VICTORIA UNIVERSITY OF WELLINGTON
Te Whare Wānanga o te Ūpoko o te Ika a Māui

School of Engineering and Computer Science
Te Kura Mātai Pūkaha, Pūrorohiko

PO Box 600
Wellington
New Zealand

Tel: +64 4 463 5341
Fax: +64 4 463 5045
Internet: office@ecs.vuw.ac.nz

Understanding Climate Change by Visualising Environmental Data

Sean Hone

Supervisor: Dr. Craig Anslow

Submitted in partial fulfilment of the requirements for
Bachelor of Engineering with Honours in Software
Engineering.

Abstract

Climate change is a change in the usual weather found in a place. It is being accelerated by the inventions of humans for activities like transportation and generating power. Climate change is an important and ongoing area of research, but the general public lacks the tools to understand how the environment is changing. Visualisation is a method of displaying data that helps people understand patterns in the data. Without such tools to increase understanding of climate change, the public is not fully exposed to the alarming consequences of the issue. Climate change could be irreversible by 2030 without drastic removal of CO2 from the air. Passing this benchmark would result in poverty, droughts, floods and a myriad of other consequences that may be detrimental to the human race. This report details the design, implementation and evaluation of a web application called ClimateVis that can visualise environmental data to increase climate change awareness. The evaluation of ClimateVis suggests it is capable of becoming an effective tool in helping raise climate change awareness.

Acknowledgments

I would like to thank my supervisor, Dr. Craig Anslow, for his guidance and encouragement throughout this project. He taught me a great deal and pushed me to reach my potential, for which I am very grateful. I would also like to thank the Victoria University Human-Computer Interaction group for their support and advice throughout the year.

Contents

Figures

Chapter 1

Introduction

"Climate change is my generation's nuclear-free moment." - Jacinda Ardern, 2017 [1].

Climate change is a change in the usual weather found in a place [2]. It is being accelerated by the inventions of humans for activities like transportation and generating power [2]. It is threatening the environment with rising sea levels, droughts and extreme weather events [3]. Raising awareness about how the environment is changing may inspire a collective effort to deal with climate change. Sadly the general public lacks ways in which they can understand how the environment is being affected by climate change. If the public cannot educate themselves and others about this environmental issue, then awareness of the issue will be inadequate to make a positive change.

1.1 The Problem

Climate change is a term used to characterise the extensive variations in the environment due to human interference. The New Zealand Ministry for the Environment (MFE) predicts climate change will cause higher temperatures, rising sea levels, more frequent extreme weather events and a change in rainfall patterns [3]. Increased floods and droughts would put communities at risk. New Zealand's native flora and fauna may be threatened as habitats become favourable for exotic species. There is an incomprehensible number of consequences that threaten New Zealand due to climate change.

The general public is partially responsible for perpetuating climate change but can lack the knowledge of how the environment is changing. People rely on the emission of CO2 and methane for transport, providing electricity and producing animal products such as milk. People may not realise how consuming these products is changing our environment. This problem is partly due to the lack of ways the general public understand climate change. Many articles cover the consequences of climate change, but few of these resources allow the general public to explore and visualise climate change. It could be very beneficial to visualise climate change as humans are better at processing colours and patterns than drawing conclusions from a body of text. By having access to visualisations, they would not only be able to see the patterns, but they could also explore the data helping them understand climate change further. A tool that could create and share these visualisations is not the only way to raise awareness about climate change, but it may be a step in the right direction.

Environmental visualisations and infographics do exist, but their limitations fail to overcome the challenges of raising climate change awareness. An in-depth discussion of current solutions and their limitations can be found in Chapter 2. A visualisation needs to be compelling to influence a person. It needs to convey information allowing people to understand how the environment is changing. Compelling visualisations should include behaviour such as being able to zoom in on data, filter out unrelated data and see finer-grained details of a datum when requested [4]. Another limitation is that the available solutions only offer a single way to visualise data. Viewing trends over time and finding correlations between cause and effect would require finding separate web applications capable of visualising environmental data. Current environmental visualisations and infographics are singular solutions that fail to implement helpful functionality and therefore are less effective when trying to raise climate change awareness.

1.2 The Solution

This project aims to create a web application to help the general public understand how the climate is changing. The web application is known as *ClimateVis*. A web application was thought to be the most accessible way for people to access a visualisation tool. Building a web application also simplifies the process of integrating with other web-based applications. ClimateVis offers the public a single interface to visualise environmental data. The web application gives the general public the ability to create visualisations of environmental data showing them how the environment is changing. ClimateVis is built so that it can be easily integrated with other websites that aim to achieve a similar goal such as Land Air Water Aotearoa (LAWA). ClimateVis should educate people by allowing them to visualise environmental data in ways that highlight patterns of climate change.

The current ClimateVis prototype is available at the link below. At this address, you will find a tutorial on the different parts of ClimateVis. It mentions the key components of the interface and also breaks down the usages of each visualisation.

`http://homepages.ecs.vuw.ac.nz/~honesean/`

ClimateVis aims to be a unique solution by offering a platform capable of visualising many aspects of environmental data while trying to address the issues of other solutions. ClimateVis offers six visualisations so people can find trends, compare, correlate and contrast environmental data in New Zealand. By consolidating all of these visualisations in a single web application people only need to learn how to use one tool. Currently, people need to learn a new set of interactions for each visualisation solution. Instead, a user can spend that time learning from the tool. The other benefit with consolidating to a single platform is that all visualisations can aim to achieve the same goal of raising climate change awareness. ClimateVis is a unique platform that offers six ways to visualise different components of New Zealand's environment.

The target audience is people from the general public who have an interest in climate change but are not experts in the field. Any member of the public should be able to use ClimateVis, but those with an understanding of climate change may be able to make better observations. A representative demographic of this audience is a student studying towards a Bachelor of Science majoring in Geography. These students would have the knowledge to make visualisations with ClimateVis that exemplify the effects of climate change. Teachers could also use ClimateVis to demonstrate climate change to the students. Another benefit of students being a key demographic is their interconnectivity with social media. If ClimateVis was integrated with social media, students could make impactful visualisations and share it with the general public. The emphasis of public information on Twitter would make it an ideal platform to share visualisations. The evaluation of ClimateVis uses a group of people from this target audience. The evaluation is a usability user study focussed on analysing the effectiveness of ClimateVis and its visualisations. Targeting this audience would make ClimateVis a way to help the general public understand how climate change is affecting our environment.

This report covers the design, implementation and evaluation of the ClimateVis solution. The background chapter looks at current solutions pinpointing their limitations as areas ClimateVis could improve on. The ClimateVis chapter discusses whom the web application is designed for and how it should be used. This chapter also looks at the design decisions that went into creating the user interface and visualisations. Finally, the ClimateVis chapter discusses the tools used to create the final solution. The user study design chapter explains the plan for evaluating ClimateVis. The user study results chapter analyses the results from the completed user study. The summary chapter looks at possible options for continuing the project in future — this chapter finishes by summarising the contributions of this research project.

Chapter 2

Background

This chapter discusses the domain space of the project and looks at current solutions involving environmental visualisations. There are many environmental components of climate change. ClimateVis focusses on water quality based components, and this chapter discusses the relevance of this data to climate change. This chapter also introduces the idea of information visualisation as a way to effectively show trends in data. Current information visualisations in an environmental capacity are analysed to extract their strengths and weaknesses. The Land Air Water Aotearoa web application is then assessed as an environmental visualisation solution in the same area as ClimateVis. This chapter provides context for the project and identifies how the project aims to produce a unique solution.

2.1 Climate Change Data

Climate change will have devastating consequences for the world [3] and understanding these consequences is key to visualising the effects on the environment. Climate change refers to the vast array of environmental changes happening to the planet such as sea levels rising, air temperature increase and extreme weather events [5]. By definition, properties of the Earth's air and water will change with the acceleration of climate change.

New Zealand's water resources are expected to increase in temperature [3]. Not only is New Zealand's water quality data readily available online, but it can be linked to the consequences of climate change. As global warming continues, summers will become hotter, longer and drier [3]. With longer summers rainfall will reduce, increasing the intensity of droughts and resulting in rising water temperature. When temperatures rise, molecular vibrations will escalate the rate at which water can ionise to form hydrogen ions [6]. The inflation of hydrogen ions will cause a body of water to be more acidic. The measurement of pH can track acidity. The temperature adjustments to New Zealand's water resources are critical and can be tracked by changes to the pH level.

Reduced rainfall expected from climate change also means the flow of New Zealand's rivers will diminish, resulting in reduced water quality. Algae are photosynthetic bacteria that build up when water temperatures increase, and water flow is low [7]. Algae build up depreciates water quality, decreasing clarity and altering pH levels [8]. Measuring Chlorophyll in a body of water is a good indicator of the total amount of algae in the water [8]. When river flows reduce, chlorophyll levels will show algae build-up, and water quality will suffer. The water quality of New Zealand would be an ideal data source for showing the effects of climate change.

2.2 Information Visualisation

Information visualisation is essential due to the oversaturation of big data. Information visualisation is the process of visually representing trends in a dataset. The idea of information visualisation is to reduce the time needed to analyse and understand trends in raw data. Visualisations make data much more natural to process for people that do not have a good understanding of the data's domain. It can be challenging to create visualisations that communicate trends in data effectively. Ben Shneiderman created the 'Information Seeking Mantra', which is a collection of properties information visualisations could implement to maximise how effectively they communicate data [4]. Shneiderman's 'Information Seeking Mantra' are listed in Section 2.2.1. There are many information visualisation tools available such as Tableau discussed in Section 2.2.2. Unfortunately, to be effective, these tools often have domain-specific visualisations. This generalisation could lack the impact needed to help people understand the gravity of climate change. To be a successful solution, ClimateVis should be an information visualisation platform that implements the 'Information Seeking Mantra' and focusses solely on environmental visualisation.

2.2.1 Information Seeking Mantra

Ben Shneiderman's 'Information Seeking Mantra' is a set of properties that visualisation software should implement to be effective. To be a successful solution, ClimateVis should aim to support these properties. The seven properties are listed below:

- **Overview**: Gain an overview of the entire collection.
- **Zoom**: Zoom in on items of interest.
- **Filter**: Filter out uninteresting items.
- **Details-on-demand**: Select an item or group and get details when needed.
- **Relate**: View relationships among items.
- **History**: Keep a history of actions to support undo, replay, and progressive refinement.
- **Extract**: Allow extraction of sub collections and of query parameters.

2.2.2 Tableau

Tableau is an information visualisation platform designed for business intelligence and analytics [9]. Tableau can create visualisations that can be used with many forms of data. This functionality is a shared goal of ClimateVis. Having a platform that can visualise a wide range of data gives the user control over what trends and patterns they are aiming to find in the data. A platform such as Tableau overcomes the issue of needing to learn a new interface for each new visualisation. Figure 2.1 shows the interface of Tableau when creating a basic scatter plot.

Tableau is a domain-specific visualisation tool that achieves the singular visualisation interface style that ClimateVis could implement, but Tableau's learning curve and irrelevance to environmental data make it a weak solution. Tableau is designed for people with visualisation experience that have extensive knowledge of their data and how it should be visualised. ClimateVis needs to be usable by the general public, not all of whom will have an understanding of environmental data. Tableau has an extensive list of visualisations, but

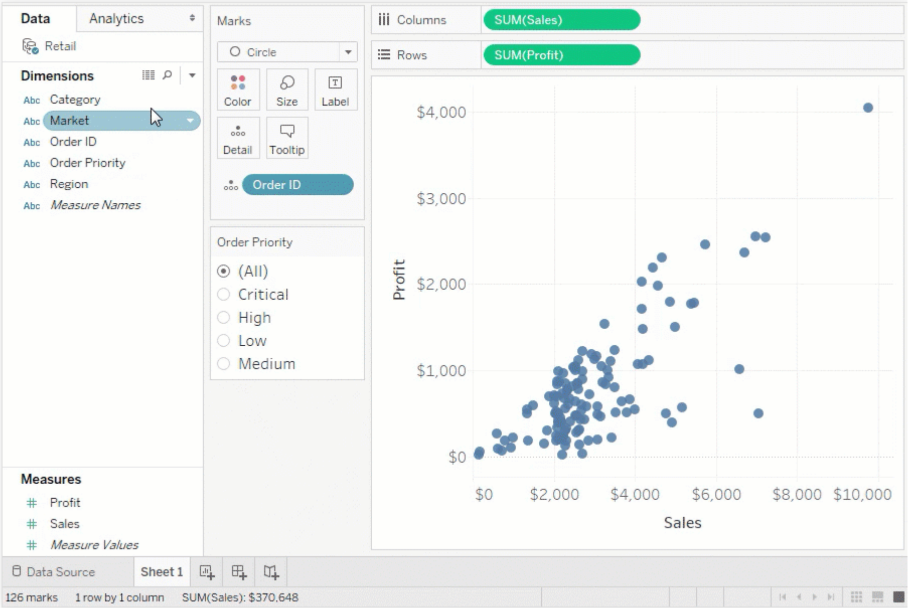


Figure 2.1: Tableau Interface for a Basic Scatter Plot [9].

the nature of the platform means they must apply to a wide variety of data. This nature means the visualisations may be less effective at increasing climate change awareness when compared to a custom made visualisation of environmental data. Tableau is a powerful platform, but a specialised solution such as those discussed in Section 2.3, would be better at raising climate change awareness.

2.3 Environmental Data Visualisations

2.3.1 Comparing Energy Consumption

The ability to compare data between categories highlights both problem areas and prosperous areas. Evoenergy created an infographic that compares the different ways the United Kingdom (U.K) consume energy, shown in Figure 2.2. A bubble on a tree represents each method of consumption. A bubble grows if it contributes more towards energy consumption. The scaling bubble size allows people to see the most popular forms of energy consumption immediately. Consequently, the infographic shows how pollutant-heavy forms of energy are more popular than electricity. The ability to compare and rank categories by a topic is an intuitive and powerful technique to visualise environmental data.

Evoenergy has used colour and size to convey the patterns in their energy consumption data effectively, but their use in an infographic reduces the reusability of what they have created. An infographic visualises data from a single data source. A visualisation can be reused on many different data sources. Several environmental properties contribute to climate change such as water contents, air composition and land usage. Each of these factors has different measurements that make them difficult to compare. This infographic would be better at raising climate change awareness if it could visualise other data sources.

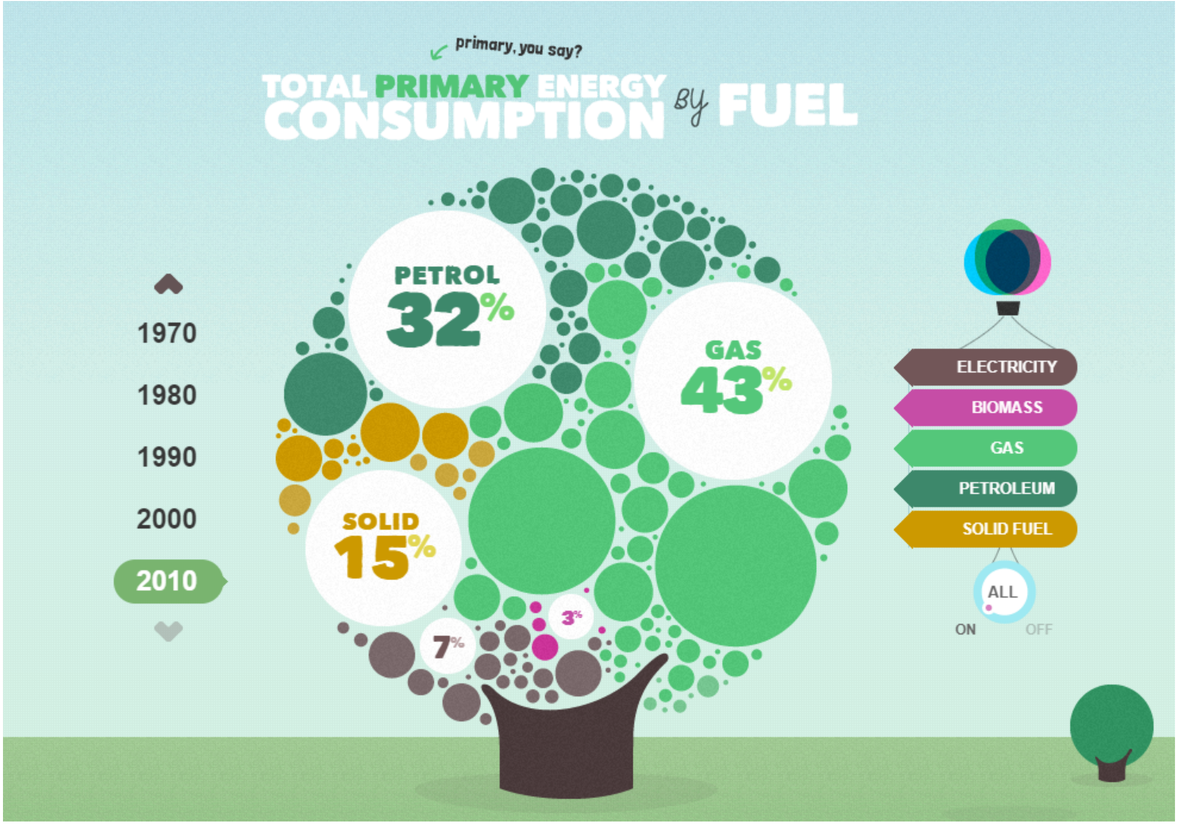


Figure 2.2: U.K. Energy Consumption [10].

2.3.2 Temperature Increase Over Time

Visualisations can show how aspects of the environment change over time. The National Aeronautics and Space Administration (NASA) created a visualisation that shows the increase in air temperature from 1880 to 2017, as seen in Appendix A. The baseline for the visualisation is the average air temperature between 1880 and 1899. A single dot represents the temperature of each year. The visualisation makes it evident that the air temperature is rising at an exponential rate. NASA's visualisation also highlights the impact of El Nino. El Nino is a weather pattern that has a significant influence over air temperature. Highlighting El Nino is important as its presence can misrepresent the impact of climate change. The ability to highlight only years with El Nino data can be toggled on and off by interacting with the visualisation. This visualisation shows the importance of visualising the change in relevant data over time.

The visualisation has a small number of components, making it easy to learn the interactions but limiting the information that can be extracted. It has no zoom functionality allowing users to focus on a more specific timeline such as the past 50 years. It also lacks the functionality to select a particular year. Users cannot get the exact details of a year to know exactly how far above the average it was. A user does not have the tools to select individual datum for comparison. The visualisation gives an overview of the air temperature data but limits the information a user can gain by interacting with it.

2.3.3 Mapping Carbon Emissions

Visualising data using location can help people understand how the data directly affects them. An article by Kennedy Elliott visualises carbon emissions on a world map [11]. As shown by Figure 2.3, areas with a high concentration of carbon dioxide emission are coloured dark red. As the emissions lessen the red intensity reduces to a pale yellow. A user can conclude that China, India and the United States are some of the worst polluting countries. This conclusion can be drawn within seconds due to the clarity of geographic data. This visualisation exemplifies how geographic data can be used to highlight patterns.

