highly dependent upon the pile depth and also upon the occurrence of very extreme and specifically local changes, so overall the vulnerability is more likely to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

There is a performance issue to consider. Beacons should be designed to have at least a 2m freeboard, and with sea level rise this freeboard will be reduced. A reduction in freeboard due to higher water levels could therefore compromise navigation requirements and could require these structures to be extended vertically, or replaced.

As discussed above, the morphological changes within an estuary could also result in a need to relocate these assets to reflect changes in navigable channels.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Signal	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"A signal in the marine and fluvial environment provides traffic control or fog warnings"

The distinction between a signal and a beacon is unclear (within the CAMC definitions).

It is possible that a signal also includes audio signals (e.g. foghorns) as well as lighted signals.

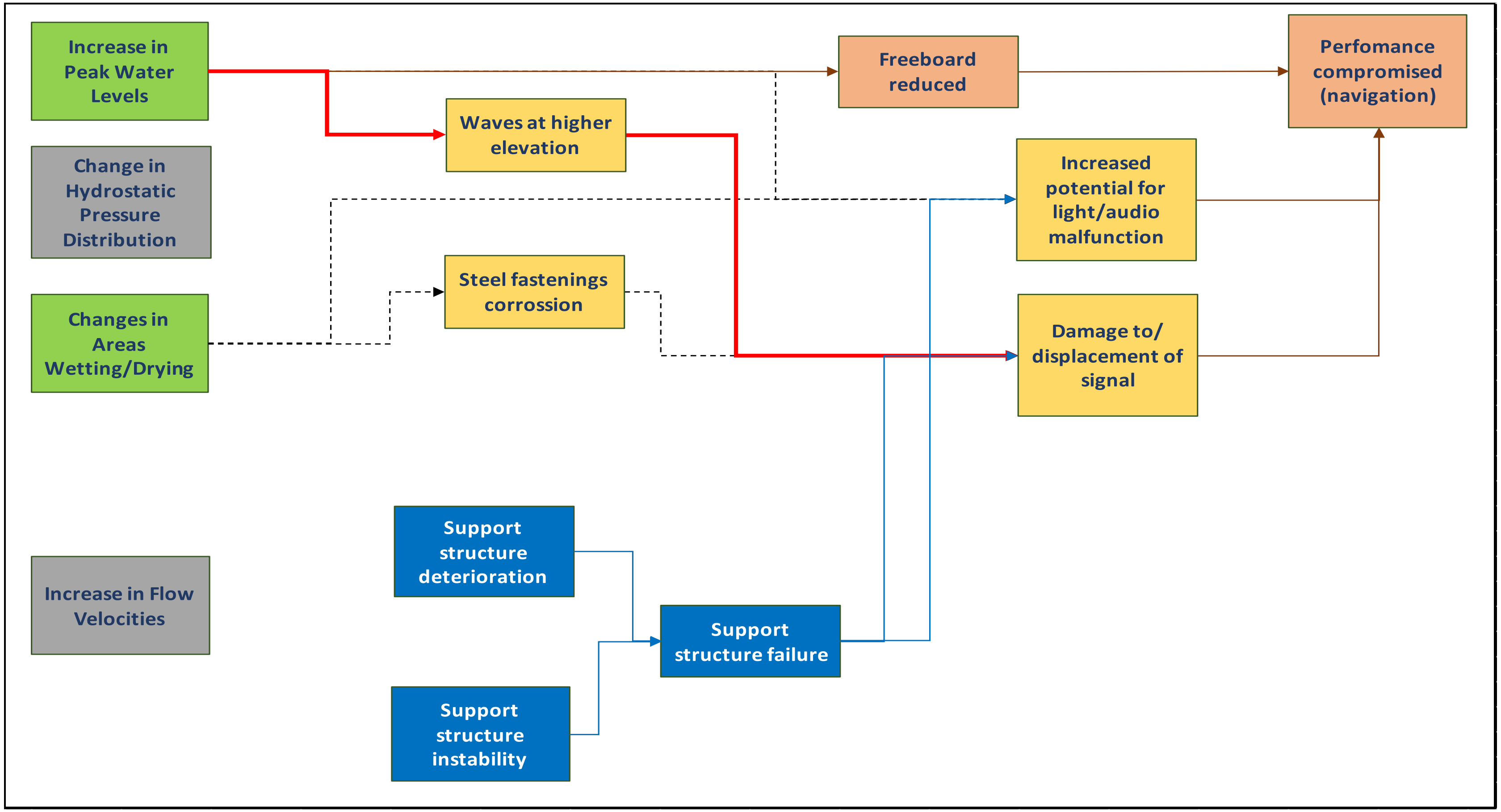
For the purpose of this assessment, the signal is considered to be only the top part of the structure and assumed to be mounted upon a pile or other supporting structure.

This assessment covers signals in the estuary environment only.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	No	No	No

ASSET TYPE: Signal	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Signal	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a signal in an estuary environment include:

- Higher water levels, allowing estuary waves to reach more elevated parts of the structure could lead to more damage of the signal.
- Higher water levels and more frequent wetting/drying could potentially lead to more regular malfunction of light or audio equipment providing the signal.
- Mountings and fixings in areas susceptible to corrosion would experience faster rates of deterioration, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.

In terms of malfunction or corrosion issues, these structures are designed for exposure to frequent wetting and drying, so the impact of climate change on these and thus any change to maintenance requirements is likely to be very slight.

Damage and/or a requirement for maintenance to the signal could possibly increase as a consequence of increased wave exposure resulting from higher water levels. However, these will not be large waves and these assets are designed to withstand storm conditions, so the effects of climate change upon their deterioration or any increase in maintenance commitment are likely to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

The main area of impact to these assets are to the structure that they are mounted upon. Damage to that could lead to instability and thus damage of the signal.

Another issue is reduction/loss of performance function. These signals will be designed to have a certain amount of freeboard; with sea level rise this will be reduced and navigational control could be compromised. To counter this, these signals may need to be raised or replaced.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Signage	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"Signage in the marine and fluvial environment provides information to aid navigation."

Signs are assumed to generally be made of steel plate with words or images painted upon their surface.

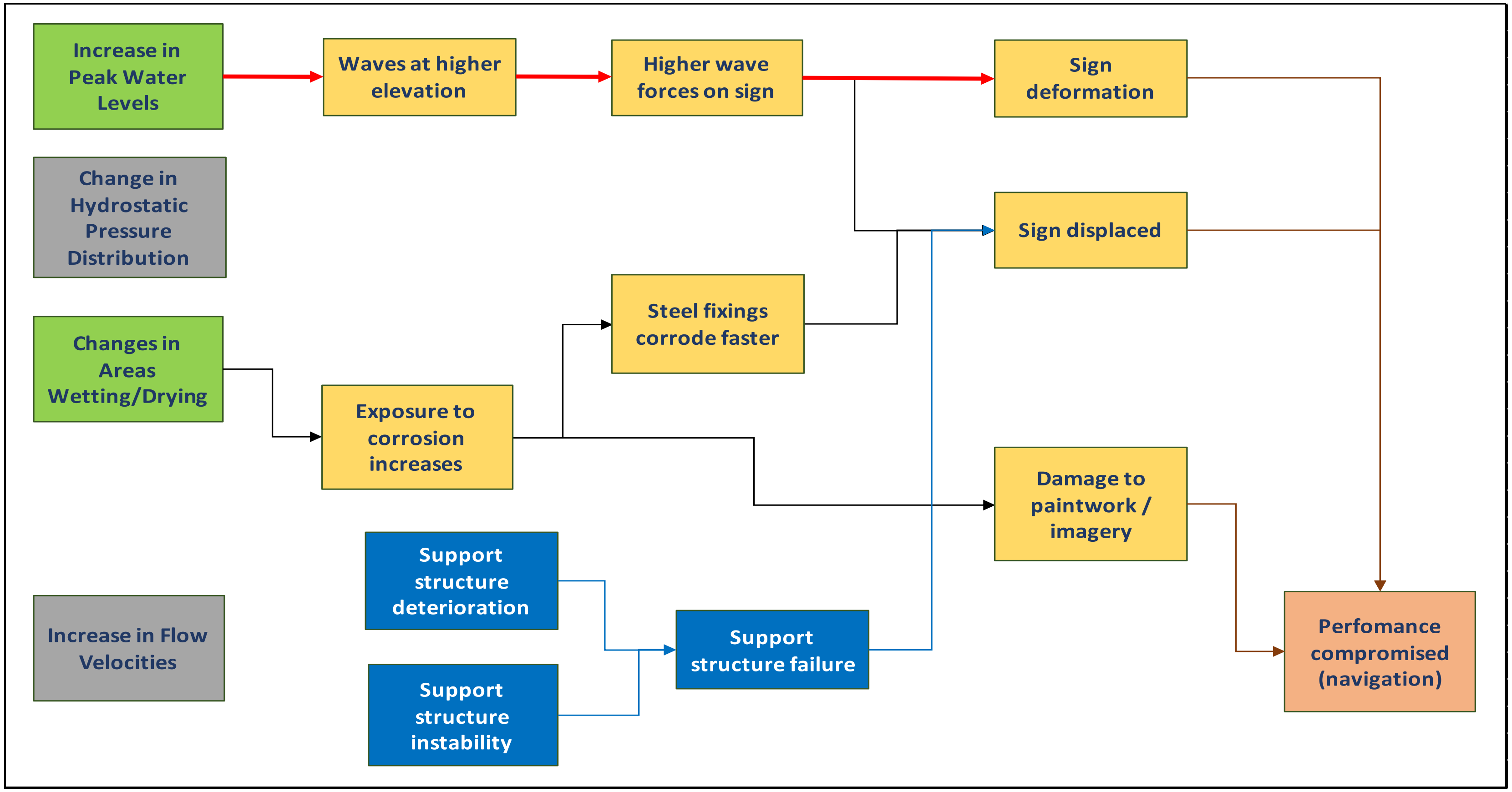
For the purpose of this assessment, the signage is considered to be only that part of the structure and assumed to be mounted upon a pile or other supporting structure.

This assessment covers signage in the estuary environment only.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	No	No	No

ASSET TYPE: Signage	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Signage		ENVIRONMENT: Estuary	

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of signage in an estuary environment include:

- Higher water levels, providing greater potential for estuary waves to reach and impact upon the sign, which could lead to deformation damage or displacement.
- Mountings and fixings in areas susceptible to corrosion would experience faster rates of deterioration, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.
- Higher rates of corrosion, and possibly abrasion, could lead to the details on the sign becoming illegible.

In terms of corrosion issues, these structures are designed for exposure to frequent wetting and drying, so the impact of climate change on these and thus any change to maintenance requirements is likely to be very slight.

Damage and/or a requirement for maintenance to the sign could possibly increase as a consequence of increased wave exposure resulting from higher water levels. However, these will not be large waves and these assets are likely to be able to withstand estuary waves, so the effects of climate change upon their deterioration or any increase in maintenance commitment are likely to be Negligible.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
			X

OTHER POTENTIAL IMPACTS

The main area of impact to these assets are to the structure that they are mounted upon. Damage to that could lead to instability and thus damage of the signage.

Another issue is reduction/loss of performance function. The words or images on this signage will be designed to have a navigation aid/warning purpose. With sea level rise the exposure above water level of these might be reduced and navigational control could be compromised. To counter this, this signage may need to be raised or replaced.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Dolphin	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Aids to Navigation'
"In the marine or fluvial environment, a dolphin provides a fixing point for signage, information or a mooring point"

A dolphin will most likely comprise a steel pile, or commonly a group of piles, driven into the bed.

