GALESS Yearbook 2024

Domain : Life Sources

GALESS CERTIFICATE TILTSHIFT CHALLENGE LIFE SOURCES 2024

for the report and presentation of two topics :

How does the blue economy impact your country ?
Is the blue economy really sustainable with climate change ?

presented to :

Palmer Trinity School

The case study approach successfully utilized team dynamics to create a broad-reaching review of the Blue Economy in the United States. Congratulations on integrating local and geographical familiarity to investigate topics on the broader scale.

Students

Nicole Schachter
Rose Parker
Mariana Mendoza
Daniela Mendoza

Conference Miami, June 2024

Jury Board
Prof. Vladan Babovic
Prof. Wim Uijttewaal
Prof. Sandra Gilchrist

GALESS CERTIFICATE TILTSHIFT CHALLENGE LIFE SOURCES 2024

for the report and presentation of 3 topics:

1. How does the economy of natural resources impact your country?
2. Is the economy of natural resources sustainable with climate change?
3. Elaborate a strategy to avoid shortage of natural resources based on sustainable use. Involve the aspect of international cooperation in your strategy.

presented to :

CEFET

The paper made it possible for us to understand the importance of the gabiroba trees in terms of their use in reforestation, in pharmaceutical use and also popular appreciation and affective memory. The students were well prepared and showed good skills to perform in front of the audience with confidence and fluency in English as well.

Students

Érica Rosa Ferraresi
Matheus de Lima Castro
Silva
Ana Júlia Fernandes Serra

Conference Varginha Brazil, September 2024

Jury Board
Prof. Vladan Babovic
Prof. Wim Uijttewaal
Prof. Sandra Gilchrist

GALESS CERTIFICATE TILTSHIFT CHALLENGE LIFE SOURCES 2024

For the report and presentation of 3 topics:

1. Investigate a waterway in your local or national area,
2. Following extensive research and discussion, propose sustainable solutions and/or strategies relating to your waterways-investigation,
3. Examine a similar waterway in another country based on your key focus researcharea.

presented to :

Camberwell Girls Grammar School

The assessment of the different ways to engage audiences and get people to see the river as a living entity was very strong demonstrating that they had undertaken clear research on the different segments of Melbourne s population. The responses to questions were very good and we were very pleased to see their use of design thinking as the underlying basis to working through their problem.

Students

Angela Liu
Megan Au
Erika Tjangdjaja

Conference Melbourne, October 2024

BOROONDARA GIFTED NETWORK

Jury Board
Prof. Vladan Babovic
Prof. Wim Uijttewaal
Prof. Sandra Gilchrist

2024 - GALESS Yearbook Life Sources

November

The 3rd GALESS Yearbook is a fact. Research reports in the 2024-domain "Life Sources" from 3 conferences in: Miami – the USA, Varginha-Brazil and Melbourne-Australia have been collected in one book and will be promoted in our network, but also to the decision makers in our world. Solid research-work, new ideas with the inspiration of our young generation and important advices are presented to us, and make us realize that we need international cooperation like never before.

It is our mission that tells you that "We bring together young students in a meeting of hearts and minds, plant the seeds of friendship and dialogue, instill in them an awareness of issues facing humanity across continents and empower them towards impactful action within their community"

Just have a look inside and you'll see that our young students do even more : they really are involved into sustainable advice and solutions into the domain Life Sources !

We, as a GALESS team, feel proud to be with you all. And that is a warm feeling and a sign of great respect when we look at your contributions in the past years and the new initiatives that are ahead of us in the upcoming year(s). We address warm feelings in all our GALESS mails to you these days and that is precious from our point of view. Let's make it a community feeling and bring this inspiration to your own communities as well !