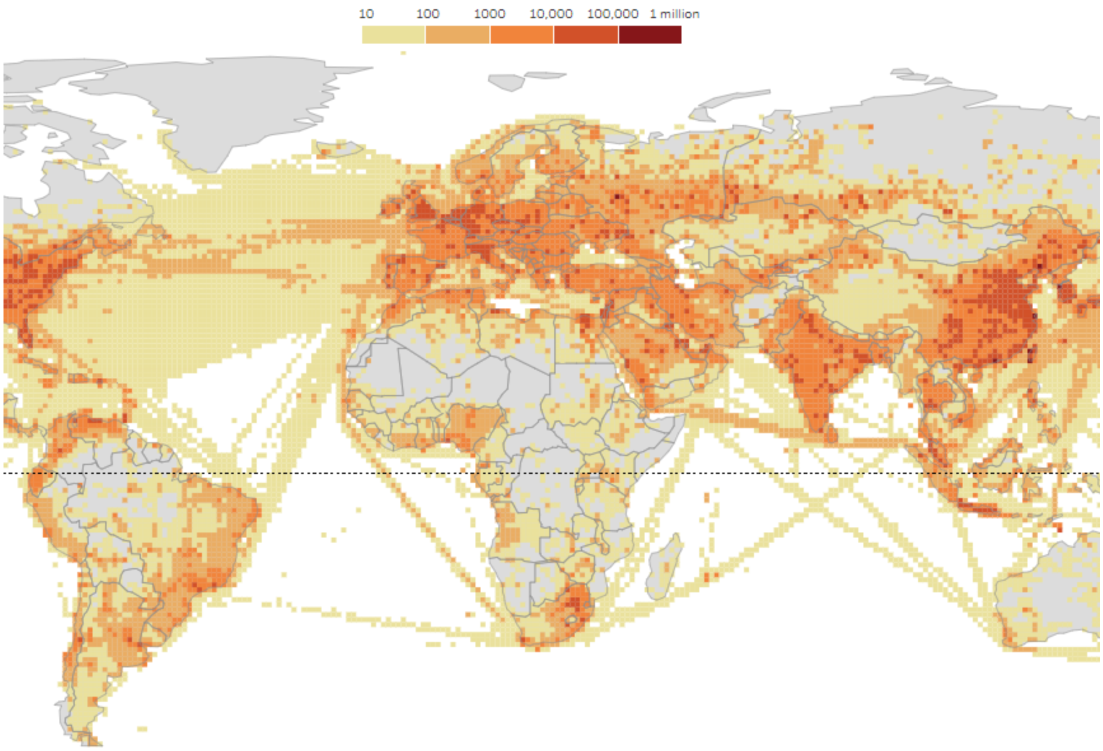


Figure 2.3: Fossil Fuel Emissions, 2001-2012 Mean, Grams of Carbon Dioxide [11].

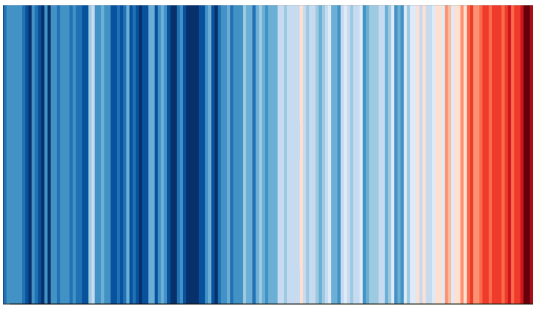
This visualisation supports some of Shneiderman's 'Information Seeking Mantra', but it limits the user in how they can explore the data. One can zoom in on the map to see each region in more detail, and they can hover over a square to see the exact location and carbon dioxide measurement. These interactions are the extent of how a user can explore the data. A user may have learnt more from the visualisation if the average carbon dioxide levels were animated over time or if they could filter the data to show the carbon dioxide levels of a specific year. The visualisation is effective, but its ability to raise climate change awareness is stumped by its limited range of ways to visualise this carbon dioxide data.

2.3.4 Warming Stripes

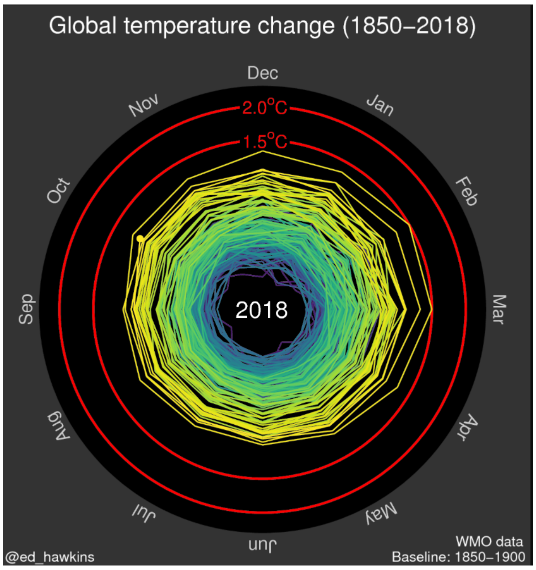
Warming Stripes is a simple static visualisation designed to communicate the complex issue of global climate change [12]. For each year between 1850 and 2017, a coloured stripe is added to a frame. The colour of the stripe depends on the average temperature of that year. The colder years use a blue colour whereas the hotter years use a red colour. The visualisation is easy to understand for people unfamiliar with environmental data. The colour choice makes the increasing temperature both visible and alarming to those viewing it. The visualisation is not interactive or animated in any way which may be less appealing to viewers. The warming stripes visualisation can be seen in Figure 2.4a. This visualisation has minimal components, yet it effectively communicates the impact of climate change, a trait that would be beneficial in ClimateVis.

The warming stripes visualisation is extremely easy for people to understand, but it lacks any form of interaction. Users cannot zoom, select, or filter data in the visualisation. The static graph conveys a strong message, but it could have done more to encourage users to explore the data. By allowing users to explore data, they become invested in what they are discovering. Hopefully, this investment builds into a passion where people feel compelled to share what they have found. This behaviour is one that ClimateVis should try to foster. The warming stripes may be effective, but it does not encourage users to explore environmental data.

2.3.5 Climate Spiral



(a) Annual Increase in Global Temperatures Covering 1.35°C.



(b) Global Temperature Increase Each Month from 1850-2018.

Figure 2.4: The Warming Stripe [12] and Climate Spiral [13] Visualisations Showing Increasing Global Temperatures Over Time.

The climate spiral is an animated visualisation that shows historical data [14]. Figure 2.4b is the climate spiral showing the changes in global temperature from 1850 to 2018. This style of visualisation resonates with a broad audience proven by its global traction on Twitter and use in the opening ceremony of the Rio Olympic games [14]. The visualisation is a single line where each point represents the temperature of a month in a year. The closer to the outside of the circle a point is the higher the temperature of that month. The visualisation demonstrates how drastically the climate is changing as the later years have very sparse rings showing bigger jumps in temperature. The two red rings act as a scale showing the temperature increase at different radii. The climate spiral engages the audience by animating the increasing global temperatures helping them understand the changing environment.

The strength of the climate spiral is the animation, but the complexity of the visualisation may reduce the clarity of the information being shown. The position of the line is used to show two different pieces of data: the temperature and the month. This dual usage means that the year cannot be visualised using the position of the line. Instead, the year is visualised by the colour of the line as it changes from purple to yellow. The fact that time is expressed in both colour and position may confuse a user. This confusion is made worse by the lack of a colour scale, and also that colour is often used to visualise temperature. The visualisation is engaging, but the overlapping use of colour and position to represent the information may be confusing for a user.

2.3.6 Land Air Water Aoteroa

Land Air Water Aotearoa [15] is a collaboration of organisations in New Zealand with a common aim: to tell the story of New Zealand's environment [16]. LAWA shows specific environmental data but lacks interactive capabilities. The original vision of LAWA was to give the community a way to view the freshwater quality of rivers and lakes in New Zealand. This goal extended to show air quality and other environmental data such as the land coverage of plant types. LAWA allows users to visualise this environmental data about a specific region. An example of visualising the air quality in Wellington is shown in Figure 2.5.

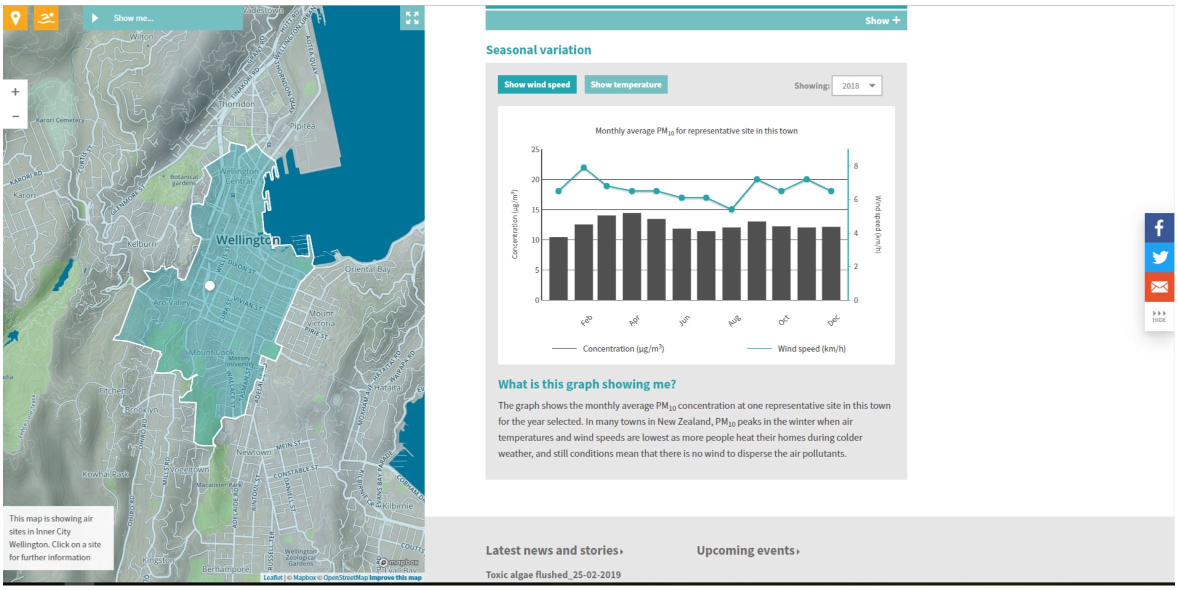


Figure 2.5: LAWA Website Showing Wellington Central Air Quality [15].

The purpose of LAWA is similar to that of ClimateVis, but its usability issues and restricted data exploration make it a less than ideal solution. LAWA has the functionality to view a range of datasets across many regions with a single interface. This functionality is desirable, but the visualisations in LAWA are limited in interaction capability. For example, the visualisation for air quality is a static graph with the option to switch between wind speed, temperature and alter the year being shown. Users may learn more if they could hover over points in the graph to learn more about the data. Limited interaction capability reduces a user's potential for data exploration. LAWA has other general usability issues that make it a less than ideal solution. A Nielsen heuristic evaluation was performed on the site by the researcher. A heuristic evaluation allows for the observation of usability issues in LAWA while limiting the potential bias of the researcher's opinion. This evaluation technique is used to find usability issues with software by analysing it against a set of 10 heuristics [17]. The serious usability issues identified by this evaluation are discussed below.

One of the Nielsen heuristics is control. This heuristic looks at how much control the user has at any point while using the application. Control over navigation, the ability to interrupt a task and allowing users to input actions are all components considered by the control heuristic. The most relevant fault in terms of user control is the lack of interactivity of the visualisations. This issue has already been discussed, but it shows how static graphs reduce the amount of control a user has over an application. The navigation system used in LAWA also limits user control. To visualise data, a user needs to navigate to a specific region and then select the type of data to see. No button automatically takes a user back to the nationwide map which could leave them trapped in a region. A user can change regions by selecting one on the map, but this behaviour is not apparent to all users. The feeling of being trapped is a complete contradiction to the concept of user control. The staggered navigation and lack of interactivity with the visualisations limit the control a user has with LAWA.

LAWA struggles to follow the minimalism heuristic. Minimalism is a heuristic that states software should only show the most crucial information to the user. Failure to do so overwhelms a user as every new element competes with every other element on the screen. Figure 2.5 partially shows how LAWA fails to be minimalist. The screenshot shows a busy graph with a full paragraph explaining how it works, a visually overloaded map, six different menus and search bars as well as a text box explaining what the map is showing. All of these components overload the aesthetics of the application and make LAWA more challenging to learn. These problems are evident throughout the application as LAWA makes heavy use of text-based explanation for a majority of its features.

The final usability issue identified by the evaluation was LAWA's use of shortcuts. The shortcut heuristic is required to support progression for users. If shortcuts are used, then novices do not become confused with complex behaviour, and experts can be more productive with the software. LAWA has a complicated navigation mechanic with the map that requires users to select a region and then often multiple other options to visualise any data. There are no shortcuts to recreate a visualisation or navigate back to one created in the past. The lack of shortcuts could be frustrating for frequent users of LAWA.

2.4 Background Summary

There are many visualisation solutions with environmental data, but they each have limitations. The singular visualisations forced users to learn a new interface for each different way the data was represented. Some of these singular visualisations also restricted the user's ability to explore the data. ClimateVis should provide a single interface to create and interact with these visualisations. LAWA offered a platform to view several types of environmental data. Unfortunately, the data was displayed in a mostly static manner. LAWA also suffered from usability problems and an overload of text-based information. The ClimateVis visualisations should allow users to explore data through interaction. To be a unique, successful solution, ClimateVis should be a user-friendly platform that can visualise environmental data in several different ways.

Chapter 3

ClimateVis

ClimateVis is a web application designed to visualise environmental data to raise climate change awareness. This chapter covers the design, usage and implementation of ClimateVis. It outlines whom the web application is designed for and what they can do with it. The chapter discusses the design decisions and challenges when building the user interface and the accompanying collection of visualisations. It describes the use-case scenarios for people who may interact with ClimateVis. The chapter also details the tools used to create ClimateVis and how those tools were utilised.

3.1 Design

ClimateVis is a prototype that gives people the ability to visualise environmental data. The web application provides a single interface that can be used for visualising this environmental data. The advantage of using a single interface means that users do not have to learn a new set of interactions to create each new environmental visualisation. They can instead learn a singular set of interactions that will allow them to visualise environmental data in many different ways.

Below is a list of the tasks ClimateVis has been designed to handle:

- The user can seamlessly create a visualisation that gives an overview of environmental data in New Zealand. This functionality is essential to implementing the overview property of the 'Information Seeking Mantra'.
- The user can quickly switch between many types of environmental data but use the same visualisation. These types of environmental data are built into ClimateVis and include properties like the acidity and clarity of New Zealand lakes.
- The user can change the visualisation while keeping the original data.
- The user can switch back and forth between all created visualisations to help with data comparison.
- The user can apply filters to refine further the data being shown in each visualisation. The filter feature supports the filter property of Shneiderman's mantra.
- The user can interact with a visualisation through hovering, clicking and zooming to explore data. Interaction is vital functionality that ensures the zoom and details-on-demand properties of Shneiderman's mantra are supported.

ClimateVis has been designed for the general public with the hopes of raising awareness about climate change. The general public is an ideal target audience as they can change the course of climate change on a large scale. Targeting the general public is also ideal as there are few visualisation tools currently focussing on this audience. There is no need to target industry professionals as there are already tools catering to this group of people. Ben Powley's AtmoVis project is an environmental visualisation program built for industry professionals [18]. An educated general public is the desireable audience because they may already have an understanding of climate change. This understanding would mean they could create more impactful visualisations and answer more complicated questions. By focussing on the general public ClimateVis aims to reach a broad audience that can use the tool to demonstrate how climate change is altering our environment.

ClimateVis has a large target audience meaning many people can use the tool. The list below highlights a few examples of people that would be suitable users for ClimateVis. When a user is referred to throughout this report, they can be thought of as any of these examples:

- A lecturer or teacher that wishes to educate their students on how New Zealand's environment is changing.
- A member of a district council that wants to see their region's environmental data over time and possibly compare it to other regions.
- An environmental scientist at an agency such as NIWA that wants a quick way to visualise environmental data without the complexity of professional-level tools.
- A university student that has partially or fully completed their degree and wants to learn about climate change. University students with a degree in Geography are preferable as they may have prior knowledge of the environmental data in ClimateVis.

3.2 Visualisations

The user interface and visualisations of ClimateVis have been designed so the general public can perform the tasks outlined in section 3.1. The interface aims to provide a fluid and straightforward way to create and explore visualisations. The features of the user interface and the visualisations were designed to support Ben Shneiderman's 'Information Seeking Mantra' [4]. This mantra has acted as a guideline when creating a cohesive collection of visualisations and a set of helpful user interface features for ClimateVis.

3.2.1 Bar Visualisation

The bar visualisation, shown in Figure 3.1a, is used for comparing a specific environmental topic against different categories. An example of a topic is the acidity level in a body of water. An example of category is the regions of New Zealand. The bar visualisation would give users an overview of the acidity of bodies of water in each region. The visualisation has a green horizontal line that represents the ideal value for a topic as defined by the standards of the New Zealand government.

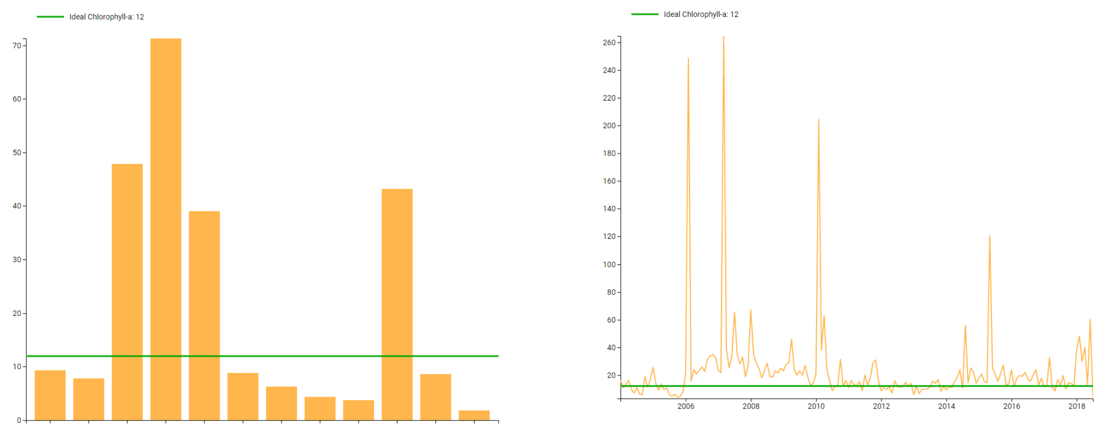
A user can then hover over a bar to see more detailed information. After hovering, a popup window shows what category the bar is from and the exact value the bar is showing.

The bar is highlighted in red when hovered over to highlight the selection. In some cases, the height of the bars may be indistinguishable from one another. In such a circumstance, users can zoom in to change the vertical scaling and see a more detailed view of each bar. Panning functionality is also implemented for the repositioning of bars. The bar visualisation is a simple way to compare an environmental topic between different categories.

3.2.2 Line Visualisation

The line visualisation is ideal for finding trends of an environmental topic over time. The example seen in Figure 3.1b shows how the average Chlorophyll-a levels in bodies of water around New Zealand have changed over time. The visualisation has a green horizontal line that represents the ideal value for a topic as defined by the standards of the New Zealand government.

Some of the lines generated show fine details of changes that happened over time. A user can zoom in on these times to see a more detailed view of how the value was changing. Panning functionality lets the user follow the line and view trends in finer detail. The line visualisation is a simple way to highlight the trends of an environmental topic over time and its interactions allow users to explore these trends.



(a) The Bar Visualisation Comparing Cholorphyll-a Levels Between New Zealand's Regions.

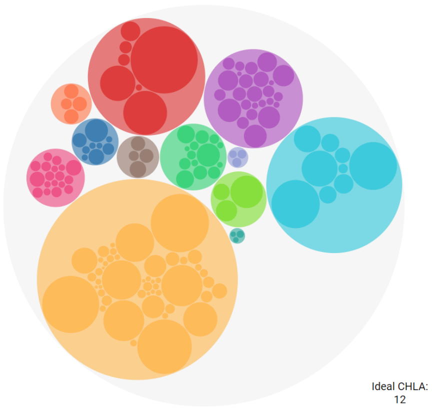
(b) The Line Visualisation Showing Cholorphyll-a Levels of New Zealand Lakes Over Time.

Figure 3.1: Line and Bar Visualisations Showing Average Cholorphyll-a Levels of New Zealand Lakes.