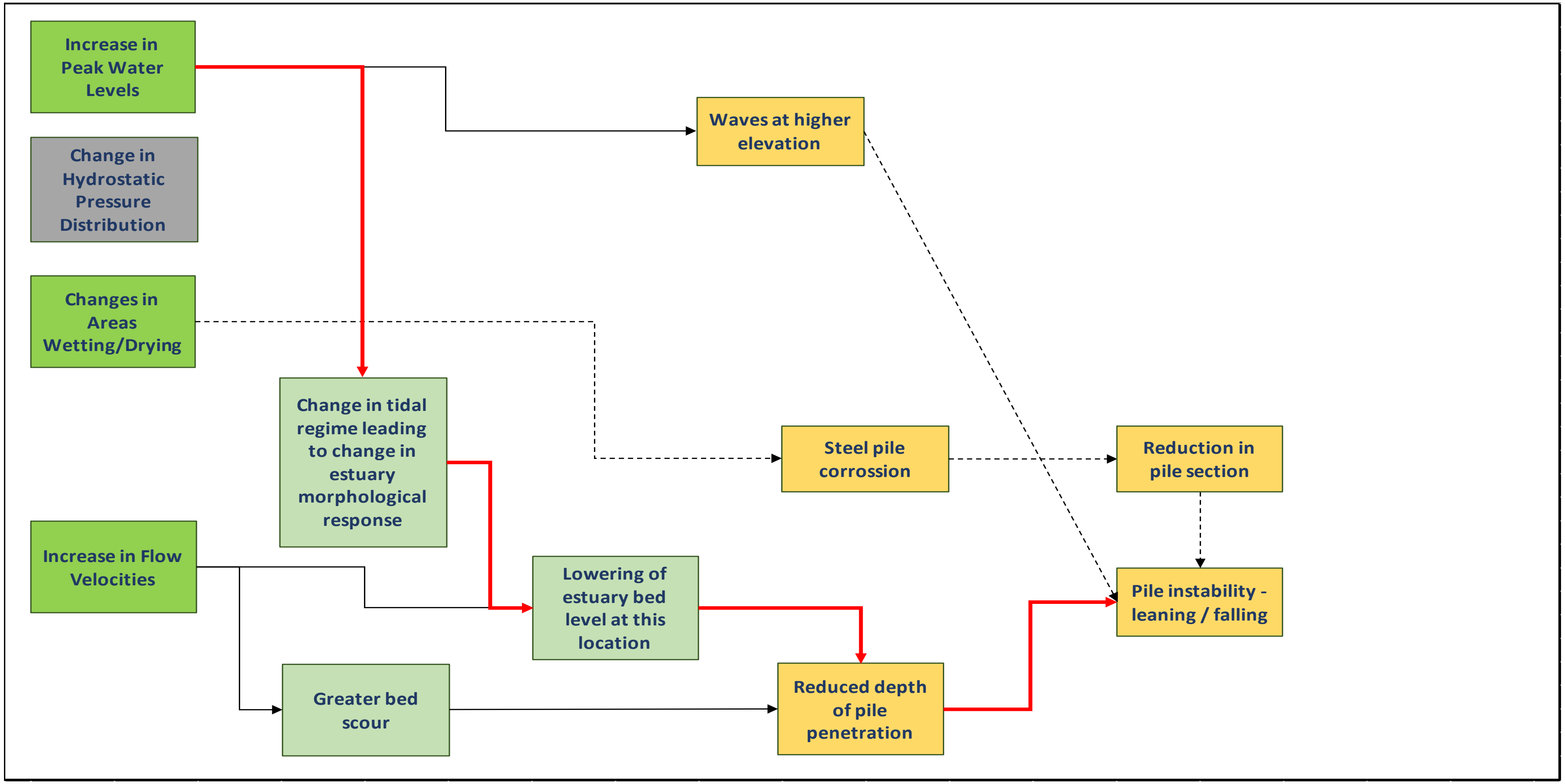
This will be very similar to a beacon, but designed to withstand mooring forces.

Primarily considering Dolphin for Estuary setting is on the basis that it is unlikely that there would be many if any of these as FCERM structures in the open sea. As such, the increase in wave heights factor is not included: the change in locally generated (within estuary) wave loading would be only due to higher water levels at the structure. These could also be affected by river flows in areas where the estuary narrows.

CLIMATE CHANGE FACTORS CONSIDERED				
Sea Level Rise	**Storm Surge**	**Wave Height**	**River Flows**	**Other**
Yes	Yes	No	Yes	No

ASSET TYPE: Dolphin	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Dolphin	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

The impacts of these climate change factors on deterioration of a dolphin in an estuary environment include:

- Higher water levels, allowing estuary waves to impact upon more elevated parts of the structure could lead higher destabilising forces.
- Increased river flow velocities at the bed could increase scour and reduce passive resistance to pile/post toppling. However, this would only be likely where the estuary is narrow.
- Sea level rise will produce a changes in tidal prism which will lead to morphological adjustment of the estuary with movement of shoals and channels. This may result in significant lowering of channel bed and destabilising of the pile.
- Changes in areas vulnerable to corrosion would occur, although these structures are designed for exposure to frequent wetting and drying, so little change in impact is likely.

The most damaging change would be the possible destabilising of the pile, which could result from wider morphological change within the estuary due to sea level rise. Although these piles are likely to have been designed to deal with fluctuations under extreme conditions, the magnitude of these morphological changes could be much greater. However, the impact depends entirely upon the nature of change at that precise location. Should any work be required, then it is It is unlikely that repairs would be adequate and more likely that works to stabilise the existing structure such as bracing or scour protection would be required. A new structure may however be required for performance reasons, as the position of the dolphin may now require relocating.

Although the impacts are potentially high, they are also highly dependent upon the pile depth and also upon the occurrence of very extreme and specifically local changes, so overall the vulnerability is more likely to be moderate at most, and more probably Low if the stability is not dependent upon a single pile.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

OTHER POTENTIAL IMPACTS

A much greater impact of climate change on these structures will be the changes in loading due to mooring forces. Higher day to day water levels (due to sea level rise) will alter the loading from vessel moorings. Likewise during storm surge events and periods of higher river flows, both mooring forces and impact forces from vessels berthed or berthing could be much greater. In all of these cases there is the potential for greater damage to the structure than those identified through deterioration processes alone.

IMPACT OF CLIMATE CHANGE ON ASSET DETERIORATION

ASSET TYPE: Pump House	ENVIRONMENT: Estuary

DESCRIPTION

DEFINITION IN CAMC:
Listed under asset type 'Buildings'
"A pump house is a building that houses pumps and the facilities necessary to support their operation"

Under the CAMC definition, this asset refers to the building itself and not the equipment that this houses. These buildings will as a rule not generally be located within the watercourse itself, so not directly subjected to the climate change factors being assessed here. The buildings will instead usually sit elsewhere within the floodplain, often elevated, so their deterioration will only be as a consequence of other assets (e.g. flood banks or channel sides) being overflowed, therefore the impacts of climate change upon the pump house itself would be considered to be negligible.

However, for the benefit of this study, the potential impacts of the climate change factors on the operational (MEICA) elements of the pump station have been considered here as increases in peak water levels and flows could result in changes in operational requirements and increased and/or new forces on the pumping station components. Furthermore, Sea Level Rise will result in a day-to-day head difference between the water channel (tidal river or estuary) and the pump intake/outflow.

Pumping stations are used to transfer water from one location to another. The two main factors describing a pumping station's performance are flow rate and head (i.e. pressure increase). Often a pumping station will have more than one pump, and be designed to operate in a duty/assist or duty/standby configuration.

A pumping station would typically consist of the following components:

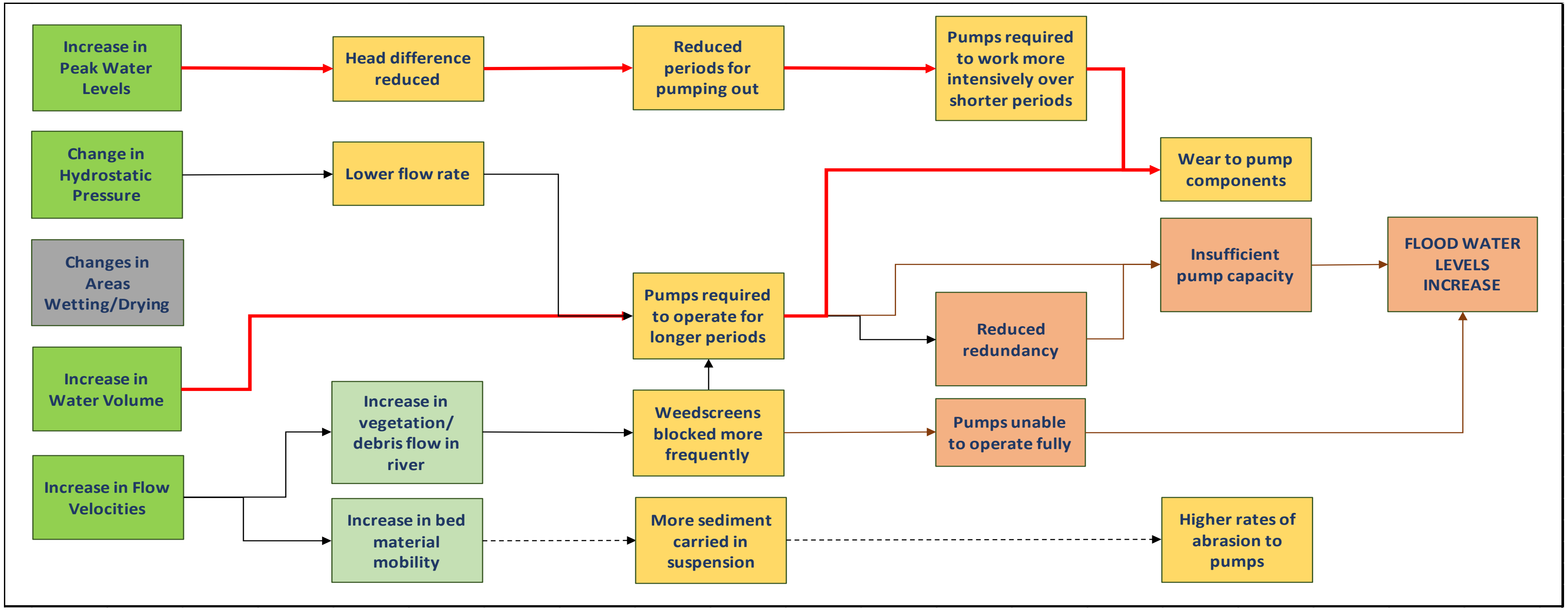
- Pumps
- Pipework
- Valves
- Gearboxes
- Motors
- Electrical equipment
- Weedscreens
- Civil structure

CLIMATE CHANGE FACTORS TO CONSIDER

Sea Level Rise	Storm Surge Increase	Wave Height Increase	Higher Peak River Flows	Other CC Factors?
Yes	Yes	No	Yes	No

ASSET TYPE: Pump House	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND CLIMATE CHANGE FACTORS



ASSET TYPE: Pump House	ENVIRONMENT: Estuary

QUALITATIVE ASSESSMENT

Climate change factors may potentially impact on pumping stations in the following ways:

- Increase in water volume requiring more frequent and longer operation of the pumping station. This could result in increased wear to components.
- An increase in flow velocities could also lead to increased bed mobility and thus result in more material passing through the pumps leading to more abrasion.
- An increase in flow velocities could increase debris transport which could either block the pumps or damage pumping station components.
- Higher day-to-day water levels resulting from sea level rise increasing the head the pumps must overcome.

Due to the way pumps operate, when there is an increase in the head of water to be overcome (for example because of a water level rise on the outlet side of the pumps), the flow rate that can be achieved decreases. This will result in the pumps having to operate for longer periods of time to move the same volume of water. This situation is complicated further by sea level rise which not only increases the peak water levels but all water levels on a day-to-day basis. If the amount of water to be pumped increases, this will also have a proportional increase on the amount of time required to do so. With pumps being required to operate for longer periods, more wear will be experienced by motors, bearings and the like. This will lead to an increased maintenance requirement. Similarly, if more debris/vegetation is transported by the flow, the weedscreens at the inlet of the pumping station will become blocked, resulting in an interruption of flow to the pumps' inlets which may lead to entrainment of air and cavitation, significantly shortening the life of the pumps.

An increase in flow velocities upstream of the pumps will not directly affect pumping operations - the flow rate through the pumping station will be determined by the pumps' ability to draw in water. However, more bed material may be present in the flow as a result of the increased upstream velocities. This would result in increased abrasive wear to the impellers and other internal parts of the pumps, reducing pumping performance and necessitating more frequent overhauls of the pumps.

Overall, there is the potential for some increase in maintenance to maintain pumps which could deteriorate more quickly as a result of climate change factors in a fluvial environment, so the vulnerability is considered to be Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

OTHER POTENTIAL IMPACTS

The purpose of pumping stations is to manage water levels. The main issue for pumping stations is that their capacity may become insufficient and that flood water levels may increase as a result. If their operation is compromised, then that could increase flood levels/flood risk to areas reliant upon their operation. Substantial upgrades, or even complete replacement, may be necessary to address this. For this reason the potential impact in performance terms would be high.