Thank you all,

The GALESS Team

GALESS Yearbook 2024 - Content

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The Blue Economy On Young People's Minds in Germany: Awareness, Environmental Perspectives & Policy

by Amelie Kleindienst*, Emina Mujović* and Felix Kapmeier*

*All authors contributed equally to this research

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Summary

The Blue Economy plays a critical role in global economic trade, energy production, recreation, ecosystem health, and climate change mitigation. Actively supporting a sustainable blue economy, which prioritizes the health and longevity of marine resources, has therefore become a global imperative. Although only 9% of the German population live in coastal areas, Germany's impact on the Blue Economy is significant. This includes Hamburg's major shipping port, a thriving fishing and recreational industry, as well as hosting critical energy infrastructure. However, it is unknown how the German population and young people in particular view the Blue Economy. To address this, we conducted a survey of our school community in Stuttgart, Germany. We used the results of this survey to understand youth attitudes and engagement toward protecting the Blue Economy in Germany and beyond. We found that German youth, although mostly unfamiliar with the concept of a Blue Economy, are highly aware and understanding of its vital role in climate change mitigation. Furthermore, we also found that youth engagement in the Blue Economy is impeded by misconceptions that can be explained by cognitive behavioral and construal level theory, which could hinder the Blue Economy from being sufficiently protected unless these misconceptions are addressed. (202 words)

Key words: Blue Economy, German Youth, Climate Change, Environmental Awareness, Sustainability Actions

Main text word count: 4.606

Introduction

The sustainable use of our oceans is crucial in order to help maintain healthy ecosystems for future generations. Recently, the Blue Economy, a concept relating to all activities in marine ecosystems, has captured the attention of environmentalists and policymakers [1], since our oceans, lakes and rivers store carbon dioxide and consequently have a direct impact on atmospheric and ecospheric processes [1].

Since the pertinence of the Blue Economy has enlarged and amplified, a variety of interested stakeholders worldwide are debating about an appropriate definition [2]. A frequently used definition from European Commission states that it includes "all economic activities related to oceans, seas and coasts. It covers a wide range of interlinked, established and emerging sectors" [4]. This definition suggests that for a country like Germany with its marine economic, ecological and social sustainability sectors that extends beyond its sea and coastline, the Blue Economy is prominent.

Since Germany is a member of the European Union, it follows sustainability agreements such as the Paris Agreement and actively promotes sustainability practices on land. However, when it comes to marine ecosystems, there is a lack of support for sustainability campaigns that relate to Germany's Blue Economy. Numerous recommendations from specific organizations such as Marispace-X [5] regarding the Blue Economy, also for Germany, already exist. However, the German government does little to publicly promote and build awareness for sustainability measures for its marine ecosystems [6].

Protecting and promoting a healthy and sustainable Blue Economy is key for tackling climate change and preventing other ecological problems. In Europe, German adolescents have been tied to pro-environmental movements such as Fridays for Future requesting more sustainable practices on land [7]. However, the idea of promoting sustainable practices related the Blue Economy has been missing among the youth's environmental movement.

Therefore, our research paper's motivation is to discover why this lack of awareness exists and how it can be addressed. More specifically, we are focusing on the lack of advocacy of Germany's adolescents on the Blue Economy, since they represent the country's future and are a substantial stakeholder when ecological issues arise. This paper will explore the topics of awareness, environmental perspectives, and policy in relation to the Blue Economy and provide potential solutions for the problems in these fields. We next overview relevant literature and pose research questions that guide our inquiry.

Background and Research Questions

Prior literature offers varying definitions of the Blue Economy which already reveals a gap: some deem the Blue Economy to be "the term of art for identifying those activities that improve the human relationship with the ocean" [10] while other research papers claim that the Blue Economy "originally implied socially equitable and sustainable development but has come to encapsulate international interest in the growth of ocean-based economic development" [11]. Consequently, later literature claims that the "(t)he Blue Economy concept is increasingly being invoked, yet clarity on definitions and implementation step remain vague" [12]. Therefore, we establish that the Blue Economy is a complex subject and these issues of competing definitions have not yet been resolved [13].

A common theme across various research papers is the strong conceptual and practical potential of the Blue Economy. According to Hussain et. al. (2018), the Blue Economy offers "useful solutions and innovations for increasing food security, alleviating poverty, improving nutrition and health, creating jobs, lifting trade and industrial profiles" [14] and Choudhary et. al. (2021) highlight in their paper that the Blue Economy is a powerhouse with enormous marine product value [15]. Thus other literature understands that in general "(t)he blue economy has become synonymous with generating wealth from ocean-related activities while protecting and supporting marine ecosystems" [16]. In addition to economic benefits, ecological opportunities are simultaneously relevant, as the Blue Economy is linked to

mitigating climate change and resolving ecological problems [17].