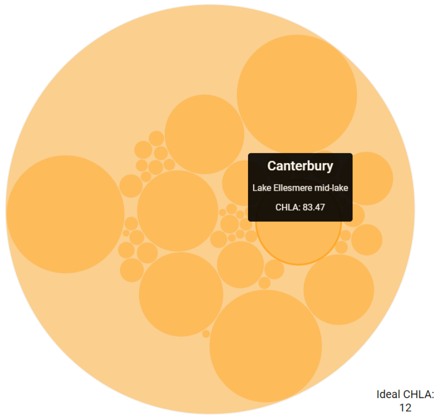
3.2.3 Bubble Visualisation

The bubble visualisation compares the relative values of an environmental topic while simultaneously showing the hierarchical geographical relationship of locations used to collect data. The smallest, darkest bubbles seen in Figure 3.2a represent the locations where the data for a topic was collected. The larger bubbles that encompass these data collection locations represent the regions where those locations can be found. The outer most bubble represents all of New Zealand. The size of each bubble is relative to the value of all lake sites that recorded data for the topic. If the topic is E.Coli levels in a body of water, then the bigger bubbles represent lake sites with a higher level of E.Coli.

The initial view is an overview of the entire nation. When a user hovers over a bubble in this view, they are shown a popup window that says what region a certain coloured bubble represents. If a user clicks on one of these bubbles, then the visualisation zooms in to show all bubbles from just that region. In this more focussed view hovering over a bubble will show what location it represents and the exact topic value collected at that location. Figure 3.2b shows an example of what the user sees after clicking a bubble and zooming in. The bubble visualisation teaches a user about the relative amounts of an environmental topic while allowing them to explore the geographical relationship of the locations used for data collection.



(a) The Initial View Giving an Overview of Cholorphyll-a Levels in New Zealand Lake Sites.



(b) The Zoomed-In View Hovering Over the Lake Ellesmere Mid Lake Site Bubble.

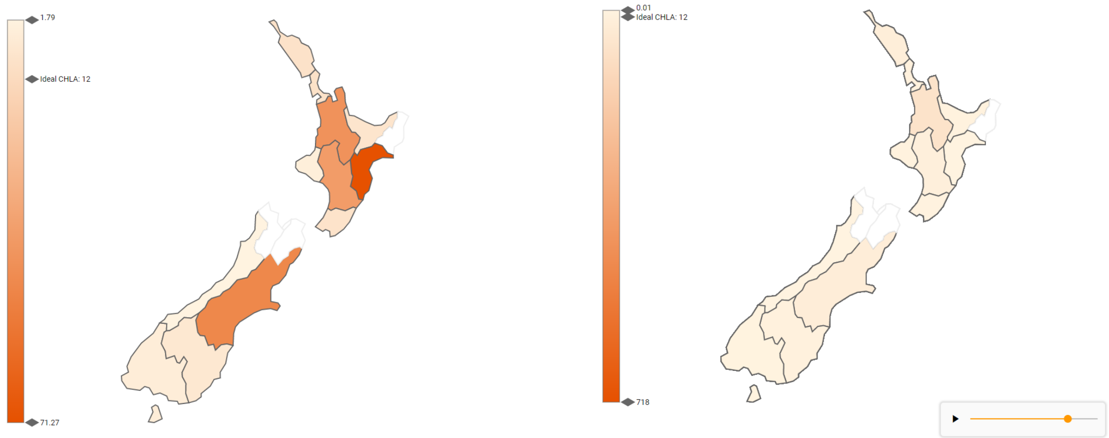
Figure 3.2: The Bubble Visualisation Showing the Relative Average Cholorphyll-a Levels from Lake Sites Across New Zealand.

3.2.4 Map Visualisation

The map visualisation displays the values of an environmental topic on a graphical depiction of New Zealand. The colour of each region represents the topic value in that region, as seen in Figure 3.3a. The regions with the highest value are coloured in a deep orange while the lowest value regions have a very faint orange. The values that these colours represent is shown on a scale to the left of the map. The regions that have not collected data for that topic are coloured white and given a faint grey outline.

The initial map shows a general overview of the topic status in each region. The user can explore the map by zooming in and panning around. If they hover over a region, they are shown a popup. The popup specifies what region is selected and gives details about the value of the topic in that region. The region is also outlined in turquoise to show the user it is currently selected. The map visualisation offers a graphically familiar way to explore environmental data around New Zealand.

There is also an animated variation of the map shown in Figure 3.3b. In this variation, the regions can be seen changing colour as their topic values increase or decrease over time. A user can pause, play and select a specific frame in the animation. The map interaction is removed in this variation to simplify the visualisation. The animated variation of the map visualisation gives users a new way to explore the data.

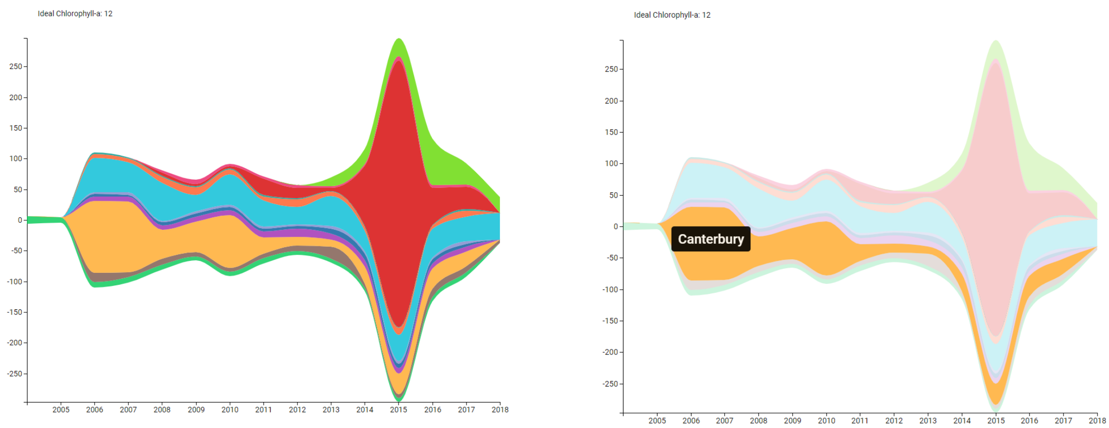


(a) Average Cholorphyll-a Level of Lakes in Regions Across New Zealand.

(b) The Animated Map Variant Stopped to Show Average Chlorophyll-a Levels of June 2015 in the Regions Across New Zealand.

Figure 3.3: The Map Visualisation Variants Showing the Relative Average Cholorphyll-a Levels of Lakes in Each of New Zealand's Regions.

3.2.5 Stream Visualisation



(a) The Initial View of the Stream Visualisation Showing Yearly Average Cholorphyll-a Levels in New Zealand.

(b) The Result of Hovering Over a Stream to Pinpoint a Region's Contribution to New Zealands Total of Average Cholorphyll-a Level.

Figure 3.4: The Stream Visualisation Showing the Contribution of Each Region to New Zealand's Average Cholorphyll-a Level Each Year.

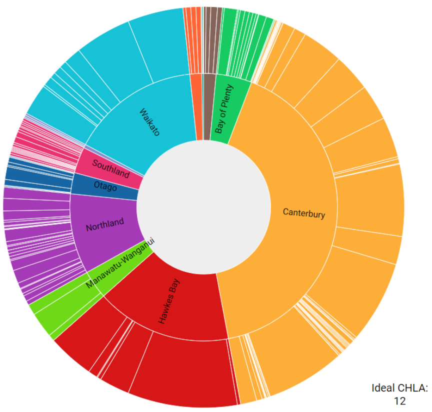
The stream visualisation is a compartmentalised view of how an environmental topic has changed over time. The total height of the stream at any point shows the total amount of a topic at that time. In the example in Figure 3.4a you can see that New Zealand had the highest average Cholorphyll-a levels in bodies of water during 2015. Each smaller stream with a different colour is a different region. The size of the smaller streams show how they contributed to New Zealand's total.

To know which region a colour represents a user must hover over that coloured stream. This action creates a popup showing the name of the region for a stream colour. All other streams are faded out during this hovering action to clarify what stream is selected. Figure 3.4b shows the result of hovering over a stream. The user can zoom and pan around the graph to analyse the trends in closer detail. The stream visualisation is ideal for seeing how each region contributed to New Zealand's environment over time.

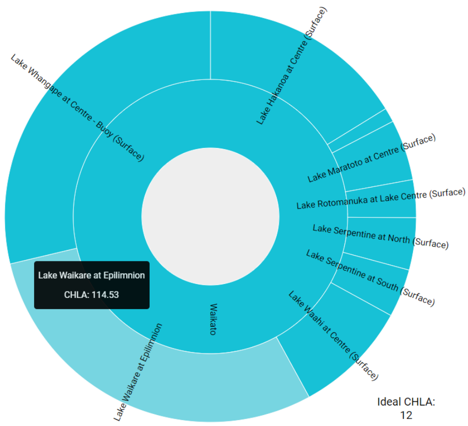
3.2.6 Sunburst Visualisation

The sunburst visualisation is another compartmentalised view of an environmental topic that shows the relative contribution of each region to New Zealands total value of the topic. The visualisation is a donut of different coloured segments shown in Figure 3.5a. Each colour is labelled with the region it represents. There is an inner and outer ring. The inner ring shows the total value of a region in regards to a particular topic. Each segment in the outer ring represents a particular location of data collection. The colour and inner segment that an outer segment aligns with relates to the region of a data collection location.

A user can hover over a segment to see more details. These details include the exact topic value and either the region name or data collection location name. If a user clicks on a segment, the visualisation will zoom in to make the entire donut display one region. The labels of the more prominent outer segments are shown. This view lets a user explore a region's data in more detail. The zoomed view is shown in Figure 3.5b. The sunburst visualisation shows the composition of an environmental topic in New Zealand based on each region and related data collection locations.



(a) The Sunburst Visualisation Showing an Overview of the Regional Cholorphyll-a Level Contirbutions.



(b) The Zoomed-In View Showing the Contribution of Waikato Lake Sites to the Region's Total of Average Cholorphyll-a Levels.

Figure 3.5: The Sunburst Visualisation Showing the Relative Contirbutions of Regions and Lake Sites to New Zealands Total of Average Cholorphyll-a Levels.

3.3 User Interface

3.3.1 Visualiser

To make the web application as simple as possible, the user interface was split into two core parts: the visualisation builder and the visualiser. The visualiser, shown in Figure 3.6, was designed to handle the viewing and interaction of one visualisation while offering the functionality to switch between multiple visualisations. The visualiser has a menu bar in light blue and a canvas. The canvas is where a visualisation is drawn and where the user can interact with it. The menu provides all of the functionality to handle multiple visualisations. The visualiser can be expanded to full screen, giving the user a more focussed view on the visualisations themselves.

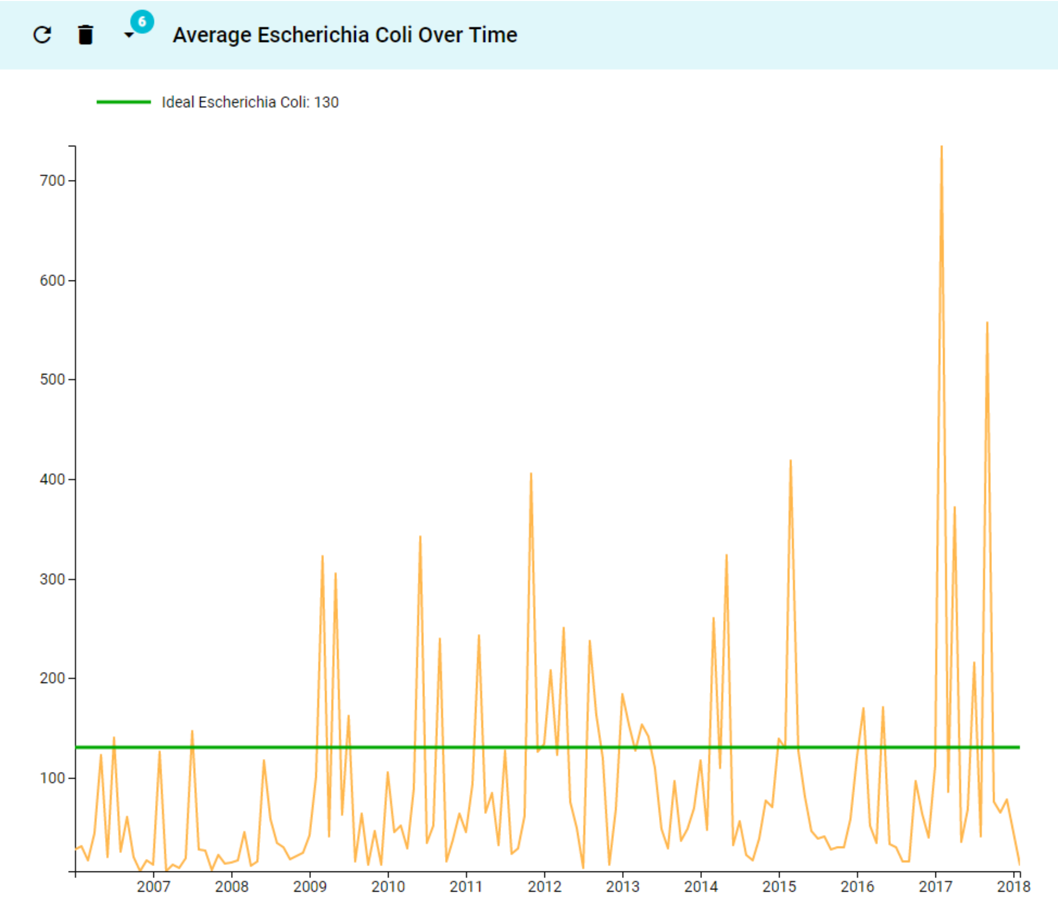


Figure 3.6: The Visualiser with A Line Visualisation on the Canvas Showing Average Escherichia Coli Levels in New Zealand Over Time.

The menu has three different functions, each represented by an icon. The dropdown arrow and badge number keep track of all created visualisations. Each time a visualisation is created, it is stored in a stack. The purpose of the stack is to allow users to recreate previous visualisations helping them reference earlier findings efficiently. This stack is shown in the dropdown menu opened by clicking the arrow. The badge number shows how many visualisations have been created. A user can switch between visualisations by selecting one from this dropdown menu. An alternative to the stack was a traditional tab-based system like most web browsers use. Each visualisation would have its own tab. This option was dismissed as this feature would have cluttered the user interface without significantly improving its functionality. The refresh icon updates the visualisation based on the current settings in the builder component. The trash bin icon deletes the currently selected visualisation. When this icon is clicked, it shows a modal that asks the user if they are sure they wish to delete the visualisation. This modal stops users from accidentally deleting a visualisation. The visualiser menu is designed to offer a user-friendly set of actions for handling multiple visualisations.

3.3.2 Visualisation Builder

The visualisation builder a form that allows a user to generate all visualisations available in ClimateVis. An example of the builder component is shown in Figure 3.7. An input form was chosen for the visualisation creation method as it is familiar, clean and simple to modify. Web forms are collections of inputs that allow users to select or enter a group of options. The output of these forms can be used for a diverse range of tasks. Examples of web forms include log in forms, credit card forms and todo list entry. Standard components in forms include text inputs, drop-down menus and toggle buttons.

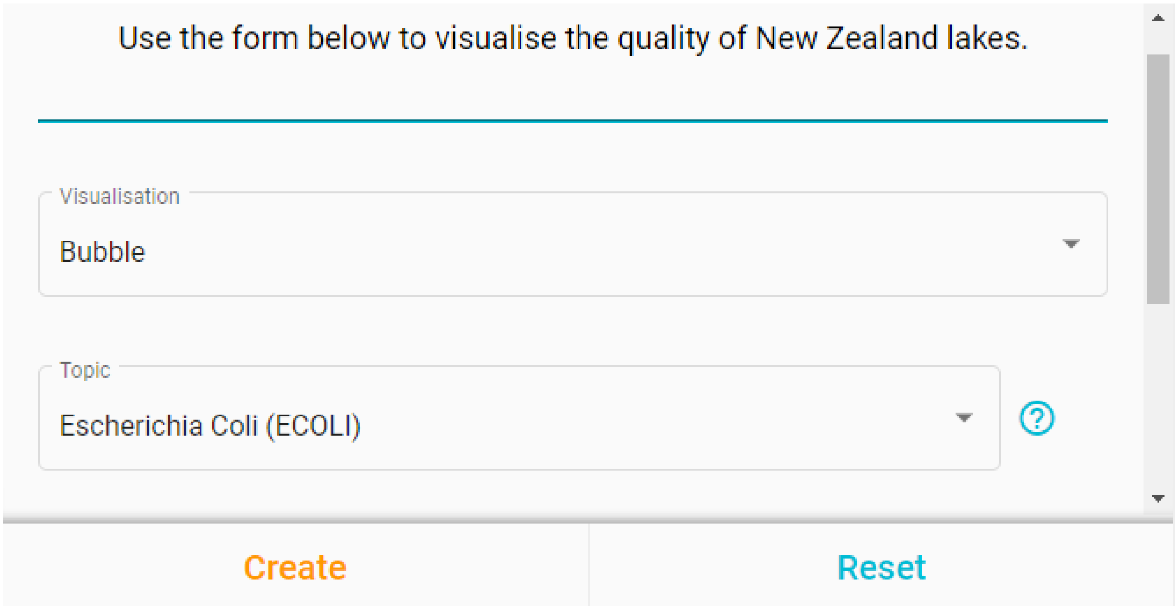


Figure 3.7: The Builder Form Showing the Options for Creating a Bubble Visualisation with Escheria Coli Data.

The builder form is made up of drop-down menus, button toggles, a create button and a reset button. The reset button clears all of the form inputs. The drop-down menu allows users to select an option from a list. The drop-down component is ideal where there is a small group of possible choices. When using this input, users can only choose valid options to create their visualisation. If options haven't been selected, then the create button is disabled to avoid creating dataless visualisations. Drop-down menus can hold an arbitrary number of items. Being able to hold any number of items makes this component suitable for choosing the visualisation, topic, and category. The topic is the type of data, for example, pH. The category is the comparative field, for example, region. Drop-down menus in the builder form are dynamically populated to show users all of the available options.

The button toggle component has similar behaviour to the drop-down menu where it lets a user select one option from a list. The difference with the button toggle is that all options are visible as oppose to hidden inside the component. The selected option is highlighted. This component is ideal for inputs that have a set number of options and are not populated dynamically. Button toggles are used for selecting the date grouping of a visualisation, and the way data is aggregated. The date grouping option lets a user decide whether data is aggregated based on the day, month or year it was collected in. The drop-down menu and button toggle components make the process of creating a visualisation quick yet precise.

There is a small help icon in the builder that offers the user to learn more about the data they are being shown. The help icon is a question mark to the right of the topic drop-down menu. When the icon is clicked, it opens a modal with an explanation of the currently selected topic. The modal has a 'Learn More!' button which takes the user to a glossary of the chosen topic on the LAWA site. This feature is crucial for helping the user understand the visualisations and become more aware of the ways our environment is changing.

Users can easily modify the form options to generate new visualisations. Users' choices are not removed when they create a visualisation. If they created a line graph showing pH levels, then it would only take them a matter of seconds to create a line graph showing Chlorophyll-a (CHLA). Switching the date grouping to year and only showing the maximum value of that year would only take seconds. Changing the graph entirely to a bar graph could be performed in a matter of clicks allowing for a quick change of perspective on the same CHLA data. This process of quickly creating new visualisations will help a user familiarise themselves with the application. Allowing users to modify their choices rapidly will hopefully decrease the learning time for ClimateVis.

3.3.3 Filters

The builder was designed to create data overview visualisations with little time and effort, so the filtering system was added to help users make detailed visualisations. One of the problems with the LAWA site was the inability to compare data between regions. The visualisation form assumes the opposite and will automatically show data from all regions. By nature, this data covers all possible dates and data collection locations. If the user wanted to view changes of pH for a particular region such as Wellington they could add a filter to the visualisation. Using the same filter system, they could also restrict the date range to be between 2014 and 2016. Recreating the visualisation will maintain the current visualisation settings but only use Wellington-based data between 2014 and 2016. The filter options currently available are the date, region, agency, site name and site id for each reading taken. The filtering system allows users to manipulate data parameters and quickly create more detailed visualisations.

