Break O'Day Council Georges Bay Coastal Inundation Vulnerability

Revision 01

Prepared for: Break O'Day Council

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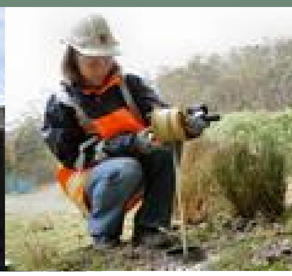
transport infrastructure | community infrastructure | industrial infrastructure | climate change



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Authorised by: Steve Edwards (signature) Date: 13 December 2011

Steve Edwards

Executive Summary

This project provides an indication of potential inundation levels that may be anticipated to occur within the Georges Bay area of St Helens on the North east coast of Tasmania in the municipality of Break O'Day.

The assessment incorporates consideration of river flood volumes estimated for George River contributing freshwater inputs to the Bay and consequently elevating surface levels if coincident with incoming tides restricting outflow from the bay. The potential impact of projected changes in rainfall intensity as a result of climate change was incorporated into projections of potential future inundation levels for 2050 and 2100.

The project also assessed the potential impact of storm surge tides and additional set-up due to wind wave effects that may be experienced with the bay. The potential impact of projected changes in sea levels as a result of climate change was also incorporated.

The following table presents a summary of various components contributing to surface levels of Georges Bay that may be expected with various recurrence intervals or probabilities and indicates how these may vary towards the end of the century

River flood contributions (flood flow contribution to surface elevation. *(m addition)*									
ARI	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**
~AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*	*0.005*	*0.002*	*0.001*
Present Day	0.13	0.28	0.40	0.52	0.69	0.82	0.95	1.12	1.26
2050	0.17	0.38	0.53	0.75	1.01	1.21	1.41	1.69	1.90
2100	0.19	0.42	0.57	0.84	1.13	1.36	1.6	1.92	2.16
Potential storm surge inundation levels - Georges Bay (m AHD)									
Present Day	0.85	0.92	0.96	1.00	1.03	1.06	1.08	1.10	1.12
2050 *(inc 0.3m SLR)*	1.15	1.22	1.26	1.30	1.33	1.36	1.38	1.40	1.42
2100 *(inc 0.9m SLR)*	1.75	1.82	1.86	1.90	1.93	1.96	1.98	2.00	2.02
Wind / Wave setup *(modified for directional strength)(m addition to surface level)*									
2000m Fetch	0.08	0.10	0.11	0.13	0.14	0.16			
5000m Fetch	0.18	0.23	0.26	0.30	0.36	0.40			

For planning purposes, an estimate was provided for a potential 1 in 100 year occurrence or 1% probability event for potential surface levels in the bay. The estimate has been provided as a minimum likely inundation level, based on potential combinations of the above events, with a potential upper limit of inundation provided determined from a coincident combination of the respective components.

Potential Inundation Levels	1% AEP (100yr ARI) Lower limit	1% AEP (100yr ARI) Upper limit
Present Day	1.25 m AHD	2.3 m AHD
2050	1.6 m AHD	3 m AHD
2100	2.3 m AHD	3.7 m AHD

It should be noted that the above values do not imply that the inundation levels will be reached or that it is not possible that inundation may in fact exceed the levels indicated. However, under conditions of climate change modelled on a potential future with increasing high greenhouse gas concentrations, the values are considered to represent a reasonable range based on available information.

1. Background

In 2009, the Break O'Day Council, with assistance from the Australian and Tasmanian Governments Natural Disaster Mitigation Program sought to develop a Floodplain Risk Management Plan for the lower George River Flood plain. This was to be based on the Coastal Risk Assessment Management Plan and template guidelines developed by the Department of Primary Industries and Water. Assets on the floodplain were considered to be of critical importance to the community including primary road access, power lines, especially for Binalong Bay settlement and Bay of Fires and the recently upgraded sewage treatment works now managed by Ben Lomond Water.

pitt&sherry, in partnership with the Water Research Laboratory (WRL) of the University of New South Wales (UNSW) and also SGS Economics and Planning were engaged to provide a technical report on potential inundation risks as an input to the risk planning process (pitt&sherry,2010).

This project represents an update to a 2009 Break O'Day Council project with the assessment of inundation levels and potential probability of inundation extended from the initial project area of the George River flood plain and river mouth to broader areas of Georges Bay, including the town of St Helens and outlying suburbs including Stieglitz.

In addition, pitt&sherry were requested to provide the update utilising recently published Climate Futures for Tasmania research.

The project area defined for this assessment is indicated in the below figure (figure 1).

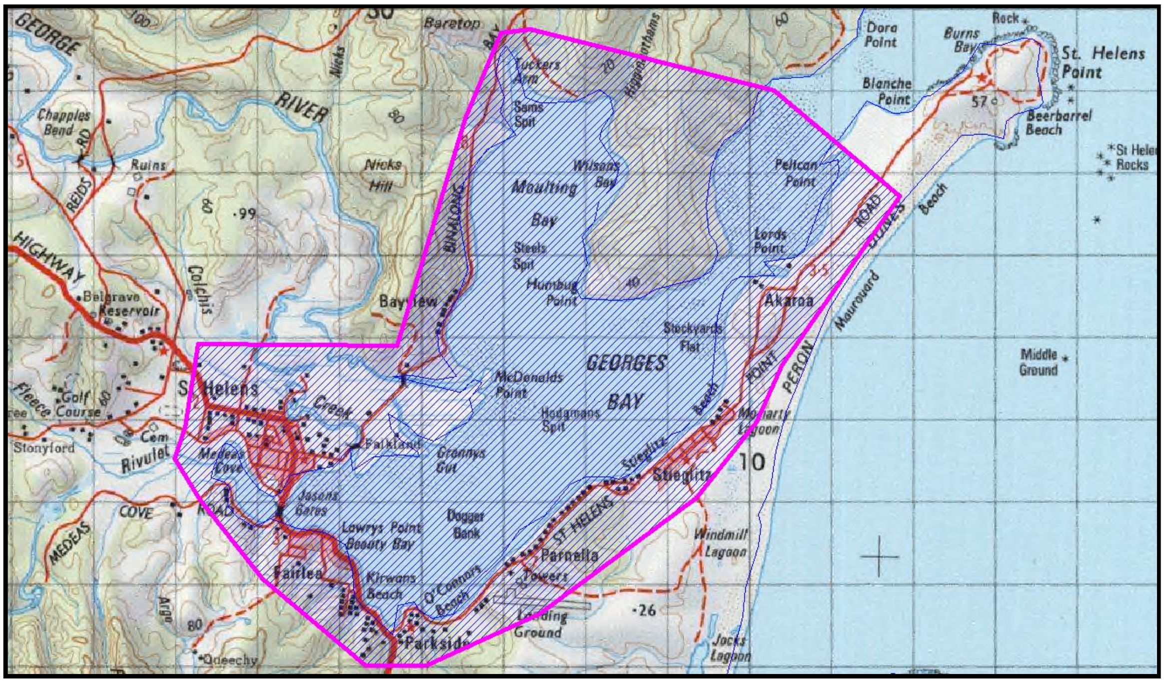


Figure 1. Project area

2. Georges Bay Inundation Levels and Climate Change Considerations

2.1 River Flood Flows

Based on the historic river flow assessment, the 2009 project identified that the river flooding observed following a significant rainfall over three days in February, 2004 was likely to represent an approximate 1 in 50 year occurrence. The assessment identified that assuming that an incoming tide significantly restricted outflow of the river water from the bay the river flow during this event was estimated to contribute to an approximate 60 cm elevation of surface levels in Georges Bay. Detailed analysis of the 23 year record of river flow data was undertaken to determine potential and projected annual recurrence interval flood flow volumes.

The below table (table 1) indicates the river flow volumes estimated to occur for a range of different recurrence interval or probability floods based on historically observed flow records (modified after SKM,2005).

Table 1. George River flow volumes based on historically observed volumes (projected by annual recurrence interval and approximated annual exceedance probability).

		Historically observed
ARI	**AEP**	**Cumecs (m3/s)**
1.01	0.990099	49.36
1.11	0.900009	55.51
1.25	0.8	66.93
2	0.5	127.57
5	0.2	270.21
10	0.1	386.42
15	0.066667	456.21
20	0.05	506.35
25	0.04	545.54
30	0.03333	577.76
50	0.02	668.84
75	0.0133	741.93
100	0.01	794.2
200	0.005	921.48
500	0.002	1092.53
1000	0.001	1224.03
2000	0.0005	1357.33

2.2 Rainfall Intensity – Break O'Day Municipality

Based on records of historically observed rainfall, the Institute of Engineers Australia have compiled a series of maps indicating rainfall intensity for Australian locations titled "Australian Rainfall and Runoff - A guide to flood estimation" (AR&R, 1987).

The figure below indicates the rainfall intensity (in millimetres volume of rain) for a 1 hour duration rainfall event estimated to occur on average once every 50 years (50 yr ARI).

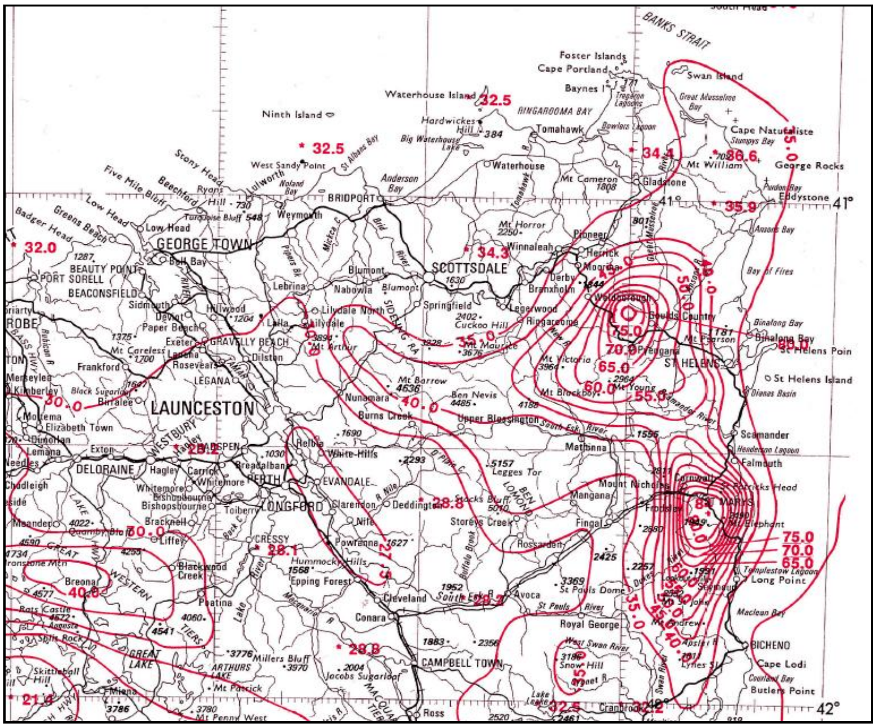


Figure 2. Rainfall intensity map for the North east of Tasmania (part reproduced from AR&R, 1987). In mm for a 1 hour volume, 50year ARI event.

The AR&R mapping indicates that the Break O'Day area of Tasmania traditionally receives the state's greatest intensity rainfall events. The area immediately centred on St Marys and Grey receives the greatest intensity events though the George River catchment and the Pyengana area receives almost equivalent intensities.

2.3 Projected Rainfall Intensity Changes

Climate change projections for Tasmania have been developed in the recently completed Climate Futures for Tasmania (CFT) project which assessed a broad range of climate variables under two potential greenhouse gas emission scenarios to the end of the century (a high greenhouse gas emissions scenario A2 and a more moderate scenario) (Grose et al, 2010).

The Climate Futures for Tasmania (CFT) project undertaken by the Antarctic Climate and Ecosystems Collaborative Research Centre (ACE CRC) is a collaborative research initiative generating high-resolution climate simulations for Tasmania on a 0.1º (~10km) grid. By applying a modelling process of dynamical downscaling of general circulation models (GCMs), the project outputs have captured processes that operate to influence local climate (Grose et al., 2010). The processes provide significant improvements over regional GCM's enabling improved spatial resolution and accuracy of outputs (Corney et al., 2010).

The outputs of the project have been integrated into a climate analysis and communication tool, ClimateAsyst from which information pertinent to rainfall in the project area was assessed.

The below figures indicate outputs from the CFT project (with the catchments contributing to inflows in the Georges Bay indicated in the red outline). The figures present indicative volumes of rainfall that may be expected during a 24 hour rainfall event under two potential recurrence intervals (a rainfall event expected to occur on average once every 20 years and also that which may be expected to occur on average once every 100 years) assuming the modelled A2 high greenhouse gas emissions scenario. Also indicated is the percentage change in volume anticipated for the two events for the period 2070 to 2099 compared to the base period of 1961 to 1990.

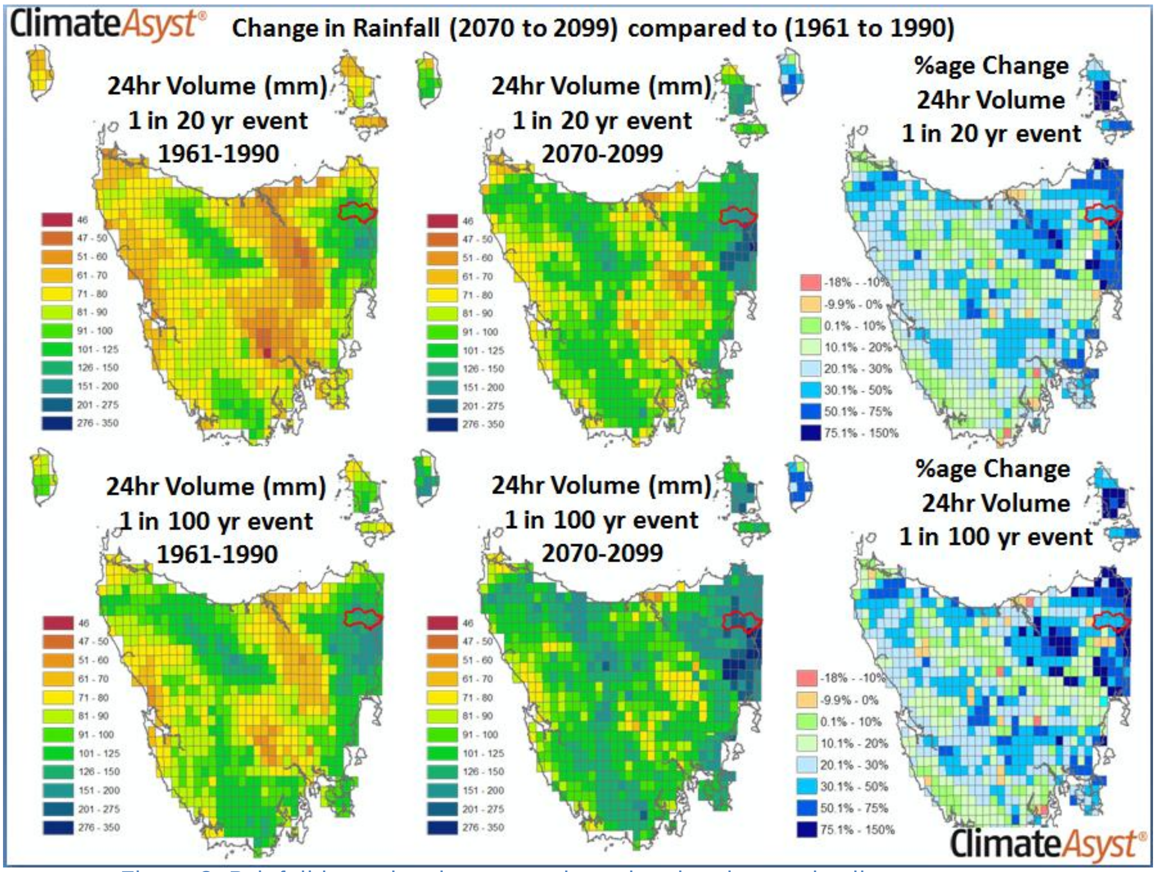


Figure 3. Rainfall intensity changes projected under changes in climate.

The following figures (figures 3 and 4) indicate, in more detail, the rainfall intensity changes for the catchments which feed into Georges Bay produced as outputs from the climate change communication tool, ClimateAsyst.

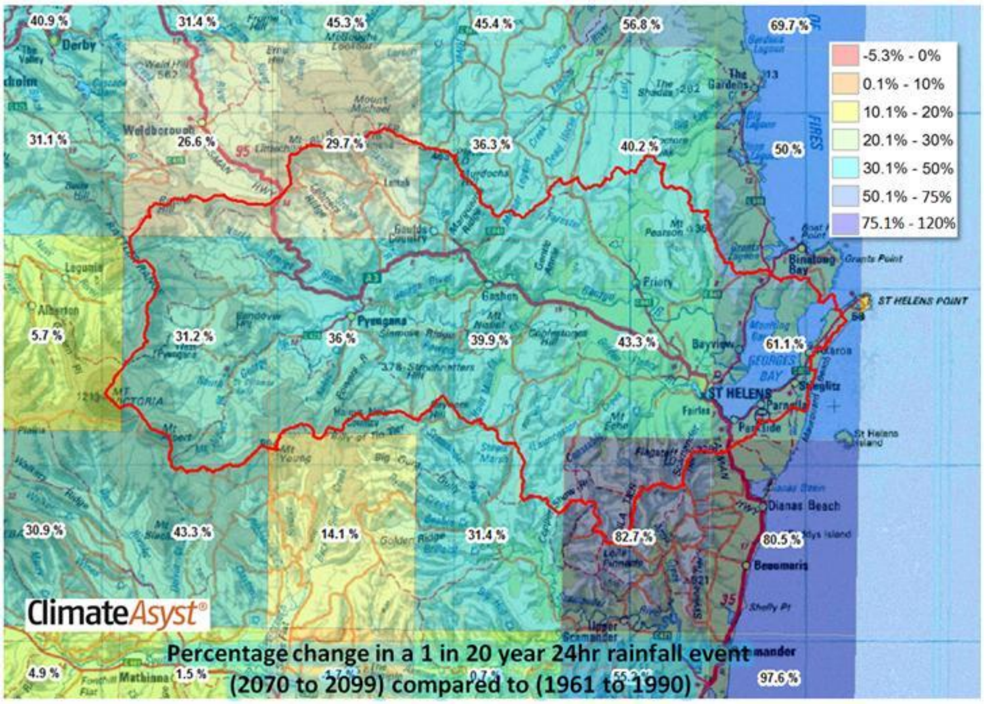


Figure 4. Projected rainfall intensity changes - Georges Bay feeder catchments - 20yr ARI event

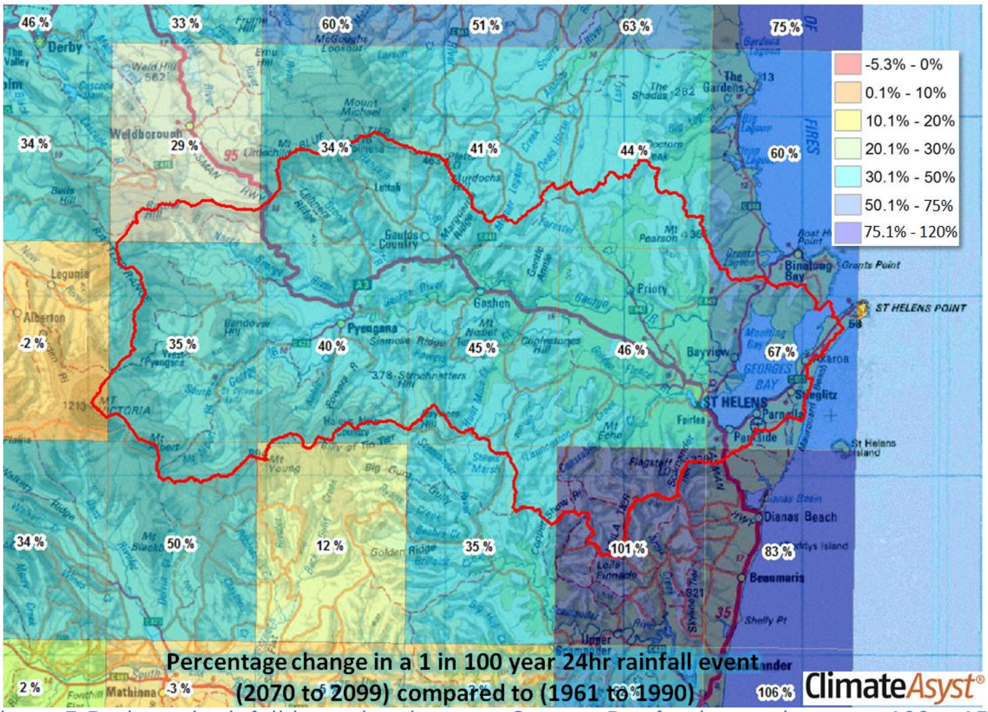


Figure 5.Projected rainfall intensity changes - Georges Bay feeder catchments - 100yr ARI event

It can be seen in figures above that projected changes in rainfall intensity for a 24 hour duration rainfall event within the catchment may vary from 12% to in excess of 100% increases.

While rainfall intensity for a 24 hr event cannot be directly related to flood occurrence and investigation of the full range of factors contributing to flooding within the catchment was beyond the scope of the study, the CFT modelling can however, provide an insight of potential changes which may occur.

The George River catchment and surrounding rivers which contribute to inflows of Georges Bay represent a total area of 566 km^2. The intersection of the catchment with various Climate Futures for Tasmania cells and their respective contribution to rainfall inflows of the catchment is shown in the below table (table 2).

The contribution of projected rainfall changes for the catchment was determined as follows:

- For each probability a rainfall event was simulated to indicate the anticipated volume of rain that may occur across the entire catchment
- The projected changes in intensity for each respective cell was then applied to the rainfall volume
- the combined volume was estimated for the entire catchment for the base period and the end of century period
- Average indicative changes in rainfall intensity (and trends in confidence intervals) as a result of projected climate change was then determined.

Table 2. Georges Bay catchment area - Climate Futures for Tasmania cell proportion.

CFT Cell Longitude	CFT Cell Latitude	Area km2	Proportion of CFT Cell
147.8	-41.3	1.1	1%
147.9	-41.2	14.7	16%
147.9	-41.3	82.2	88%
147.9	-41.4	10.3	11%
148.0	-41.2	42.9	46%
148.0	-41.3	87.7	94%
148.0	-41.4	0.5	1%
148.0	-41.4	0.1	0%
148.1	-41.2	25.3	27%
148.1	-41.3	87.8	94%
148.1	-41.4	9.5	10%
148.2	-41.2	27.7	30%
148.2	-41.3	93.0	100%
148.2	-41.4	28.9	31%
148.3	-41.2	0.0	0%
148.3	-41.3	53.2	57%
148.3	-41.4	1.1	1%
		566.1	

Table 3. Indicative rainfall intensity changes for Georges Bay feeder catchment.

Volume of rain in catchment over 24 hours (ML)		Simulated Storm volumes for George Bay catchments - Recurrence Interval (yrs ARI)								
Georges Bay Feeders		2	5	10	20	50	100	200	500	1000
Base dataset:	5% CI	35,075	43,040	48,657	53,670	59,266	62,770	65,884	69,336	71,552
1961-1990	MEAN	38,501	48,200	55,454	62,620	71,996	79,010	85,955	95,028	101,804
(1/1/1976)	95% CI	42,860	57,371	72,390	85,193	100,003	111,058	122,013	136,320	147,006
CFT Projection	5% CI	44,661	57,834	67,296	75,881	85,604	91,753	97,175	103,239	107,065
2070-2099	MEAN	49,068	64,804	70,741	88,629	104,217	115,871	127,369	142,420	153,544
(17/7/2084)	95% CI	77,264	100,540	121,025	145,323	163,535	145,833	181,566	205,218	222,756
Relative to Base period Mid scenario										
Low range		16%	20%	21%	21%	19%	16%	13%	9%	5%
Mid range		27%	34%	28%	42%	45%	47%	48%	50%	51%
High range		101%	109%	118%	132%	127%	85%	111%	116%	119%

The overall contribution of the projected change in rainfall intensity averaged over the Climate Futures for Tasmania cells is an increase in intensity of rainfall within a 24 hour period of between 27% for an event anticipated to occur on average once every 2 years to an increase of 51% for an event that may be expected to occur on average once every 1000 years.

The below figure graphically indicates the projected changes in rainfall volume recurrence intervals with indicative trend lines of the approximate 5% and 95% confidence intervals (around the mean value).

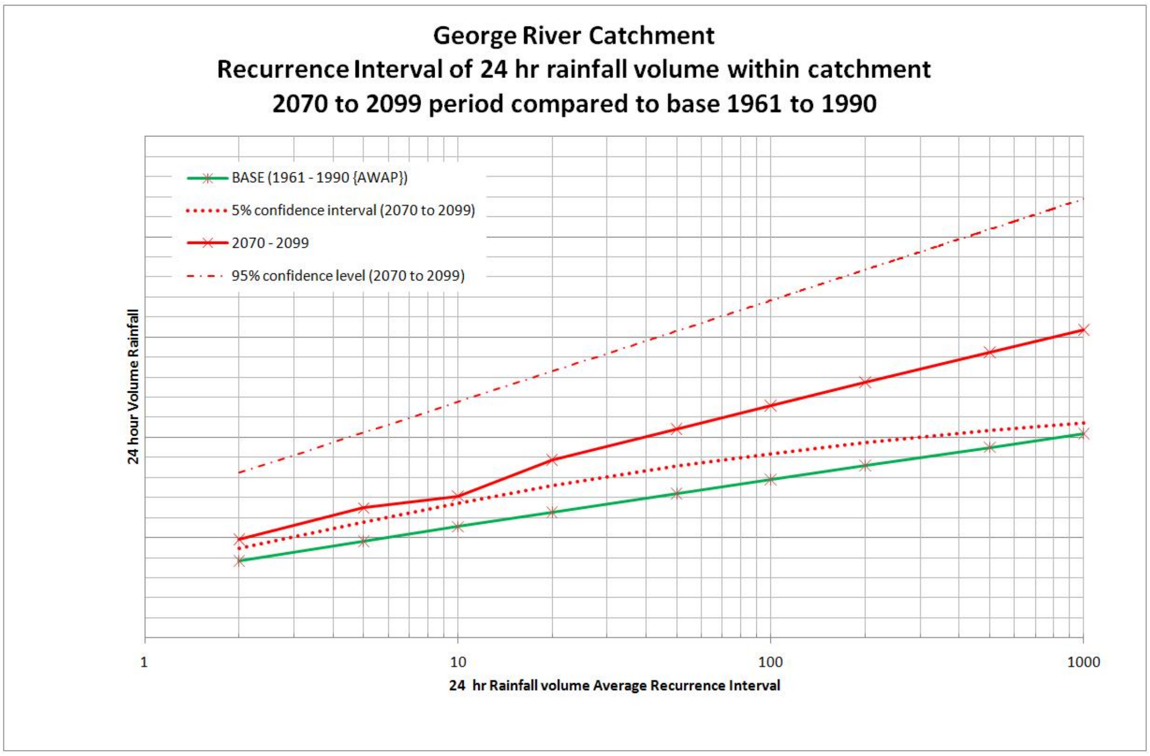


Figure 6. Indicative changed recurrence intervals for George Bay feeder catchments under projected changes in climate.

When considered in 20 year increments, changes in 24 hour duration rainfall event volumes with various recurrence intervals are indicated below.

Table 4. Projected rainfall intensity changes Georges Bay in incremental periods.

Georges Bay Feeders	2	5	10	20	50	100	200	500	1000
20 years (by 2031)	14%	18%	14%	21%	23%	24%	25%	25%	26%
40 years (by 2051)	19%	24%	19%	29%	31%	32%	33%	35%	35%
60 years (by 2071)	24%	30%	24%	36%	39%	41%	42%	44%	45%
80 years (by 2091)	29%	36%	29%	44%	47%	49%	51%	53%	54%

The above projected changes in rainfall intensity are indicated graphically in the following figure (figure 7).

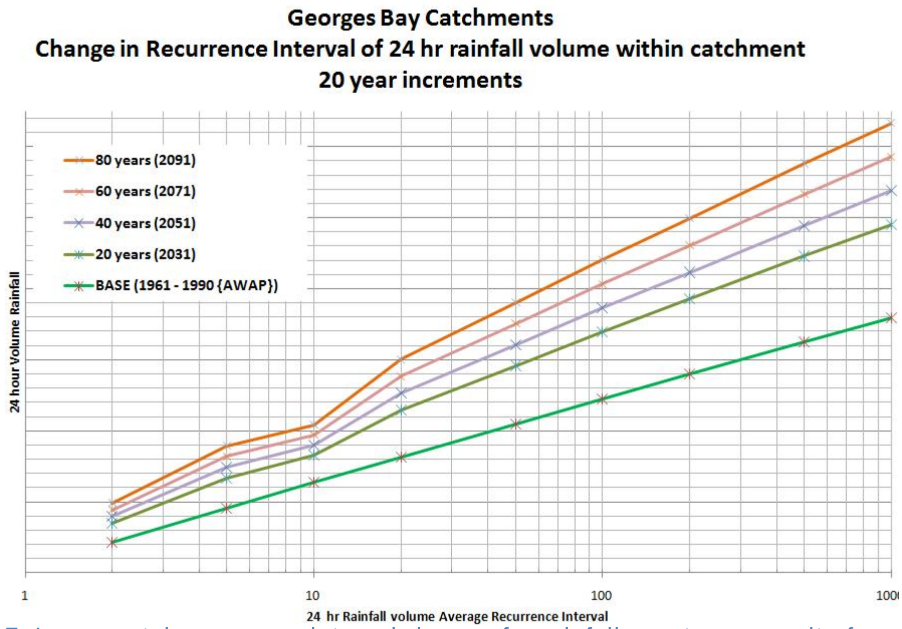


Figure 7. Incremental recurrence interval changes for rainfall events as a result of projected changed rainfall intensity.

2.4 Rainfall Runoff Changes

The Climate Futures for Tasmania project modelled potential changes in rainfall run-off that may be experienced in a warmer world as projected under climate change. In summary, the projections generally indicated negligible change for low run-off events but potentially significant increases in high run-off events, essentially reflecting the changes in rainfall extremes but suggesting changes to the shape and character of stream flows, with peak flows rising faster to higher peaks (Bennett et al, 2010). Investigation into the cause of the run-off changes, including meteorological drivers and changes in rainfall frequency was beyond the scope of the CFT analysis but is indicated to be the subject of subsequent research.

Run-off outputs for the Georges Bay projected area have been processed in ClimateAsyst to determine potential impacts on the project area. The projected changes in total annual runoff for the George Bay feeder catchments vary from a negligible change (-1% in the upper George R catchment) to more significant 30% increases for lower altitude sections of the catchment area.

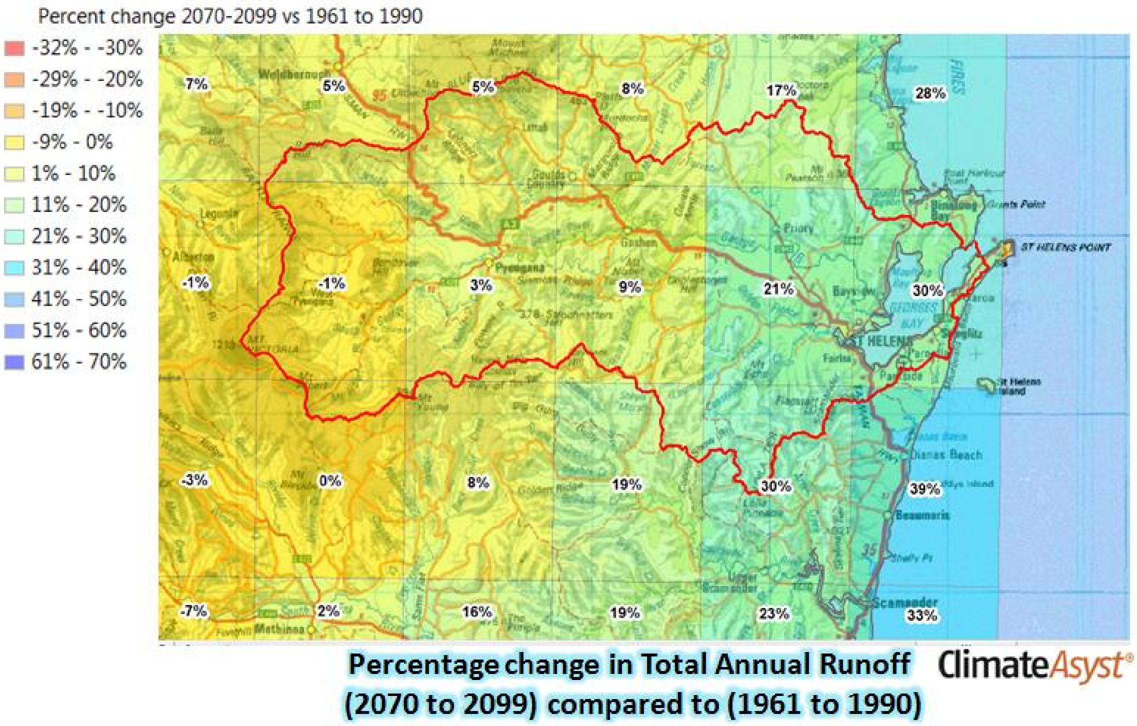


Figure 8. Projected changes in runoff for Georges Bay catchment areas.

The weighted average change in runoff for the catchment areas which feed Georges Bay is 11.7 %. However, it should be noted that the change in runoff is projected to vary considerably on a seasonal basis with changes projected for summer months (November to March) projected to exceed 60% (Grose pers com).

The change in runoff projected for the catchment area will contribute to significantly increased flood volumes experienced within the project area.

2.5 George River Flood Flow Contribution to Georges Bay Surface Levels

As identified in previous sections, rainfall contributions observed as flood flows in the George River, and others that feed Georges Bay have been estimated to have potentially significant impacts on water surface levels within the bay.

The following table provides an indication of the combined effects of changed rainfall intensity events relative to the flood volumes estimated for a range of recurrence interval events.

While it is acknowledged that rainfall is not directly related to flooding and that a range of factors must be determined to calculate flood volumes the projected changes in rainfall intensity can be used as a potential guide to possible increases in flood volume that may be expected under climate change scenarios. The projected changes for 24 hour events have been applied to the historically observed flood volumes in the below table to provide indicative future flood volumes. Also indicated is the indicative effect that a change in runoff may have on flood volume contributions.

Georges Bay represents an enclosed bay with an elongated shallow mouth and bar way. The area of the bay is approximately 21km^2.

According to anecdotal reports, peak river flooding observed during the 2004 flood event, and subsequent floods, occurs over an extended time frame exceeding 12 hours with significant flows still observed after 24 hours. The flood events therefore can be approximated to represent periods in which both incoming and outgoing tides occurred.

The contribution of the river flood to inundation levels within Georges Bay can be broadly estimated by assuming that an incoming tide will contribute to restricting the river water from exiting the bay. In the event that peak river flows occur for the full incoming tide, corresponding to fully restricted outflow from the bay, the inundation depth of freshwater can be estimated through simply distributing the inflowing volume evenly across the surface area of the bay.

It should be acknowledged that the assumptions represent an oversimplification of the processes of river contributions to the bay. A simple bathtub model has been applied with no gradient modelled for the surface, whereby in reality the impact on the Georges Bay surface levels may be greater at the immediate inflow point of the river mouth and lower at the point of exit. It is also possible that the inflow of fresh water may contribute to increased velocities experienced at the mouth of the bay which may subsequently alter the outflow rates and reduce the surface level elevation. Modelling of the distribution of the river water inflows was beyond the scope of this report.

The empirical modelling undertaken suggests that while river flood contributions will increase inundation depths within the floodplain area and also contribute to inundation depths within the bay, increased flow volumes only marginally expand the flood plain area affected. The contribution to increased surface levels of the bay has been determined by simple distribution of a 6 hour volume of inflow spread evenly across the entire surface area of the bay (table 5).

Table 5. Projected impact of climate change on George River flood flows and their potential contribution to Georges Bay surface levels.

Recurrence interval (Annual Exceedance Probability AEP)		Historically observed volumes	Projected Rainfall intensity changes		Potential volume impacts *(rainfall intensity)* Cumecs (m3/s)		Volume increases including effects of *(+11.7% runoff)* Cumecs (m3/s)		Georges Bay surface elevation (6hr inflow) Metres *(over 21 km2)*		
			by 2050	by 2091	by 2050	by 2091	by 2050	by 2091	2011 *(No climate change impacts)*	by 2050	by 2091
ARI	**AEP**	**Cumecs (m3/s)**	***%age change***								
1.01	*0.990099*	49.4									
1.11	*0.900009*	55.5									
1.25	*0.8*	66.9									
2	*0.5*	127.6	**19%**	**29%**	***152***	***165***	*170*	***184***	**0.13**	**0.17**	**0.19**
5	*0.2*	270.2	**24%**	**36%**	***335***	***369***	*374*	***412***	**0.28**	**0.38**	**0.42**
10	*0.1*	386.4	**19%**	**29%**	***460***	***499***	*514*	***558***	**0.40**	**0.53**	**0.57**
15	*0.0666666*	456.2									
20	*0.05*	506.4	**29%**	**44%**	***652***	***729***	*728*	***815***	**0.52**	**0.75**	**0.84**
25	*0.04*	545.5									
30	*0.03333*	577.8									
50	*0.02*	668.8	**31%**	**47%**	***876***	***986***	*979*	***1101***	**0.69**	**1.01**	**1.13**
75	*0.0133*	741.9									
100	*0.01*	794.2	**32%**	**49%**	***1051***	***1187***	*1174*	***1326***	**0.82**	**1.21**	**1.36**
200	*0.005*	921.5	**33%**	**51%**	***1229***	***1392***	*1373*	***1555***	**0.95**	**1.41**	**1.60**
500	*0.002*	1092.5	**35%**	**53%**	***1470***	***1670***	*1642*	***1865***	**1.12**	**1.69**	**1.92**
1000	*0.001*	1224.0	**35%**	**54%**	***1655***	***1883***	*1849*	***2104***	**1.26**	**1.90**	**2.16**

2.6 Tidal Surface Levels in Georges Bay

To further understand the potential inundation surface levels that may be experienced around George Bay it is important to understand the surface levels anticipated as a result of the normal tidal cycle for St Helens.

The predicted tidal plane for St Helens is published by the Royal Navy Hydrographic Service (2008) and has been reproduced in the below table.

Table 6. St Helens tidal plane.(Mole and Carley,2010)

Tidal Plane St Helens
(Table 2.3 WRL)
(Royal Australian Navy Hydrographic Service 2008).

	Chart Datum	relative to MSL
HAT *(highest astronomical tide)*	1.4	0.8
MHHW *(Mean high high water)*	1.1	0.5
MLHW *(Mean low high water)*	0.7	0.1
MSL *(Mean sea level)*	0.6	0
MHLW *(Mean high low water)*	0.5	-0.1
MLLW *(Mean low low water)*	0.1	-0.5
LAT *(lowest astronomical tide)*	0	-0.6

2.7 Present Extreme Tide or Surge Tide Inundation Levels

The predictable tidal cycle is an important component in addressing the normal range of potential sea surface levels that may be experienced within the bay project area.

During storm conditions, however, barometric (atmospheric) pressures may be reduced below 'normal' which can contribute to an elevation of sea surfaces above the predicted astronomical tide. In addition, waves resulting from the atmospheric contributions (low pressures and potentially increased wind speeds) can contribute further sea level elevations, known as a storm surge.

The combination of these elements is shown in the following figure.

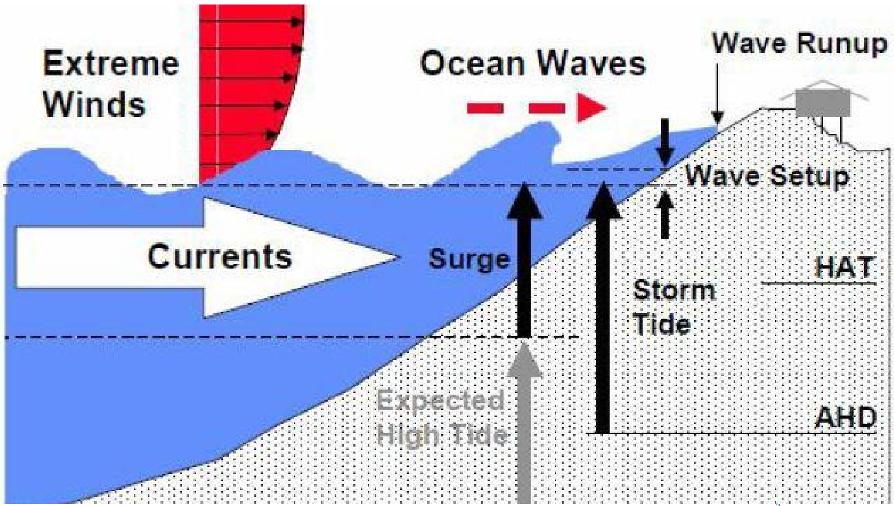


Figure 9.Storm surge 'extreme tide anomaly' contributions [1].

Analysis of potential storm surges that may be experienced for the project area has been undertaken as part of a broader Tasmanian study by Dr McInnes et al (2010) of the Centre for Australian Weather and Climate Research (a partnership between the CSIRO and the Bureau of Meteorology)(in press).

The following figure provides a schematic indication of outputs of the McInnes analysis (figure 10). Of note is that for the Georges Bay project area of eastern Tasmania

- The modelled storm surge height for an anticipated 1 in 100 year event is in the order of 0.3m.
- The estimated 99% tide height (the height that may be experienced on average in 1 out of every 100 high tides) is between 0.6 and 0.7 m AHD
- The potential storm surge height for a 1 in 100 year event is between 0.9 and 1.0 m AHD.

[1] reproduced from Sano, SEQ ACCARNSI Workshop, April, 2010

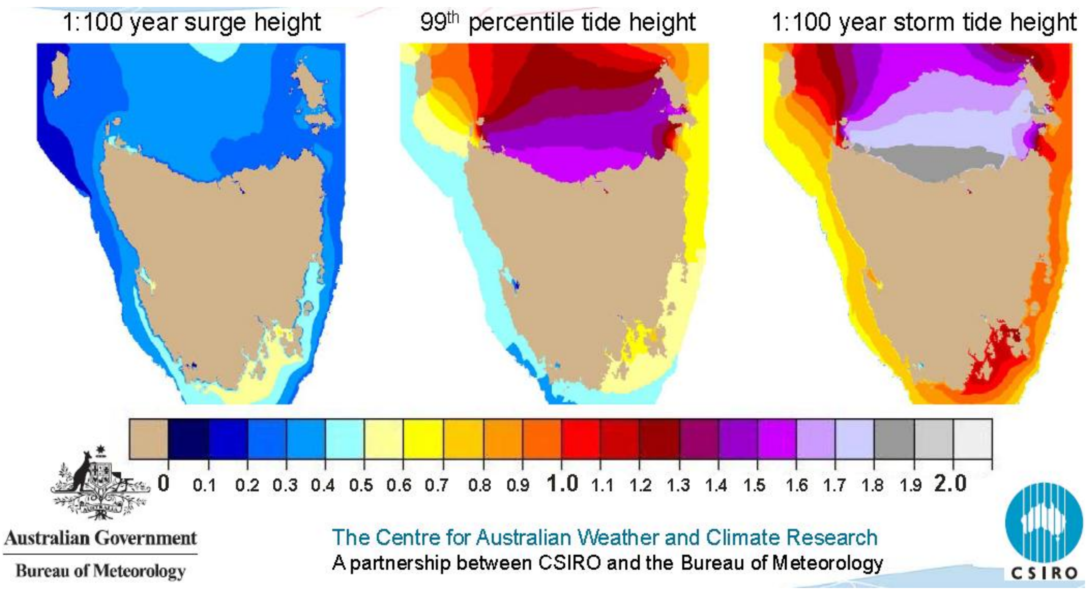


Figure 10. CSIRO modelling of storm surge and tide for Tasmania. (reproduced from McInnes et al, 2010)

Based on the modelled storm tide outputs, Dr Hunter of the ACE CRC has provided further more detailed outputs for individual locations within the George Bay project area. However, the modelled variation for the various sites is generally no more than 0.05 m and a mean value has been adopted. Surface levels have been modelled for a range of potential recurrence intervals with the mean surface level for the project area summarised in the below table.