Unfortunately, the capacity and aptitude of the Blue Economy is often disregarded and neglected by society even though "[s]ustained ocean observations provide an essential input to ocean scientific research. They also support a wide range of societal and economic benefits related to safety [and] operational efficiency" [18]. However, there are "various ways environmental information can be unintentionally left with insufficient attention or purposefully neglected" [19]. For instance "[a]nalyses of public perceptions have indicated that climate change is perceived as distant on a number of dimensions" [20]. Other research papers showcase that "[m]any youth are expressing dissent toward economic, social and environmental policies and practices that contribute to climate change in diverse ways" [21], even though "[s]cientifically accurate knowledge generally increase[s]with age, although misconceptions persist[...] across the age range" [22]. Additionally, when ecologically-driven demonstrations are considered "[r]easons for non-attendance include prioritizing schoolwork and low efficacy in protest or participatory action" [23]. In contrast, other research papers state that the youth participates in sustainability movements and engages with the government [24]. We intend to explore how youth engagement relates to the Blue Economy by dissecting the awareness, misconceptions and the initiation of action of adolescents.

In summary, we conclude that the research papers provide a clear overview of Blue Economy yet little is known about youth awareness, perceptions, and engagement. In our research paper we are going to focus on the mentioned gaps and improve what was not sufficiently covered in the discussed literature. To do so, we seek to answer the following research questions:

- **RQ1a:** To what extent do young people believe that climate change affects the Blue Economy?
- **RQ1b**: How does this belief influence policy support for different marine energy resources?
- **RQ2:** How does psychological distance to the coast influence perceptions and awareness, policy support, and attitudes towards the Blue Economy?
- **RQ3a**: How does the attitude of individuals towards the Blue Economy impact their reported protective actions?
- **RQ3b**: To what extent does the perception of collective behavioral intention affect the degree of action being taken by individuals?

To address these research questions, we conducted a survey of youth in Germany which we discuss in the following section.

Methods of investigation

We fielded a survey of a high school community, the Dillmann-Gymnasium in Stuttgart, Germany to bridge the gap between youth perception, awareness, efficacy and ecological issues within the framework of the Blue Economy. We received written informed consent before participants began our survey. Participants were informed that taking the survey was completely voluntary, anonymous, and could be stopped at any time.

In the introduction of the survey, we assessed participant knowledge about the Blue Economy and provided them with a working definition. Next, the survey questions were organized based on four major conceptual themes that were measured with our survey instrument (See Table 1). These themes were informed by previous literature and our research questions and include lifestyle, politics and energy, tourism and transportation. We also collected sociodemographic information from the participants.

Table 1: Survey content overview and key themes

Survey category	Content
Introduction	• Tested participants knowledge about ***Blue Economy*** • Stated definition of Blue Economy
Lifestyle	• Assessed current ***habits and actions*** of participants with an impact on the Blue Economy ◦ ***Consciousness*** when buying products that either harm or benefit the Blue Economy ◦ Participants mental attitude towards ***climate change*** in relation to the Blue Economy ◦ Willingness of participants to ***adapt their lifestyle*** (individual and societal level)
Politics and energy	• Investigated preferences of participants regarding different types of ***energy generation***, all related to the Blue Economy ◦ Two ***renewable*** energy resources ◦ Two ***fossil fuels*** • Assessed what participants expected from the ***government*** in terms of promoting different energy resources
Tourism	• Investigated participants ***traveling habits*** and the related impact on the Blue Economy ◦ ***Time spent*** in the German and European Blue Economy • Assessed participants ***activities*** when staying in coastal regions
Transportation	• Asked participants about their ***means of travel*** ◦ E.g. airplanes, ships, ferries, etc. • Included statements about ***consumption habits*** ◦ Receiving and sending products overseas
Sociodemographic information	• Personal information like ◦ ***Age, gender, educational qualification, postal code***

The survey included questions with the majority of responses being five-point Likert scales, some binary responses, individual response categories such as choosing between on one or more options, and text-based open-response questions.

After testing the survey with 41 people in the beginning of February 2024, we finalized the survey design at the end of

February. We used the software Qualtrics to create and field the survey. In total we surveyed 243 respondents of which 189 reported being part of the Dillmann-Gymnasium-community (including teachers, students and the students' families). We conducted our survey from February 29 through March 15, 2024. The age of participants ranged from 15 to 62 years, with the majority between 15 and 22 years. At our school we personally visited all classes from grade 10 to 12 to invite the students to participate. We provided iPads that participants could use to complete the survey. On average, it took participants 9 minutes to complete the survey.