There are currently two types of filter that can be added: value filters and range filters. A user selects a field, and the value or range filter options are shown according to the data type of the field. The value filter is for text properties that have a set group of possible options such as region or agency. This filter has a single text input. When focussed the input will show a list of possible options for that field. A user can type in one of these shown values or select it straight from the displayed list automatically populating the input. Filters can only be saved if the input value is a valid option. New filters cannot be added while there is an unsaved filter. The value filter lets users efficiently search for known values or identify new values to create more specified visualisations.

The range filter, shown in Figure 3.8, is for range based properties such as dates or numerical properties. The range filter component offers two forms of input. There is a double range slider where users can slide a handle along a line to change the maximum or minimum value of the range. There is also maximum and minimum input boxes where

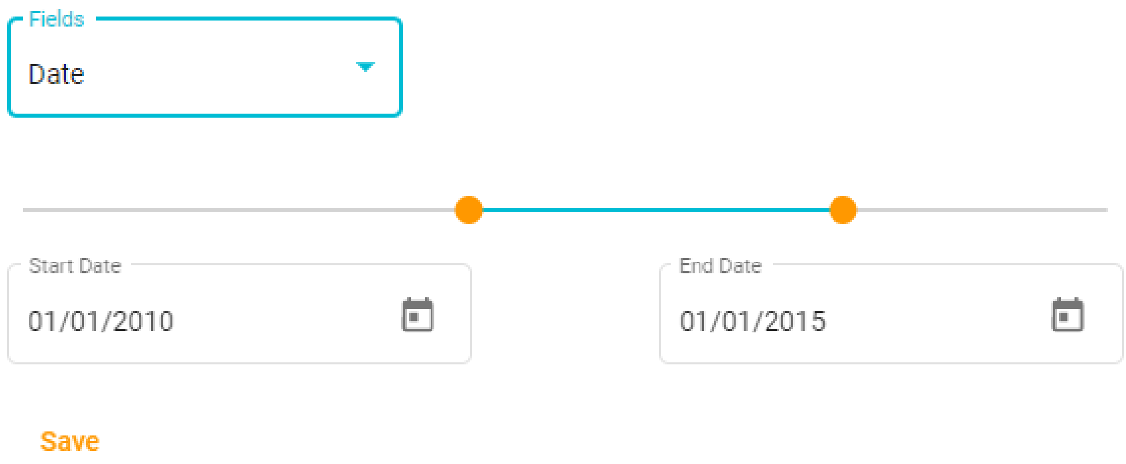


Figure 3.8: The Range Filter Specifying a Five Year Date Range Between January 1st 2010 and January 1st 2015.

users can directly enter the range they desire. Both of these input components are linked, meaning changing one will update the other and vice versa. If the filter field is a date, then users can also select range values using a calendar component. Although the components themselves differ, the process of adding, saving and editing filters remains consistent. These generalised filter components can handle a diverse range of data, and the consistent style of interaction makes them easy to understand.

3.3.4 Responsive Design

The web application has been designed to work on screens of differing sizes to make it suitable for the general public. In 2018, 58% of site visits were from mobile devices [19]. To accommodate the majority of people visiting websites, ClimateVis has been designed to function on a mobile device. On a mobile device, the visualisation builder takes up the entire screen. The user can then toggle the visualiser component to take up the whole screen so they can interact with the created visualisation. Appendix B shows the builder in full view on a simulated mobile device and it shows the visualiser in full view on the same device. All input components of the builder are designed to be used via touch and mouse. For example, the double slider in the range filter is ideal for mobile users that find typing with the on-screen keyboard difficult. The visualisations have not been optimised for touch gestures. All features of ClimateVis were tested and are usable on a mobile device. By changing the layout of the application on particular device sizes and making components work with touch input people can use the application on several devices.

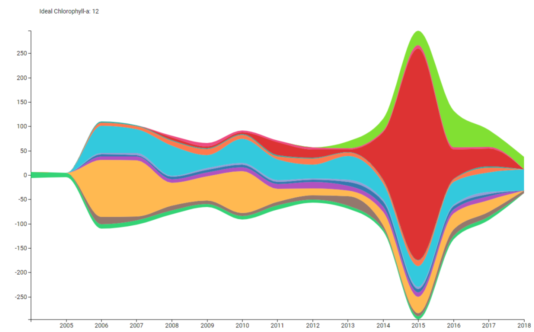
3.4 Case Study

This section covers two possible use-case scenarios that members of the target audience may complete with ClimateVis. These scenarios show common ways the web application may be used and how these actions are performed in ClimateVis. ClimateVis is designed for the general public, so it is vital to ensure that a user can easily step through common use-case scenarios.

3.4.1 Scenario 1: The Student's Question

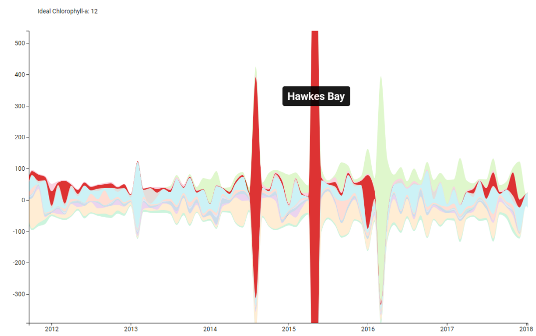
A Geography student has just attended a lecture that talked about the consequences of climate change. One of the consequences they remember was that the flow of water in New Zealand rivers would stagnate and this may aggravate water quality sparking algae growth. The New Zealand government also discusses this consequence in their material about climate change [3]. The student wonders how this consequence may already be affecting our environment and decides to use ClimateVis to answer the question. A visual example of each step the geography student makes in this scenario can be found in Figure 3.9. The student performs the following actions:

(a) The Learn More Modal for Cholorphyll-a



(b) The Stream Visualistion with Default Options

(c) Switching Date Grouping from Year to Month



(d) Highlighting Hawkes Bay in the Updated Stream Visualisation

Figure 3.9: The Actions of Scenario 1: The Student's Question

1. The student is unsure what environmental topic best shows algae growth levels in bodies of water around New Zealand. They begin selecting topics and pressing the help icon to learn more about a topic. The 'learn more' modal for Cholorphyll-a states that this topic indicates algae levels in a lake. The student decides they will visualise Cholorphyll-a to answer their question.

2. The student decides to create a stream visualisation as they have seen this graph used to display other sets of environmental data. The student creates the stream visualisation leaving all of the default options. The student can see that there was a spike in Cholorphyll-a during 2015.

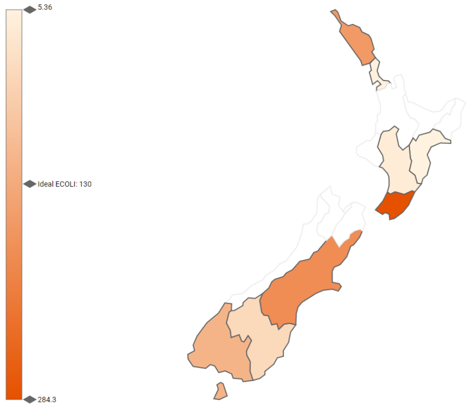
3. The student wants to explore this spike in more detail. They notice the grouping option and change it from year to month. They update the visualisation and see a much

more detailed stream graph showing the changes over time. This is a minimal change to the visualisation but offers a new perspective on the data.

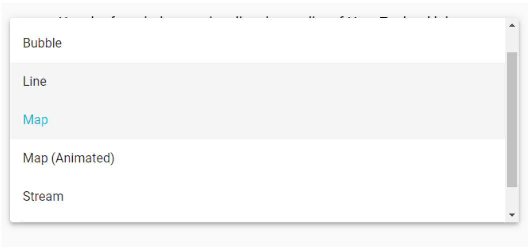
4. The student finds it difficult to see the individual streams, so they zoom in and pan around to explore the trends shown in the visualisation. They hover over the most considerable stream to find that Hawkes Bay is the most significant contributor. They conclude that there is, in fact, increasing amounts of algae growth in lakes across New Zealand, and this may be an indicator of climate change.

3.4.2 Scenario 2: The Teacher's Demonstration

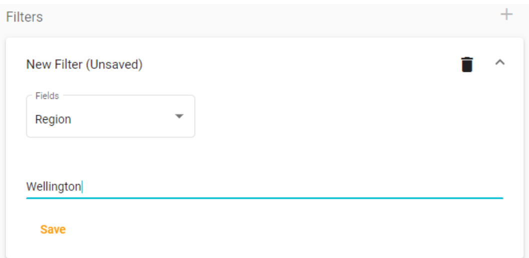
A highschool earth and space science teacher is aware that climate change threatens to increase the water temperature in bodies of water around New Zealand. They are also aware that Escherichia Coli (E.Coli) bacteria thrive in higher temperatures [20]. The teacher decides they want to visualise E.Coli levels around New Zealand to help educate their students. A visual example of each step the teacher makes in this scenario can be found in Figure 3.10. The teacher performs the following actions:



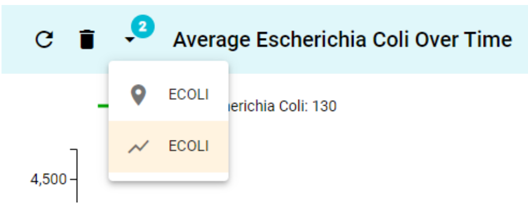
(a) The Map Visualisation of Average E.Coli



(b) Selecting the Line Visualisation for Creation



(c) Creating a Value Filter to Refine Data



(d) The Visualiser Menu When Switching Visualisations

Figure 3.10: The Actions of Scenario 2: The Teacher's Demonstration

1. The teacher begins by creating a map of New Zealand that shows the average E.Coli levels around New Zealand. They use the map as they know this type of visualisation is familiar to their students, making it easier to understand. The teacher also likes the ability expressly point out details about the Wellington region as this is where the school is located.

2. The teacher notices that the Wellington region has higher average levels of E.Coli. They want to show how this has changed over time to highlight any notable trends.

The teacher creates a line chart by merely changing the visualisation option in the builder and pressing the create button.

3. The teacher realises that this line chart is grouping the data from all around New Zealand, but they would like to show only how E.Coli has changed in the Wellington region. To do so, they create a value filter that refines the data to be only data collected in the Wellington region. They update the line visualisation and notice that the higher E.Coli levels in Wellington are due to spikes from 2010-2012.

4. The teacher notices that can switch between the visualisations using the visualiser menu. They decide they could use this feature to demonstrate to their students both the trends over time for E.Coli and then also compare this topic to regions around New Zealand.

3.5 Architecture and Implementation

This section discusses the software architecture of ClimateVis. It talks about the technical tools used to build the different components of the web application. It also explains the structure of these components mentioning how they communicate and how they are hosted on the Cloud. The decisions made when building this software architecture were aimed at making ClimateVis an industry-standard web application capable of further development after the conclusion of this research project.

3.5.1 Three-Tier Architecture

ClimateVis has been built using a three-tier architecture. Each tier or layer is responsible for handling different behaviour. The three layers are the data layer, application layer, and presentation layer [21]. The data layer stores all of the information for the web application. The application layer is responsible for handling business logic and moving data between the data and presentation layers. The presentation layer is the web application that users see. Splitting behaviour into separate layers makes the web application modular and flexible.

The presentation layer was built from the ground up using the Angular Framework. Visualisations in the presentation layer are created using the D3 library [22]. An Application Programming Interface (API) has been built from scratch with the express library. This API acts as the application layer by handling data parsing and communication between the front-end and database. The data layer has been set up as a PostgreSQL database and currently stores lake water quality data from LAWA. An overview of the software architecture and technical tools used in the architecture can be seen in Figure 3.11.

Modularising the web application with the three-tier architecture increases its scalability. Each layer can be scaled up individually as needed. For example, adding new visualisations will only require changes to the presentation layer. Separating behaviour means that a developer could improve and maintain parts of the web application with little knowledge of the logic behind the other layers. Companies in the technology industry take advantage of this by hiring front-end and back-end developers that specialise in separate layers of the three-tier architecture [23]. By implementing this architecture into the web application, ClimateVis benefits from the scalability increase and aligns it with industry practice.

Another benefit of the three-tier architecture is the ease of integrating new features. Integrating web analytics is an excellent example of adding a new feature. Web analytics are

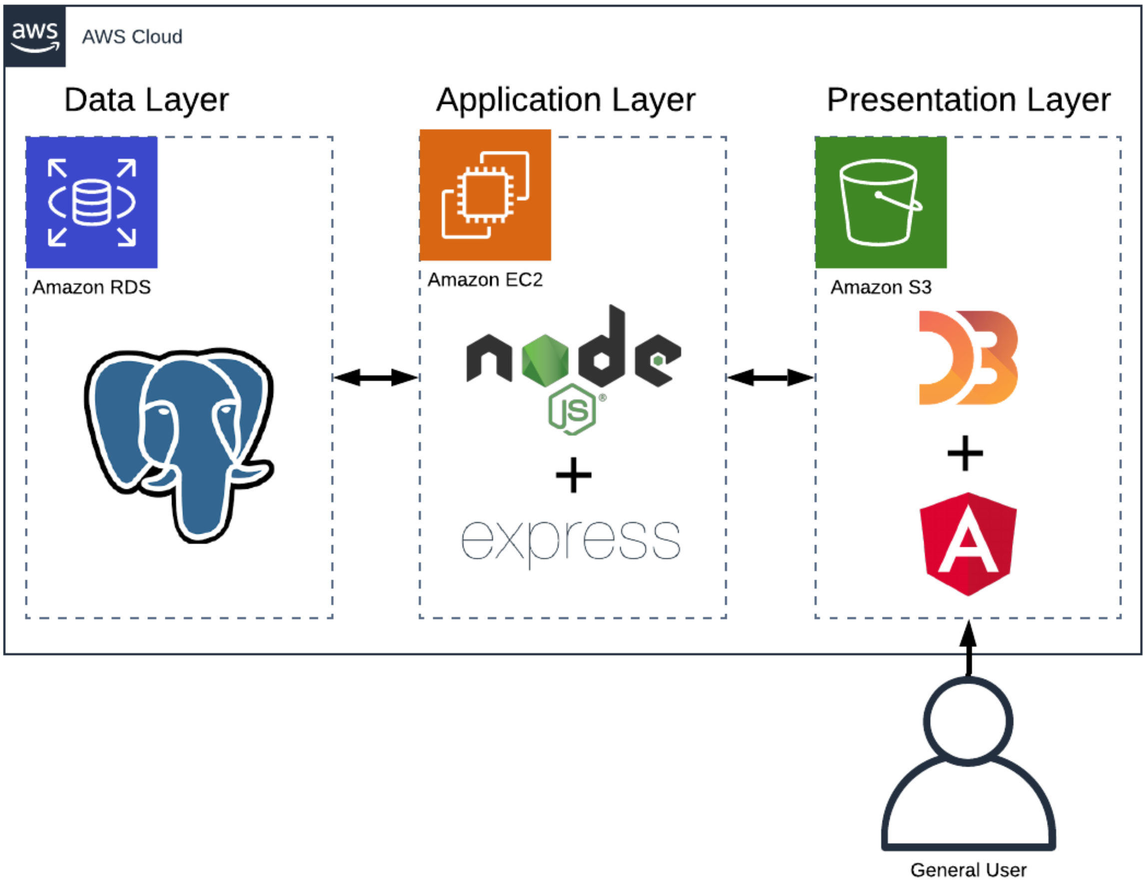


Figure 3.11: The Three-Tier Software Architecture of ClimateVis

statistics of how a web application is used [24]. How this data is processed can be a time-consuming development task and can change as an application evolves. When using the three-tier architecture, this data processing step could be centralised to the application layer. Consolidating analytics data processing reduces coupling of layers meaning that as the processing step evolves, it will not affect the data or presentation layer. Centralising code to one layer also means a developer with knowledge of other layers can still integrate new features.

Having separate modules for each layer in the three-tier architecture is ideal for hosting the web application in the cloud. Each layer is treated as a separate codebase. They can run individually but offer limited functionality. When a module can run individually, it can be hosted on a cloud platform service. Amazon Web Services (AWS) is a cloud platform offering over 165 fully-featured services [25]. Three AWS services are being used to host the web application. Relational Database Service (RDS) is hosting the data layer, Elastic Compute Cloud (EC2) is running the application layer, and Simple Storage Service (S3) is hosting the presentation layer. The three-tier architecture has been crucial to setting up a comprehensive cloud hosting strategy.

3.5.2 Front-End

The presentation layer of the web application is implemented with the Angular framework. Angular is an all-in-one framework that gives developers the tools and design patterns to build websites for various platforms [26]. Angular was chosen as it has a universally accepted code structure for building applications make it easy for developers to understand a new code base if they know the framework. Angular is built on typescript which allows for the validation and control of variable types. The framework offers dependency injection of services. This injection capability means that behaviour and logic not associated with a visual component can be extrapolated to a separate service. Dependency injection makes these services available in any component of the application. Angular also comes with a premade HTTP client that can communicate with web addresses such as the URL of an API. The HTTP client is responsible for communicating with the application layer. These qualities and the universally accepted code structure made Angular the ideal choice for building the web application from scratch.

Angular projects are comprised of NgModules and components [26]. An NgModule defines how the components of a project should be compiled. A component is a view in the web application. A component can be the view of a single item such as a button or a view made by combining multiple components. The visual design of these components is defined using standard HTML and CSS. A typescript file handles the behaviour for these components. Data binding ensures that the variables in a component are representative of what a user sees on their screen. Using inputs and outputs, data can be passed between child and parent components. ClimateVis has a module for the entire application, one for the single page the user interacts with and a module for shared components that can be used anywhere in the application. Shared components include the search input, the double slider and D3 visualisations. D3 is a powerful library that manipulates HTML, SVG and CSS to create data-driven visualisations. D3 was used in ClimateVis because it is an industry-standard library for creating data visualisations that can handle live-updating, animations and user interaction. The directory structure of the web application groups components based on the modules they belong to, implementing the standard Angular coding structure.

3.5.3 Application Programming Interface

The Application Programming Interface for ClimateVis was created using the Express framework. This API acts as the application layer in the three-tier architecture. Express is a Node.js web application framework that provides HTTP utility methods to create API's [27]. Creating and running an Express app will listen for HTTP requests to the URL and port it is running on. This URL could be the localhost or a URL to a cloud instance running the app. The express app listens for these requests and can execute predefined behaviour when called. This behaviour could include business logic, interacting with the database, and return data to the client that made the request. These capabilities mean the Express app can process and pass data between the presentation and data layers.

The Express app uses routing to handle multiple pre-defined behaviours. Routing allows a client to append extra information to the end of a URL when making a request to the API. For example, a request using 'apiurl/start' would return different information from 'apiurl/end'. A client can also pass in query parameters. A query parameter can be any type of information including a string, number or JSON object. Query parameters allow clients to perform unique behaviour with the same route. Using routes and query parameters, the API can handle a range of different behaviours for the web application.

The express app listens for these unique routes and uses controllers and scripts to execute the desired behaviour. Each route is linked to a controller method. The controller is responsible for processing the request, extracting query parameters needed to execute the desired behaviour. The controller validates and shapes data as required. This controller then calls a method with the extracted parameter information. The method uses this information to perform the desired behaviour. The body of the method can include business logic and retrieving information from the database. Once complete the result is returned from the method back through the chain of calls to the client. Modularising the API in this way means that route names can be updated freely, business logic is contained to a single method, and the shaping of data does not affect business logic. Modularisation also means that the data layer can only be changed with valid input. These modules work together to process requests from a client and execute the desired behaviour. An example of how routes are defined and linked to a controller in express is shown in Listing 3.1.

```
const express = require('express');
const router = express.Router();

// API Connected Test Route
router.get('/', (req, res) => res.send('Server is running'));

// Lake Water Quality Routes
router.get('/lwq', require('../controllers/lwq').getChosenLWQData);
router.get('/lwq/types', require('../controllers/lwq').getTypes);
router.get('/lwq/filter-types', require('../controllers/lwq').getFilterTypes)
    ;

module.exports = router;
```

Listing 3.1: Defining Routes for the API and Linking Them to Controllers

The Express Library was chosen for ClimateVis as it offers a rich set of HTTP features for handling communication between the three layers. These features offer easy to use methods for processing HTTP requests using Javascript. The use of Javascript is beneficial as the presentation layer uses a similar language, thereby reducing the learning curve to understand the entirety of the codebase. Another benefit is that it allowed for the dynamic creation of SQL queries for retrieving data based on user-selected options. Building this query in the API protects the database from security risks such as SQL injection as the possible queries have been strictly defined in the application layer. All interactions with the database are handled through the API to define a strict set of possible queries which reduces the threat of security risks. There are alternative languages for creating APIs such as PHP, but prior knowledge with Express along with its rich feature base made the Express library a better choice for this project. The Express library allowed for the creation of an industry-standard API that can process HTTP requests to pass data between the three layers of ClimateVis.