There is also a potential increase in inspection and maintenance activities not related to deterioration. If more debris/vegetation is transported by the flow, the weedscreens at the inlet of the pumping station will also become blocked more frequently and will need to be cleared more often.

6 Supplementary Assessments

<table>
<tr><th colspan="2">ASSET TYPE: Simple Culvert</th><th colspan="2">ENVIRONMENT: Estuary</th></tr>
<tr><td colspan="4">DESCRIPTION
The majority of culverts are found in fluvial situations, but there are examples of them being found in estuary settings (more specifically tidal rivers).

When considering this definitions it should be noted that in the context of the CAMC definitions being used for this study, culverts form part of the main watercourse and do not include outfalls or bridges.

QUALITATIVE ASSESSMENT
The main difference in conditions resulting from climate change for culverts in an estuary setting rather than a fluvial setting, would be the higher day-to-day water levels occurring as a consequence of sea level rise. This may affect the capacity of the culvert to accommodate flows, but that is a performance and not a deterioration issue.

The other difference is the exposure to saltwater and its potential effect on reinforced concrete degradation. However, these structures should have been designed with that exposure already taken into account, so although this may differ from a fluvial situation, it is unlikely to make any significant difference to the deterioration of structures already in this setting.

The vulnerability to deterioration due to climate change factors of culverts in an estuary is therefore not expected to be any more severe than those stated for culverts in a fluvial setting, i.e. Low.</td></tr>
<tr><td colspan="4">MAGNITUDE:</td></tr>
<tr><td>HIGH</td><td>MODERATE</td><td>LOW</td><td>NEGLIGIBLE</td></tr>
<tr><td></td><td></td><td>X</td><td></td></tr>
</table>

ASSET TYPE: Embankment (Revetment)		ENVIRONMENT: Estuary	

DESCRIPTION

An embankment in an estuary setting may be robustly protected to the standards required for a seawall, as described for a coastal setting, or depending upon level of exposure only require lighter protection as described for embankments with either permeable or impermeable revetments in a fluvial environment.

QUALITATIVE ASSESSMENT

The exposure of the embankment in an estuary will be less than that on the open coast, where impacts on deterioration are considered to be High, with less volatility of the foreshore and smaller waves to resist. Nonetheless, foreshore lowering due to currents may still increase, leading to undermining of the toe (which may be of less substantial construction) with displacement of the revetment, and potential for increased erosion damage due to waves overtopping (also a performance issue) will also be a consequence of higher water levels due to sea level rise and storm surges. Higher water levels will also lead to the same potential issues of increased geotechnical instabilities.

The potential deterioration mechanisms affecting embankments in a fluvial setting, where impacts are considered to be Moderate, will all also apply to a similar embankment in an estuary.

The point at which the issues from fluvial processes or coastal processes will dominate depend upon the location of the asset within an estuary/tidal river, but the overall assessment is that the effects upon deterioration are likely to be High.

MAGNITUDE:			
HIGH	MODERATE	LOW	NEGLIGIBLE
X			

ASSET TYPE: Embankment (Turfed – Unprotected)		ENVIRONMENT: Estuary	

DESCRIPTION

Grassed embankments without any other form of protection over a clay core can often be found in estuary settings. For a description, see details for unprotected embankments in a fluvial setting.

QUALITATIVE ASSESSMENT

Embankments in an estuary setting will be subject to the same climate change factors and associated impacts as those in a fluvial setting, plus any impacts resulting from higher sea levels on a day-to-day basis, which will also alter the area exposed to locally generate waves, and storm surges. Therefore, in addition to the deterioration processes described for unprotected embankments in a fluvial environment, within an estuary there will be much greater potential for erosion of the face due to wave exposure, erosion of the crest and rear face due to overtopping (also a performance issue), and geotechnical instabilities caused by change in hydrostatic pressures. These all increase the potential vulnerability of these assets, with none of the vulnerability in a fluvial setting diminishing, so the magnitude remains High.

MAGNITUDE:			
HIGH	MODERATE	LOW	NEGLIGIBLE
X			

ASSET TYPE: Wall (Vertical)		ENVIRONMENT: Estuary	

DESCRIPTION

Walls in an estuary/tidal setting are considered to be most similar in nature to vertical faced seawalls, or vertical faced impermeable lined river channels. For the purposes of this assessment, they are considered to be primarily addressing erosion issues, rather than flooding, which is covered by embankments.

Walls in an estuary environment might be constructed of; concrete, masonry, steel (sheet piling), timber, gabions.

QUALITATIVE ASSESSMENT

One of the key issues in a coastal setting, where impacts have been assessed to be High, is the undermining of the wall due to the increased volatility of the foreshore. Another is the increase in dynamic forces due to waves, leading to a deterioration in structural integrity. These would still be issues within an estuary, but to a lesser extent.

Issues for lined channels in a fluvial setting, where the impacts are assessed to be Moderate, also include potential for scour and undermining due to higher river flows. Other impacts in this setting would be the potential for higher overtopping from waves due to higher water levels (also a performance issue), and hydrostatic pressures affecting the stability of the wall, as well as material degradation due to saltwater.

Due to some of the key reasons for walls being considered High at the coast being of lesser consequence in an estuary, the overall assessment made here for walls in an estuary is Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

ASSET TYPE: Flood Gate	ENVIRONMENT: Estuary

DESCRIPTION

Flood gates will be designed to normally be above and out of water, but with water against it when closed in peak water level events. These gates will often be set in the top of a wall or other flood defence, allowing access through when open. Closure of the gates might be a purely manual operation or, in the case of more substantial sliding gates, include an actuation mechanism.

QUALITATIVE ASSESSMENT

The main difference in conditions resulting from climate change for flood gates in an estuary setting rather than a fluvial setting, where impacts are assessed as Low, would come as a result of higher sea levels and storm surges. The two key impacts will be similar to that in a fluvial setting; the increase in forces on the gate and the increase in level of operation, but are likely to be much greater in an estuary due to these factors. Higher sea levels and storm surges will mean that the frequency with which the gate requires operating could increase significantly. That will potentially lead to faster deterioration and wear and tear on components of the gate such as hinges, actuation mechanisms, seals, requiring their maintaining or replacement on a more regular basis.

Although the gate should have been designed to withstand the hydrostatic loadings upon it, higher water levels could see the gate directly exposed to new dynamic forces due to waves within the estuary being at higher elevations than previously. This increase in forces on the gate could cause vibration and/or additional loadings onto the frame and fixings, again requiring more frequent replacement and potentially some improvements to be made to the design. In those circumstances the effects of climate change on deterioration of flood gates in an estuary might increase to Moderate in a few open estuary situations. Other factors will include the exposure to saltwater and its potential effect on steel and concrete degradation. However, those impacts will be relatively small compared to the above.

These factors will also affect the standard of service provided by the gate, but that is a performance and not a deterioration issue. Likewise the increase in human input to operate the gate would also be increased, but again this is a performance rather than deterioration matter.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

ASSET TYPE: Flood Gate	ENVIRONMENT: Coastal

QUALITATIVE ASSESSMENT

The assessment made for flood gates in an estuary setting would apply also in a coastal setting, but most significantly with the additional factor of an increase in wave height. This increase may be magnified also by the potential for foreshore lowering, further reducing the depth limiting effects on the wave forces. For this reason, the potential requirements for repair and perhaps redesign of the flood gates are expected in increase notably, and therefore the vulnerability is considered to be Moderate. Another factor at the coast includes the potential for higher abrasion of the steel in particular due to beach sand and shingle being mobilised in this more aggressive environment. That will however be of lesser consequence than the aforementioned issues.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

ASSET TYPE: Demountable		ENVIRONMENT: Estuary	
DESCRIPTION Demountables of various designs can be found in a variety of settings including estuaries and coasts. Their form and composition is usually very specific to the defence required, therefore only generic principles can be considered here in these assessments. **QUALITATIVE ASSESSMENT** The main difference in conditions resulting from climate change for demountables in an estuary setting rather than a fluvial setting, would be the higher water levels occurring as a consequence of sea level rise and storm surges. This may also affect the wave forces on these assets, with local waves being of similar size to pre-climate change conditions, but at higher elevation. This may affect the stability of the demountable, but mostly this would be a performance not a deterioration issue. The main impact from climate change upon deterioration of demountable defences is likely to be the increased frequency of deployment, leading to more rapid wear and tear and thus more regular repairs or replacement. This greater requirement, although potentially greater than in a fluvial setting, is still considered to be of Low magnitude and it is more probable that redesign/re-fabrication is necessary to address the change in performance requirements.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
		X	

ASSET TYPE: Demountable		ENVIRONMENT: Coastal	
QUALITATIVE ASSESSMENT The assessment made for demountable defences in an estuary setting would apply also in a coastal setting, but with the additional factor of an increase in wave height and impacts upon the demountable, depending upon its location and form. Although there are performance issues relating to this, which would be a primary consideration, these forces could also result in vibration and movements which result in components working loose and at risk of failure. In those circumstances it would be essential to repair and possibly need to replace either the demountable or its seating/fixings. For this reason, the potential vulnerability is considered to be Moderate.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		

ASSET TYPE: Control Gate		ENVIRONMENT: Estuary	

DESCRIPTION

Some control gates, e.g. Mitre Gates, may also be present in estuary environments, to limit backflow of water along channels where downstream levels rise due to extreme sea levels and storm surges.

QUALITATIVE ASSESSMENT

If the purpose of a control gate in an estuary or tidal river is to limit flows to upstream, then sea level rise and an increase in storm surge are going to see a much more frequent operation of these assets.

The main issue therefore will be an increase in wear and tear resulting from more frequent, and potentially more difficult, operation that will be required. Forces on the gates and gate supports both during operation and when closed will also be greater. Although the gates may not need replacement (other than for performance reasons), for some the replacement of parts could be a substantial operation, so if required more regularly the vulnerability would be categorised as Moderate.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

ASSET TYPE: Outfall		ENVIRONMENT: Estuary	

DESCRIPTION

Outfalls can take many forms and serve different purposes. Several outfalls in estuary settings will be associated with land drainage, taking water for example from agricultural land through a defence such as an embankment into the estuary. These will frequently have a flap valve and may also have a penstock associated with it.

QUALITATIVE ASSESSMENT

The main difference in conditions resulting from climate change for outfalls in an estuary setting rather than a fluvial setting, would be the higher day-to-day water levels occurring as a consequence of sea level rise. This may affect the ability of the outfall to discharge flows so efficiently due to the change in head difference, but that is a performance and not a deterioration issue. The other difference is the exposure to saltwater and its potential effect on material degradation. However, these structures should have been designed with that exposure already taken into account, so although this may differ from a fluvial situation, it should not make a significant difference to the deterioration of structures already in this setting.

The effects on deterioration due to climate change factors of outfalls in an estuary is therefore not expected to be any more severe than those stated for culverts in a fluvial setting, i.e. Low.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
		X	

ASSET TYPE: Outfall		ENVIRONMENT: Coastal	

DESCRIPTION

Outfalls at the coast will often be much more substantial structures, perhaps taking the form of a culvert with a screen, or a pipe with a concrete headwall structure upon which the flapvalve will be mounted. Outfalls may also take the form of a steel or concrete pipe laid across the beach with some form of protective casing over and around it (sometimes just poured concrete). These structures will however often be present for pluvial storm water drainage discharge; it is not clear how many or what form those designed for FCERM purposes would take.

QUALITATIVE ASSESSMENT

The issues facing outfalls on the coast will be similar to many other structural assets located in this environment, notably; potential for undermining and collapse of any structure due to increased beach level volatility caused by changes in hydrodynamics, increased abrasion damage caused by sand and shingle, direct damage/displacement resulting from exposure to larger waves. The vulnerability to these will be highly dependent upon the type and setting of the outfall however.

Comparisons might be made with other coastal assets, such as concrete slipways, steps and ramps, for which the assessment of vulnerability to deterioration has been assessed as Moderate, and a similar degree of impact is considered likely for outfalls.