In our analysis we applied the full sample. We analyzed our data by using descriptive statistics to gain an understanding of the collected data and answer our research questions. With the help of statistical measures such as median, mode or range, we identified patterns of interest in our data, trends and outliers. To get a better understanding of our data, we created bar charts to visualize data distributions. Using techniques such as bivariate crosstabs and 2x2 comparisons, we explored the relationship between different responses among survey participants. After analyzing the collected data we then used our findings to discuss and answer our research questions, presented in the following section.

Results of Investigation

First, we investigated to what extent people believe that climate change affects the Blue Economy (RQ1a) and how it affects policy support for different marine energy resources (RQ1b). Our data revealed that 98% of participants agree that climate change strongly affects seas and coastal regions (Fig. 1). This suggests that Germany's young people are aware of the consequences of climate change. Similarly, when asked about which energy supply sources governments should support, a strong majority of 83.4% favors renewable energy resources, such as offshore wind and 76.7% favor wave energy generation (Fig. 2-3).

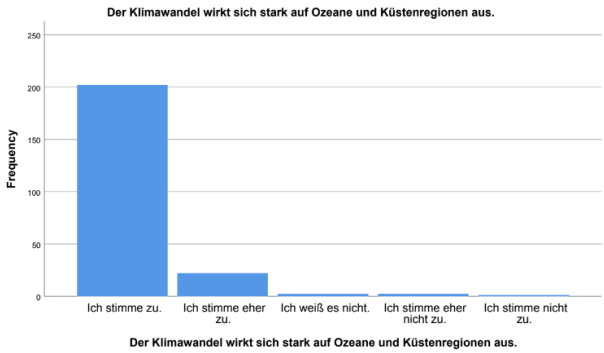

Figure 1: Climate change strongly impacts coastal regions. On a scale ranging from "I agree" (left) to "I disagree" (right).

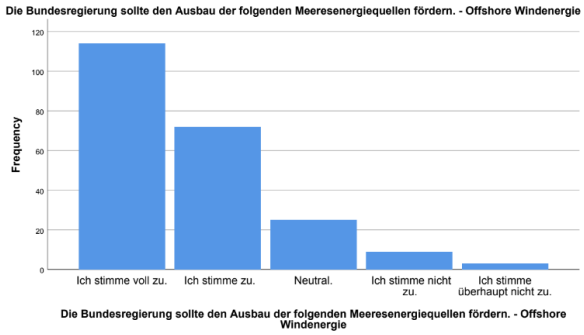

Figure 2: The government should promote offshore wind energy. On a scale from "I agree" (left) to "I do not agree at all" (right).

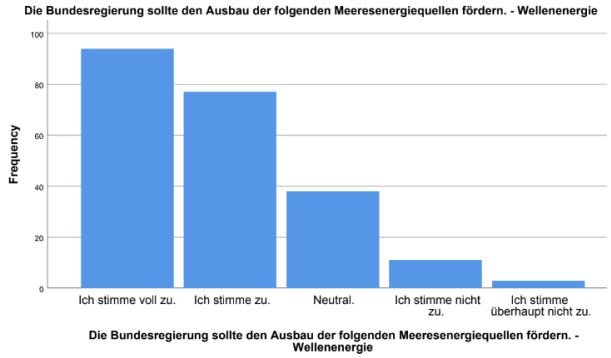

Figure 3: The government should promote wave energy. On a scale ranging from "I agree" (left) to "I do not agree at all" (right).

About half of the participants, 53.1%, would prefer the government to not support fossil fuels, offshore oil mining and about a third, 31.1%, are unsure (Fig. 4). Interestingly, more than a quarter of participants, 26.5%, favor the promotion of fossil-fuel LNG and investments in natural gas infrastructure (Fig. 5). Moreover, 43.9% of participants did not state their opinion on this topic at all (Fig. 5). Only less than a third, 29.6%, are against promoting this fossil fuel (Fig. 5).