3.5.4 Database

A PostgreSQL database is used in the data layer of ClimateVis. PostgreSQL is a powerful, open-source object-relational database system that uses and extends the SQL language [28]. Being an open-source project means there is no extra cost when using it for ClimateVis. There are many interfaces available for managing the database. The ability to create functions means that the storage and access behaviour of the data can be kept separate. An SQL database allowed for the use of data warehousing techniques that are ideal for Online Analytical Processing (OLAP). OLAP is a computing method that enables users to easily and selectively extract and query data in order to analyse it from different points of view [29]. By definition, OLAP aligns well with the purpose of ClimateVis that is to visualise environmental data in different ways to raise climate change awareness. MongoDB was investigated as a NoSQL alternative, but the cost of hosting them on AWS and losing the data warehousing potential made SQL a better choice for this project. These qualities made PostgreSQL an ideal choice for use in the web applications data layer.

The database has been built to retrieve data about the water quality of lakes in New Zealand. One table holds the dataset with the key columns being reading type and reading value. The reading type is the type of measurement that the row represents and the reading value is the value of that measurement type. All other information for a reading defines the data and location the reading was taken. The structure of this table made it easy to reduce the dimensionality of the data using slice and dice data warehousing techniques through a 'WHERE' clause. Roll-up functionality through aggregates was another helpful data warehousing technique used to simplify the data shown to the user. Table 3.1 shows three sample rows of data from the lake water quality table currently in the database.

Agency	**Region**	**Site_Name**	**Site_ID**	**Reading_Date**	**Reading_Value**	**Reading_Type**
BOPRC	Bay of Plenty	lake okaro site 1	FI680541	2005-01-20	0.032	NH4N
BOPRC	Bay of Plenty	lake okaro site 1	FI680541	2005-01-20	0.144	TP
BOPRC	Bay of Plenty	lake okaro site 1	FI680541	2005-01-20	0.370000005	Secchi

Table 3.1: Three Rows From the Lake Water Quality Data Table

There is also a table that holds information about each of the available environmental topics. This information includes the ideal value, a description of the topic and even a link to a more in-depth glossary. The information in this table is built around providing learning opportunities in ClimateVis. Being able to tell a user what a topic means and how the topic should be visualised is essential to educating the target audience.

The database solution, although suitable for this project, is only temporary. The initial goal was to retrieve data from an external API owned by the LAWA. Retrieving the data from LAWA would be more reliable as this is a government-funded organisation that has access to live data. This functionality was not complete as the external API is not public, and time constraints limited the amount of external integration that occurred during the project. In future, the database strategy could be redesigned to integrate better with LAWA's external API.

3.6 ClimateVis Summary

ClimateVis was designed to be an easy to learn web application that allows members of the general public to visualise environmental data. The user interface components and visualisations aim to support Shneiderman's 'Information Seeking Mantra'. ClimateVis has been built around the idea that any person from the target audience should be able to complete the basic use cases defined in Section 3.4. The technical tools used to build ClimateVis were chosen for their industry relevance and ability to form a robust software architecture. The design decisions and their implementation lead to the creation of a highly capable tool that was ready to be tested by members of the target audience.

Chapter 4

User Study Design

A user study was designed to evaluate the effectiveness of the ClimateVis prototype. The purpose of the user study was to identify the strengths and weaknesses of the prototype and ultimately assess the solution's effectiveness. This chapter outlines the design decisions involved in building the user study. It covers the research questions the study aimed to answer, the participants involved, the tasks they performed, and how the data was collected.

4.1 Research Questions

ClimateVis was designed to visualise environmental data to raise awareness about climate change. To fulfil this purpose the tool needed to be usable by any member of the general public and the visualisations needed to be understood by these people. The usability of the tool and the difficulty of understanding the visualisations are clear indicators of ClimateVis' effectiveness in relation to its purpose. The user study tasks were designed to test the usability and visualisation comprehension of ClimateVis to answer questions about its effectiveness.

The research questions this user study aimed to answer are listed below:

- How effective is the ClimateVis user interface?
- How effective are the visualisations at helping raise awareness of climate change?
- How could ClimateVis be improved?

These questions require both quantitative and qualitative data to be answered comprehensively. A quantitative study involves some form of measurement to generate a statistical analysis of the results. Qualitative studies often collect detailed descriptions and require questions designed to explore the thoughts and feelings of a user. The research questions regarding the effectiveness of the interface and visualisations would be best answered using quantitative results. This user study takes advantage of two different metrics for gathering quantitative results. The first is the percentage of participants that correctly complete a task. The other metric is a difficulty rating between one and five from the participant for each task. These metrics quantify the effectiveness of ClimateVis and its visualisations. The question involving the improvement of ClimateVis asks the user to provide their thoughts on the web application. The methods of analysing the quantitative and qualitative data are discussed further in Section 4.5.

4.2 Participants

25 people were recruited to participate in the user study. These people are all members of the general public and cover the range of example users discussed in section 3.1. The study itself was anonymous as participants were not required to provide any personal information. Interactions with participants after the study and the people the study was advertised to provide an idea of who took part in the study. The study was advertised to people with a range of occupations. These included students, environmental scientists, ministry of the environment members and council members involved with environmental data in New Zealand's regions. Students accounted for the majority of the participants. The specialisations of the students included Software Engineering, Geography and Media Design. Although there was no bias towards gender, the final group of participants appeared to have a higher number of men over women. The table in Appendix C collates all of the known information about the participants. The data in this table provides insight into the different demographics of the general public that were represented in the user study. The participants covered a broad range of demographics from the general public, which is ClimateVis' desired target audiences.

4.3 Study Tasks

The user study has three distinct sections: a practical set of tasks, a set of 10 usability questions and an additional comments section. The first section asks the participant to answer six questions about lake water quality using ClimateVis. Each question asks the participant to use a different visualisation. They then rate how difficult they found the task to complete on a scale of one to five. The first section is designed to determine the relative effectiveness of each visualisation. The second section is a series of usability questions designed to assess how effective participants found the ClimateVis user interface. This set of 10 usability questions are modelled on the Software Usability Scale (SUS) — a proven system for assessing the usability of software [30]. SUS is not the sole metric of measurement as the output only provides a "quick and dirty" look into how each participant found the usability of the web application [31]. A "quick and dirty" look is not statistically significant enough to make meaningful observations about ClimateVis' effectiveness. The final section is a single question where the participant can offer feedback on their experience. This feedback was necessary for answering how ClimateVis could be improved. A complete list of the questions a participant were asked can be found in Appendix D.

The six tasks were designed to test the effectiveness of ClimateVis' visualisations and introduce participants to the features of the user interface. Each task asks the participant to use a different visualisation. The effectiveness of a visualisation is judged on the results from the related task. All participants completed the tasks in the same order starting with the bar visualisation based task and finishing with the sunburst visualisation task. Some tasks are designed to introduce participants to the features of ClimateVis' user interface. For example, the third task involving the line visualisation requires participants to create a filter. These tasks try to make sure participants use all features of ClimateVis, but this can also negatively impact the clarity of results. The limitations of having participants learn how to use the web application during these tasks are discussed in Section 5.4. The tasks of section one collect information for analysing the effectiveness of each visualisation and ensure the participants have the chance to use ClimateVis' features.

The six tasks in order along with the visualisation they focus on and their intended purposes are listed below:

- **Task 1 - Bar Visualisation:** They are asked to find what region in New Zealand has the highest average Cholorphyll-a level. This task familiarises the user with how visualisations are made. It also introduces them to the type of language common in the web application, e.g. average and Chlorophyll-a.
- **Task 2 - Bubble Visualisation:** They are asked what lake site in Wellington has the highest average ammoniacal nitrogen level. This task is used to introduce the user to visualisation interaction. To complete it properly, they must click and hover over bubbles. Hopefully, they will realise that interaction is a common feature they can use with all visualisations.
- **Task 3 - Line Visualisation:** They are asked how do the average total nitrogen levels of Taranaki lake sites compare to the ideal value. This task is the first time users will need to create a filter to answer the question. It should help familiarise the user with the filter feature.
- **Task 4 - Map Visualisation:** They are asked what region has the highest average Escheria Coli levels. There is no other purpose for this task.
- **Task 5 - Stream Visualisation:** They are asked what year was there a peak in average Cholorphyll-a levels around New Zealand. This task is answered most effectively if the date grouping is switched to year. The task is designed to introduce the user to the toggle button mechanic with the date grouping option.
- **Task 6 - Sunburst Visualisation:** They are asked what lake site has the highest average total phosphorus level. There is no other purpose for this task.

4.4 Procedure

Each participant could fill out the user study using an online form found through the ClimateVis homepage. The recruitment email for the user study contained a link to the ClimateVis homepage. Participants would begin by navigating to this page which explains what ClimateVis is and the purpose of the project. From the homepage, participants had the opportunity to access an online tutorial. This tutorial explains the core features of ClimateVis so participants can begin learning to use the application before jumping into the user study. The second page of the tutorial lists all of the visualisations. It details what the visualisation shows, how it should be interpreted, and how to interact with it. The tutorial not only teaches people how the tool works before starting the study, but it can also act as a 'help' resource if the participant gets stuck during the study. From the tutorial page, a participant can open the ClimateVis application and the user study form.

To complete the user study participants would fill out an online google form. To answer the questions in the first section of this form, participants needed to complete a series of six tasks using ClimateVis. Participants could then move onto the second and third questions where they could base their answers on their experience with ClimateVis on the first section of the user study. Based on cognitive walkthroughs and participant feedback, the user study would take about 20 minutes to complete. All responses from the user study were completely anonymous to protect the identity of those taking part. All participants were offered an honorarium as a thank you for completing the study. To receive it, the participant would email the researcher and a time to exchange the reward would be organised. The relatively short completion time and ability to complete the study from a distance was ideal for recruiting participants.

The homepage, tutorial and ClimateVis itself were all designed to work on a range of different screen resolutions. This meant users had the choice of which device they could use for the study whether this is mobile phones, tablets or a desktop. Although the web application was functional on all device resolutions, the touch-based interactions were not well implemented. Despite this, there were still at least two participants that were able to complete the study on a mobile device. Touch-based interactions were not a focus of ClimateVis' development making mouse and keyboard the preferred way to use ClimateVis and complete the user study.

4.5 Data Collection and Analysis

Each section has a different method of analysis to ensure each research question is answered as accurately as possible. The analysis of the first section begins by looking at the difficulty rating of each task. These ratings use a five-point Likert scale. A Likert scale is a range of inputs going from one extreme attitude to another. Likert scales (named after their creator, American social scientist Rensis Likert) are quite popular because they are one of the most reliable ways to measure opinions, perceptions, and behaviours [32]. In the first section, the attitude is the participant's perception of how difficult a task is to complete. One means they found the task extremely easy, and five means they found the task extremely challenging. The difficulty ratings have been graphed in a box and whisker plot. Box and whisker plots show the distribution of ratings across the population of participants. Showing a distribution reduces the significance of outliers when making observations about the results. A Likert scale collects the perceived difficulty of tasks, and the results are graphed in a box and whisker plot to reduce the impact that outliers have on drawn conclusions.

The average difficulty rating and the standard deviation of all ratings from the population were calculated to help draw statistically significant conclusions. The average gives an overview of the ratings and allows the tasks to be ranked in terms of difficulty. The standard deviation is an indication of how spread out the ratings were. Tasks with a higher standard deviation had a broader spread of ratings meaning the average is less reliable. Both of these are important statistics when drawing conclusions about visualisation effectiveness in terms of perceived task difficulty.

In the first section, the number of participants that correctly answered each task was used as a measurement as it was uninfluenced by opinion. The rating system is based heavily on participants experience with environmental data and visualisation tools. This reliance can generate inaccurate results due to the inconsistency of participant backgrounds. Analysing the percentage of correct answers removes the reliance on participant opinions. This percentage indicates how effective a visualisation is because a higher percentage shows that participants were better at interpreting the data being displayed. Being able to interpret a visualisation's data means it can effectively convey the state of our environment in some capacity. The percentage of correct guesses is unaffected by participant opinion and can show how effectively a visualisation communicates information about our environment, making it an ideal measurement for the user study.

The 10 usability questions in the second section are based on the Software Usability Scale (SUS). The SUS gives an at-a-glance snapshot of how usable or unusable a system is. Another great benefit of using SUS is that it is easy to use on any number of test participants. In SUS, the user is given 10 usability statements and asked how much they feel ClimateVis relates to the statement. They score this on a Likert scale of one to five, one, meaning they strongly disagree with the statement and five meaning they strongly agree. The SUS has its own method of interpreting the results. To interpret the results, you calculate a single value for each response.

Calculating this value requires three steps. The first step is subtracting one from all of the odd-numbered questions to make the rating between 0 and 4 [30]. For each even-numbered question, you subtract their value from 5 [30]. The subtraction is necessary as the best possible answer for every second statement is one, meaning the participant strongly disagreed with the statement. Finally, you sum these converted numbers and multiply the sum by 2.5 [30]. The result is a score out of 100. This result is not a percentage, but a clear way of seeing your score [30]. Based on research, a SUS score above a 68 would be considered above average and anything below 68 is below average [31]. The SUS score of CliamteVis will be compared to this universal average to get a snapshot of the web applications usability.

The final section gives qualitative results meaning they are difficult to process statistically. One method of analysing these results would be to read all of the feedback and draw conclusions about the problem areas of ClimateVis. This may be a valid method, but it risks being influenced by the feedback of a single person. One person may have a strong opinion about what they think is a fault in the system, but they may be the only one to have this opinion. This inconsistency makes it difficult to decipher whether or not the concern is a usability issue or not. To combat this bias the qualitative feedback will be linked to Nielsen's usability heuristics [17]. The responses from section three will be dissected to see what features of ClimateVis could have been improved. These features will then be analysed to see which of Neilsen's usability heuristics are not being met. This methodology means that the qualitative results from the user study can be used to draw conclusions about ClimateVis in relation to well-known usability guidelines. All three sections of the user study have a unique way of analysing the responses so that the research questions can be answered as effectively as possible.

4.6 Ethics Approval

An application for ethics approval for this user study with the ID 27652 and titled 'Understanding Climate Change by Visualising Environmental Data' was approved by the VUW Human Ethics Committee on 24/06/2019. The ethics application can be found in Appendix E.

Chapter 5

User Study Results

There were 25 different people that participated in the user study. This chapter summarises the responses of these participants. Each section explains the results from one of the three user study parts. The sections also discuss the implications of these results in relation to the goals of the project. The task numbers defined in Section 4.3 are referred to throughout the results analysis. The chapter discusses how these results answer the research questions and summarises what knowledge has been gained during the evaluation of ClimateVis.

5.1 Task Difficulty Results

All 25 participants rated the difficulty of each of the six tasks. Participants provided a rating between one and five for each task. One meaning they found the task extremely easy and five meaning they found it extremely challenging. Their responses have been graphed in the box and whisker plot in Figure 5.1. This type of graph shows the distribution of ratings across all 25 responses. Graphing the distribution of results is essential as it is less affected by outliers compared to other statistical metrics. For example, the average difficulty would be severely impacted by a poor score. The distribution of ratings exemplifies how a majority of the participants rated the difficulty of the different tasks. The outlying difficulty ratings from all participants are shown as the dots on the graph. The box shows how the middle 50% of participants rated a task. If a box is smaller, it shows that participants had a more unified perception of the difficulty of a task. The whiskers show the ratings of the upper and lower 25% of ratings. These whiskers show the maximum and minimum difficulty ratings for each task with the exception of the outliers. Each component of the box and whisker plot has statistical significance that avoids the effects of outliers.

The graph in Figure 5.1 shows there are three levels of difficulty amongst the visualisation tasks. The tasks rated easiest by the participants involved the bar (Task 1) and map (Task 4) visualisations. In both of these tasks, 75% of participants rated the difficulty either a one or two. The remaining participants gave a difficulty rating of three except for an outlier rating at five. The condensed size of the boxes and a maximum rating of three show that participants tended not to struggle when completing Task 1 and Task 4. This observation is an indication that the bar and map visualisations may have been two of the most effective.

The difficulty ratings of the bubble (Task 2) and line (Task 3) visualisation tasks had a far greater spread. Half of the participants rated these tasks a difficulty of between two and four. A further 25% rated these tasks, either four or five. The spread-out difficulty ratings of these two tasks show that participants had a split perception of how challenging they

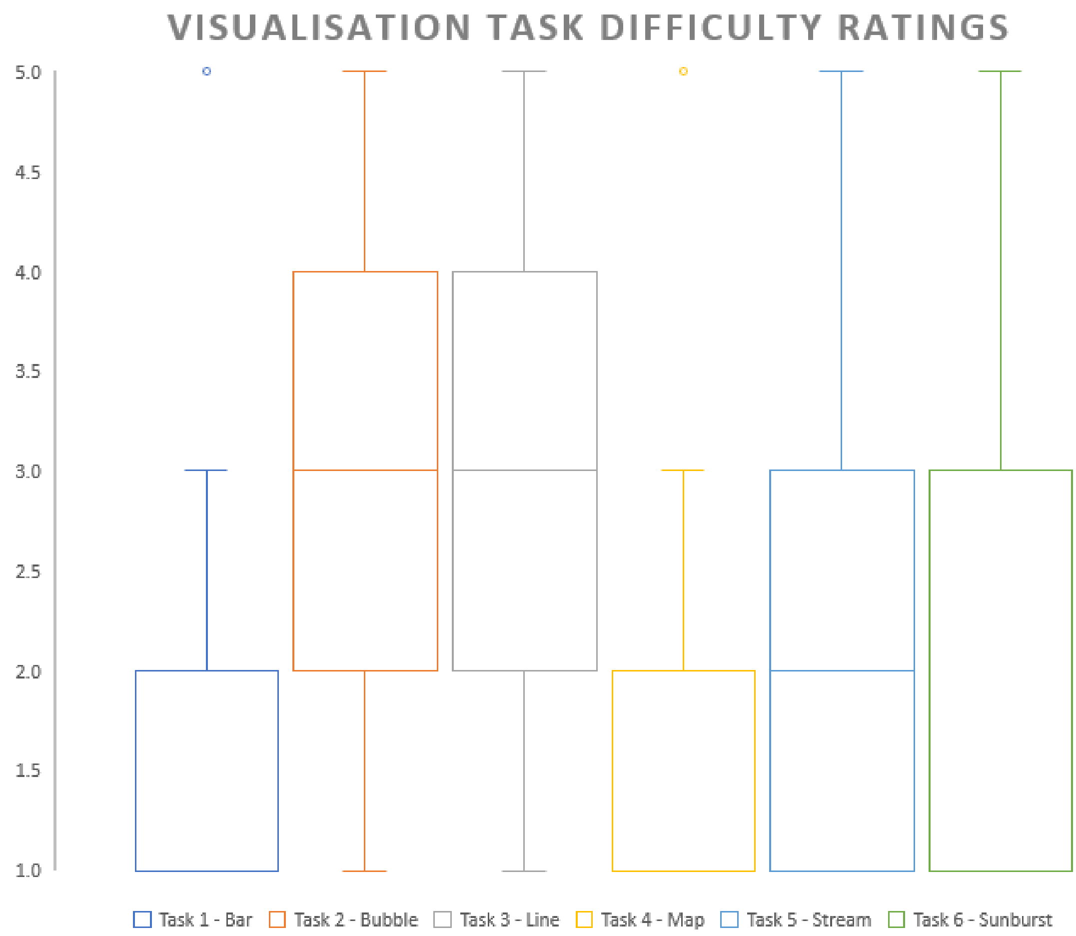


Figure 5.1: Distribution of Visualisation Task Difficulty Ratings

were. The position of the boxes indicates that a majority of participants tended to find the line and bubble visualisations more challenging to use than the bar and map visualisations. This perceived difficulty suggests that the bubble and line visualisations may be the least effective in ClimateVis.