MAGNITUDE:

HIGH	MODERATE	LOW	NEGLIGIBLE
	X		

ASSET TYPE: Weir		ENVIRONMENT: Estuary	
DESCRIPTION Weirs are mostly found in river settings but may also be present in an estuary. **QUALITATIVE ASSESSMENT** Although there will be increased water levels due to sea level rise and increased storm surges, these are not anticipated to significantly alter the deterioration processes for a weir. However, all of the processes described for weirs in a fluvial environment would also apply to a weir in an estuary, therefore the same assessment of magnitude is made, i.e. Moderate.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		

ASSET TYPE: Jetty		ENVIRONMENT: Fluvial	
DESCRIPTION See description of a jetty in an estuary, specifically tidal river, for details. **QUALITATIVE ASSESSMENT** The assessment for a Jetty in an estuary setting includes consideration of this asset type in a tidal river. That same assessment is applicable to a fluvial setting, with the most likely area of deterioration being the potential for destabilisation of the supporting structure due to higher river flows causing scour of the channel bed in combination with higher water levels altering the forces upon the supports. For that reason, the same assessment of magnitude is appropriate, i.e. Moderate.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
	X		

ASSET TYPE: Beacon		ENVIRONMENT: Fluvial	
DESCRIPTION Similar to that described for beacon in an estuary environment. **QUALITATIVE ASSESSMENT** The primary reason for beacons being assessed as having Moderate vulnerability in an estuary setting was due to the wider morphological changes that can take place to the navigable channels. Although increased river flows could also cause bed lowering in a fluvial setting, the piles should be designed to accommodate a degree of change and this is therefore considered to be Low vulnerability.			
MAGNITUDE:			
HIGH	**MODERATE**	**LOW**	**NEGLIGIBLE**
		X	

7 Additional Climate Change Factors

ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Embankment	ENVIRONMENT: Fluvial & Estuary

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers all forms of embankment, namely unprotected (i.e. turfed), permeable protected (i.e. open cell covering on channel face), and impermeable protected (i.e. solid channel face).

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	Increased Storm Frequency	Changed Rainfall	Changed Temperature
No	No	Yes	Yes

VULNERABILITY

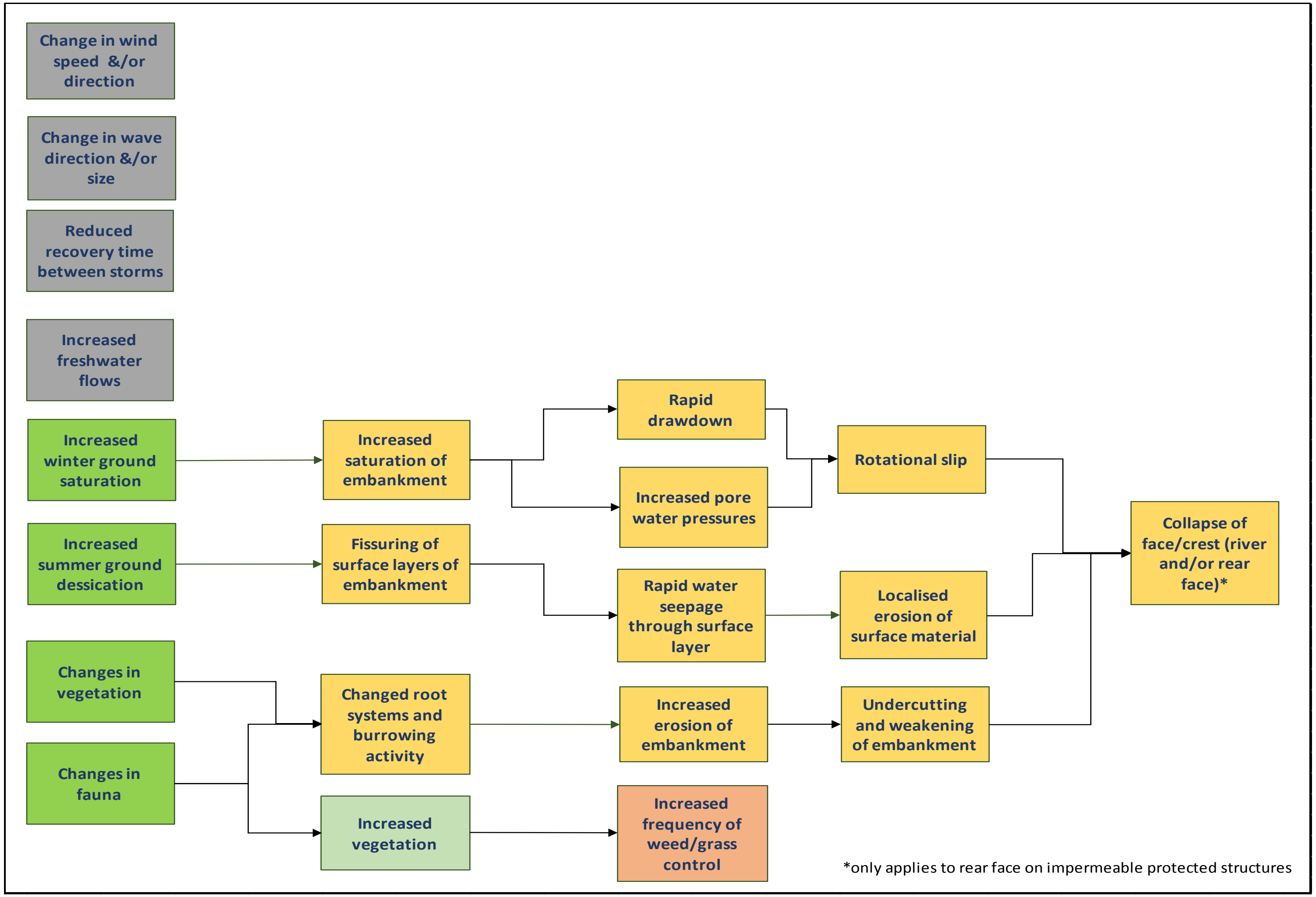
Changes in rainfall would potentially impact embankments both directly and indirectly. An increase in rainfall volume (most likely in winter) would be expected to increase the occurrence of saturation of the earthen embankment, creating conditions where rotational failure is more likely to occur. Conversely, extended periods of low rainfall could result in desiccation of the permeable embankment surfaces and the development of fissures which would allow water (during subsequent flood/rainfall conditions) to seep into the structure and potentially cause surface erosion, which could lead to collapse of the embankment face.

Changes in rainfall together with changes in average temperature (either in combination or individually), will also potentially affect flora and fauna which could impact these assets. Changed vegetation and/or animals could increase the potential for animal burrowing and root impacts to the embankment, weakening the structure and increasing the potential for collapse. Further, additional growth of vegetation on the embankment would require an increased frequency of grass and weed mowing/clearance.

The potential effect of these factors on Embankments is though no greater than the Moderate and High categorisations assigned through the qualitative assessment of vulnerability due to hydrodynamic factors.

ASSET TYPE: Embankment	ENVIRONMENT: Fluvial & Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: High Ground	ENVIRONMENT: Fluvial

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers both unprotected (i.e. vegetated), and protected (i.e. permeable lined) high ground (channel banks).

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	Yes	Yes

VULNERABILITY

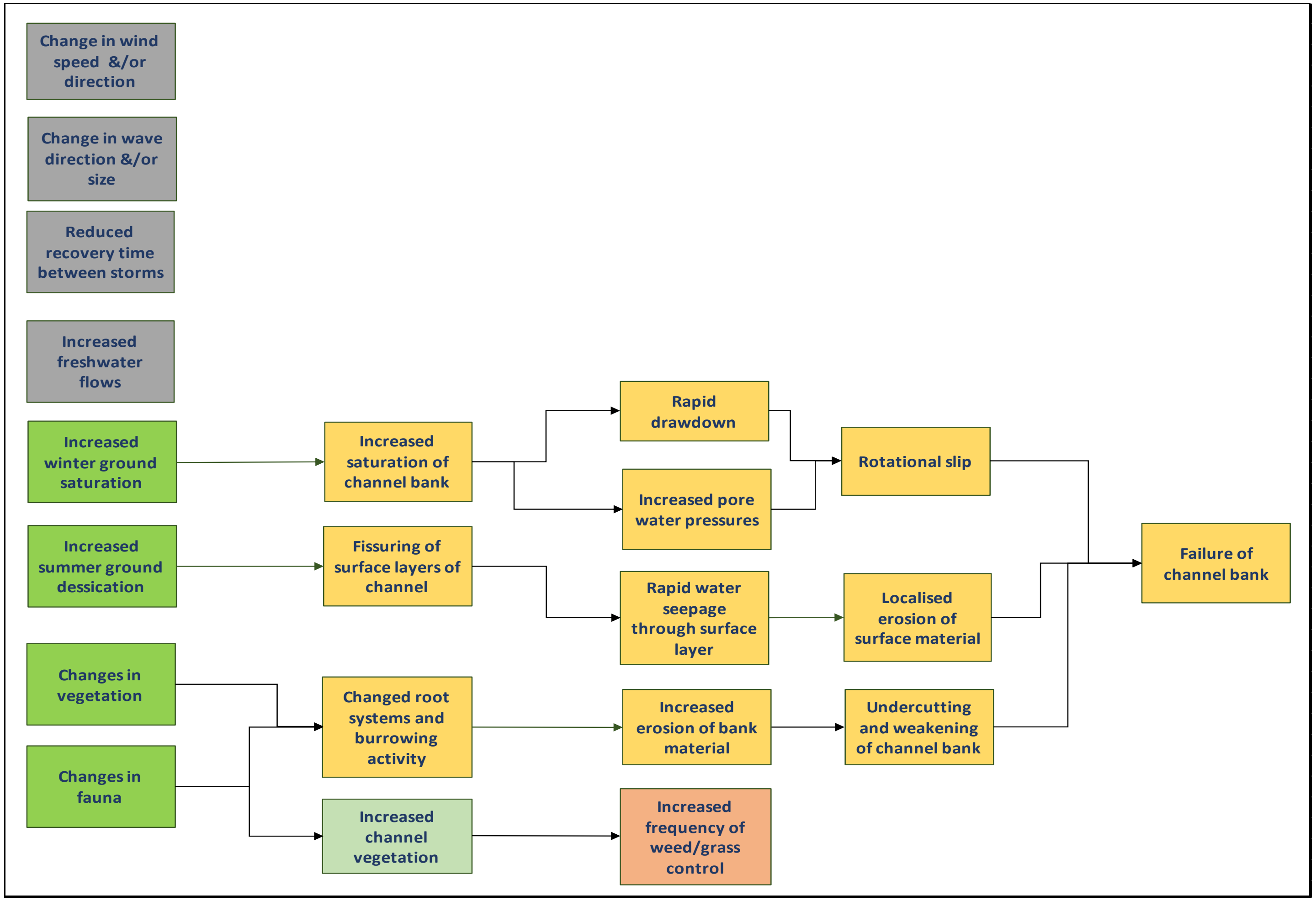
Changes in rainfall would potentially impact high ground both directly and indirectly. An increase in rainfall volume (most likely in winter) would be expected to increase the occurrence of saturation of the channel banks, creating conditions where rotational failure of the bank is more likely to occur. Conversely, extended periods of low rainfall could result in desiccation of banks and the development of fissures which would allow water (during subsequent flood/rainfall conditions) to seep into the bank and potentially cause surface erosion, which could cause localised bank failure.

Changes in rainfall together with changes in average temperature (either in combination or individually), will also potentially affect flora and fauna which could impact these assets. Changed vegetation and/or animals could increase the potential for animal burrowing and root impacts to channel banks, weakening the structure and increasing the potential for bank failure. Further, additional growth of vegetation within the channel and banks would require an increased frequency of grass and weed mowing/clearance.

The effects of these changes will though not increase the qualitative categorisation of vulnerability above the Moderate rating assigned due to hydrodynamic factors.