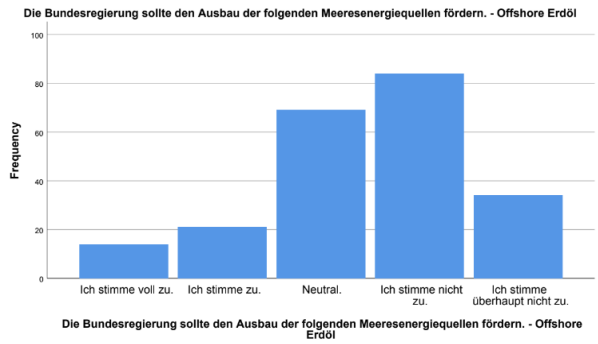

Figure 4: The government should promote offshore crude oil energy. On a scale from "I agree" (left) to "I do not agree at all" (right).

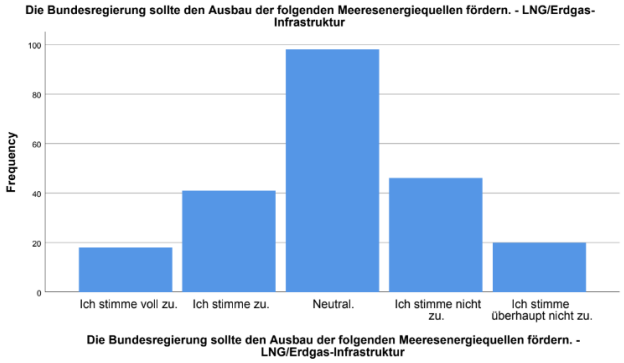

Figure 5: The government should promote LNG and natural gas infrastructure. On a scale ranging from "I agree" (left) to "I do not agree at all" (right).

From our data we were able to deduce that participants with a higher awareness of the Blue Economy are less likely to support fossil-fuel based energy resources. Instead, they suggest the government promotes renewable energy such as offshore wind or wave energy. They also claim to be aware of the importance of the Blue Economy in climate change mitigation.

Looking at our second research question (RQ2), our data revealed that even though the anticipated energy turnaround is related to the Blue Economy, young people in Germany are not aware of the opportunities its Blue Economy offers. The primary questions of our survey revealed a lack of knowledge about the Blue Economy: 89.9% of participants had not heard of the Blue Economy before; yet 37.6% claimed that German coastal areas are of great importance to them (Fig. 6-7).

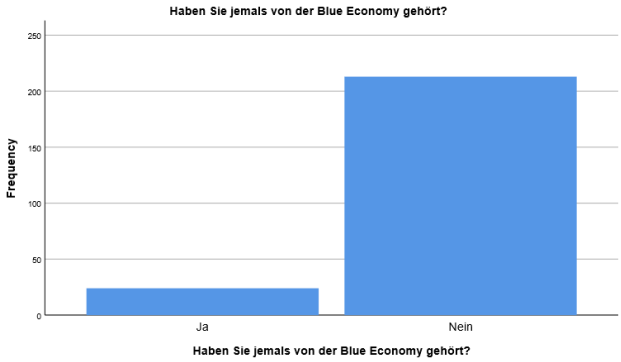

Figure 6: Have you ever heard of the Blue Economy? Responses are "Yes" (left) and "No" (right).

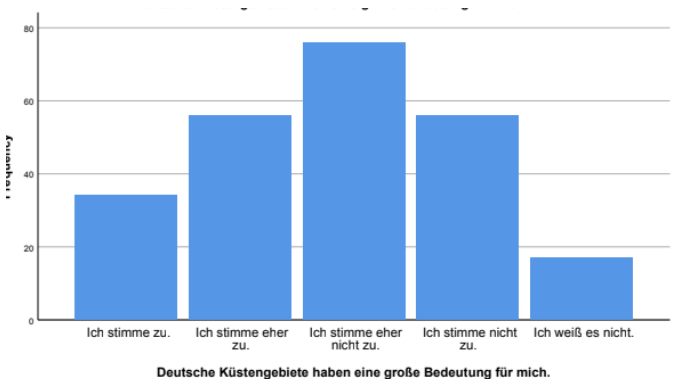

Figure 7: German coastal areas are of great importance to me. On a scale ranging from "I agree" (left) to "I disagree" (right).

The assessment of touristic actions young Germans participate in, revealed a strong trend towards staying by the Mediterranean Sea and therefore not in German coastal areas (Fig. 8). In the survey 67% of participants claim to not visit the North Sea at all while 78.3% have never visited the Baltic Sea (Fig. 9-10).