The stream (Task 5) and sunburst (Task 6) visualisation tasks showed difficulty ratings in between the four previously discussed, suggesting they had average effectiveness. The ratings of these tasks were skewed towards the lower end of the scale, which shows that participants tended not to find these tasks challenging. These perceived difficulties suggest that the bar and map visualisations were the two most effective and the bubble and line were the two least effective with the remaining visualisations lying in the middle.

The box and whisker plot shows the distribution of ratings but having only five possible values make it challenging to separate the difficulty of some visualisations. Table 5.1 shows the average difficulty and standard deviation of all 25 participants ratings for each visualisation task. A high standard deviation shows that the data is widely spread (less reliable), and a low standard deviation shows that the data are clustered closely around the mean (more reliable) [33]. Task 2 and Task 3 have the highest average difficulty rating with Task 3 task being the highest overall. This high average reinforces previous observations that the bubble and line visualisations may be the least effective. Task 3 has the highest standard

Task	Mean Rating	SD Rating	Correct Answers %
Task 1 - Bar	1.851	1.078	70.8
Task 2 - Bubble	3.000	1.122	91.7
Task 3 - Line	2.740	1.235	70.8
Task 4 - Map	1.777	1.133	100
Task 5 - Stream	2.148	1.112	79.2
Task 6 - Sunburst	1.925	1.184	100

Table 5.1: Statistics of the Difficulty Ratings

deviation. The higher standard of Task 3 suggests that its average difficulty rating may be an inaccurate representation of the perceived difficulty. This uncertainty means that the line visualisation may not be as ineffective as the average rating suggests. This uncertainty also affects Task 6 that has the second-highest standard deviation. The average ratings and standard deviation of Task 1 and Task 4 are both among the lowest. The low standard deviation reinforces the observation that the bar and map visualisations are the most effective visualisations. These statistics reinforce the effectiveness of the bar, bubble and map visualisations while introducing uncertainty about the effectiveness of the line and sunburst visualisations.

The observations made so far are based on the quantitative analysis of difficulty ratings, but these ratings are the perception of participants. The perception of difficulty may differ between participants making it challenging to draw meaningful conclusions about the effectiveness of visualisations. Table 5.1 shows the percentage of participants that correctly answered each visualisation task. This metric is an objective way of assessing a task's difficulty. Task 1 and Task 3 had the lowest percentage of correct answers scoring only 70.8%. The low percentage reinforces the potential ineffectiveness of the line visualisation. Previous observations suggested that the bar visualisation was effective, but this low percentage implies that participants may have misunderstood the task. If a participant incorrectly answers the question but found the task easy, then the visualisation was ineffective, or the question was hard to understand. Making this distinction is difficult, but it introduces uncertainty around the effectiveness of the bar visualisation. All participants correctly answered Task 4 and Task 6. This indicates that the map and sunburst visualisations were the most effective, but it could also mean that the questions were easier to understand. The percentage of correct answers reinforce previous observations about the effectiveness of the map and line visualisations, but it raises concern about the validity of the bar visualisation difficulty ratings.

5.2 Software Usabiltiy Scale Results

All 25 participants completed each of the 10 questions from the Software Usability Scale (SUS) questions. The SUS score for each participant's responses has been calculated, and the distribution of these scores are shown in Figure 5.2. The graph is another box and whisker plot that shows how the population of participants tended to score the web application. The box and whisker plot also highlights one outlier. The SUS score has been calculated using the steps discussed in section 4.5. The scale used is from 0 to 100, but the scores do not represent a percentage. The scores offer a quick understanding of how usable each participant found ClimateVis to be.

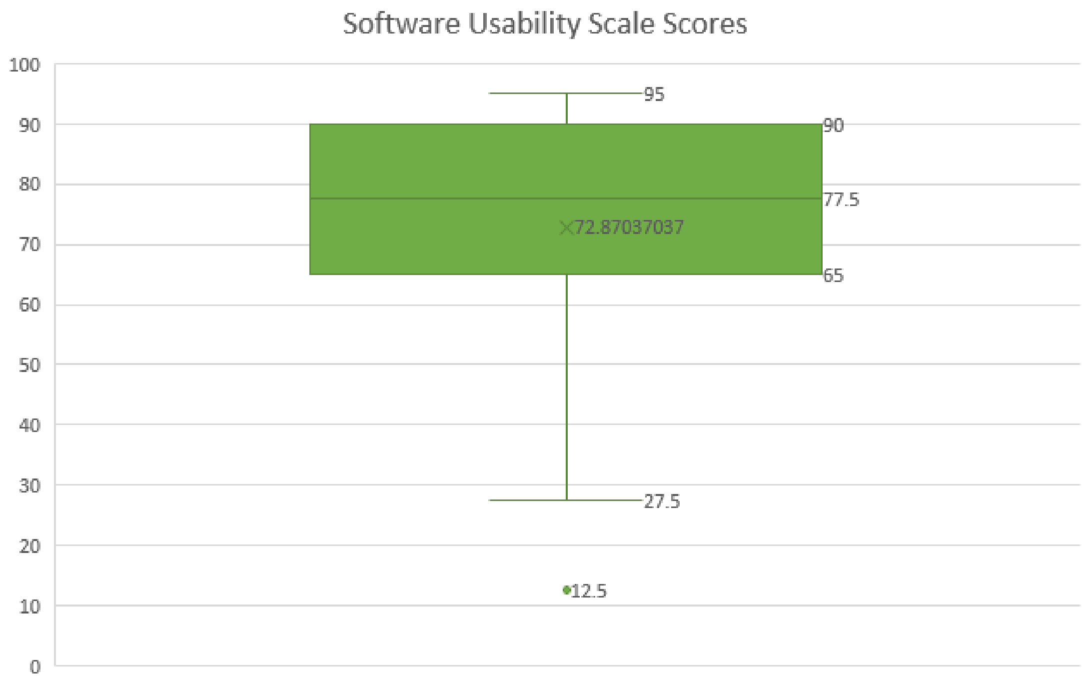


Figure 5.2: Distribution of Software Usabililty Scores

The median SUS score was 77.5, which is nearly 10 points above what is considered an average score. Based on research, a SUS score above a 68 would be considered above average and anything below 68 is below average [31]. This research means that ClimateVis is considered to have well above average usability by at least half of the participants. The lower quartile of users scored it between 77.5 and 65. The lower quartile accounts for 25% of the participants. These participants scored ClimateVis either just above or just below average. These results show that a majority of users felt the usability of ClimateVis was satisfactory.

5.3 Qualitative Results

This section analyses the qualitative results gathered from the user study. The final section of the user study asked the participants to provide any additional comments they had about their experience. The additional comments from participants included a mixture of positive feedback and constructive criticisms. This section summarises the qualitative feedback and highlights how ClimateVis could be improved.

Many participants appeared to have very positive experiences with ClimateVis. Some made comments about the design of ClimateVis as a platform such as *"I think the app is great overall and quite easy to learn how to use"* and *Very easy to use, grasped the idea within a few minutes of testing different visualisations*. This feedback is a reassurance that ClimateVis is approachable for new users. Other participants found the visualisations easy to understand, one saying *Nice and easy to use, the graphs made sense without needing them explained*. Evidently, this participant found the visualisations to be very effective. One enthusiastic participant made this comment about ClimateVis *It surprised me how easily I could answer all the questions, This application is revolutionary and beautiful to use!*. These are just a few of the participants that had positive experiences completing the user study. This feedback is hugely positive and is a great reassurance that ClimateVis is capable of being an effective and approachable tool for the general public. Positive feedback is great when identifying the strengths of ClimateVis but some participants still had minor critcisms about the usability of the web application. There were three areas of concern from the participants.

Unsaved Filters - One of the main areas of concern was the filter feature. The main focus of ClimateVis was the environmental visualisations, but the filter feature was added to give users more control over what data the visualisations showed. Unfortunately, this split focus has resulted in some usability issues. One participant said *"My filters seemed to disappear when I created them"* and another said *"I expected the filter to automatically apply without me having to click save"*. These comments, among others, refer to the fact that a filter must be saved before it is applied to a visualisation. This condition makes sure that the chosen filter is valid. All unsaved filters are discarded when a visualisation is created to ensure the form is consistent with the data being shown. This functionality was considered frustrating by some users.

This discarding behaviour of the filter feature enforces Nielsen's consistency heuristic, but it is breaking the recovery heuristic. The recovery heuristic means that a system should be able to help a user recover from any unintentional errors they have made. One solution would be to create a pop-up window known as a modal that alerts the user if they have unsaved filters. This alert would give them the chance to save a valid filter rather than ClimateVis removing it without permission. Another solution would be to remove the save button altogether. If the save button were removed, then the filters would always need to show a valid possibility. To fulfil this requirement, the value filter would need to change from text input field to a drop-down menu. The drop-down may be a cumbersome way to select filters with an extensive list of possible values, but it could save frustration by fixing the unsaved filter removal behaviour. Both solutions would require little effort to change, so their effectiveness could be assessed in future testing. These solutions may reduce or remove one of the biggest usability problems with the filter feature.

Live Updating Visualisations - Another problematic area the participants mentioned was the expectation of the visualiser updating automatically when the builder form was changed. A user must press the create button with a set of valid options to generate a new visualisation. They can then change the options as they wish, but they will not see the changes until they refresh the visualiser or create a new visualisation. Some participants did not respond well to this functionality making comments such as *"I was really confused to why I had to press create before I saw the graph"* and *"It would be less cumbersome if it automatically updated to selections instead of having to select 'create'"*. Although there were only a few participants that mentioned this problem, it still highlights issues with the flow of ClimateVis.

The usability issue of live updating the visualiser is heavily linked to Nielsen's control heuristic. Adhereing to this heuristic means that a user has control over the actions of the web application and interrupting them if need be. The current visualisation creation flow was designed to take advantage of the fact that a user can switch between multiple visualisations. The creation flow lets a user choose the options for new visualisations without overwriting the current one. To try and solve the usability flow issue, this level of control could be moved around ClimateVis. Editing the builder form could automatically update the visualiser, and a user could decide to create a new visualisation by pressing a button on the visualiser menu. This functionality would maintain the same level of control but would make ClimateVis more approachable for new users.

Visualisation Labelling - Some participants were not enthusiastic about the method of looking at details in the visualisations. Most of the visualisations show limited text based information. To discover more about what a visualisation shows, a user needs to interact with it by hovering and clicking. These actions often show a pop-up window that gives details about the information being dispalyed. Some users did not like this style of detail discovery making comments such as *"Often I did not realise I could click on the data visualisation to see more in-depth data"* and *"Maybe it's because I'm on a mobile device but there is literally no labels at all for anything"*. Their comments show a potential issue with requiring a user to interact with a visualisation to see details.

This usability issue creates a conflict with the minimalism and status heuristics. Status requires that the application always shows the user what is happening. Removing labels hides the status of a visualisation from the user. Adding in labels can fix this, but it can also clutter the visualisation hindering the minimalism heuristic. Minimalism aims only to include the most important information to avoid confusing the user. Minimalism was favoured in the design of ClimateVis to make it more approachable for the general public. One solution to this problem would be to find a medium between status and minimalism. This solution could be difficult to execute as every user would have a different opinion on where this medium should lie. The other solution would be to encourage users to interact with the visualisation. Visual cues such as flashing components or elevating user interface items with shadows might entice the user to interact with the visualisations. Encouraging interaction would familiarise users with how they should be discovering details of the data. This familiarity would remove the need to clutter the visualisations with labels. If users were more aware of the fact they should be interacting with each visualisation, then they may prefer the minimalist design of removing labels.

These qualitative results gave an insight into the experience of participants using ClimateVis. Many participants had a positive experience which shows ClimateVis is capable of becoming a great tool. The criticisms outlined in this section highlight how the web application could be improved. These improvements include building auto-save functionality into the filters feature, live-updating the visualiser and adding labels to visualisations. The issues mentioned by participants were relatively minor usability issues in relation to Nielsen's heuristic evaluation technique. This feedback showed that many participants had a positive experience with ClimateVis, and it explains why some of them may have struggled to complete the visualisation tasks.

5.4 Discussion

The user study results were crucial to answering the three research questions: how effective is the ClimateVis user interface, how could ClimateVis be improved and how effective are the visualisations at helping raise awareness of climate change? The software usability score results suggest how effective participants found the ClimateVis user interface. The SUS score gives a quick look at how usable a participant found the web application. The participant's scores showed that almost 75% of them felt ClimateVis was above average in terms of overall usability. This result is very positive as ClimateVis must be easy to use to reach the general public as a target audience.

The additional comments left by participants provided insight into how ClimateVis could be improved. The main area of concern was the filter feature. Users did not like that unsaved filter were being automatically removed. To solve this ClimateVis could modify the filter feature to have components that only allow a valid input. Then the saving functionality could happen automatically. Users also voiced concerns about the need to press the create button when generating a visualisation and that the visualisations needed more labels. These were minor concerns, but they could be solved by increasing the interconnectivity between the visualiser and the builder form components as well as adding more labels to the visualisations. These are all helpful observations taken from participant feedback that would make ClimateVis a more user-friendly web application.

The visualisation difficulty ratings provided insight into the effectiveness of each visualisation. The bar and map visualisations appeared to be the most effective, with 75% of participants rating them either extremely easy to use or just below. The map was undisputed as the most effective as all participants correctly answered the question along with it having the lowest average rating and relatively low spread of ratings. Task 1, based on the bar visualisation, only had 70.8% of participants answer the question correctly. Although it had the second-lowest average rating and the lowest spread, this low percentage indicates a false perception of difficulty in this task. The low number of correct answers suggests that the participants did not understand the question or could not interpret the visualisation correctly. The latter implies that the bar visualisation was not very effective. Another possibility is that this task was subject to learning bias. Learning bias refers to the fact that participants must learn how to use ClimateVis to complete the task. Each participant completes the set of tasks in the same order, which means the bar visualisation is always used first. The percentage of incorrect answers may have been a result of people not knowing how to use ClimateVis as opposed to the bar visualisation being ineffective.

The bubble and line visualisations were presumed to be the least effective due to their task's high difficulty ratings, but both Task 2 and Task 3 were also subject to learning bias. Task 2 required the user to click on a bubble to find the answer. This task is the first time the user needs to interact with a visualisation. If they struggle to learn the interaction, then they are likely to answer the question incorrectly. This creates learning bias as the difficulty ratings may be based on learning interactions rather than the effectiveness of the bubble visualisation. The high percentage of correct answers and a relatively low spread of ratings suggest learning bias did not have a significant effect on Task 2's results.

Task 3 using the line visualisation was ranked the second most challenging task, but more participants answered this question incorrectly when compared to Task 2. Task 3 required participants to create a filter. Again this meant that learning a new feature could have contributed to the high difficulty rating. Complaints about the usability of the filter feature back up the idea that participants struggled to use ClimateVis rather than struggled to understand the visualisation. These observations, combined with the low percentage of correct answers at 70.8% and the highest spread of ratings, indicate learning bias had a significant impact on Task 3's difficulty ratings. The impact of learning bias suggests that the line visualisation is more effective than the difficulty perceptions of Task 3 imply.

A majority of the user study responses were valid with a participant's negative or positive scores being justified by their additional comments. There was one exception. One participant did not answer a single task; they rated each task as extremely challenging and gave a SUS score of 12.5 out of 100. After investigating the outlier, it appears this participant was a user on a mobile device and did not realise they could interact with the visualisations.

Without interacting with the visualisations, the user could not answer any of the questions. This issue does highlight a usability problem but skews the quantitative results as they could not answer the questions correctly.

5.4.1 User Study Limitations

The user study gave a set of quantitative and qualitative results for evaluating ClimateVis, but the user study itself could have been improved to help draw more reliable and impactful conclusions. Learning bias was one of the main limitations of this version of the user study. The learning bias could have been diminished if the participant went through some form of pre-training. An example of pre-training would be creating a set of tasks designed to introduce participants to ClimateVis features and then excluding the answers of these tasks from any results. Pre-training would ensure the difficulty ratings would be focussed on the effectiveness of the visualisations rather than the usability of ClimateVis.

Another reason learning bias was a main limitation was that the tasks were always completed in the same order. Maintaining task order meant users would always be learning a new feature during the same visualisation task. Counterbalancing could have been implemented to reduce the negative impact of learning bias concerning task order. Implementing counterbalancing would mean participants would complete the visualisation tasks in different orders. Changing the order would minimise the effect a participants learning experience has on the difficulty ratings.

An absence of participant information was a limitation of this user study. The responses were anonymous to protect the identity of participants, but a lack of background data reduced the significance of the feedback. To improve the user study, a pre-study questionnaire could be added to collect information about the occupation, gender, age and visualisation experience of the participant. This information could have been used to draw statistically significant conclusions about demographics in the target audience. For example, the analysis of data could have compared the percentage of correct answers between students and teachers or people inexperienced with visualisations against those with experience. The qualitative feedback would have another layer of context as the background of a participant may have justified why they had a positive or negative experience with ClimateVis. Collecting background information from participants would have added more depth to the analysis of the user study results.

The quantitative data was partially comprised of a participants opinion of difficulty, limiting the result accuracy of the user study. This type of data can be difficult to analyse as everyone's perception of difficulty is different. The quantitative data could have been more accurate if standardised mathematical metrics were used. A future version of ClimateVis could track the time it takes for a participant to complete a task and where the participant clicks to do so. These metrics would provide a standardised metric to measure how a task is completed without being affected by opinion. This information could have been used to assess whether or not a participant struggled with a task using a standard benchmark. Using a standard set of quantitative metrics excluded from participant opinion would have improved the accuracy of the user study results.

The user study successfully helped answer the research questions. Overall users appeared to have a pleasant experience with ClimateVis finding the visualisations effective, and the user interface easy to learn. The map visualisation was the most effective and the bubble visualisation was the least effective. The bar (Task 1), bubble (Task 2) and line (Task 3) visualisation tasks may have given participants a false perception of difficulty due to learning bias introduced by the tasks. Pre-training and counterbalancing could have diminished the negative effects of learning bias. Collecting background information from participants could have resulted in a more in-depth analysis of the responses. Implementing standard metrics such as time to track participant behaviour would have given more accurate quantitative results. The results of the study provided a clear view of ClimateVis' favourable usability and the satisfactory effectiveness of its visualisations.

Chapter 6

Summary

6.1 Conclusion

Climate change is a looming threat that could cause more frequent extreme weather events, increased floods and more droughts [3]. The general public is partially responsible, but some people do not understand how our environment is being affected by climate change. If the general public could see the effects of climate change, they may be inspired to make a difference.

This project discussed the design, implementation and evaluation of ClimateVis, a web application that can visualise environmental data to help raise climate change awareness. Some environmental visualisations try to achieve a similar goal, but as single visualisations, the user is forced to learn a new set of interactions for each different perspective on the issue. LAWA is a tool that visualised environmental data, but its static visualisations and usability issues made it a less than ideal solution for raising climate change awareness. ClimateVis aimed to be a unique solution offering a single interface that allowed users to create a series of compelling visualisations with environmental data.

The design decisions involved when creating the web application were focussed on building a clean user interface and effective visualisations suitable for the general public. ClimateVis gives users the ability to create and interact with visualisations, switch between multiple visualisations and filter data to make the visualisations more specific. These features aimed to maximise user control. A minimalist mindset was used when creating the visual design of ClimateVis to avoid overwhelming the user with unnecessary features.