ASSET TYPE: High Ground	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Beach	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers both sand and gravel beaches. As natural features, created and defined by the processes that form them, beaches are inherently vulnerable to any climate changes that alter those processes.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
Yes	Yes	No	No

VULNERABILITY

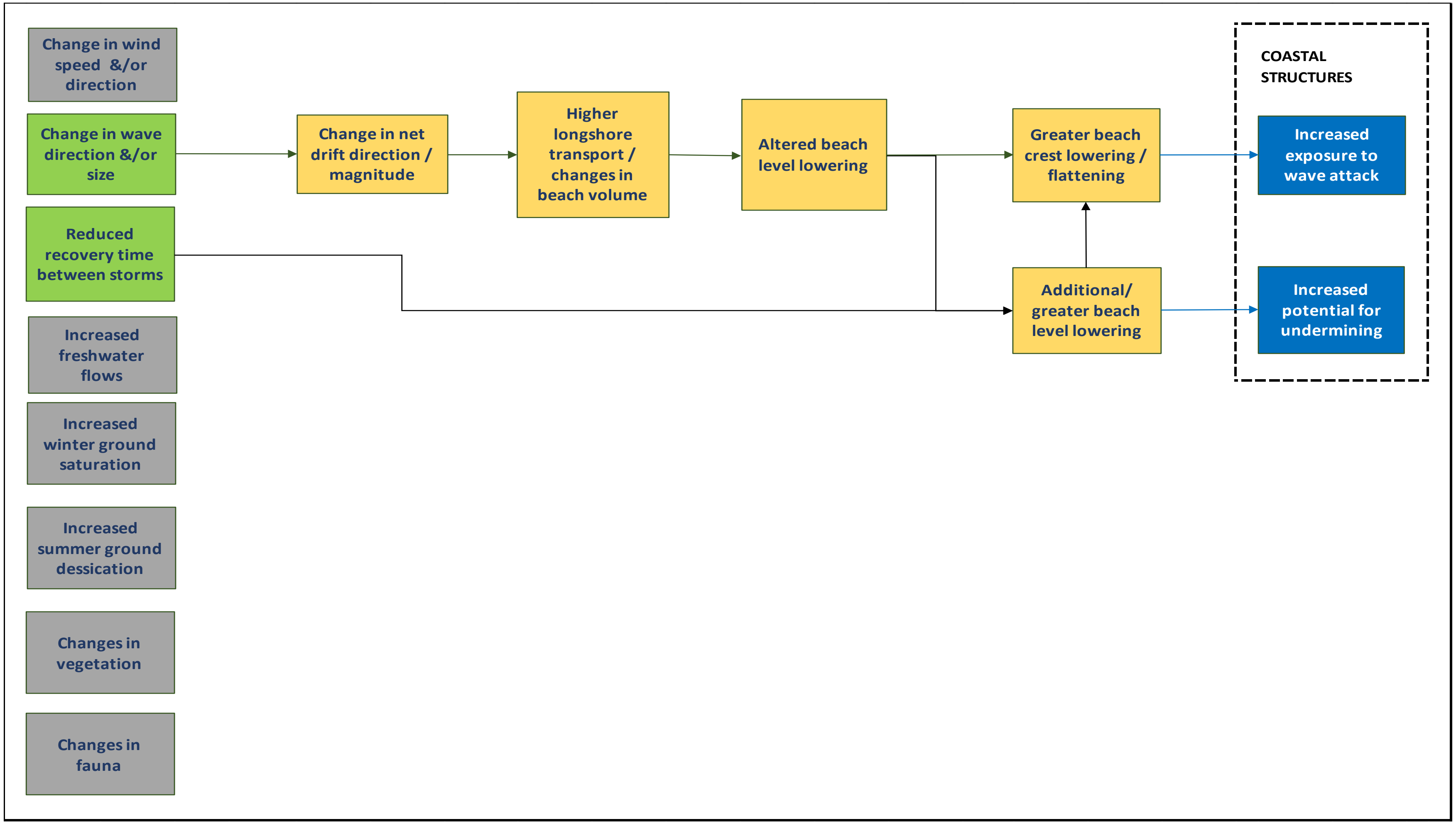
The wave exposure of beaches is a critical characteristic on both managed and unmanaged beaches. In particular, wave direction drives the process of longshore sediment transport which defines how and where beach material moves and accumulates, and hence the amenity and coast protection function of the beach. Consequently, any change in the gross and/or net wind direction impacting locally wind generated waves has potential to alter longshore transport processes which in turn have potential to significantly alter beach characteristics. Where the beach has natural or man-made cross-shore features (e.g. rock outcrops or groynes) this change in longshore drift could be particularly significant.

The other potential climate change impact that could affect beach performance and deterioration is the sequencing and patterns of storms. The antecedent conditions at the beach are important to the resilience of the beach under storm conditions. During a storm event the draw-down of beach material will typically lower beach levels, which then gradually rebuild under subsequent ‘typical’ (day-to-day) conditions. However, if the frequency/sequencing of storms was to change such that events regularly impact a beach in quick succession, the beach will not have opportunity to naturally recover, and hence potentially cause greater draw-down and beach erosion. This can result in greater exposure of backing features and potentially draw beach material further off-shore beyond ‘typical’ wave conditions, and hence cause an overall reduction in beach volume.

As with other climate change factors the effects of these variables will differ depending upon the beach material and exposure. However, the qualitative assessment of hydrodynamic factors has already categorised vulnerability as being High, so these additional effects do not further increase that.

ASSET TYPE: Beach	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Dune	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

As natural features, created and defined by the processes that form them, dunes are inherently vulnerable to any climate changes that alter those processes.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
Yes	No	No	Yes

VULNERABILITY

Wind is the formative process for dunes and, as such, any change in the wind regime due to climate change would impact directly on dunes. The degree of impact will depend on the overall exposure of the site and the maturity/stability of the existing dunes.

With a change in the direction or speed of wind at a dune system, there is potential for sand to be moved (by Aeolian processes) in different directions/distances and in so doing to change the form of the dune. This will not necessarily lead to a deterioration in the integrity of the dunes, however it is possible that the dunes could be lowered, reducing their flood protection benefit, or move into areas where they are disruptive and/or create a hazard.

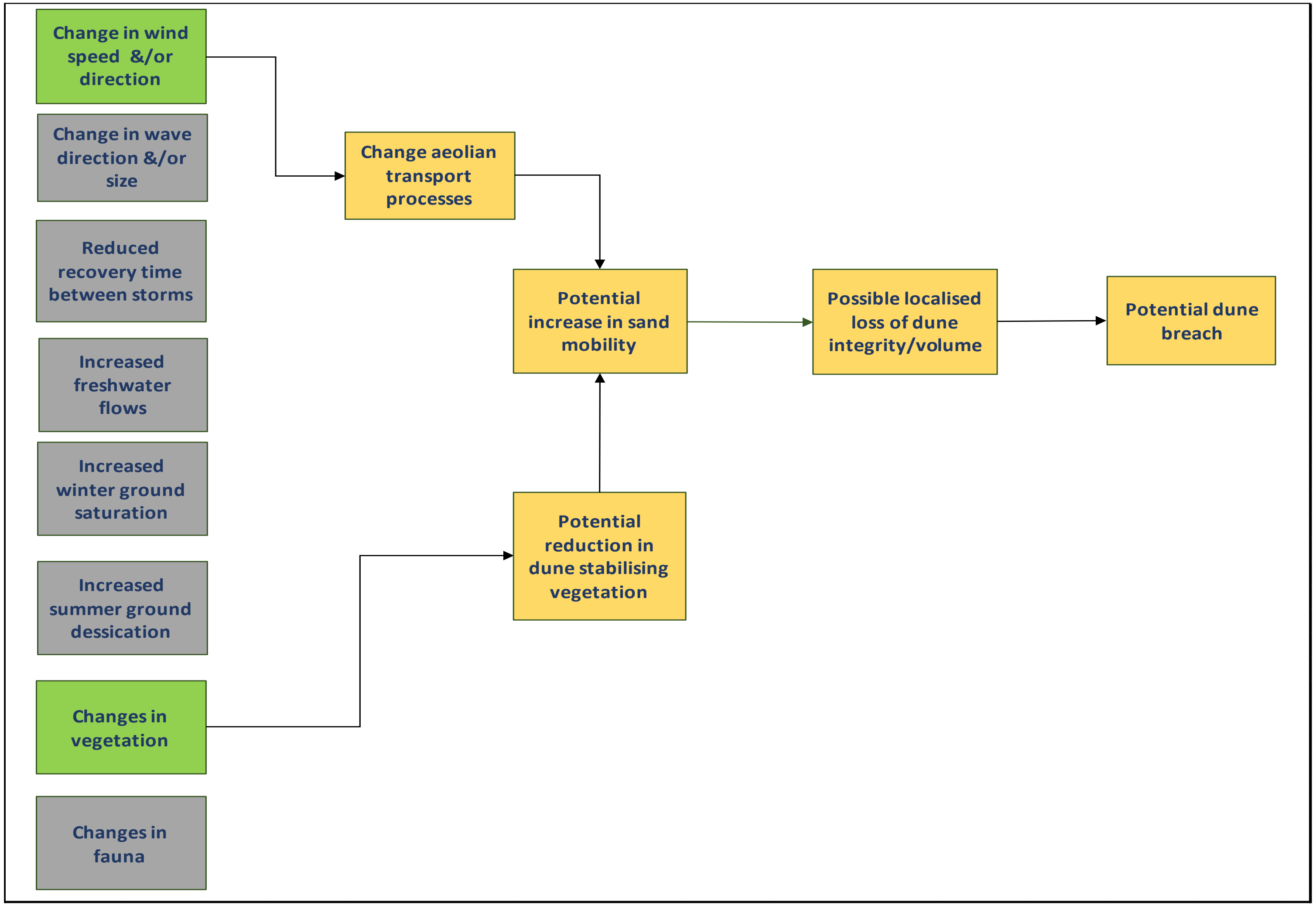
In addition to the wind changes, there is potential for future changes in temperature to impact dune stabilising vegetation such as marram. If the coverage of this vegetation is reduced, this would increase the exposure of the underlying sand surface, increasing the potential for transport (erosion) of the dune surface.

Together, and individually, these wind and vegetation changes can impact dune integrity, and could potentially lead to dune blow-outs and breach.

Overall the potential vulnerability of dunes to these factors is considered to be no greater than Moderate, i.e. similar to the qualitative assessment category assigned for the effect of the hydrodynamic factors. While dune systems are critically dependent upon wind driven processes for their formation, it is likely that the consequences of a change in the wind regime would not be dramatic in terms of overall asset function.

ASSET TYPE: Dune	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Barrier Beach	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

As natural features, created and defined by the processes that form them, barrier beaches are inherently vulnerable to any climate changes that alter those processes.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
Yes	Yes	No	Yes

VULNERABILITY

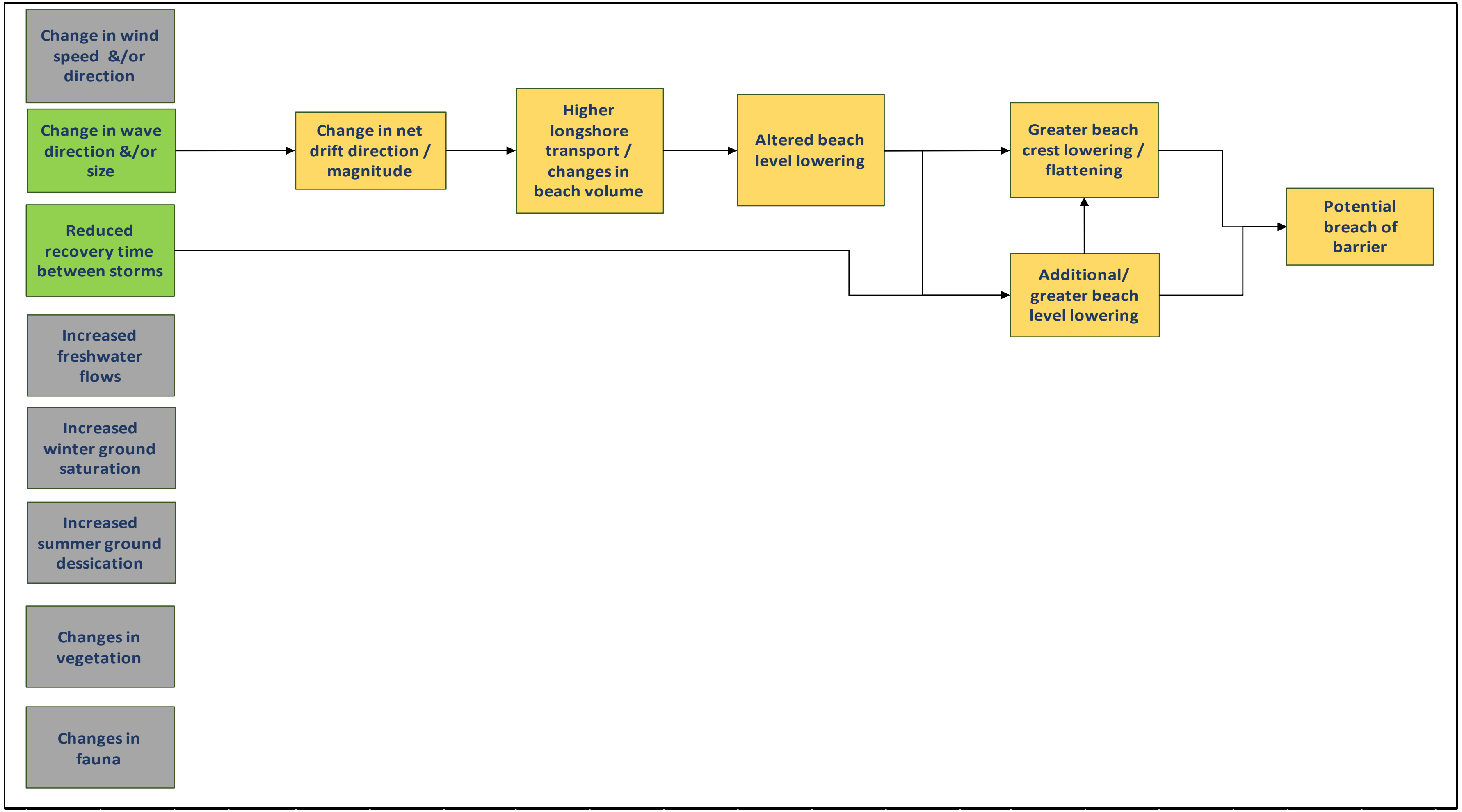
The wave exposure of barrier beaches is a critical characteristic on both managed and unmanaged beaches. In particular, wave direction drives the process of longshore sediment transport which defines how and where beach material moves and accumulates, and hence the amenity and coast protection function of the beach. Consequently, any change in the gross and/or net wind direction impacting locally wind generated waves has potential to alter longshore transport processes which in turn have potential to significantly alter beach characteristics. Where the beach has natural or man-made cross-shore features (e.g. rock outcrops or groynes) this change in longshore drift could be particularly significant.

The other potential climate change impact that could affect beach performance and deterioration is the sequencing and patterns of storms. The antecedent conditions at the beach are important to the resilience of the beach under storm conditions. During a storm event the draw-down of beach material will typically lower beach levels, which then gradually rebuild under subsequent ‘typical’ (day-to-day) conditions. However, if the frequency/sequencing of storms was to change such that events regularly impact a beach in quick succession, the beach will not have opportunity to naturally recover, and hence potentially cause greater draw-down and beach erosion. This can have significant consequences on a barrier beach if the crest is lowered to a point where water can overtop of flow into the backing lagoon. This can create conditions for a full breach of the barrier beach, impacting flood risks and salinity in any backing lagoon.

As with other climate change factors the effects of these variables will differ depending upon the beach material and exposure. Although the potential vulnerability to these factors is considered to be High for barrier beaches, this is consistent with the categorisation already attributed due to hydrodynamic factors.

ASSET TYPE: Barrier Beach	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Cliff	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers both natural and stabilised cliffs. As natural features, cliffs are strongly influenced by the processes that form them, and are inherently vulnerable to any climate changes that alter those processes.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	Yes	Yes

VULNERABILITY

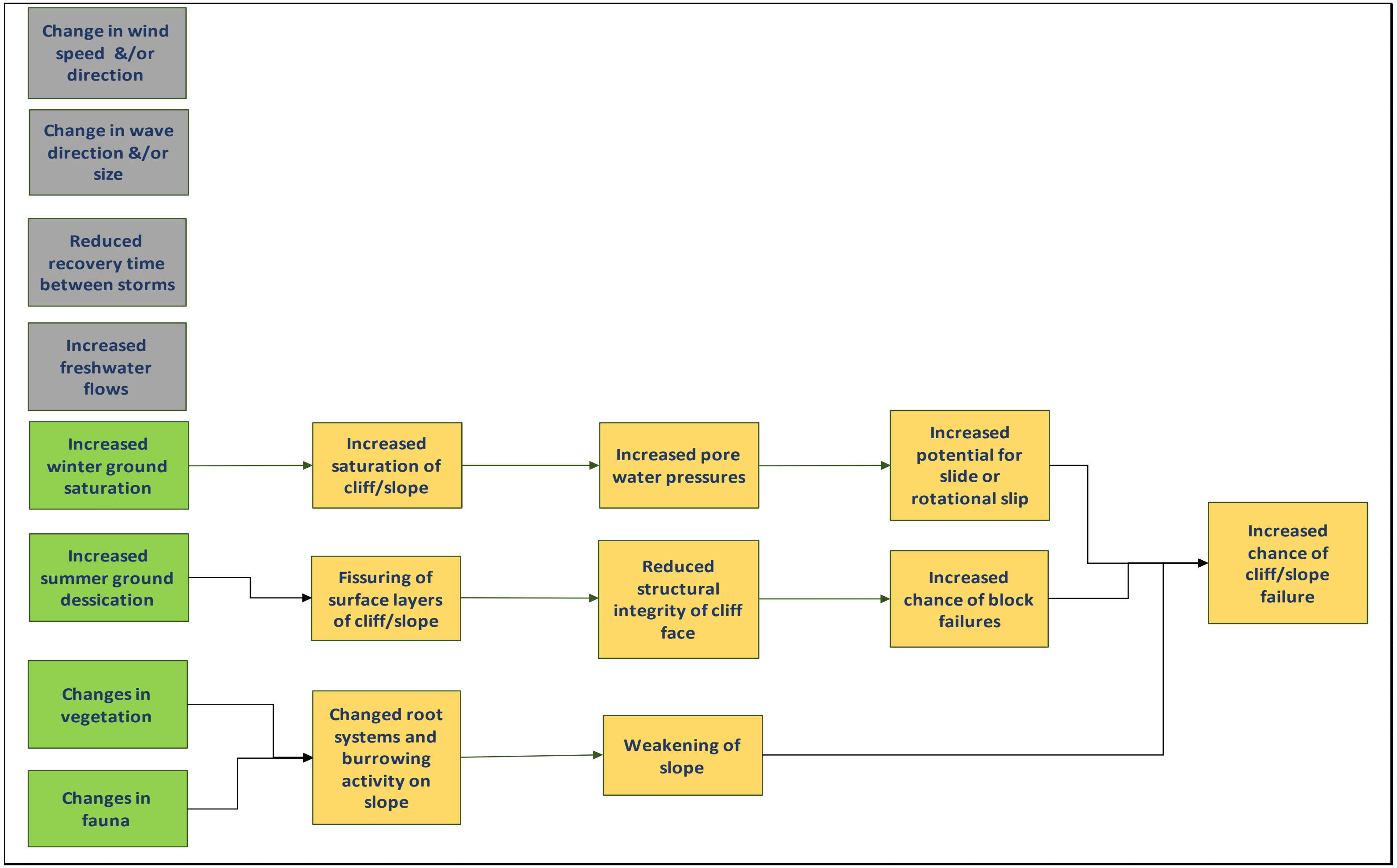
Cliffs, and in particular soft rock cliffs, are particularly susceptible to deterioration through changes in rainfall patterns. While toe erosion through typical coastal processes are important (particularly on hard rock cliffs), the failure mechanisms of soft cliffs are highly influenced by ground water levels. High levels of autumn/winter rainfall are proven to correlate directly to increased land-sliding and slope failure activity. The increased weight in the slope and increased pore water pressure can exceed stability thresholds within the unsupported slope, resulting in failure. The form and extent of failure is typically limited/dictated by the specific geology of the cliff. The detailed failure mechanisms are reported in detail in references such as the 2002 'Investigation and Management of Soft Rock Cliffs'.

Soft Rock cliffs are also susceptible to deterioration due to desiccation processes under reduced rainfall processes, which can reduce the structural integrity of the slope surface. Similarly, changes to vegetation and/or fauna (resultant from temperature and rainfall changes) could also impact the surface integrity of coastal slopes due to changes in root systems and/or animal burrowing activity. All of these changes could potentially weaken the surface of the slope making it more prone to failure.

As discussed, the impact of these variables will differ depending upon the cliff geology. So, although for some cliffs the effects will be Low, on others the potential vulnerability to these factors may be to be Moderate to High, due to the significance of rainfall on soft cliff failure mechanisms. So, in some instances the vulnerability might be greater than the Moderate (natural) and Low (stabilised) ratings due to hydrodynamic factors alone.

ASSET TYPE: Cliff	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Saltmarsh	ENVIRONMENT: Estuary

ADDITIONAL CLIMATE CHANGE FACTORS

As natural features, created and defined by the processes that form them, saltmarshes are inherently vulnerable to any climate changes that alter those processes.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
Yes	No	Yes	Yes

VULNERABILITY

Saltmarshes are defined by their position in relation to tidal elevations, their low energy exposure, and the presence of saltmarsh vegetation. There is potential for these factors to be impacted by altered rainfall, temperature and wind patterns.

Changes in wind speed or direction would have potential to increase the local wind generated wave energy. This energy would result in increased erosion of the exposed saltmarsh edge reducing the overall area of saltmarsh. Similarly, increased wave propagation over the saltmarsh surface could result directly in erosion of the saltmarsh surface as well as reducing the potential for sedimentation on the marsh surface. This would both directly impact the marsh feature as well as potentially reducing the saltmarsh vegetation.

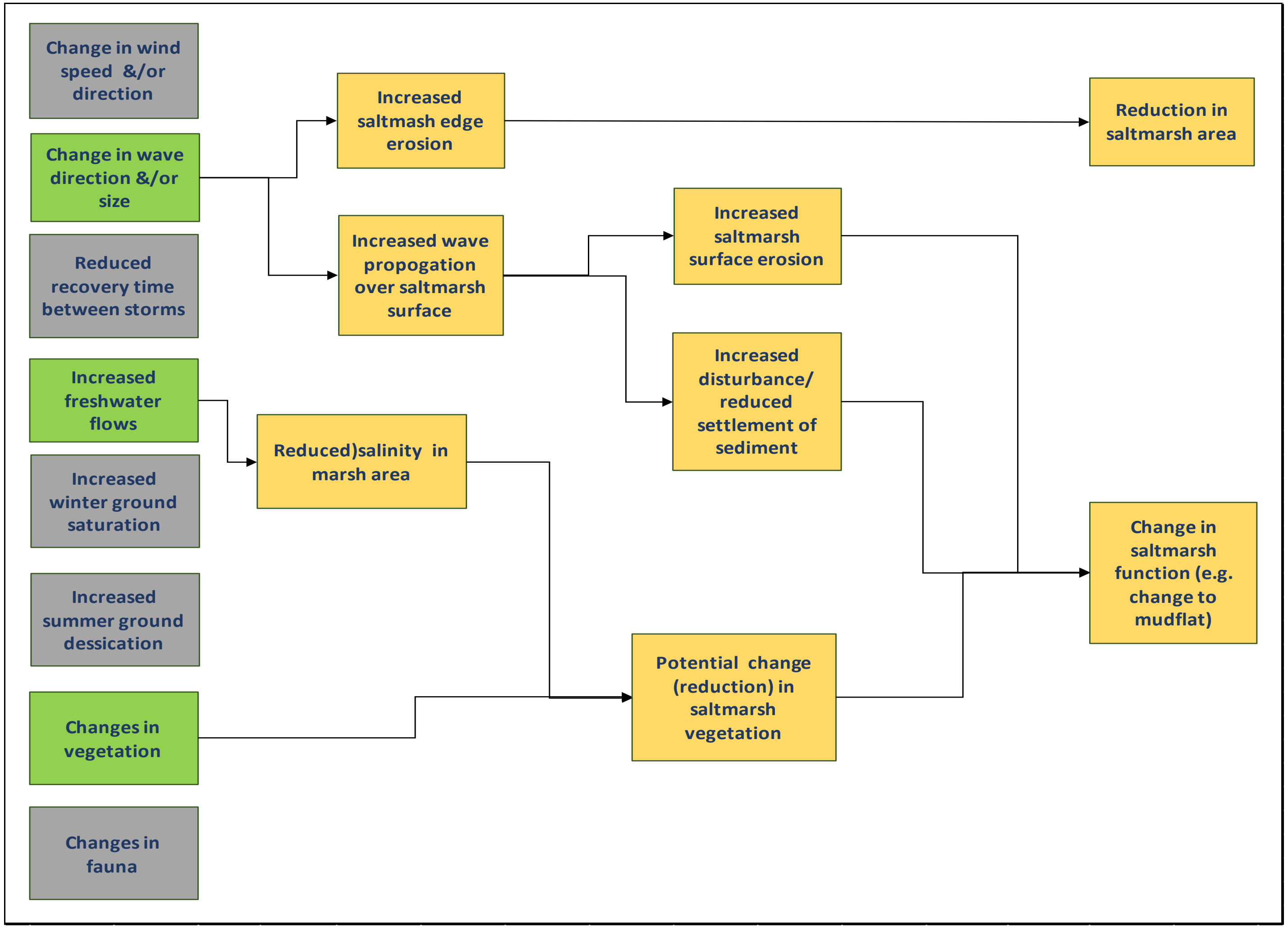
Changes in rainfall, in particular increased rainfall (likely in winter) could increase freshwater flows to the saltmarsh area, altering the salinity regime which in turn could impact vegetation.