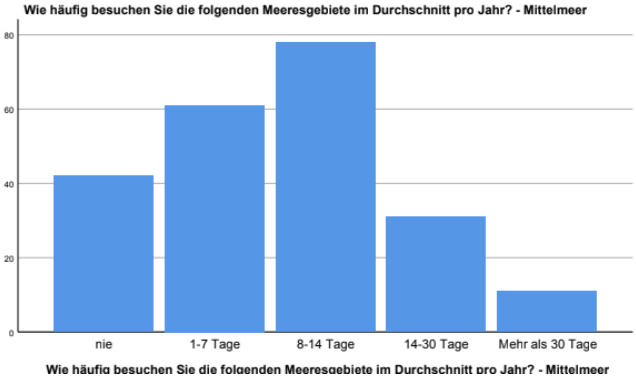

Figure 8: How often do you visit the Mediterranean Sea on average per year? Options from left to right are "Never", "1-7 days", "8-14 days", "14-30 days", "More than 30 days".

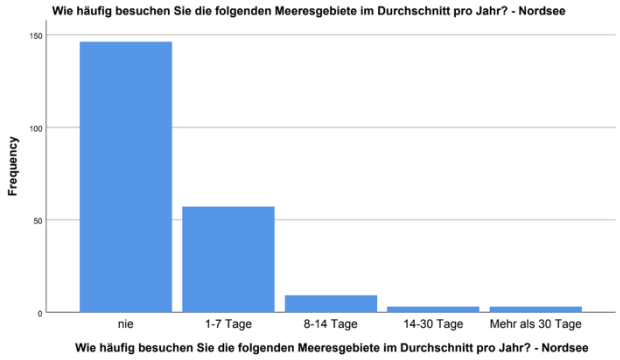

Figure 9: How often do you visit the North Sea on average per year? Options from left to right are "Never", "1-7 days", "8-14 days", "14-30 days", "More than 30 days".

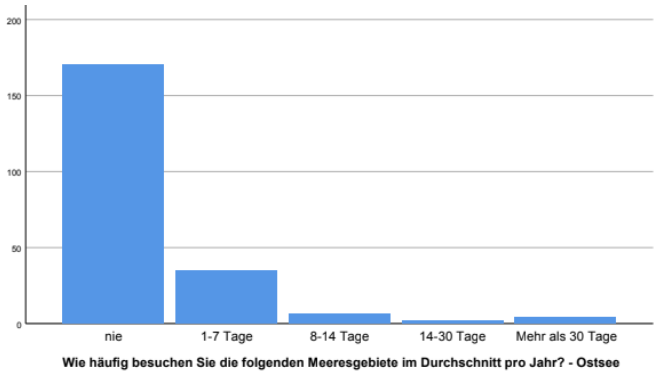

Figure 10: How often do you visit the Baltic Sea on average per year? Options from left to right are "Never", "1-7 days", "8-14 days", "14-30 days", "More than 30 days".

Understanding youth attitudes towards the Blue Economy and how it impacts their reported protective actions (RQ3a) required us to analyze youth perceptions and opinions regarding the Blue Economy.

Our data revealed that although 89.9% of participants claim to have never heard of the Blue Economy before (Fig. 6), 87.7% agree that the Blue Economy is an essential factor in

climate change mitigation (Fig. 11). Half of the participants, 50.6% further claim to have a direct influence on the Blue Economy (Fig. 12).

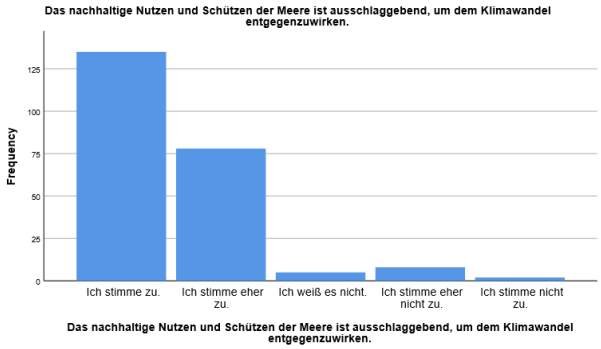

Figure 11: The Blue Economy is a decisive factor in mitigating climate change. On a scale ranging from "I agree" (left) to "I disagree" (right).