ClimateVis has six different visualisations that can visualise seven properties of lake water quality in New Zealand. The visualisations follow Shneiderman's 'Information Seeking Mantra'. All of the visualisations can be interacted with which not only fosters engagement but lets users explore the data. The six visualisations aim to help the general public learn more about how the environment is changing.

The three-tier architecture resulted in the development of three primary software artifacts to complete the web stack for ClimateVis. These were an SQL database, an API using the Express library and a client-facing web app built with Angular and D3. These architecture components were built to support content expansion and integration with other applications. The design and implementation portion of this project resulted in the creation of ClimateVis, a clean web application that gives the general public a way to visualise New Zealand's changing environment.

The evaluation of ClimateVis showed that all visualisations were relatively effective. Most of the visualisations were rated extremely easy to use or just under by a majority of participants. The map visualisation was considered the most effective while the bubble visualisation was considered the least effective. The software usability scale results showed that at least half of the participants found the web application very easy to use reinforcing that ClimateVis has a very effective user interface. The qualitative results showed that many participants had a positive experience with ClimateVis. The feedback also identified that the filter feature could be improved along with the addition of increasing the interconnectivity between the builder and visualiser components. The evaluation results showed that ClimateVis was an effective tool capable of teaching the general public about New Zealand's changing environment.

ClimateVis is one step in the right direction to help raise climate change awareness. The web application stack is robust, flexible and ready for continued development. The user interface is easy to use and approachable for the general public. The current visualisations are engaging and understandable. The evaluation of ClimateVis showed the potential for it to be a revolutionary web application. With continued development, ClimateVis may genuinely be able to make a difference in raising climate change awareness. Awareness is just the first step in fighting climate change, but it will take a collective effort to make the planet safe for future generations. ClimateVis can be a part of the journey to restore environmental prosperity.

6.2 Future Work

Usability Improvements - The response to ClimateVis was positive, but the evaluation results highlight areas of the web application that can be improved. The filter feature needs to redesigned to support better error recovery. By removing the saving functionality behind the filters, the web application can become more automated for the user. The emphasis of automation is reinforced by the desire to modify the visualisation creation flow. By automatically updating a visualisation based on the builder form, users will not have to continuously recreate a visualisation. This live update would make the two core components of ClimateVis far more cohesive. The visualisations could also be improved by adding more labels and encouraging interactions. These improvements would satisfy most of the concerns raised by users in the user study.

Content Expansion - The evaluation of ClimateVis discovered a few areas of improvement, but the entire web application has been built around content expansion. The first area of content expansion would be adding a new dataset, preferably air quality data. Air quality data would give users a better understanding of how the environment is being affected by climate change. Air temperature and carbon dioxide are two key components of air-based data that would be beneficial to show. The air data would need to be added to the database, and a route would need to be set up in the API to fetch the new data. The current user interface and all visualisations would work with this new data. Continuing the idea of content expansion, new visualisations could also be added. These visualisations could be generalised or have a more specific focus on the water or air quality data. These changes would contribute to making more impactful environmental data visualisation that would show the effects of climate change.

Integrations - To help ClimateVis reach the general public it could be integrated with many tools. The three-tier architecture is ideal for integrating with other environmental web applications or social media. ClimateVis could be integrated with the LAWA application. For example, when exploring air quality data on LAWA, you could click a link that takes you to ClimateVis where the same data could be visualised differently. To raise climate change awareness the general public need to be able to share with people what ClimateVis has shown them. If visualisations from the application could be saved and shared on social media, then they could reach a much larger audience. These integrations would help ClimateVis reach the most substantial amount of its target audience as possible.

Continued Development - Climate change is a huge issue, and unfortunately, ClimateVis is only a small step in the way of helping people realise this. The improvements that could be applied to ClimateVis may genuinely make a difference. One of the best ways for this to happen would be to pass the artifacts created in this project onto another researcher who can continue to improve ClimateVis. Further development could fix the usability issues and put a focus on making the data visualisations as effective as possible.

Bibliography

[1] Newshub. Jacinda ardern: 'climate change is my generation's nuclear-free moment'. [Accessed 10-October-2019]. [Online]. Available: https://www.newshub.co.nz/home/election/2017/08/jacinda-ardern-climate-change-is-my-generation-s-nuclear-free-moment.html

[2] D. Stillman. (2019, May) What is Climate Change? [Accessed 04-June-2019]. [Online]. Available: https://climate.nasa.gov/resources/global-warming/

[3] New Zealand Ministry for the Environment. (2019, Mar.) Likely climate change impacts in new zealand. [Accessed 04-June-2019]. [Online]. Available: https://www.mfe.govt.nz/climate-change/likely-impacts-of-climate-change/likely-climate-change-impacts-new-zealand

[4] B. Shneiderman, "The eyes have it: A task by data type taxonomy for information visualizations," *IEEE Symposium on Visual Languages*, vol. 96, 1996.

[5] NASA. (2019, May) What's in a name? weather, global warming and climate change. [Accessed 04-June-2019]. [Online]. Available: https://climate.nasa.gov/resources/global-warming/

[6] Westlab Blog Canada. (2019, Nov.) How does temperature affect ph. [Accessed 04-June-2019]. [Online]. Available: https://www.westlab.com/blog/2017/11/15/how-does-temperature-affect-ph

[7] Government of South Australia. (2019, May) Blue green algae. [Accessed 04-June-2019]. [Online]. Available: https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/protecting+public+health/water+quality/blue+green+algae

[8] Land, Air, Water, Aoeteroa. Chlorophyll-a-1. [Accessed 04-June-2019]. [Online]. Available: https://www.lawa.org.nz/learn/glossary/c/chlorophyll-a-1/

[9] Tableau. Business Intelligence and Analytics Software. [Accessed 24-September-2019]. [Online]. Available: https://www.tableau.com/

[10] Evoenergy. U.k. energy consumption guide. [Accessed 06-June-2019]. [Online]. Available: https://www.evoenergy.co.uk/uk-energy-guide/

[11] K. Elliott. (2015, Mar.) Where carbon emissions are greatest. [Accessed 06-June-2019]. [Online]. Available: https://www.washingtonpost.com/graphics/national/carbon-emissions-2015/

[12] E. Hawkins. (2018, May) Warming stripes. [Accessed 04-June-2019]. [Online]. Available: https://www.climate-lab-book.ac.uk/2018/warming-stripes/

[13] ——. (2018, Dec.) Global temperature change (1850-2018). [Accessed 04-June-2019]. [Online]. Available: http://blogs.reading.ac.uk/climate-lab-book/files/2018/12/spiral_2018_WMO_large.gif

[14] ——. Climate spirals. [Accessed 04-June-2019]. [Online]. Available: https://www.climate-lab-book.ac.uk/spirals/

[15] Land, Air, Water, Aoeteroa. Land, air, water, aoeteroa (lawa). [Accessed 04-June-2019]. [Online]. Available: https://www.lawa.org.nz/

[16] ——. About lawa. [Accessed 04-June-2019]. [Online]. Available: https://www.lawa.org.nz/about

[17] J. Nielsen, *Usability Engineering*. San Francisco: Elsevier Science and Technology, 1994.

[18] B. T. Powley, "Atmovis: Visualization of air quality data," Master's thesis, Victoria University of Wellington, 2019.

[19] E. Enge. (2019, Apr.) Mobile vs desktop traffic in 2019. [Accessed 04-June-2019]. [Online]. Available: https://www.stonetemple.com/mobile-vs-desktop-usage-study/

[20] D. M. Oliver and T. Page, "Effects of seasonal meteorological variables on e. coli persistence in livestock faeces and implications for environmental and human health," *Scientific Reports*, vol. 6, 2016.

[21] JReport. 3-tier architecture: A complete overview. [Accessed 05-June-2019]. [Online]. Available: https://www.jinfonet.com/resources/bi-defined/3-tier-architecture-complete-overview/

[22] M. Bostock, V. Ogievetsky, and J. Heer, "D3 data driven documents," *IEEE Transactions on Visualization and Computer Graphics*, vol. 17, pp. 2301–2309, 2011.

[23] Izenda Editorial Staff. (2017, Mar.) 5 benefits of a 3-tier architecture. [Accessed 12-June-2019]. [Online]. Available: https://www.izenda.com/5-benefits-3-tier-architecture/

[24] Optimizely. Web analytics. [Accessed 05-June-2019]. [Online]. Available: https://www.optimizely.com/anz/optimization-glossary/web-analytics/

[25] Amazon Web Services. Cloud computing with aws. [Accessed 05-June-2019]. [Online]. Available: https://aws.amazon.com/what-is-aws/

[26] Angular. Architecture Overview. [Accessed 05-June-2019]. [Online]. Available: https://angular.io/guide/architecture

[27] Express. Fast, Unopionated, Minimalist Web Framework for Node.js. [Accessed 05-June-2019]. [Online]. Available: https://expressjs.com/

[28] PostgreSQL. What is PostgreSQL? [Accessed 05-June-2019]. [Online]. Available: https://www.postgresql.org/about/

[29] M. Rouse. Olap (online analytical processing). [Accessed 12-October-2019]. [Online]. Available: https://searchdatamanagement.techtarget.com/definition/OLAP

[30] N. Thomas. (2015, Jul.) How to use the system usability scale (sus) to evaluate the usability of your website. [Accessed 06-October-2019]. [Online]. Available: https://usabilitygeek.com/how-to-use-the-system-usability-scale-sus-to-evaluate-the-usability-of-your-website/

[31] Usability.gov. System usability scale (sus). [Accessed 03-October-2019]. [Online]. Available: https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

[32] Survey Monkey. What is a likert scale. [Accessed 11-October-2019]. [Online]. Available: https://www.surveymonkey.com/mp/likert-scale/

[33] Science, Halley Hosting. Standard deviation part ii. [Accessed 10-October-2019]. [Online]. Available: http://science.halleyhosting.com/sci/soph/inquiry/standdev2.htm

[34] National Aeronautics and Space Administration. (2018, Jan.) Annual global surface temperatue, relative to late 19th century average. [Accessed 06-June-2019]. [Online]. Available: https://www.nytimes.com/interactive/2018/01/18/climate/hottest-year-2017.html

Appendix A

Temperature Increase Over Time

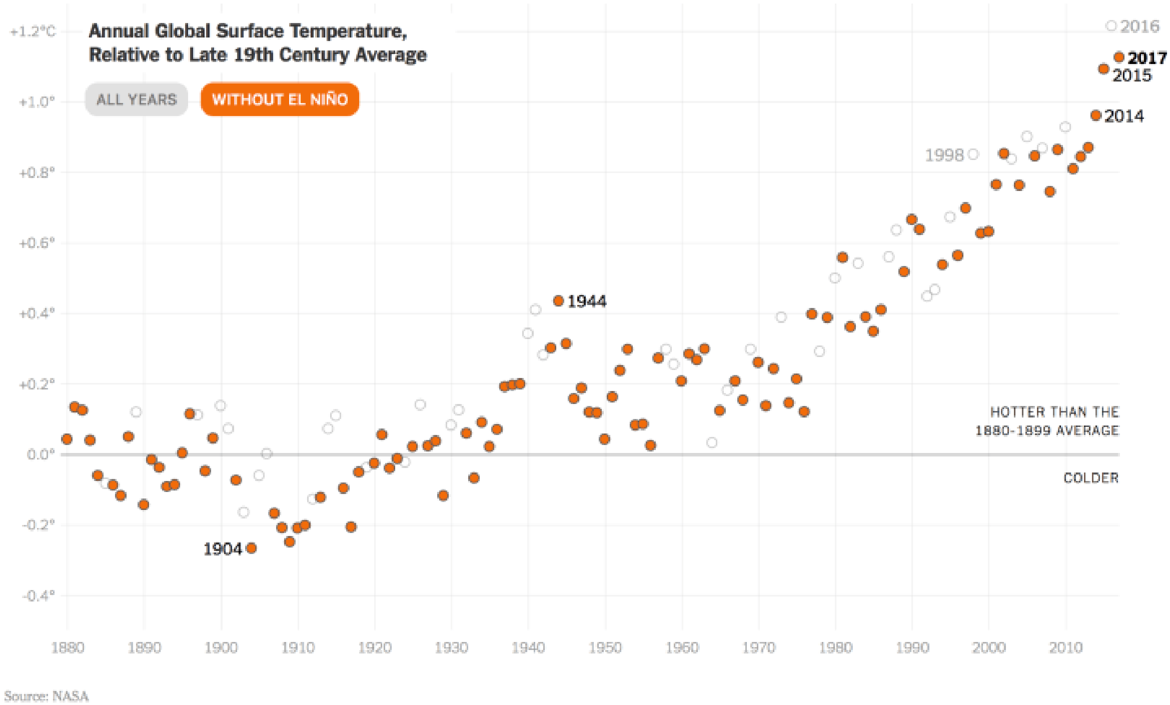
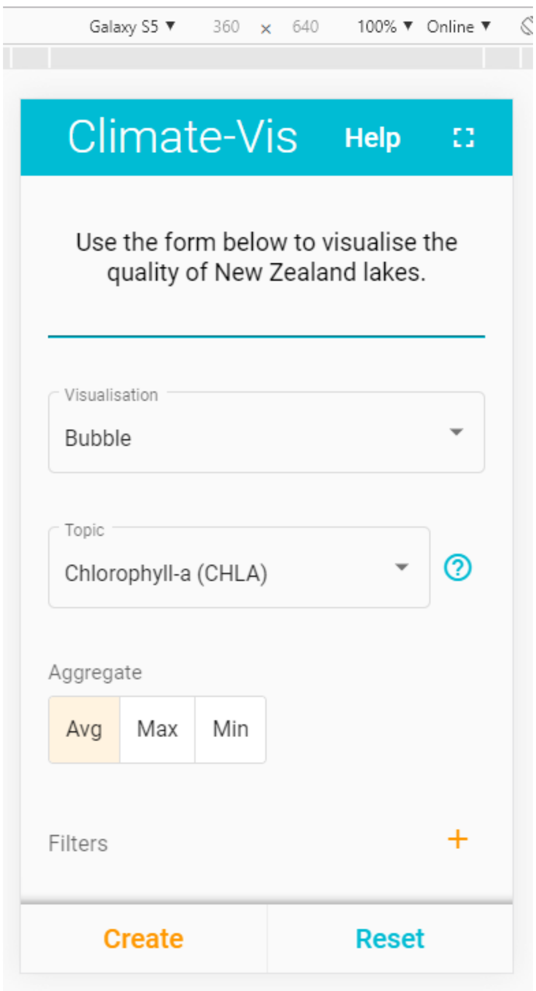


Figure A.1: Annual Global Surface Temperature [34].

Appendix B

ClimateVis at Mobile Device Resolution



(a) The Builder on a Mobile Device

(b) The Visualiser on a Mobile Device

Figure B.1: ClimateVis Web Application running at the Resolution of a Samsung Galaxy S5

Appendix C

Known Participant Information

ID	Occupation	Gender	Vis Experience
1	Student	Male	3 Years
2	Student	Male	None
3	Student	Female	None
4	I.T Support	Male	None
5	Teacher	Female	5+ Years
6	Student	Male	1 Year
7	Student	Male	None
8	Student	Female	None
9	Student	Male	None
10	Teacher	Male	5+ Years
11	Graphic Designer	Male	None
12	Industrial Designer	Female	None
13	Climate Scientist	Male	10+ Years
14	Student	Male	1 Year
15	Student	Male	None
16	Student	Male	None
17	Student	Male	None
18	N/A	N/A	N/A
19	N/A	N/A	N/A
20	N/A	N/A	N/A
21	N/A	N/A	N/A
22	N/A	N/A	N/A
23	N/A	N/A	N/A
24	N/A	N/A	N/A
25	N/A	N/A	N/A

Appendix D

User Study Questions

D.1 User Study Consent and Information

Hi there!

You are invited to participate in this user study to assess ClimateVis. ClimateVis is a web application that lets you visualise environmental data. ClimateVis hopes to raise awareness about climate change and educate the public on how New Zealand's environment is changing.

ClimateVis is an Honours Project in Software engineering being developed by Sean Hone at Victoria University of Wellington. The project is being supervised by Dr Craig Anslow of Victoria University of Wellington.

If you decide to take part in this user study you will:

1. Perform six different tasks with ClimateVis (15min).
2. Complete a usability survey (5min)

This research has been approved by the Victoria University of Wellington Human Ethics Committee, Application Number: 0000027652.

Participation is voluntary, and you will not be identified personally in any written report produced as a result of this research, including possible publication in academic conferences and journals. Your answers will be submitted anonymously, meaning the researchers will not be aware of your personal details.

If you have any questions or would like to receive further information about the project, please contact the researcher honesean@myvuw.ac.nz or you may contact the supervisor Dr Craig Anslow at craig.anslow@ecs.vuw.ac.nz.

If you have any concerns about the ethical conduct of the research, you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

You can find ClimateVis here: http://climate-vis.s3-website.us-east-2.amazonaws.com/

You can find a tutorial for ClimateVis here: http://homepages.ecs.vuw.ac.nz/ honesean/

* Required

If you agree to participate in this user study, then you understand that:

- All information submitted with this form is anonymous.
- Answering questions in this user study is optional.
- All information submitted with this form will only be used for the analysis of ClimateVis.
- If I have questions about the project, I can contact the researcher or supervisor.

D.2 Questions

Participant Consent:

1. Do you agree to participate in this user study?

Tasks:

1. What region has the highest average Cholorophyll-a level? (with bar visualisation).
2. How difficult did you find this task?
3. What lake site in Wellington has the highest average ammoniacal nitrogen level? (with bubble visualisation).
4. How difficult did you find this task?
5. How do the average total nitrogen levels of Taranaki lake sites compare to the ideal value? (with line visualisation)
6. How difficult did you find this task?
7. What region has the highest average Escheria Coli levels? (with map visualisation)
8. How difficult did you find this task?
9. What year was there a peak in average Chlorophll-a levels around New Zealand? (with stream visualisation)
10. How difficult did you find this task?
11. What lake site has highest average total phosphorus level? (with sunburst visualisation)
12. How difficult did you find this task?

Usability Survey. Rate each statement from one (Strongly Disagree to five (Strongly Agree):

1. I think that I would like to use this web application frequently.
2. I found this web application unnecessarily complex.

3. I thought this web application was easy to use.
4. I think that I would need assistance to be able to use this web application.
5. I found the various functions in this web application were well integrated.
6. I thought there was too much inconsistency in this web application.
7. I would imagine that most people would learn to use this web application very quickly.
8. I found this web application very cumbersome/awkward to use.
9. I felt very confident using this web application.
10. I needed to learn a lot of things before I could get going with this web application.

Additional Notes:

1. Please add any additional comments you had about the web application.

Honorarium:

Thanks for completing the survey! To recieve the honorarium send an email to honesean@myvuw.ac.nz saying you've completed the survey.

Appendix E

Human Ethics Application

ResearchMaster

Human Ethics Application

Application ID :	0000027652
Application Title :	Understanding Climate Change by Visualising Environmental Data
Date of Submission :	N/A
Primary Investigator :	Sean Michael Hone; Principal Investigator
Other Personnel :	Dr Craig Anslow; Supervisor

Research Form

Application Type

1.

IMPORTANT: Please select type of research below and click on 'Save' to access the rest of the form.