2.8 Sea Level Rise Considerations

A vast array of scientific evidence has concluded that sea levels have risen globally over the last century (figure 11). Many studies and reports have been undertaken investigating potential future sea levels including major reports published by the Intergovernmental Panel on Climate Change (IPCC, 2001 and 2007). Australian scientists and a range of Australian institutions Australia including the Antarctic Climate and Ecosystems Cooperative Research Centre ACE CRC and CSIRO's Marine and Atmospheric Research division provide detailed analysis of potential sea levels that may occur around the Australia and for Tasmania.

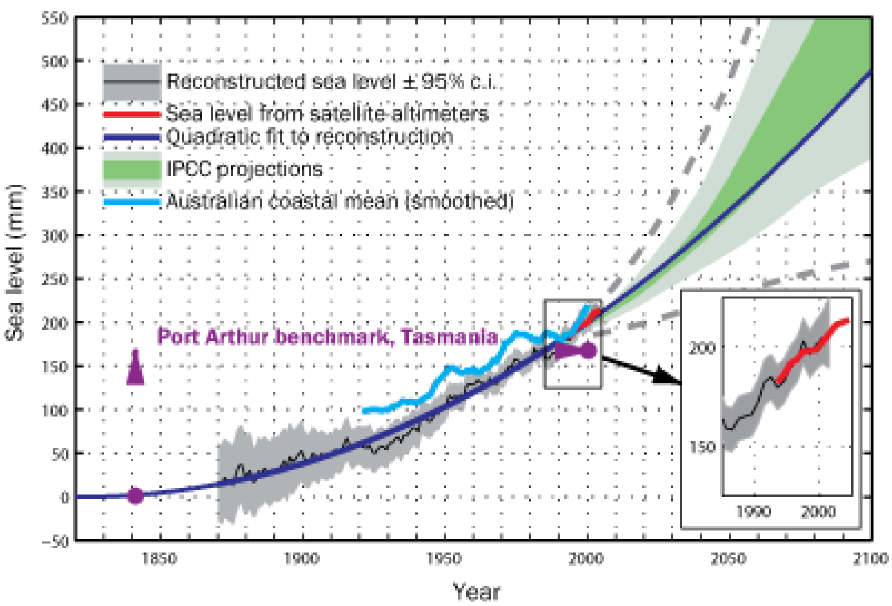


Figure 11.Observed sea level rise and projected changes (ACE CRC, 2010)

Most Australian states with the exception of Tasmania have policies which specify sea level rise benchmarks for coastal planning. These are largely based on IPCC projections and, where specified around Australia, range between 80 cm and 100cm by the end of the century (Good, 2011).

The impact of climate change on sea surface levels for the project area was estimated through incorporation of an adopted fixed sea level rise of 30 cm and 90 cm for 2050 and 2100 respectively[2] as described in the WRL technical report to Council assessing potential inundation for the George River floodplain (Mole and Carley, 2010).

The values used (30cm by 2050 and 90cm by 2100) are simplified engineering estimates published by the Engineers Australia, National Committee on Coastal and Ocean Engineering (NCCOE,2004) consistent with IPCC projections (2001 and 2007) for a "high sea level rise scenario". Potential variability in future sea level values was not incorporated.

It should be noted that while the adopted value of 90cm for an end of century rise in sea level is consistent with the upper levels of the IPCC projections the IPCC reports state that "Larger values cannot be excluded...". Recent research suggests that the rate of sea level rise is exceeding IPCC projections (Dr Hunter pers. com, 2011). Scenario modelling recently completed by CSIRO (OZCoasts, 2011) assessed a high sea level rise scenario of 1.1m by the end of the century.

Table 7. Storm surge tidal surface levels for Georges Bay incorporating climate change induced sea level rise.

Potential storm surge inundation levels - Georges Bay (m AHD)									
ARI	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**
~AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*	*0.005*	*0.002*	*0.001*
Present Day	0.85	0.92	0.96	1.00	1.03	1.06	1.08	1.10	1.12
2050 *(inc 0.3m SLR)*	1.15	1.22	1.26	1.30	1.33	1.36	1.38	1.40	1.42
2100 *(inc 0.9m SLR)*	1.75	1.82	1.86	1.90	1.93	1.96	1.98	2.00	2.02

Graphs indicating more detailed projected storm surface level outputs are provided in the following figures (figures 12 and 13).

[2] The value of a 90cm increase by the end of the century is considered to be a feasible possibility though this is at the upper level of sea level projections. Current best available science suggests that levels are unlikely to exceed 200cm rise by 2100.

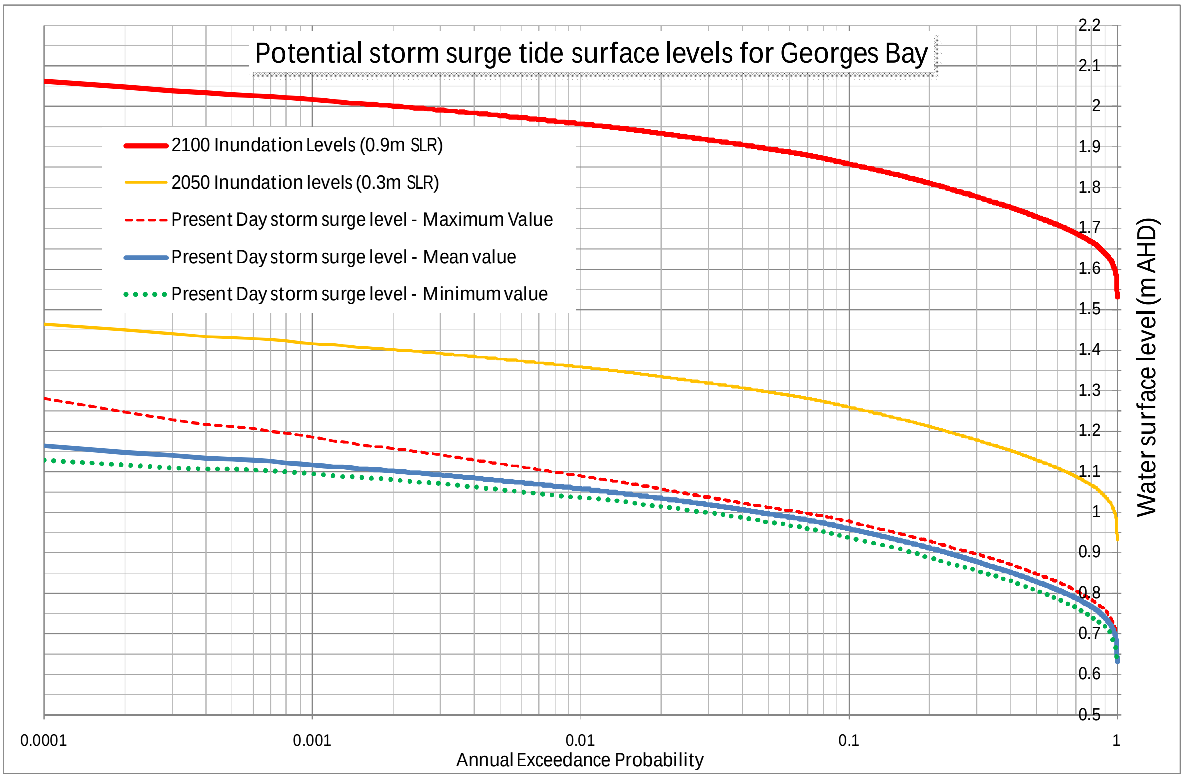


Figure 12. Potential storm surge sea surface levels for Georges Bay

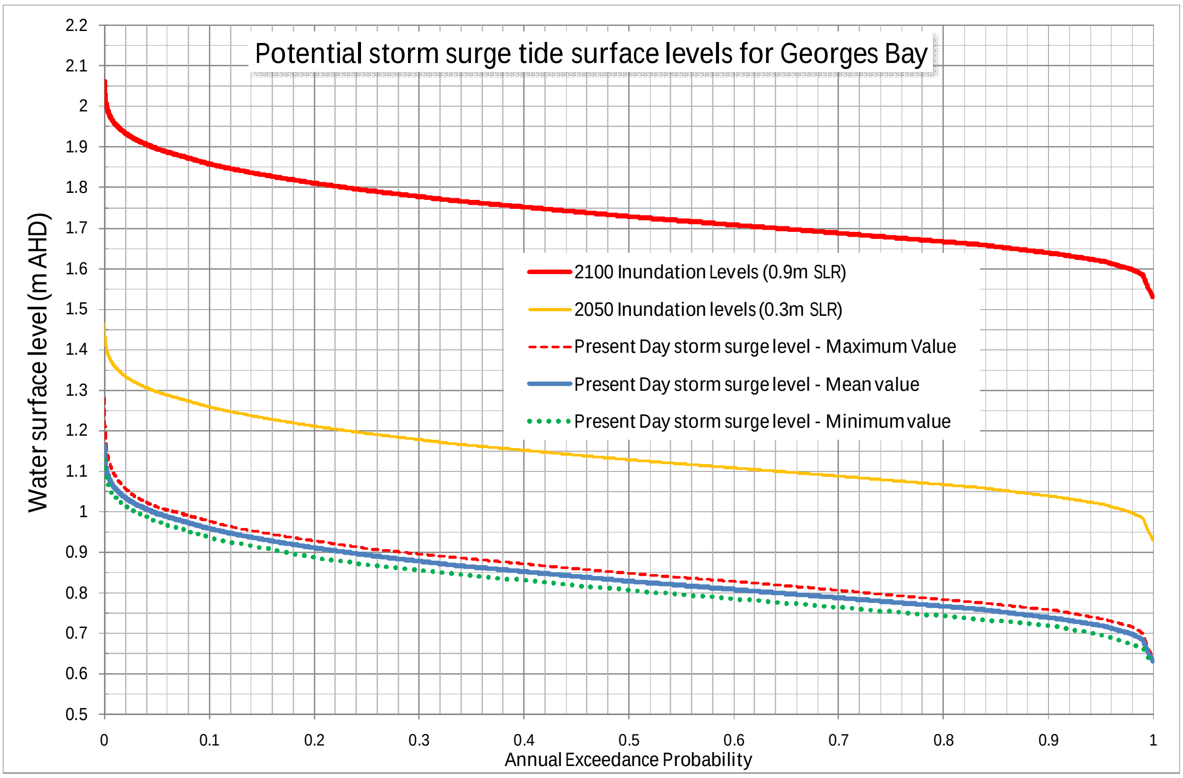


Figure 13.Potential storm surge sea surface levels for Georges Bay

2.9 Wind and Wave Setup Contributions

For the 2009 George River floodplain project, WRL modelled wind and wind/wave set-up for the George River mouth (Mole and Carley, 2010). The values were determined based on AS 1170 design wind velocities with fetch distances determined for the river mouth area to be a maximum of 1920m.

Table 8. Wind/wave setup for George river floodplain (WRL, 2010)

George R Floodplain - Wind/Wave Setup			
	wind setup	wave setup	Combined Setup
ARI			
1	0.03	0.06	0.09
10	0.05	0.09	0.14
100	0.07	0.11	0.18

Fetch distances for other sections of Georges Bay extend up to 5000m, South of Moulting Bay for Northerly wind directions and at the South West corner of the Bay (Apex Park) from a North easterly wind direction.

Indicative modelling of the set-up based on significantly increased fetch distance indicates that the setup contribution may exceed 0.4m for the maximum contribution directions as in the following table.

Table 9. Modified wind-wave setup for Georges Bay

George R Floodplain - Wind/Wave Setup				
	wind setup	wave setup	Combined Setup	*Maximum fetch directions (5000m)*
ARI				
1	0.03	0.06	0.09	0.225
10	0.05	0.09	0.14	0.35
100	0.07	0.11	0.18	0.45

Specific wind directions and strengths were assessed for the project based on wind rose diagrams produced from St Helens post office wind records.

The estimated setup contributions for wind waves (table 9 above) were modified to reflect reduced wind strengths and modified probabilities from those calculated by WRL for the George River floodplain project. The resulting wind setup contributions adopted in this project are indicated in the below table.

Table 10. Wind wave setup contributions (interpolated probabilities).

Wind / Wave setup *(modified for directional strength)(m addition to surface level)*						
ARI	**2**	**5**	**10**	**20**	**50**	**100**
~AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*
2000m Fetch	0.08	0.10	0.11	0.13	0.14	0.16
5000m Fetch	0.18	0.23	0.26	0.30	0.36	0.40

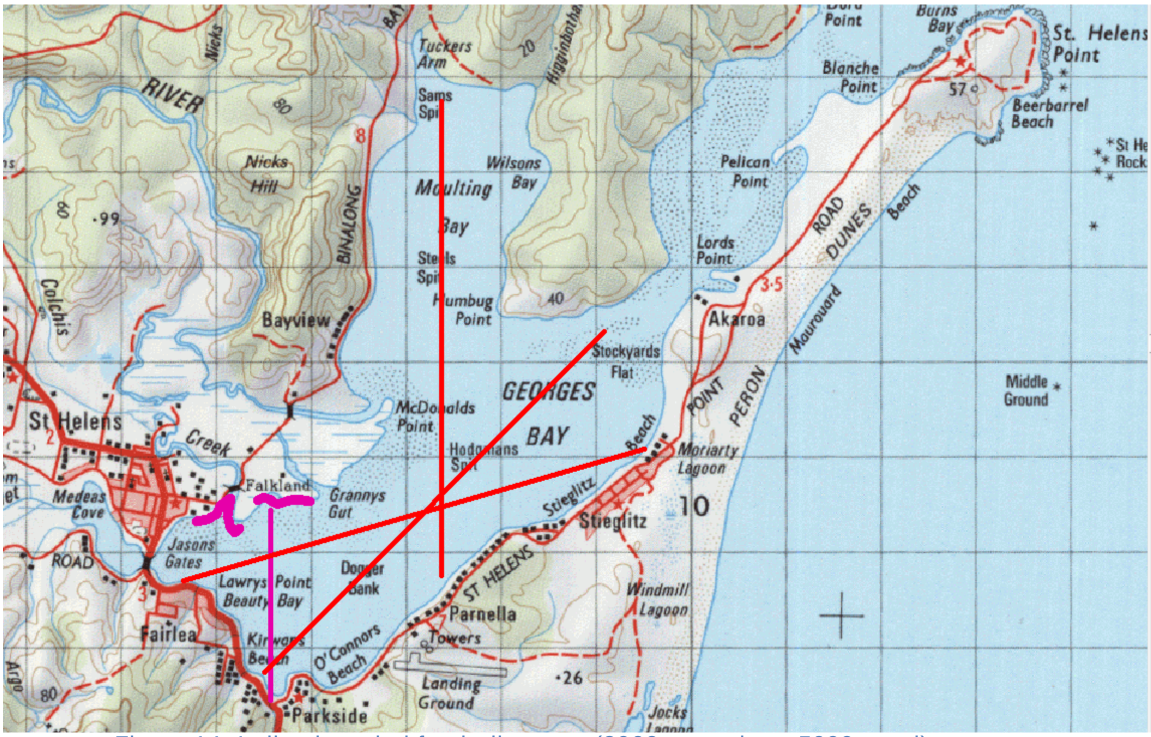


Figure 14. Indicative wind fetch distances (2000m purple or 5000m red).

The figure above (figure 14) indicates that with the exception of south-westerly facing portions of the George River floodplain, the majority of Georges Bay coastal sites are exposed to winds with a fetch in the order of 5000m.

Further modification and reduction in the proportional contribution of wind and wind wave setup is likely with more detailed analysis of wind incidence angles and inclusion of bathymetric considerations for specific locations around the bay though this was beyond the scope of the analysis.

2.10 Water Surface Level Contributions

The below table provides a summary of components contributing to elevated surface levels in Georges Bay as described in previous sections.

Table 11. Georges Bay surface level contributing components (m addition or m AHD)

River flood contributions (flood flow contribution to surface elevation. *(m addition)*									
ARI	**2**	**5**	**10**	**20**	**50**	**100**	**200**	**500**	**1000**
~AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*	*0.005*	*0.002*	*0.001*
Present Day	0.13	0.28	0.40	0.52	0.69	0.82	0.95	1.12	1.26
2050	0.17	0.38	0.53	0.75	1.01	1.21	1.41	1.69	1.90
2100	0.19	0.42	0.57	0.84	1.13	1.36	1.6	1.92	2.16
Potential storm surge inundation levels - Georges Bay (m AHD)									
Present Day	0.85	0.92	0.96	1.00	1.03	1.06	1.08	1.10	1.12
2050 *(inc 0.3m SLR)*	1.15	1.22	1.26	1.30	1.33	1.36	1.38	1.40	1.42
2100 *(inc 0.9m SLR)*	1.75	1.82	1.86	1.90	1.93	1.96	1.98	2.00	2.02
Wind / Wave setup *(modified for directional strength)(m addition to surface level)*									
2000m Fetch	0.08	0.10	0.11	0.13	0.14	0.16			
5000m Fetch	0.18	0.23	0.26	0.30	0.36	0.40			

The various components are combined in table 12 following. The table indicates two alternative probabilities (upper and lower rows) representing respectively

- Coincident probabilities where the three contributing components are treated as totally dependent events (if one occurs then each of the other occurs at the same intensity) or
- Totally independent events.

Neither of these possible combination methods is considered to necessarily provide a definitive realistic combination. The range of the two outcomes, however, is considered to provide reasonable effective upper and lower bound of likelihoods.

For example, it is considered highly improbable that a 1 in 100 year river flood will coincide exactly with a 1 in 100 year anomalous storm tide which coincides with 1 in 100 year winds. However, it is considered likely that meteorologic conditions generating anomalous storm surge tidal events will also contribute to some level of rainfall and ultimately flood flows in Georges River potentially with some level of coincident wind effects in the project area.

Table 12. Surface levels (m AHD) and probabilities from combined events.

Probabilities *(if totally dependent)*						
ARI	**2**	**5**	**10**	**20**	**50**	**100**
~AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*
Combined (surge tide, river flood and wind wave setup) (m AHD)						
	short fetch					
Present Day	1.07	1.30	1.47	1.64	1.87	2.03
2050	1.41	1.70	1.90	2.17	2.48	2.72
2100	2.03	2.34	2.54	2.86	3.21	3.48
	long fetch					
Present Day	1.17	1.42	1.62	1.82	2.08	2.27
2050	1.51	1.83	2.05	2.35	2.70	2.96
2100	2.13	2.47	2.69	3.04	3.42	3.71
Probabilities *(if totally independent)*						
~AEP	*0.061163*	*0.00603*	*0.001*	*0.000125*	*0.000008*	*0.000001*
ARI	*16*	*166*	*1,000*	*8,000*	*125,000*	*1,000,000*

2.10.1 Upper limits

To determine possible upper limits the worst case scenarios for each of the individual components were added together. For example the 1 in 100 year surge was added to a 1 in 100 year river flood combined with the additional wave setup that may occur from a 1 in 100 year long fetch wind. If these were all caused by the same weather event then they could be thought to be a 1 in 100 event. While we know this is certainly not the case for all weather events, this would represent an upper limit for planning.

In reality this combination may be considered to be a 1 in a million year combination (100x100x100) if all these events are truly independent.

2.10.2 Lower limits

For planning purposes, inundation levels presenting the combination of events as totally independent is considered to represent a reasonable lower limit of inundation (using the probabilities indicated in the lower row of the previous table). For the lower limit, short wind fetch wave setup was used.

The table above does not have a column with an ARI of 100 (1 in 100 year) for independent events and the result lies somewhere between the first and second columns. To determine the lower limit inundation values for typical planning likelihoods, the above combined values were graphed (using table 12 lower row probabilities) with a trend line fitted to enable interpolation of inundations values from 2 yr to 100 yr ARIs (approximately 0.01 to 0.5 annual exceedance probabilities – AEP) (figure 15).

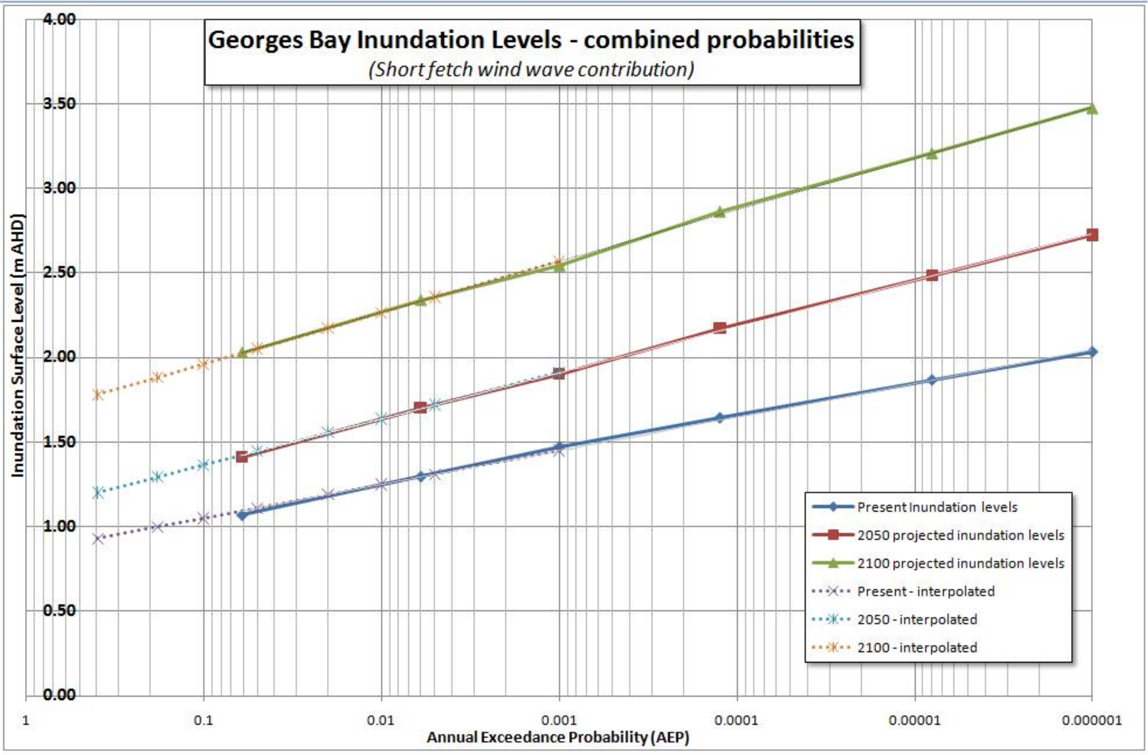


Figure 15. Present and projected inundation levels and probabilities (assuming components are independent).