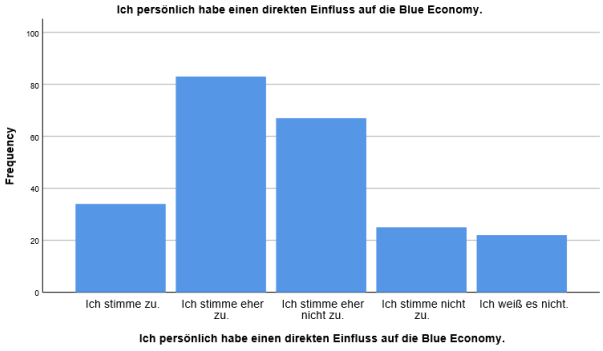

Figure 12: I have a direct influence on the Blue Economy. On a scale ranging from "I agree" (left) to "I disagree" (right).

We primarily focused on the impact these perceptions have on the self-efficacy of participants. To measure self-efficacy, we analyzed how willing participants are to adapt their lifestyle in order to protect the Blue Economy (Fig. 13). We found that 85.9% of the participants who believe the Blue Economy plays an essential role in climate change mitigation are also willing to adapt their lifestyle in order to protect the Blue Economy and therefore report high levels of self-efficacy (Table 2). Even out of the participants that do not believe in the importance of the Blue Economy in terms of climate change mitigation 70% would be willing to adapt their lifestyle and protect the Blue Economy (Table 2).

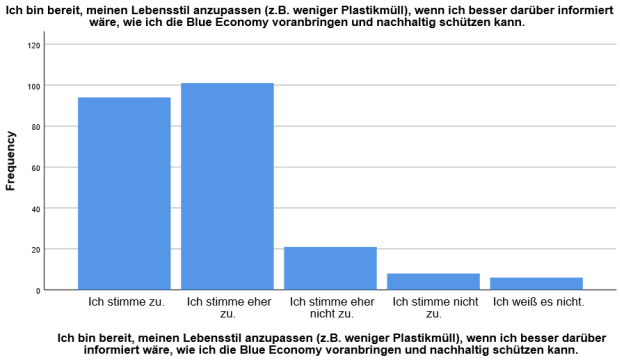

Figure 13: I would be willing to adapt my lifestyle (e.g., consuming less plastic). On a scale ranging from "I agree" (left) to "I disagree" (right).

Table 2: Percentage of participants willing to adapt their lifestyle within percentage of participants that are aware of the Blue Economy's essential role in climate change mitigation.

	awareness: participants that believe the Blue Economy plays an essential role in climate change mitigation	**lack of awareness**: participants that believe the Blue Economy does not play an essential role in climate change mitigation
willingness: participants that are willing to adapt their lifestyle in order to protect the Blue Economy (self-efficacy)	**85.9%**	**70%**
lack of willingness: participants that are not willing to adapt their lifestyle in order to protect the Blue Economy (lack of self-efficacy)	**11.2%**	**30%**

In total, 84.8% of participants claimed to be willing to adapt their lifestyle and take protective action, therefore reporting high self-efficacy (Fig. 13). Yet, the identified behavior of participants contradicts these reported beliefs and the perceived self-efficacy.

Through the use of crosstabs we were able to identify a deviating gap which is also known as the Intention-Behaviour-Gap [30]: Out of the participants who are willing to adapt their lifestyle in order to protect the Blue Economy the majority, 49.5% claimed to not take any protective action towards the Blue Economy (Table 3). This clearly contradicts the initial 84.4% of participants who claim to be willing to change their lifestyle as only half of the participants that report high self-efficacy actually initiate action (Fig. 13; Fig. 14).