*

Research

Application Details

Category

B

3. Application ID

0000027652

5. Title of project
*(Click the ? icon for more info)**

Understanding Climate Change by Visualising Environmental Data

6. School or research centre*

Engineering and Computer Science

7. Personnel*

1	Given Name	Sean
	Surname	Hone
	Full Name	Sean Michael Hone
	AOU	Engineering and Computer Science
	Position	Principal Investigator
	Primary?	Yes

8. Are any of the researchers from outside Victoria?*

- ○ Yes
- ◉ No

9. Is the principal investigator a student?*

- ◉ Yes
- ○ No

Student Research

9a. What is your course code (e.g. ANTH 690)?*

ENGR489

9b. Supervisor*

1	Given Name	Craig
	Surname	Anslow
	Full Name	Dr Craig Anslow
	AOU	Engineering and Computer Science
	Position	Supervisor

9c. What is your email address? (this is needed in case the committee needs to contact you about this application)*

honesean@myvuw.ac.nz

Project Details

10. The following question is meant to help applicants consider their research application and any protocols that should be uploaded and to help committee members review the application. Please check the box if if your research:

- [ ] Is an anonymous questionnaire
- [x] Uses tertiary students as participants
- [ ] Is a health or disability research project
- [ ] Includes Māori participants, or otherwise has an impact on Māori
- [ ] Includes participants from another significant cultural group, or has an impact on that group
- [ ] Uses highly sensitive information (see Policy for definition)
- [ ] Collects or uses human tissue, including blood, saliva and genetic material
- [ ] Uses noninvasive physiological procedures (e.g., EEG, heart rate monitor)
- [ ] Uses equipment (e.g., TMS) that may temporarily alter mental function
- [ ] Administers substances (e.g., food, alcohol, placebo pill) to be ingested by participants

11. Does this application relate to any previous applications submitted to an ethics committee?*

○ Yes

◉ No

12. Describe the aims and objectives of the project
Provide a brief summary in plain language of the purpose, research questions/hypothesis, and objectives of your project. *

This research project aims to create a web application that can effectively visualise environmental data. The purpose of such a web application is to help the public understand climate change. It will help by allowing people to create graphs and other visuals that show how New Zealand's environment has changed over time. The visuals would give them the means to conclude how climate change is affecting our environment. The user testing will ask participants to use the web application. The user testing portion aims to assess whether the website is easy to use and comprehend. I hope the application will give participants a greater understanding of how New Zealand's environment is being affected by climate change.

13. Describe the benefits and scholarly value of the project
*Briefly place the project in perspective, explaining its significance and worthwhile outcomes. Include how this project will build on relevant literature, including references if appropriate.**

Climate change is a hugely pressing issue in today's society. Victoria University has members of staff researching this very problem. This project would provide an application that would increase the number of people that can investigate and understand this area of ongoing research. The application will have a user interface suitable for people that are not experienced scientists in the field of climate change. This would hopefully encourage the uptake of research and understanding of climate change in a less knowledgeable audience. Lecturers and researchers could also use the application to demonstrate different aspects of climate change to students.

14. Explain any ethical issues your research raises for participants, yourself as the researcher, or wider communities and institutions, and how you will address these. This is an opportunity to present what you think the key risks are in your project and show how you have taken them into account.*

The most significant ethical implication this research project has is the ability to effect a participants outlook on the issue of climate change. It is a severe problem that affects the wellbeing of the human race as a whole. If the application can exemplify how serious the problem is to participants, they may have a negative emotional response to using the application. To minimise this, I will be asking the user to perform tasks and answer questions mostly on the usability of the web application as opposed to forcing an understanding of climate change upon the participant.

Key Dates

If approved, this application will cover this research project from the date of approval

15. Proposed start date for data collection*

08/07/2019

16. Proposed end date for data collection*

30/09/2019

17. Proposed end date for research project*

18/10/2019

Proposed source of funding and other ethical considerations

18. Indicate any sources of funding, including self-funding (tick all that apply)

Internally: by a University grant, such as the University Research Fund
Externally: funding from an external organisation for this project, or a scholarship awarded by an external organisation
Self-funded: paying for research costs such as travel, postage etc. from your own funds

- [x] Internally funded
- [ ] Externally funded
- [ ] Self-funded

19. Is any professional code of ethics to be followed?*

○ Yes

◉ No

20. Do you require ethical approval from any other organisation, such as another tertiary institution in New Zealand or overseas, or a District Health Board?*

○ Yes

◉ No

Data Collection and Recruitment

21. Please select all forms of data collection you will use in your project*

☑ Interviews

☐ Focus groups

☑ Questionnaires

☐ Observation

☐ Other

22. Provide an explanation of the sampling rationale for your study.
E.g. representative sampling of a particular population, purposive sampling, convenience sampling. Include here your eligibility criteria for potential participants -- will there be particular criteria for participants to be included in your study, or criteria that will exclude them? *

> The user participants will be open to Victoria University staff and students. The study will be advertised mainly to undergraduate students as they will better represent the level of understanding the general public have about climate change and environmental data. The type of major the student is undergoing will not exclude them from participating in the study. It would, however, be more favourable if they had a background in software or geography as they could give more meaningful feedback on how practical the application is.

23. How many participants will be involved in your research?
If there will be several different groups of participants, please specify how many groups and how many participants in each group. *

> The ideal number of participants for this study is 30 students. This amount would give a sufficient amount of data to draw conclusions about the usability and effectiveness of the application.

24. What are the characteristics of the people you will be recruiting?*

> The participants in this study will be students or staff at Victoria University. The majority of these participants will be undergraduate students so they may have a lesser understanding of environmental visualisations than students in a post-graduate position. This means the study may better reflect on how the general public would react to the product.

25. Outline in detail the method(s) of recruitment you will use for participants in your study. *Include here how potential participants will be identified, who will contact them and how. Please include copies of all advertisements, online posts or recruitment emails in the 'Documents' section.* *

> I will begin by emailing lecturers in both the School of Geography, Environment and Earth Sciences and the School of Engineering and Computer Science. I will inform them of the web application I have been creating as part of my research project and request they ask if any of their students or themselves would be interested in taking part in the user study. This email will have my supervisors and my contact information so potential participants could email us and organise a time to take part in the study.

26. Explain the details of the method of data collection. For example, describe the location of your research procedures, if appropriate (e.g. where your interviews will take place). If necessary, upload a research protocol in the 'Documents' section.*

> The study will take place in a computer lab in the cotton building of Victoria University. In these labs, the participant and the researcher will both have a place to sit for the duration of the study. They will each have access to a computer which will be pre-loaded with the application. The participant will be asked to use the application and interviewed on how they found the experience. The mouse movement and mouse clicks will be tracked to generate data about how the web application is used. At the end of the study, the participant will be asked to fill out a short questionnaire to rate the application and offer any improvements.

27. Will your research project take place overseas?*

○ Yes

◉ No

28. Does the research involve any other situation which may put the researcher at risk of harm (e.g. gathering data in private homes)?*

○ Yes

◉ No

Participants and Informed Consent

29. Does your research target members of a vulnerable population?
*This includes, but is not limited to, children under the age of 16, people with significant mental illness, people with serious intellectual disability, prisoners, employees and students of a researcher, and people whose health, employment, citizenship or housing status is compromised. Vulnerability is a broad category and encompasses people who may lack the ability to consent freely or may be particularly susceptible to harm.**

○ Yes

◉ No

30. Have you undertaken any consultation with the groups from which you will be recruiting, regarding your method of recruitment, data collection, or your project more widely?*

- (●) Yes
- ( ) No

30a. Provide details of consultation you have undertaken or are planning.*

> I have had meetings with the Human-Computer Interaction group. Many members of this group have undergone and shared experiences of usability testing with software products. My supervisor Dr. Craig Anslow who runs this group, has overseen many usability studies and shared material that helped me create a focussed user testing procedure.

31. Will your participants receive any gifts/koha in return for participating?*

- (●) Yes
- ( ) No

31a. Describe the gifts/koha and the rationale.*

> The gift will be a $10 supermarket voucher. The gift is meant to be a thank you to the student for participating in the study. The value of the voucher is chosen, so that is a sufficient thank you for a participants time but not the sole reason they take part in the study.

32. Will your participants receive any compensation for participation (for instance, meals, transport, or reimbursement of expenses)?*

- ( ) Yes
- (●) No

33. How will informed consent be obtained? (tick all that apply to the research you are describing in this application)*

- [ ] Informed consent will be implied through voluntary participation (anonymous research only)
- [x] Informed consent will be obtained through a signed consent form
- [ ] Informed consent will be obtained by some other method

Treaty of Waitangi

How does your research conform to the University's Treaty of Waitangi Statute? (you can access the statute from Victoria's Treaty of Waitangi page)*

> The results from the study will not affect exclude any particular party from further decision making or leadership in the environmental research area of the University. The participants of this study are not included or excluded based on any racial quality. This means that whether someone participates in the study or not they will not be disadvantaged in any way in terms of leadership decision making or equality.

Minimisation of Harm

34. Is it possible that participants may experience any physical discomfort as a result of the research?*

- ( ) Yes
- (●) No

35. Is it possible that participants may experience any emotional or psychological discomfort as a result of the research? (E.g. asking participants to recall upsetting events, viewing disturbing imagery.)*

- ( ) Yes
- (●) No

36. Will your participants experience any deception as a result of the research?*

- ( ) Yes
- (●) No

37. Is any third party likely to experience any special hazard/risk including breach of privacy or release of commercially sensitive information? This may occur in the instance participants are asked to discuss identifiable third parties in the research.*

- ( ) Yes
- (●) No

38. Do you have any professional, personal, or financial relationship with prospective research participants? *

- (●) Yes
- ( ) No

38a. Give details and indicate how you will manage this.*

> If students from the School of Engineering and Computer Science take part in the study, then it is possible I would have a personal friendship with the participant as we may have attended the same classes or socialised at faculty events. It will be optional for these students to take part in the test. My relationship with them would not change whether they decide to take part in the user study or not. To manage conflict of interest, these participants would strictly follow the outlined interview schedule the same as any other participant, and they would also receive the same thank you gift for participation in the study. The questions required by a participant are focussed entirely on the web application meaning their feedback would in no way change the personal relationship I had with the participant.

39. What opportunity will participants have to review the information they provide? (tick all that apply)*

- [ ] Will be given a full transcript of their interview and given an opportunity to provide comments
- [ ] Will be given a full transcript of their interview and NOT given an opportunity to provide comments
- [ ] Will be given a summary of their interview
- [ ] Other opportunity
- [x] Will not have an opportunity to review the information they provide

39a. Please give details*

The participants will be given a chance to amend any answers before completing the study but not the chance to change it once the session has finished. The information they are providing is going to be reactive to what they are doing with the application, so restricting information to this time will keep results relevant. None of the information provided will directly affect the participant's ongoing life, so amendments to their answers should not need to be made.

Confidentiality and Anonymity

40. Will participation in the research be anonymous?
*'Anonymous' means that the identity of the research participant is not known to anyone involved in the research, including researchers themselves. It is not possible for the researchers to identify whether the person took part in the research, or to subsequently identify people who took part (e.g., by recognising them in different settings by their appearance, or being able to identify them retrospectively by their appearance, or because of the distinctiveness of the information they were asked to provide).**

- ( ) Yes
- (•) No

41. Will participation in the research be confidential?
*Confidential means that those involved in the research are able to identify the participants but will not reveal their identity to anyone outside the research team. Researchers will also take reasonable precautions to ensure that participants' identities cannot be linked to their responses in the future.**

- (•) Yes
- ( ) No

41a. How will confidentiality be maintained in terms of access to the identifiable research data? (tick all that apply)*

- [ ] Access to the research will be restricted to the investigator
- [x] Access to the research will be restricted to the investigator and their supervisor
- [ ] Focus groups will have confidentiality ground rules
- [ ] Transcribers will sign confidentiality forms
- [ ] Other

41b. How will confidentiality be maintained in terms of reporting of the data? (tick all that apply)*

- [x] Pseudonyms will be used
- [x] Data will be aggregated
- [ ] Participants will be referred to by role rather than by name
- [ ] Other

41b. i) Please provide details*

The participants will not be referred to in my final report by name or any other personal characteristic. Some of the data will be numerical. This data will be analysed and visualised as a whole, so an individual's answers could not be traced back to them.

42. Will participation in the research be neither confidential nor anonymous, and participants will be identifiable in any outputs or publications relating to the research? *

- ( ) Yes
- (•) No

Access, storage, use, and disposal of data

43. Which of the following best describes the form in which data generated in your study will be stored during the study?
*See help text for guidance on these terms. Further info available on human ethics website**

- (•) Identifiable
- ( ) Potentially identifiable
- ( ) Partially de-identified
- ( ) De-identified
- ( ) Anonymous
- ( ) Other

44. Which of the following best describes the form in which data generated in your study will be stored after the study is completed?
*See help text for guidance on these terms. Further info available on human ethics website**

- ( ) Identifiable
- ( ) Potentially identifiable
- (•) Partially de-identified
- ( ) De-identified
- ( ) Anonymous
- ( ) Other

45a. Proposed date for destruction of identifiable research data (i.e. the date when data will be de-identified and personal information on participants destroyed)

*

09/11/2019

45b. Proposed date for destruction of de-identified research data, including anonymous data

*

09/11/2019

46. Will any research data will be kept for longer than 5 years after the conclusion of the research?*

- ( ) Yes
- (•) No

47. Who will have access to identifiable, de-identified or anonymous data, both during and at the conclusion of the research?*

- ( ) Access restricted to the researcher only (whoever is named as PI)
- (•) Access restricted to researcher and their supervisor
- ( ) Access restricted to researcher and immediate research team, e.g. co-investigators, assistants
- ( ) Other

48. Are there any plans to re-use either identifiable, de-identified or anonymous data?*

- ( ) Yes
- (•) No

49. What procedures will be in place for the storage of, access to and disposal of data, both during and at the conclusion of the research? (Check all that apply)
Information regarding appropriate data storage is available on the human ethics website. Note that storing research data on USB drives is strongly discouraged for security reasons. *

- [x] All hard copy material will be stored securely e.g. in a locked filing cabinet
- [x] All electronic material will be held securely, e.g. only on University servers, password protected
- [x] All hard copy material will be appropriately destroyed (e.g. shredded) on the dates given above
- [x] All electronic data will be deleted on the dates given (ITS should be consulted on proper method)

Dissemination

50. How will you provide feedback to participants?*

Feedback will be provided on the day.

51. How will results be reported and published? Indicate which of the following are appropriate. The proposed form of publications should be indicated to participants on the information sheet and/or consent form*

- [ ] Publication in academic or professional journals
- [ ] Dissemination at academic or professional conferences
- [ ] Availability of the research paper or thesis in the University Library and Institutional Repository
- [x] Other

51a. Describe how the results will be disseminated*

The results will be in a report submitted to the ENGR489 course. The report will be used for marking purposes but not publicly released.

52. Is it likely that this research will generate commercialisable intellectual property?
*(Click the ? icon for more info)**

- ( ) Yes
- (•) No

Documents

53. Please upload any documents relating to this application. Sample documents are available on the Human Ethics web page.

Please ensure that your files are small enough to upload easily, and in formats which reviewers can easily download and review. To replace a document, click the tick in the column to the right of the document title. A green arrow will appear - click this arrow to upload a new document. To add a new document click on 'Add New Document', at top right of the documents window. Then enter the document name in the box that appears and click the green tick. A green arrow will appear to the right of the file name which allows you to upload the new file.

Please also collate all your documents into one PDF or Word file, and upload as a new document. This should be labelled as 'Combined Documents'.*

Description	Reference	Soft copy	Hard copy
Participant information sheet(s)	participant-information-sheet.pdf	✓	
Participant consent form(s)	paricipant-consent-form.pdf	✓	
Interview questions or guide	user-study-guide.pdf	✓	
Questionnaire or survey	questionnaire.pdf	✓	

Amendment or extension request (available only for approved applications)

43. Are you applying for an extension, an amendment, or both?*

○ Extension

○ Amendment

○ Both an extension and an amendment

This question is not answered.

Please check that you have answered all mandatory questions and have saved the application before submitting your form. Any new or amended documents (e.g. Participant Information Sheet) to be added to your application should be emailed to ethicsadmin@vuw.ac.nz before submission. To submit your form, click on the Action tab and then click on Submit for review

44. Do you have a second amendment/extension request to make?

○ Yes

○ No

This question is not answered.

45. Do you have a third amendment/extension request to make?

○ Yes

○ No

This question is not answered.

46. Do you have a fourth amendment/extension request to make?

○ Yes

○ No

This question is not answered.

Date Reapproved

(For Admin Use Only)

This question is not answered.

Incident Reporting

Research teams must immediately advise the Human Ethics Committee if an adverse incident occurs in the course of their research project.

Adverse incidents are instances of potential or actual physical harm to participants or researchers; emotional harm or distress to participants or researchers; and any other unforeseen events that raise ethical issues.

A full incident report must be completed and emailed to ethicsadmin@vuw.ac.nz. You can download this form here (link to be added). After you have emailed the form, please complete the questions below, then click on the **Action** tab and click **Report Incident**

Do you have an incident to report?

☐ Yes

This question is not answered.

Please go to the **Action** tab and click on **Report Incident** to complete the process.

SCHOOL OF ENGINEERING AND COMPUTER SCIENCE
TE KURA MATAI PUKAHA, PUROROHIKO
ROOM CO 358, COTTON BUILDING, VICTORIA UNIVERSITY OF WELLINGTON, GATE 7, KELBURN PARADE, WELLINGTON
PO Box 600, Wellington 6140, New Zealand
Phone +64 4 463 5341 **Email** office@ecs.ac.nz **Website** www.victoria.ac.nz/ecs
If you have any concerns about the ethical conduct of the research, you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

Participant Information Sheet

Research Project Title: Understanding Climate Change by Visualising Environmental Data

Researcher: Sean Hone, School of Engineering and Computer Science, Victoria University of Wellington

As part of the completion of my Bachelor of Engineering, this study involves creating a website designed to help people understand how the New Zealand environment is being affected by climate change. The website will do this by allowing people to visualise environmental data from New Zealand. The visualisations will help people understand how our environment is changing from climate activity. Victoria University requires, and has granted, approval from the School's Human Ethics Committee.

I am inviting all students or staff with an interest in climate change or visualisation software to participate in this research. Participants will be asked to take part in a half hour usability test of the website. They will be asked to perform several tasks using the website and interviewed on their experience performing these tasks. The participants activity on the site will be collected to better understand how the website is used.

Participation is voluntary, and you will not be identified personally in any written report produced as a result of this research, including possible publication in academic conferences and journals. All material collected will be kept confidential, and will be viewed only by myself and my supervisor Dr. Craig Anslow. The honours research project will be submitted for marking to the School of Information Engineering and Computer Science. Should any participant wish to withdraw from the project, they may do so until 30th of September 2019, and the data collected up to that point will be destroyed.

If you have any questions or would like to receive further information about the project, please contact me at honesean@myvuw.ac.nz or you may contact my supervisor Dr. Craig Anslow at craig.anslow@ecs.vuw.ac.nz.

If you have any concerns about the ethical conduct of the research, you may contact the Victoria University HEC Convenor: Dr Judith Loveridge. Email hec@vuw.ac.nz or telephone +64-4-463 6028.

Sean Hone

SCHOOL OF ENGINEERING AND COMPUTER SCIENCE
TE KURA MATAI PUKAHA, PUROROHIKO
ROOM CO 358, COTTON BUILDING, VICTORIA UNIVERSITY OF WELLINGTON, GATE 7, KELBURN PARADE, WELLINGTON
PO Box 600, Wellington 6140, New Zealand
Phone +64 4 463 5341 **Email** office@ecs.ac.nz **Website** www.victoria.ac.nz/ecs

Participant Consent Form

Research Project Title: Understanding Climate Change by Visualising Environmental Data

Researcher: Sean Hone, School of Engineering and Computer Science, Victoria University of Wellington

I have been given and have understood an explanation of this research project. I have had an opportunity to ask questions and have them answered to my satisfaction.

I understand that I may withdraw myself (or any information I have provided) from this project, without having to give reasons, by e-mailing honesean@myvuw.ac.nz by the 30th of September 2019.

I understand that any information I provide will be kept confidential to the researcher and their supervisor, the published results will not use my name, and that no opinions will be attributed to me in any way that will identify me.

I understand that the data I provide will not be used for any other purpose or released to others.

I understand that the movement of the mouse and the position of clicks on the screen will be tracked throughout the test.

I understand that the information recorded during the user study will be used to evaluate the product of the research project and submitted in partial fulfilment of the requirements for a Bachelor of Engineering with Honours in Software Engineering.

Signed:

Name of participant:

Date: