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| **ENCN375 – Assignment 1** |
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| **ENCN375**  **Sustainable Engineering for a Changing Climate** |
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| **Date Submitted: 13 September 2020** |
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Executive Summary

The objective of this report is to estimate Christchurch’s climate risk to sea level rise and discuss the implications of such risk on the people of Christchurch and its infrastructure.

Due to the narrow nature of this assessment it is recommended that treatment options presented in this report are considered in conjunction with recommendations regarding other risks from alternative sources.

A basic risk assessment was undertaken using data obtained from various sources.

Following either the RCP2 or RCP8 prediction, it is expected that 13.5% of the population, 8.5% of roading, 19.5% of bridges, and 10% of the potable water pipes in Christchurch will be exposed to risk due to sea level rise by 2040.

Some potential interventions are to nourish the beaches, build a seawall, or relocate affected people and infrastructure. Beach nourishment is a softer measure and cheaper than the other options which are hard and likely expensive.

The recommended intervention depends largely the acceptable level of risk and the proposed location of the intervention. The ecological state and cultural significance of the area will also be relevant. Softer measures such as beach nourishment can be used as required, but harder measures such as a sea wall or relocation should require a long period of community consultation and involvement so that the best solution for all parties involved can be selected.

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# Background

Climate change is an issue that has seen heightened attention in recent years and will likely see more attention in the future, as implications of neglecting its effects greaten. The Christchurch community, like all communities, must prepare for the effects of climate change. Christchurch being a coastal city, has a significant risk of exposure to rising sea levels.

## Project Scope and Objectives

The objective of this report is to estimate Christchurch’s climate risk to sea level rise and discuss the implications of such risk on the people of Christchurch and its infrastructure. The issue of sea level rise is a broad one, and naturally involves many different parties, namely the Christchurch City Council, the Canterbury Regional Council, and the residents of Christchurch. The scope of this report only includes risk due to sea level rise, but Christchurch will experience many different climate risks in the future and should be prepared for each of them. Due to the narrow nature of this assessment it is recommended that treatment options presented in this report are considered in conjunction with recommendations regarding other risks from alternative sources.

## Hazard Identification

Sea level rise is primarily caused by an increase in global temperature. The increased temperature invokes thermal expansion of water in the sea, as well as accelerating the rate that glaciers and ice sheets melt into the ocean.

Sea level rise can cause destructive erosion, flooding of low-lying areas and salt contamination among other things, all of which can influence people.

A variety of soft and hard measures can be implemented to mitigate risk from sea level rise, such as seawalls, beach nourishment, and community relocation. The best option will be different depending on the exposure to risk, the concerns of the community, and the potential maladaptation, among other things.

# Exposure Assessment

A basic risk assessment was undertaken using data obtained from various sources. The data were shape files mapping people and infrastructure to a location and shape files representing flooding in each location associated with each 0.1 m increment of sea level rise. The flooding data was obtained from the National Institute of Water & Atmospheric Research, NIWA, (Paulik et al, 2020) and the people and infrastructure data were obtained from the 2018 Census (Stats NZ, 2020). The population shape file was clipped, using the SLR shape files, and then plotted according to RCP2 and RCP8 sea level rise predictions (IPCC Representative Concentration Pathways). The 95% confidence intervals were obtained via the Monte Carlo method of uncertainty. The graphs produced are presented in the following section as Figures 1-8

## Exposure of People and Infrastructure

Four different variables were analysed. These were the amount of people exposed, the length of road exposed, the amount of bridges exposed, and the length of potable water pipeline exposed. For each variable two graphs were produced, one with the expected number or length exposed and the other as a percentage of the total amount or length.

A close up of a map

Description automatically generated

Figure 1: Risk assessment of population in Christchurch.

A close up of a map

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Figure 2: Risk assessment of population as a percentage.