Changes in temperature (air and water) could also directly impact the coverage of saltmarsh vegetation. If the current species were not replaced by others tolerant of the warmer conditions, then a reduction in vegetation potentially exposing the surface to greater erosion and transforming into mudflats.

Overall the potential vulnerability to these factors is considered to be Low for saltmarsh (i.e. no greater than that identified for hydrodynamic factors). While saltmarshes are critically dependent upon environmental conditions for their formation, it is likely that the consequences of a change in the locally generated wave regime would not be significant in terms of overall asset function.

ASSET TYPE: Saltmarsh	ENVIRONMENT: Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Washland	ENVIRONMENT: Fluvial

ADDITIONAL CLIMATE CHANGE FACTORS

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	Yes	Yes

VULNERABILITY

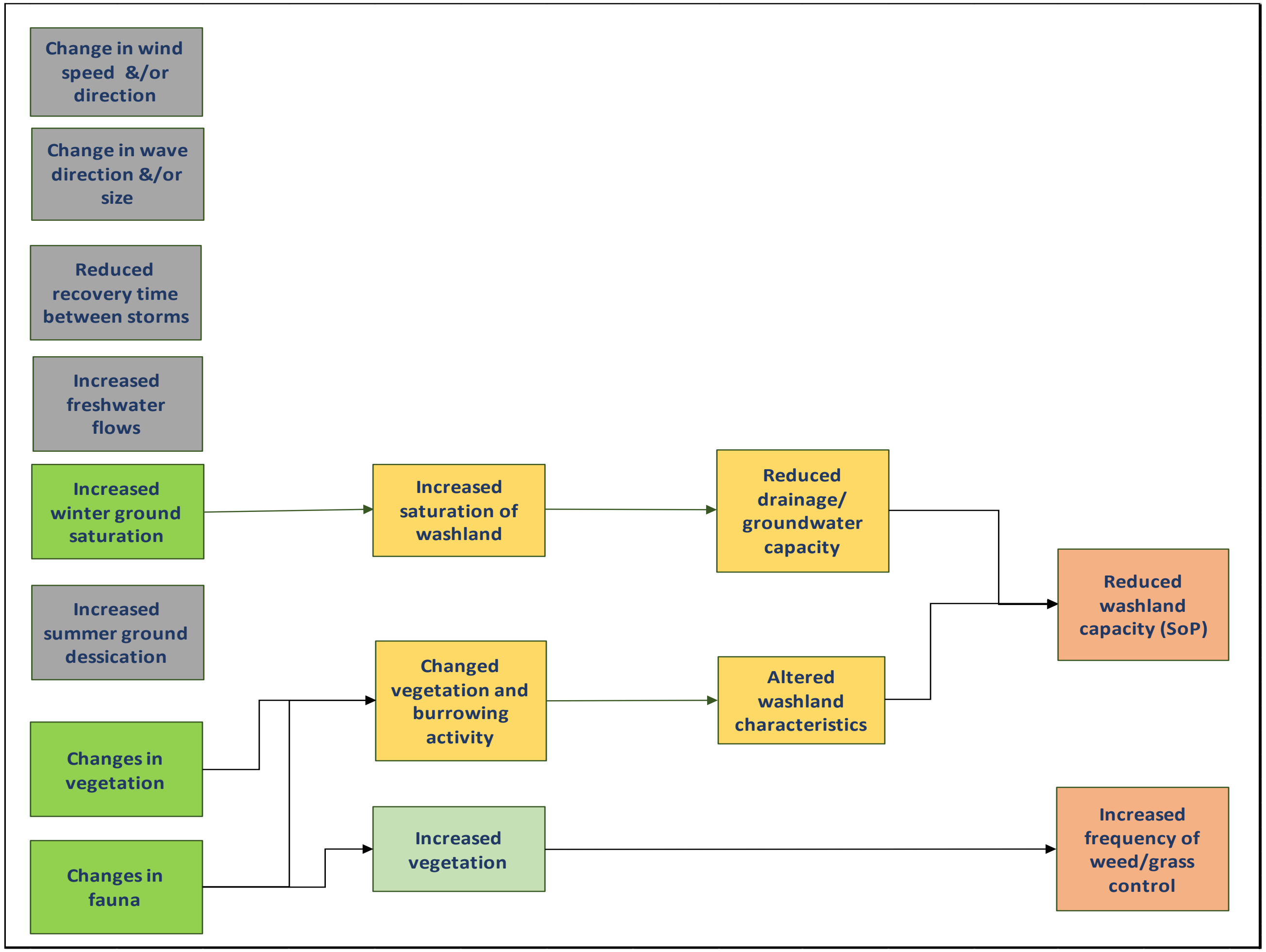
Changes in rainfall would potentially impact washlands, as an increase in rainfall volume (most likely in winter) would be expected to increase the occurrence of saturation of the washland ground reducing its capacity to drain flood waters. This would consequently reduce the capacity of the washland for flood storage. This is primarily a capacity/Standard of Protection impact.

Changes in rainfall together with changes in average temperature (either in combination or individually), will also potentially affect flora and fauna which could impact washlands. Changed vegetation and/or animals could alter the surface characteristics of the washland, through patterns of animal burrowing and roots/vegetation, which could potentially impact its capacity if the vegetation cover significantly increases. Further, additional growth of vegetation within the channel and banks would require an increased frequency of grass and weed mowing/clearance, a maintenance impact.

These impacts are likely to have a negligible effect on washland deterioration, as the consequences primarily relate to the Standard of Protection.

ASSET TYPE: Washland	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Control Gate (Guillotine Gate and Penstock)	ENVIRONMENT: Fluvial

ADDITIONAL CLIMATE CHANGE FACTORS

There are several types of Control Gate, but this assessment only includes Guillotine Gates and Penstocks.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	Yes	No

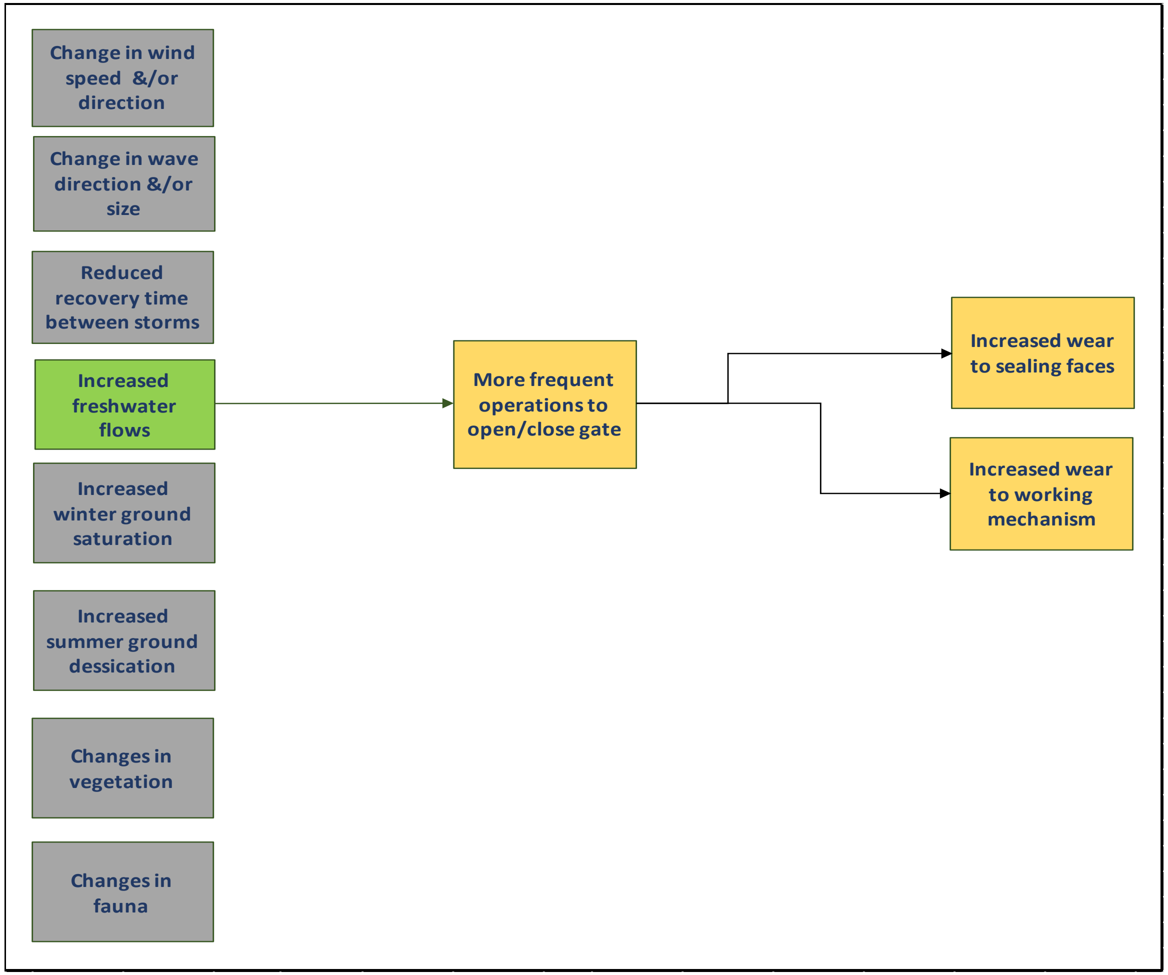
VULNERABILITY

Changes in rainfall could directly impact Guillotine Gates and Penstocks, rather than other forms of control gate, as they are generally used to control the flow of rainfall run-off into the main river channel whereas other forms of gate manage in channel flows. An increase in rainfall volume (most likely in winter) would be expected to increase frequency of operation of the gates. This may also result in increased wear to components, and therefore an increase in maintenance requirements.

The effects of these changes will though not increase the qualitative assessment of vulnerability above the Low rating assigned due to hydrodynamic factors.

ASSET TYPE: Control Gate (Guillotine Gate and Penstock)	ENVIRONMENT: Fluvial

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONALCLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Jetty	ENVIRONMENT: Fluvial & Estuary

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers timber jetties in estuarine and tidal river environments.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	No	Yes

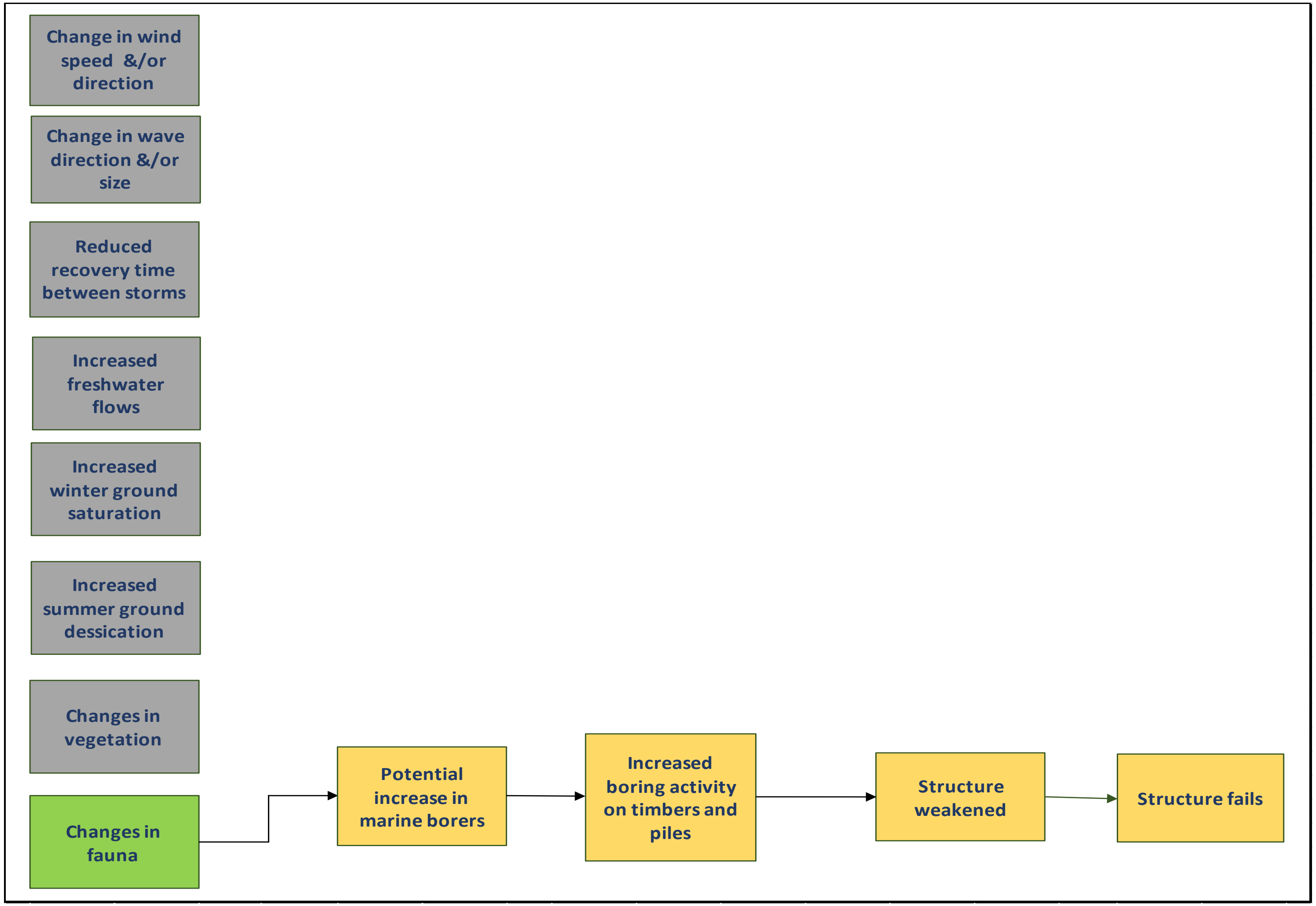
VULNERABILITY

Timber structures in the water environment are vulnerable to deterioration through typical weathering processes and in the marine environment, to the activity of marine organisms. Under future conditions of increased temperature, there could be a change in water temperature, which in turn has potential to alter ecology and biodiversity of marine organisms. In particular, this could change the extent and form of marine borers present in tidal areas, which may impact upon their activity on timber structures, which in turn could increase deterioration rates. This would require increased maintenance activity and could compromise performance.

This is however unlikely to result in a significant change in the deterioration rate of these structures, and is considered to be of Low magnitude, and as such less than the Moderate rating assigned due to hydrodynamic factors.

ASSET TYPE: Jetty	ENVIRONMENT: Fluvial & Estuary

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Groyne	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers timber groynes in coastal environments. The performance of groynes will also be affected by any changes to beach processes, however those performance factors are not considered here (see separate assessment for beaches).

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	No	Yes

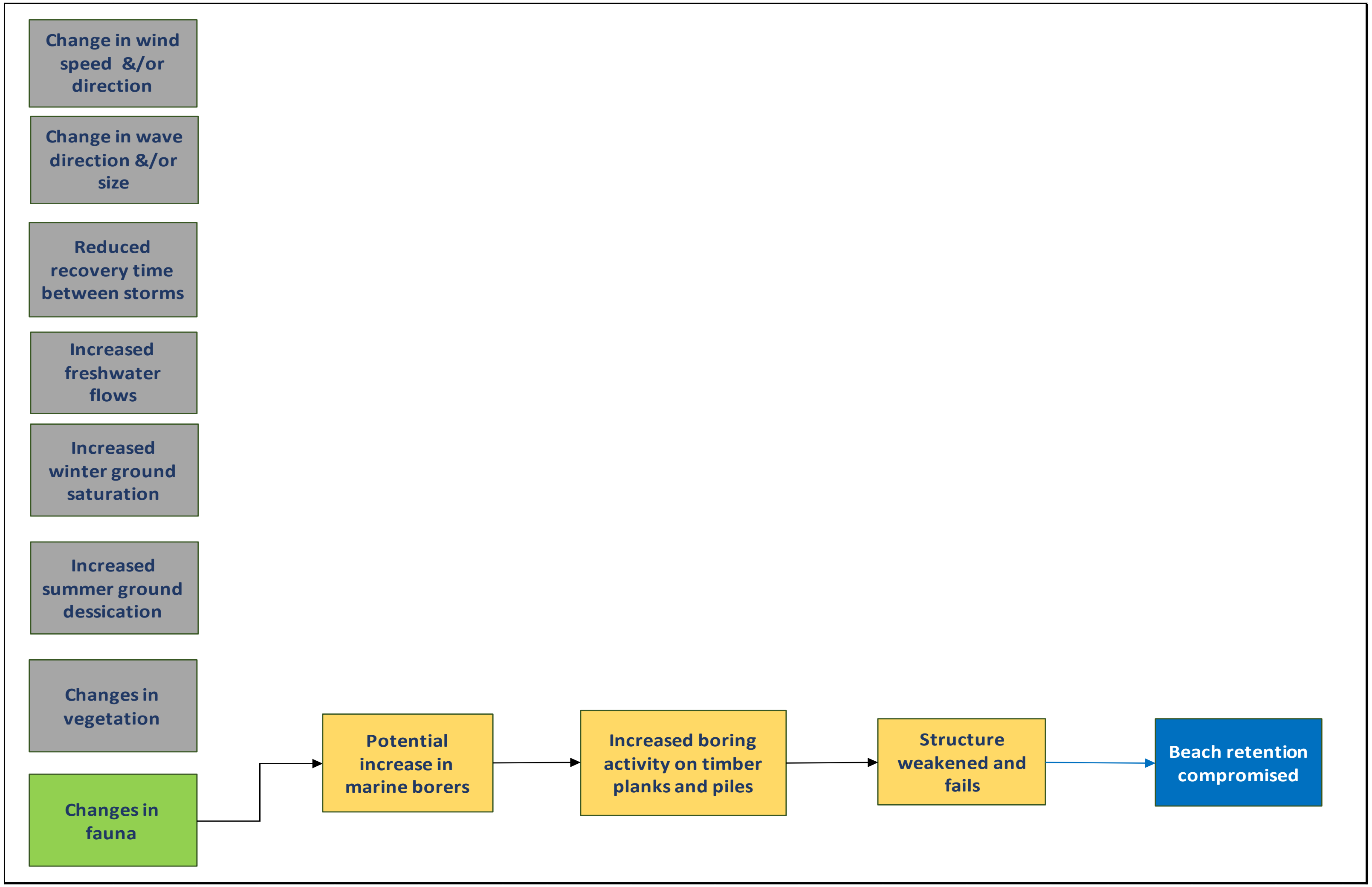
VULNERABILITY

Timber structures in the water environment are vulnerable to deterioration through typical weathering processes and in the marine environment, to the activity of marine organisms. Under future conditions of increased temperature, there could be a change in water temperature, which in turn has potential to alter ecology and biodiversity of marine organisms. In particular, this could change the extent and form of marine borers present in tidal areas, which may impact upon their activity on timber structures, which in turn could increase deterioration rates. This would require increased maintenance activity and could compromise performance.

The effects of these changes will though not increase the qualitative assessment categorisation above the Moderate rating assigned due to hydrodynamic factors.

ASSET TYPE: Groyne	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



ADDITIONAL CLIMATE CHANGE FACTORS

ASSET TYPE: Slipway	ENVIRONMENT: Coastal

ADDITIONAL CLIMATE CHANGE FACTORS

This assessment covers timber slipways in coastal environments. The performance of slipways can also be affected by any changes to beach processes around them, however those performance factors are not considered here.

The potential for other climate change factors (i.e. in addition to those changes in hydrodynamics considered for the primary qualitative assessments) was identified for these assets as below.

ADDITIONAL CLIMATE CHANGE FACTORS CONSIDERED			
Wind Speed/Direction	**Increased Storm Frequency**	**Changed Rainfall**	**Changed Temperature**
No	No	No	Yes

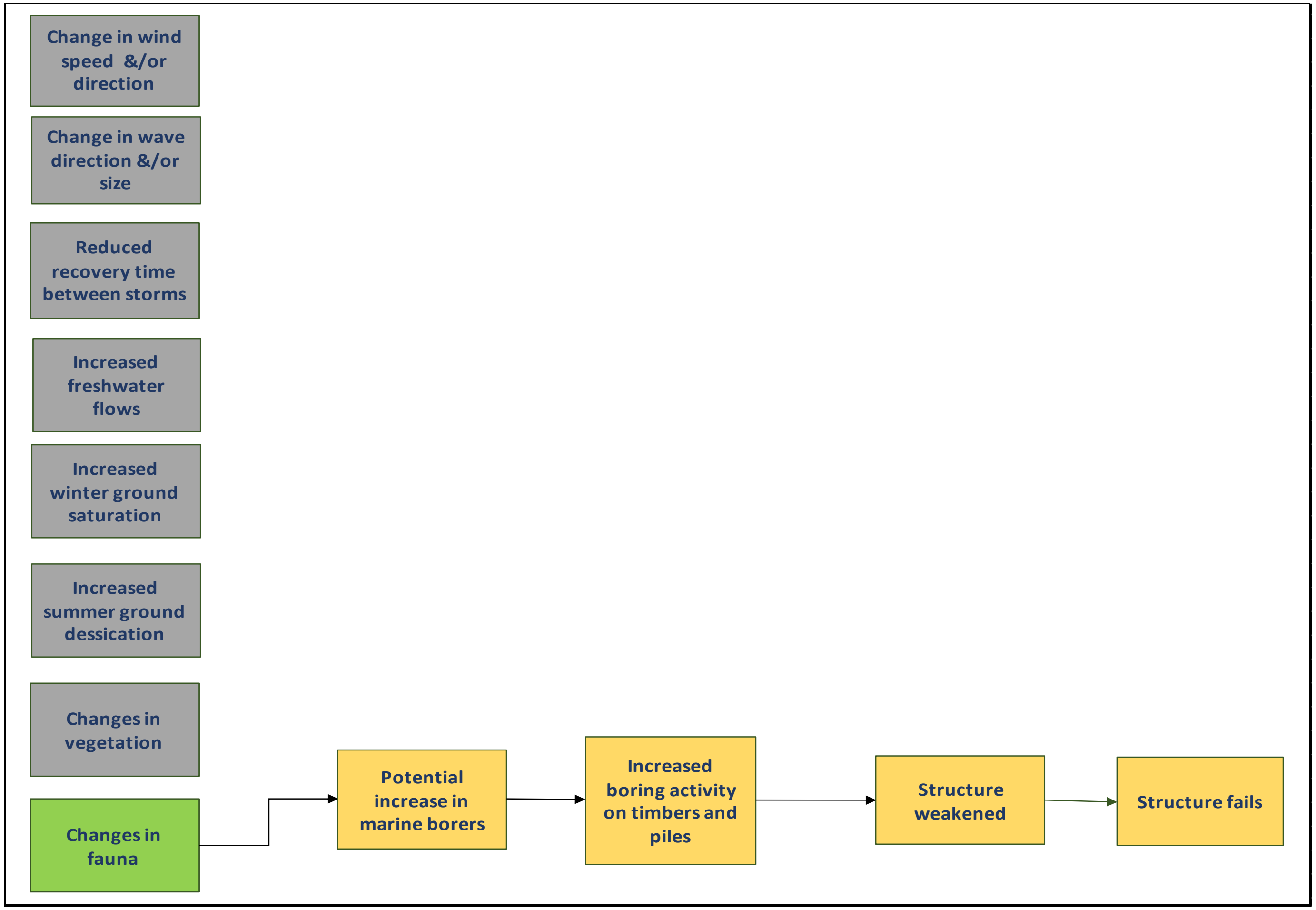
VULNERABILITY

Timber structures in the water environment are vulnerable to deterioration through typical weathering processes and, in the marine environment, to the activity of marine organisms. Under future conditions of increased temperature, there could be a change in water temperature, which in turn has potential to alter ecology and biodiversity of marine organisms. In particular, this could change the extent and form of marine borers present in tidal areas, which may impact upon their activity on timber structures, which in turn could increase deterioration rates. This would require increased maintenance activity and could compromise performance.

The effects of these changes will though not increase the qualitative assessment of vulnerability above the Moderate rating assigned due to hydrodynamic factors.

ASSET TYPE: Slipway	ENVIRONMENT: Coastal

RELATIONSHIP BETWEEN DETERIORATION PROCESSES AND ADDITIONAL CLIMATE CHANGE FACTORS



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