The table following (table 13) provides the interpolated values adopted as reasonable lower inundation levels (short wind fetch values adopted).

Table 13. Inundation levels and probabilities, interpolated for Georges Bay (lower limit).

INUNDATION LEVELS (m AHD) *(lower bound - Interpolated assuming totally independent events)*								
ARI	2	5	10	20	50	100	200	1000
AEP	*0.394*	*0.182*	*0.1*	*0.05*	*0.02*	*0.01*	*0.005*	*0.001*
	combination surge tide, river flood and short fetch wind waves (m AHD)							
Present Day	0.9	1.00	1.05	1.1	1.19	1.25	1.3	1.4
2050	1.2	1.3	1.36	1.44	1.55	1.64	1.7	1.9
2100	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.6

3. Planning / Mapping Inundation Levels (1 in 100 year or 1% probability events)

To provide potential 1% probability or 1 in 100 year occurrence inundation levels for planning purposes the lower value of assessed potential inundation was selected as a reasonable lower limit as indicated in table 13 above.

The upper limit of potential maximum inundation level was determined from the potential combination of individual components using long fetch wind derived surface elevations (with the probability determined assuming these are totally dependent events – the upper row in table 12). As previously described, this coincidence of events is considered a possible but highly unlikely combination and therefore represents a reasonable potential upper limit on potential inundation.

The projected surface inundation levels estimated for future periods increase through a combination of projected increases in rainfall intensity exacerbating river flood contributions and a projected rise in sea level. The projected changes are based on a high greenhouse gas emissions scenario over the remainder of this century (refer to limitations in the following section).

The following table (Table 14) summarises the projected limits *(rounded values indicated).*

Table 14. 1% Annual Exceedance Probability (100 yr ARI) - Planning inundation levels

Potential Inundation Levels	1% AEP (100yr ARI) Lower limit	1% AEP (100yr ARI) Upper limit
Present Day	1.25 m AHD	2.3 m AHD
2050	1.6 m AHD	3 m AHD
2100	2.3 m AHD	3.7 m AHD

Graphically the ranges in estimated potential inundation levels are presented in figure 16 below.

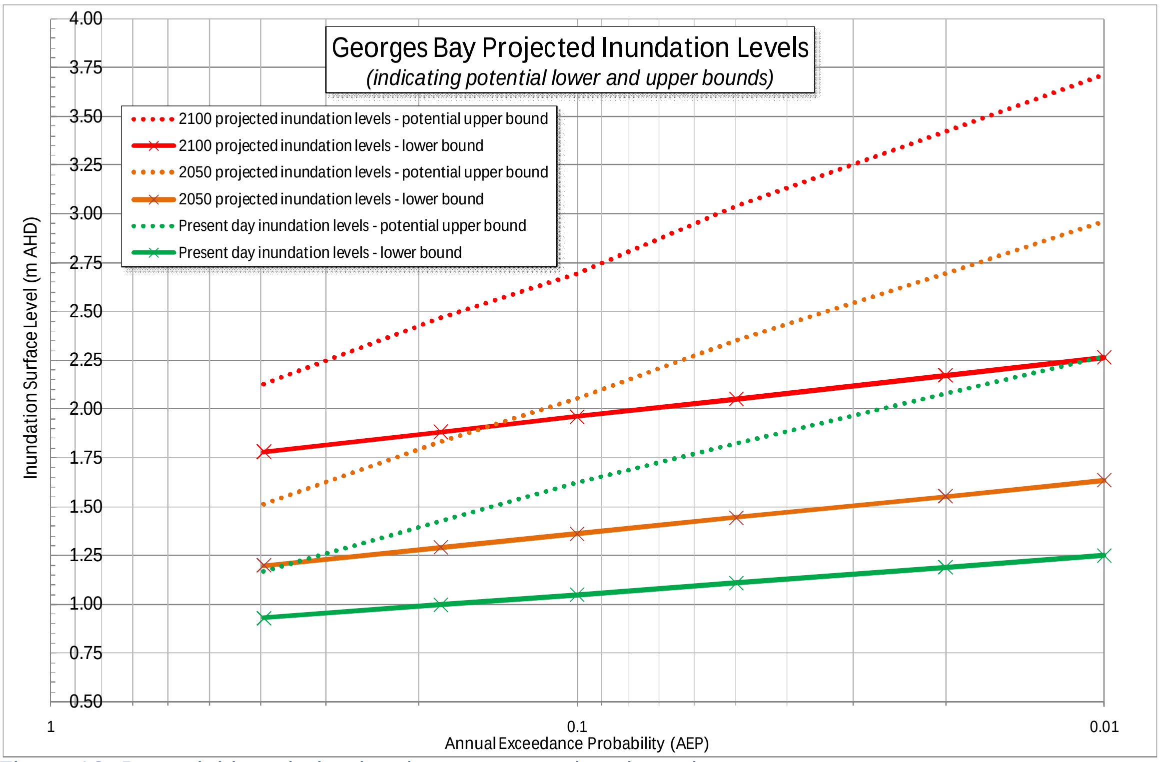


Figure 16. Potential inundation levels - present and projected

The inundation levels have been mapped to indicate locations affected by potential inundation. The following figures schematically indicate the projected inundation levels in the vicinity of St Helens and also the Stieglitz turnoff area (figures 17 and 18 respectively).

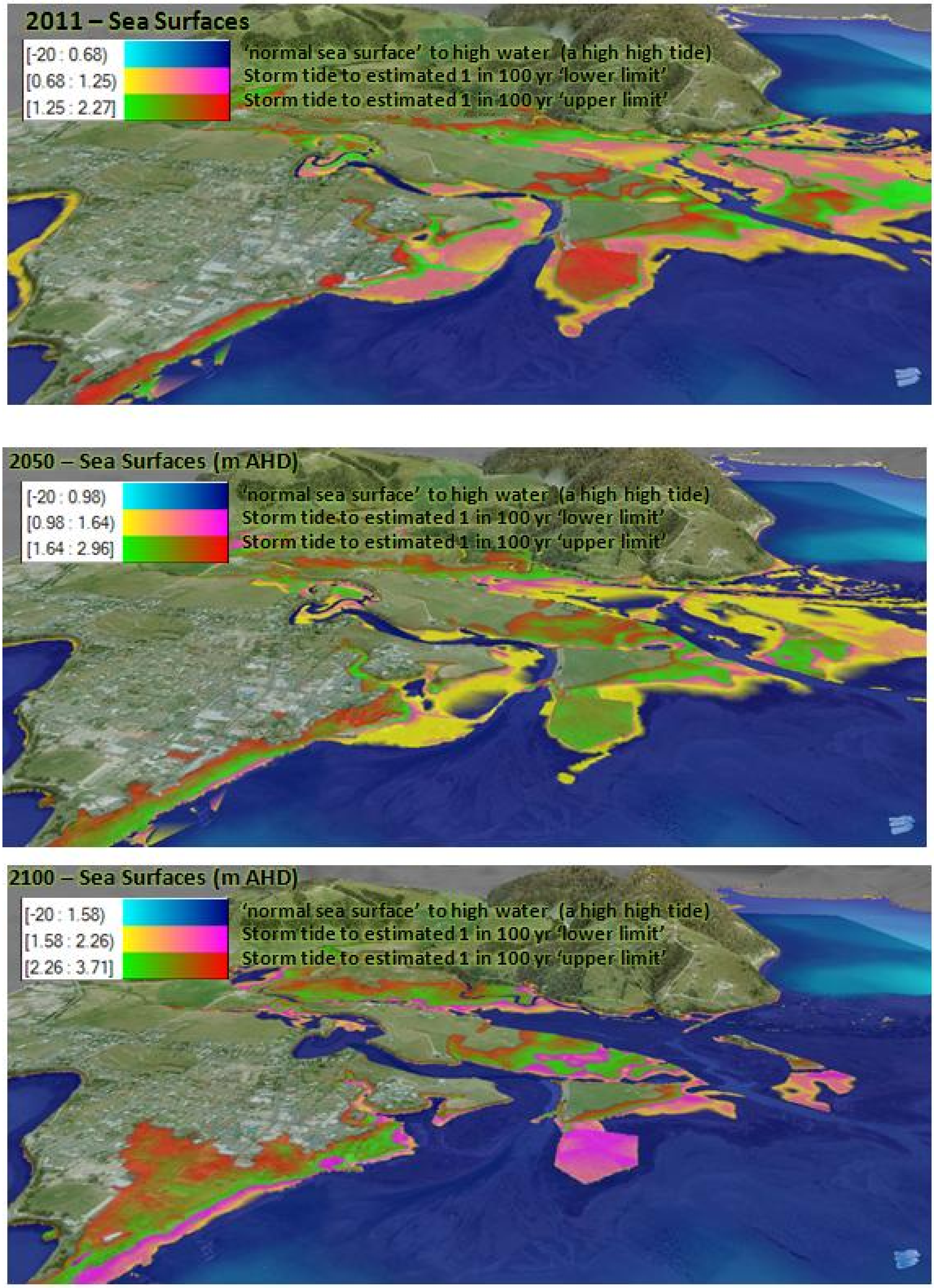


Figure 17. Indicative sea surface inundation levels - St Helens area

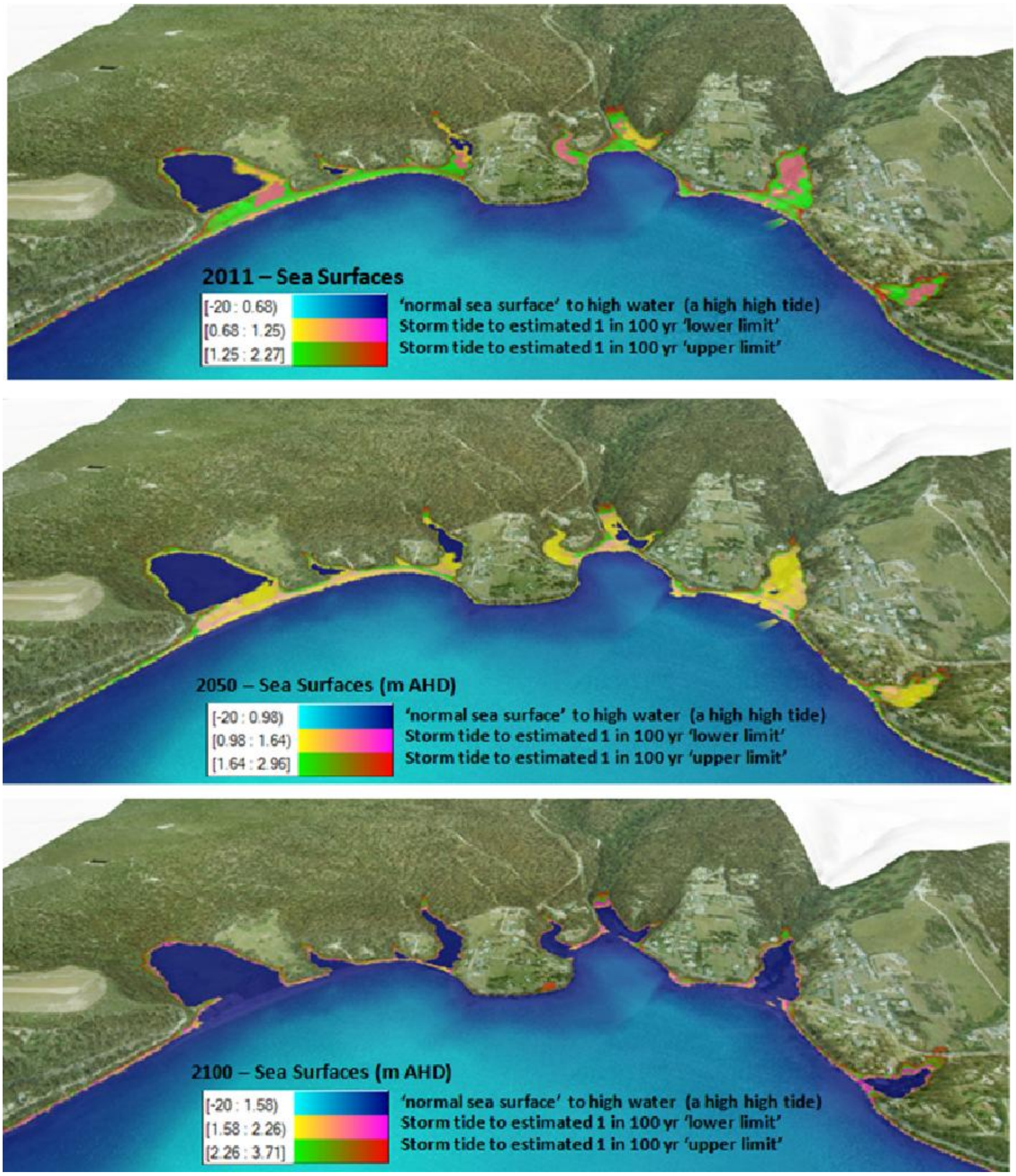


Figure 18. Indicative sea surface inundation levels - Stieglitz turnoff area

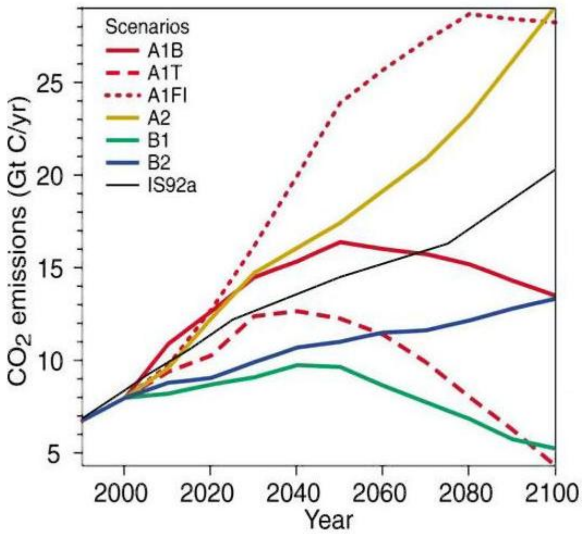
Inundation surfaces for the project area have been provided as a series of MapInfo polygons for use by Council.

4. Limitations

It is important to note that the information compiled in this assessment is based on combinations of data sets, estimations and projections which all involve a range of uncertainties. However, the information presented is considered to provide a reasonable overview of the potential effects of the range of contributions to Georges Bay surface levels and in particular the potential effects that projected changes in climate may have on the levels towards the end of the century.

The following limitations apply to this report:

- Datasets Used
  The basis of the considerations in this report are datasets available publically, provided by the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) for the Climate Futures for Tasmania project (CFT) and the Climate Futures for Tasmania – Infrastructure project (CFT-I) [the output tool now registered as ClimateAsyst] and information made available to pitt&sherry. The assessment also draws on information presented to Break O'Day Council in 2010 from the technical report on potential sea surface inundation of the George River floodplain produced by the Water Research Laboratory (WRL) of University of New South Wales (UNSW)(Mole and Carley, 2010). River flood volume assessment also incorporated analysis completed by SKM in 2005 on river flood mitigation for the lower George River floodplain provided by Council.
- High Greenhouse Emissions scenario Used (A2)
  The information and model outputs are based on greenhouse gas emission projections for the end of the century using a high emissions scenario (A2 of the IPCC 2001 refer figure below) as modelled by the Climate Futures for Tasmania project (Corney et al, 2010). Actual emissions may vary from those projected under this scenario. Similarly, the impacts resulting from the emissions are based on modelling and the actual responses may be greater or lower than those used. While the scenario modelled represents continuation of currently observed high greenhouse gas emissions to the end of the century it does not represent the most pessimistic of the IPCC projections. It should be noted that since 2001, the observed global greenhouse gas emissions have been tracking above A1FI, the highest emissions scenario (Corney et al, 2010).



- 24hr events analysed only – shorter duration events may have greater change
  The magnitude of changes for short term duration events is not currently available from the Climate Futures for Tasmania modelling and has not been interpolated for this project. It has been suggested that shorter duration events may have greater proportional change than longer duration events[3], though as stated, the analysed outputs are for 24hr event volumes only. Longer duration rainfall events, 48 hr or 72 hr event volumes, were not used in the modelling though were overviewed to identify potential effects on the modelled outputs. Longer duration events tended to have lower magnitude of changes than the 24 hr event dataset.
  Users of the analysis should consider that for many smaller catchments the time of concentration may be much less than the 24 hours modelled and a greater proportional change may be appropriate for shorter duration events.

[3] Pers com Dr Chris White, extreme events analyst ACE CRC and also Fiona Ling, Water and catchments analyst, Entura.

- Simulated storm events
  The project assessed potential impacts of changed rainfall intensity for various recurrence intervals by simulating precipitation events for each catchment across the range of specified recurrence intervals. For modelling purposes, the simulations assumed the same intensity of storm across the entire catchment. For example it was assumed that once in 100yr storm precipitation volumes occur across the entire catchment, as opposed to a once in 100yr storm volumes in one cell and different events in other cells. While the CFT data models different volumes for the same event depending on a range of factors influencing each individual cell, the assumption may represent an oversimplification. However, the project area catchments are relatively constrained and the assumption is considered reasonable.

- Linear Interpolation to end of century period
  The modelled rainfall data uses only the end of century period outputs (from CFT) for comparison with the CFT base data set (1961 to 1990). While intermediary periods are available from the CFT data (eg 2010 to 2039 and 2040 to 2069) a linear interpolation is consider sufficient to provide the order of magnitude of the changes for required design considerations. A linear interpolation has been applied between the central dates of the start (base: 1961 to 1990) and end (2085: 2070 to 2099) period to enable indicative changes in future years relative to the current year. The linear interpolation may be overstating the degree of change for the earlier part of the century.

- Not flood modelling
  It is important to recognise that, while the technical outputs of rainfall intensity changes and potential rainfall volumes represent reasonable estimates of projected changed rainfall intensity for periods to the end of the century, the outputs do not directly represent changed flood volumes.

  Flood volumes require assessment of time of concentration of water volumes which will vary for each individual catchment. Flood impacts are affected by rainfall events which may be of significantly shorter duration than the 24hr events modelled and are impacted by local geographic variations for each catchment.

- The outputs are based on gridded data and are 'averaged' for a large area.
  The underlying datasets produced for the CFT project are based on gridded datasets which represent an average over the approximately 0.1 degree square (approximately 92 km2 for each 'cell'). Consequently, the indicated changes should be applied as a proportional change to local or geographic specific information and should not be used to obtain 'absolute values' considered correct at any single point within the grid cell.

- The analysis provided represents the mean value
  The CFT process used 6 different global climate models (GCM's) to produce the output datasets. The values applied in this assessment, unless stated otherwise, represent the mean value (considered the best estimate or most likely outcome) of all the model datasets combined. The data ranges considerably around the mean value and an indication of the variation or uncertainty is provided as indicative 5% and 95% confidence intervals for the end of century period (representing a 90% likelihood that the value will be within the projected range).

- Only George River inflows have been used in estimation of the surface contributions to Georges Bay. A number of other drainages and catchments inflowing to the Georges Bay area have not been incorporated in the estimation of contributions to the bay. The time of concentration of rainfall contributing to flood outflows for George River and other catchment inflowing to Georges Bay has not been incorporated in the analysis. The George River catchment represents approximately 378 km2 of the total 566 km2 'feeder catchment' for Georges Bay (66%). While the other rivers and drainages entering Georges Bay represent generally much shorter systems and consequently may be affected more rapidly by shorter duration events, their inflows may contribute to sea surface inundation levels in excess of those estimated in this analysis. Assessment of this aspect was beyond the scope of the project.

- Lidar precision
  The contour information used to present potential inundation levels is based on the topography generated from Lidar information obtained from TheList. The elevation information is stated to be accurate to approximately 20cm.
- Projections have been estimated only to 2100
  It is likely that the trends indicated are anticipated to continue for many hundreds of years beyond the end of the century.
- The inundation does NOT consider the impacts on stormwater and drainage systems. Increased inundation is likely to contribute to significant restrictions on outflows which may contribute to further inundation at levels higher in the stormwater or drainage system. Further more detailed hydraulic analysis may assist in identifying areas where this occurrence may create issues of concern though this was beyond the scope of this project.
- The potential inundation events identified in this report are strongly dependent on the tidal cycle and therefore the peak inundation identified is likely to occur only during the peak of high tides. This inundation may therefore last for a period of several hours only but may be repeated at subsequent high tides.
- Wind fetch
  The lower inundation value used in the assessment has been determined assuming wind wave setup equivalent to that resulting from a short fetch wind while the upper 'possibility' level is determined from incorporating potential wind wave setups equivalent to those generated by long fetch winds. The relative proportion of wind wave contributions will vary with individual locations around the project area. It is possible that surface elevations as a result of the wind wave setup component may in fact exceed the value indicated and detailed modelling incorporating bathymetry and specific directional components would be required to determine likely contributions which were beyond the scope of this project. The contribution of wind wave setup to elevating surface levels in the bay is proportional to the depth of water across which the wind is travelling. With increasing depth the effect becomes less. The effect is therefore also dependent on the tidal influences.
- No allowance for altered surface area. As the depth of water increases in the bay the surface area will also expand as the water spreads into shallow embayments etc. No allowance for this increased area has been incorporated into the estimations of surface elevations.

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