The people exposed to risk were assessed as is shown in figure 1. Following either RCP2 or RCP8 it is expected that approximately 13.5% of the population will be exposed by 2040. Knowing the percentage of people exposed allows the allocation of resources and funding in proportion to the amount of people affected.

A close up of a map

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Figure 3: Risk assessment of roads in Christchurch.

A close up of a map

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Figure 4: Risk assessment of roads as a percentage.

The length of road exposed to risk was assessed as is shown in figure 3. Following either RCP2 or RCP8 it is expected that approximately 8.5% of the roading in Christchurch will be exposed by 2040. The lengths of road affected were analysed because the people of Christchurch are very reliant on roads because housing is very low density. Most people need to travel a fair distance each day and all of Christchurch’s mainstream public transport is road-based also.

A close up of a map

Description automatically generated

Figure 5: Risk assessment of bridges in Christchurch.

A close up of a map

Description automatically generated

Figure 6: Risk assessment of bridges as a percentage.

The bridges exposed to risk were assessed as is shown in figure 5. Following either RCP2 or RCP8 it is expected that approximately 19.5% of the bridges in Christchurch will be exposed by 2040. The amount of bridges affected was analysed because there are many braided rivers in Christchurch and the surrounding region. Higher water levels could flood over bridges or flood a greater area than they were designed to cover. Water and salt can cause corrosion in reinforced concrete which could easily occur if the bridge was not designed considering this.

A close up of a map

Description automatically generated

Figure 7: Risk assessment of potable water pipes in Christchurch.

A close up of a map

Description automatically generated

Figure 8: Risk assessment of potable water pipes as a percentage.

The length of pipes exposed to risk was assessed as is shown in figure 7. Following either RCP2 or RCP8 it is expected that approximately 10% of the potable water pipes in Christchurch will be exposed by 2040. The lengths of potable water pipes affected were analysed because these pipelines are susceptible to salt contamination. The pipe systems in Christchurch are old and expected to need a lot of replacement in future. This greater occurrence of failure allows for a greater frequency of potential contamination.

## Evaluation of Uncertainty

An analysis of this scale naturally comes with uncertainty. The population shape files represented areas with a certain number of people associated. If any of the area matched the flooding shape file, every person associated with that location was considered exposed, regardless of the amount of cross-over.

Within RCP predictions there is uncertainty in the extent of predicted sea level rise. This uncertainty was managed by the Monte Carlo method of uncertainty. From each RCP mean and 33% confidence intervals, a set of standard deviation was produced. From these standard deviations, a normal distribution was produced, and a 95% confidence interval was produced.

# Treatment

This assessment should be used to inform decision-making in conjunction with recommendations regarding other risks from alternative sources. Outlined in the following sections are some potential interventions to reduce exposure to the people and infrastructure.

## Potential Interventions

Some potential interventions are to nourish the beaches, build a seawall, or relocate affected people and infrastructure. Beach nourishment is a softer measure and cheaper than the other options which are hard and likely expensive.

Beach nourishment is largely a temporary solution but has the benefit of not having any serious cultural or ethical impacts and is significantly cheaper than the other potential interventions. It also leaves the beach in a usable condition and has little maladaptation potential.

A seawall is a semi-permanent and relatively expensive solution. A seawall often results in the beach being unusable or less accessible. It also may result in habitat loss of animals and plants, which is an ethical and cultural concern. A seawall may not be aesthetically appealing which may be a cultural concern. A seawall also has a large potential for maladaptation. It gives a sense of safety and security to those living in areas at risk and may reduce the inclination for people to relocate.

Community relocation involves moving people away from the area that is exposed to the hazard. This is a very expensive solution, especially for large communities and has ethical and cultural concerns associated with asking people to leave, especially if the land has cultural significance to the people. While relocation may have a slight maladaptive effect associated with the new location being safe, this is largely insignificant, and the main deterring factor of this intervention is the cost.

## Communication with the Public

Community and iwi engagement are recommended throughout the consideration and design process. Community meetings should be arranged, utilizing online noticeboards or similar methods. The Christchurch City Council has processes in place for iwi consultation.

Information should be communicated in a simple, engaging way. A press release will be produced along with the publication of this report that can be utilized along with the figures in this report.

A participatory design process involving all stakeholders is recommended, to streamline engagement processes.

## Recommendations

The recommended intervention depends largely the acceptable level of risk and the proposed location of the intervention. The ecological state and cultural significance of the area will also be relevant. Softer measures such as beach nourishment can be used as required, but harder measures such as a sea wall or relocation should require a long period of community consultation and involvement so that the best solution for all parties involved can be selected.

# References

Paulik, R., Stephens, S. A., Bell, R. G., Wadhwa, S., & Popovich, B. (2020). *National-Scale Built-Environment Exposure to 100-Year Extreme Sea Levels and Sea-Level Rise.* Sustainability: Science Practice and Policy, 12(4), 1513.

Stats NZ Geographic Data Service. (2020). *2018 Census Individual (part 1) total New Zealand by Statistical Area 1.* Stats NZ, New Zealand

# press Release: CHristchurch Residents and Infrastructure at Risk

Up to 14% of the population will be exposed to risk due to sea level rise in the next 20 years, according to a new report from the University of Canterbury. The risk assessment analysed sea level rise data from Crown Research Institute NIWA and how people and infrastructure in Christchurch will be affected.

It showed that 13.5% of the population, 8.5% of roading, 19.5% of bridges, and 10% of the potable water pipes in Christchurch will be exposed to risk due to sea level rise by 2040.

“While 13.5% may not seem like a lot, that’s 55,000 people that are at risk and the amount of affected people grows every year.”

The report suggests that some options to reduce the risk could be beach nourishment, a sea wall or to eventually relocate the people affected.

“Designers need to actively involve the community in the process so that outcome best suited for all parties can be achieved”

1. Python Code
2. """Program to create risk assement data in relation to sea level rise"""
3. # use directory cd "Desktop\Uni\2nd Pro\375\Assignment\_1"
5. # import packages
6. **import** geopandas as gpd
7. **import** numpy as np
9. # import data
10. bridges = gpd.read\_file('data/infrastructure/bridges.shp')
11. pipes = gpd.read\_file('data/infrastructure/potablewater\_pipe.shp')
12. roads = gpd.read\_file('data/infrastructure/street\_centre\_line.shp')
13. census = gpd.read\_file('data/socioeconomic/2018-census-christchurch.shp')
15. # create data lists
16. bridges\_list = []
17. pipes\_list = []
18. roads\_list = []
19. census\_list = []
21. # import each slr file and clip with variables
22. **for** i **in** np.arange(0, 300, 10):
24. **print**(i)
26. slr\_file = 'data/hazards/extreme\_sea\_level/esl\_aep1\_slr{}.shp'.format(i)
27. slr = gpd.read\_file(slr\_file)
29. bridges\_clip = gpd.clip(bridges, slr)
30. bridges\_list.append(len(bridges\_clip))
32. pipes\_clip = gpd.clip(pipes, slr)
33. pipes\_list.append(pipes\_clip.length.sum())
35. roads\_clip = gpd.clip(roads, slr)
36. roads\_list.append(roads\_clip.length.sum())
38. census\_clip = gpd.clip(census, slr)
39. census\_list.append(census\_clip['C18\_CURPop'].sum())
41. # print data to the shell
42. **print**(bridges\_list)
43. **print**(pipes\_list)
44. **print**(roads\_list)
45. **print**(census\_list)
47. # write to csv
48. risk\_dict = {'Bridges' : bridges\_list, 'Pipes' : pipes\_list, 'Roads' : roads\_list, 'Population' : census\_list}
49. risk\_data = gpd.GeoDataFrame(risk\_dict)
50. risk\_data.to\_csv('Risk\_data.csv')
51. """Program to plot risk assessment data from a csv file"""
52. # use directory cd "Desktop\Uni\2nd Pro\375\Assignment\_1"
54. # import packages
55. **import** numpy as np
56. **import** matplotlib.pyplot as plt
57. **import** geopandas as gpd
59. # import data
60. data = np.genfromtxt('Risk\_data.csv', delimiter=',')
61. data\_cropped = data[1:,1:]
62. bridges = data\_cropped[:,0]
63. pipes = data\_cropped[:,1]
64. roads = data\_cropped[:,2]
65. census = data\_cropped[:,3]
66. #data clipped in 0.1m increments
68. # sea level rise data
69. data\_slr = np.genfromtxt('slr\_projection.csv', delimiter=',')
70. years = data\_slr[2:,0]
71. rcp2\_mean = data\_slr[2:,1]
72. rcp2\_upper = data\_slr[2:,2]
73. rcp2\_lower = data\_slr[2:,3]
74. rcp8\_mean = data\_slr[2:,4]
75. rcp8\_upper = data\_slr[2:,5]
76. rcp8\_lower = data\_slr[2:,6]
78. std2\_list = []
79. std8\_list = []
80. **for** i **in** range(11):
81. std2 = (rcp2\_upper[i] - rcp2\_mean[i]) / 1.96
82. std8 = (rcp8\_upper[i] - rcp8\_mean[i]) / 1.96
83. std2\_list.append(std2)
84. std8\_list.append(std8)
85. stds = std2\_list, std8\_list
87. **def** construct\_uncertainties(variable, stds, data\_slr):
88. """Contructs uncertainty"""
90. rcp2\_std, rcp8\_std = stds
91. rcp2\_mean = data\_slr[2:,1]
92. rcp8\_mean = data\_slr[2:,4]
94. rcp2\_array = []
95. **for** i, std **in** enumerate(rcp2\_std):
96. population = []
97. **for** j **in** range(1000):
98. random\_point = np.random.normal(rcp2\_mean[i], std) \* 100
99. value = np.interp(random\_point, np.arange(0, 300, 10), variable)
100. population.append(value)
101. mean = np.mean(population)
102. upper = np.percentile(population, 95)
103. lower = np.percentile(population, 5)
104. array\_row = [round(mean, 3), round(upper, 3), round(lower, 3)]
105. rcp2\_array.append(array\_row)
107. rcp8\_array = []
108. **for** i, std **in** enumerate(rcp8\_std):
109. population = []
110. **for** j **in** range(1000):
111. random\_point = np.random.normal(rcp8\_mean[i], std) \* 100
112. value = np.interp(random\_point, np.arange(0, 300, 10), variable)
113. population.append(value)
114. mean = np.mean(population)
115. upper = np.percentile(population, 95)
116. lower = np.percentile(population, 5)
117. array\_row = [round(mean, 3), round(upper, 3), round(lower, 3)]
118. rcp8\_array.append(array\_row)
119. **return** rcp2\_array, rcp8\_array
121. bridges\_array = np.array(construct\_uncertainties(bridges, stds, data\_slr))
122. pipes\_array = np.array(construct\_uncertainties(pipes, stds, data\_slr))
123. roads\_array = np.array(construct\_uncertainties(roads, stds, data\_slr))
124. people\_array = np.array(construct\_uncertainties(census, stds, data\_slr))
126. # plot bridges
127. plt.figure(1)
128. axes = plt.axes()
129. axes.plot(years, bridges\_array[0][:, 0], label='RCP2', color='b')
130. axes.plot(years, bridges\_array[0][:, 1], label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
131. axes.plot(years, bridges\_array[0][:, 2], color='b', linewidth=1, linestyle='--')
132. axes.plot(years, bridges\_array[1][:, 0], label='RCP8', color='r')
133. axes.plot(years, bridges\_array[1][:, 1], label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
134. axes.plot(years, bridges\_array[1][:, 2], color='r', linewidth=1, linestyle='--')
135. axes.set\_title("Risk assement of bridges in Christchurch")
136. axes.set\_xlabel("Year")
137. axes.set\_ylabel("Number of bridges affected")
138. axes.grid(True)
139. axes.legend()
140. plt.show()
142. # plot pipes
143. plt.figure(2)
144. axes = plt.axes()
145. axes.plot(years, pipes\_array[0][:, 0], label='RCP2', color='b')
146. axes.plot(years, pipes\_array[0][:, 1], label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
147. axes.plot(years, pipes\_array[0][:, 2], color='b', linewidth=1, linestyle='--')
148. axes.plot(years, pipes\_array[1][:, 0], label='RCP8', color='r')
149. axes.plot(years, pipes\_array[1][:, 1], label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
150. axes.plot(years, pipes\_array[1][:, 2], color='r', linewidth=1, linestyle='--')
151. axes.set\_title("Risk assement of pipes in Christchurch")
152. axes.set\_xlabel("Year")
153. axes.set\_ylabel("Length of pipes affected (m)")
154. axes.grid(True)
155. axes.legend()
156. plt.show()
158. # plot roads
159. plt.figure(3)
160. axes = plt.axes()
161. axes.plot(years, roads\_array[0][:, 0], label='RCP2', color='b')
162. axes.plot(years, roads\_array[0][:, 1], label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
163. axes.plot(years, roads\_array[0][:, 2], color='b', linewidth=1, linestyle='--')
164. axes.plot(years, roads\_array[1][:, 0], label='RCP8', color='r')
165. axes.plot(years, roads\_array[1][:, 1], label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
166. axes.plot(years, roads\_array[1][:, 2], color='r', linewidth=1, linestyle='--')
167. axes.set\_title("Risk assement of roads in Christchurch")
168. axes.set\_xlabel("Year")
169. axes.set\_ylabel("Length of roads affected (m)")
170. axes.grid(True)
171. axes.legend()
172. plt.show()
174. # plot census
175. plt.figure(4)
176. axes = plt.axes()
177. axes.plot(years, people\_array[0][:, 0], label='RCP2', color='b')
178. axes.plot(years, people\_array[0][:, 1], label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
179. axes.plot(years, people\_array[0][:, 2], color='b', linewidth=1, linestyle='--')
180. axes.plot(years, people\_array[1][:, 0], label='RCP8', color='r')
181. axes.plot(years, people\_array[1][:, 1], label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
182. axes.plot(years, people\_array[1][:, 2], color='r', linewidth=1, linestyle='--')
183. axes.set\_title("Risk assement of population in Christchurch")
184. axes.set\_xlabel("Year")
185. axes.set\_ylabel("Number of people affected")
186. axes.grid(True)
187. axes.legend()
188. plt.show()
190. # import gpd data for percentage calculations
191. bridgesraw = gpd.read\_file('data/infrastructure/bridges.shp')
192. pipesraw = gpd.read\_file('data/infrastructure/potablewater\_pipe.shp')
193. roadsraw = gpd.read\_file('data/infrastructure/street\_centre\_line.shp')
194. censusraw = gpd.read\_file('data/socioeconomic/2018-census-christchurch.shp')
196. # plot bridges as %
197. plt.figure(1)
198. axes = plt.axes()
199. axes.plot(years, bridges\_array[0][:, 0] \* 100 / len(bridgesraw), label='RCP2', color='b')
200. axes.plot(years, bridges\_array[0][:, 1] \* 100 / len(bridgesraw), label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
201. axes.plot(years, bridges\_array[0][:, 2] \* 100 / len(bridgesraw), color='b', linewidth=1, linestyle='--')
202. axes.plot(years, bridges\_array[1][:, 0] \* 100 / len(bridgesraw), label='RCP8', color='r')
203. axes.plot(years, bridges\_array[1][:, 1] \* 100 / len(bridgesraw), label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
204. axes.plot(years, bridges\_array[1][:, 2] \* 100 / len(bridgesraw), color='r', linewidth=1, linestyle='--')
205. axes.set\_title("Percentage of bridges in Christchurch exposed")
206. axes.set\_xlabel("Year")
207. axes.set\_ylabel("Percentage of bridges affected (%)")
208. axes.grid(True)
209. axes.legend()
210. plt.show()
212. # plot pipes as %
213. plt.figure(2)
214. axes = plt.axes()
215. axes.plot(years, pipes\_array[0][:, 0] \* 100 / pipesraw.length.sum(), label='RCP2', color='b')
216. axes.plot(years, pipes\_array[0][:, 1] \* 100 / pipesraw.length.sum(), label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
217. axes.plot(years, pipes\_array[0][:, 2] \* 100 / pipesraw.length.sum(), color='b', linewidth=1, linestyle='--')
218. axes.plot(years, pipes\_array[1][:, 0] \* 100 / pipesraw.length.sum(), label='RCP8', color='r')
219. axes.plot(years, pipes\_array[1][:, 1] \* 100 / pipesraw.length.sum(), label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
220. axes.plot(years, pipes\_array[1][:, 2] \* 100 / pipesraw.length.sum(), color='r', linewidth=1, linestyle='--')
221. axes.set\_title("Risk assement of pipes in Christchurch")
222. axes.set\_xlabel("Year")
223. axes.set\_ylabel("Percentage of pipes affected (%)")
224. axes.grid(True)
225. axes.legend()
226. plt.show()
228. # plot roads as %
229. plt.figure(3)
230. axes = plt.axes()
231. axes.plot(years, roads\_array[0][:, 0] \* 100 / roadsraw.length.sum(), label='RCP2', color='b')
232. axes.plot(years, roads\_array[0][:, 1] \* 100 / roadsraw.length.sum(), label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
233. axes.plot(years, roads\_array[0][:, 2] \* 100 / roadsraw.length.sum(), color='b', linewidth=1, linestyle='--')
234. axes.plot(years, roads\_array[1][:, 0] \* 100 / roadsraw.length.sum(), label='RCP8', color='r')
235. axes.plot(years, roads\_array[1][:, 1] \* 100 / roadsraw.length.sum(), label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
236. axes.plot(years, roads\_array[1][:, 2] \* 100 / roadsraw.length.sum(), color='r', linewidth=1, linestyle='--')
237. axes.set\_title("Risk assement of roads in Christchurch")
238. axes.set\_xlabel("Year")
239. axes.set\_ylabel("Percentage of roads affected (%)")
240. axes.grid(True)
241. axes.legend()
242. plt.show()
244. # plot census as %
245. plt.figure(4)
246. axes = plt.axes()
247. axes.plot(years, people\_array[0][:, 0] \* 100 / censusraw['C18\_CURPop'].sum(), label='RCP2', color='b')
248. axes.plot(years, people\_array[0][:, 1] \* 100 / censusraw['C18\_CURPop'].sum(), label='likely range (+/-95%)', color='b', linewidth=1, linestyle='--')
249. axes.plot(years, people\_array[0][:, 2] \* 100 / censusraw['C18\_CURPop'].sum(), color='b', linewidth=1, linestyle='--')
250. axes.plot(years, people\_array[1][:, 0] \* 100 / censusraw['C18\_CURPop'].sum(), label='RCP8', color='r')
251. axes.plot(years, people\_array[1][:, 1] \* 100 / censusraw['C18\_CURPop'].sum(), label='likely range (+/-95%)', color='r', linewidth=1, linestyle='--')
252. axes.plot(years, people\_array[1][:, 2] \* 100 / censusraw['C18\_CURPop'].sum(), color='r', linewidth=1, linestyle='--')
253. axes.set\_title("Risk assement of population in Christchurch")
254. axes.set\_xlabel("Year")
255. axes.set\_ylabel("Percentage of people affected (%)")
256. axes.grid(True)
257. axes.legend()
258. plt.show()