Table 3: Percentage of participants that claim to take protective action towards the Blue Economy within percentage of participants willing to adapt their lifestyle.

	high self-efficacy: participants willing to adapt their lifestyle in order to protect the Blue Economy	**low self-efficacy**: participants not willing to adapt their lifestyle in order to protect the Blue Economy
action: participants that claim to take protective action towards the Blue Economy	**42.3%**	**24.1%**
lack of action: participants that claim to not take protective action towards the Blue Economy	**49.5%**	**69%**

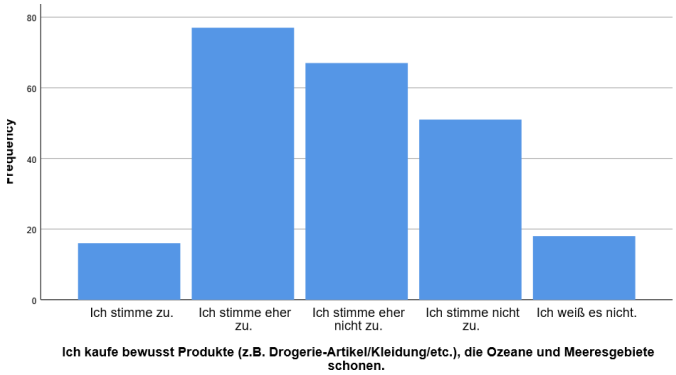

Figure 14: I consciously consume products that protect the ocean. On a scale ranging from "I agree" (left) to "I disagree" (right).

As previously shown, the awareness of participants about the importance of the Blue Economy has a direct impact on perceived self-efficacy (Table 2). Our data however, suggests a further and even more profound impact: We were able to identify a correlation between the awareness of participants and the degree of reported protective action taken by them. Similarly to the previous finding, we identified a gap between the awareness of participants about the Blue Economy and the degree of reported protective action. The majority of aware participants, 50.9% claim to not take any action. Nevertheless, the data clearly shows that twice as many aware participants claim to be taking protective action (41.5%) compared to participants unaware of the importance of the Blue Economy (20%) (Table 4). This clearly suggests a relationship between participants being aware of the importance of the Blue Economy and actually initiating action.

Table 4: Percentage of participants that claim to take protective action towards the Blue Economy within percentage of participants aware of the importance of the Blue Economy.

	awareness: participants that believe the Blue Economy plays a critical role in climate change mitigation	**lack of awareness**: participants that believe the Blue Economy does not play a critical role in climate change mitigation
action: participants that claim to take protective action towards the Blue Economy	**41.5%**	**20%**
lack of action: participants that claim to not take protective action towards the Blue Economy	**50.9%**	**70%**

The reported protective actions included measures like consciously buying products that protect oceans and marine areas (40.6%, Fig. 15), paying attention to whether products are sourced locally or shipped overseas (57.9%, Fig. 16) or consuming food that is labeled (e.g. with the MSC-label) to contribute to the sustainable use of oceans (57.8%, Fig. 17).

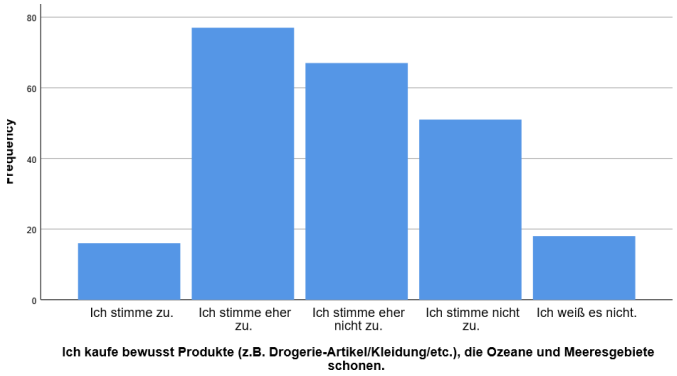

Figure 15: I consciously consume products that protect the ocean. On a scale ranging from "I agree" (left) to "I disagree" (right).

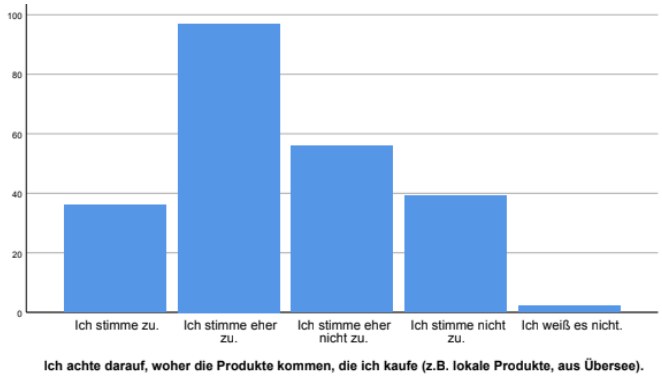

Figure 16: I pay attention to whether products I buy are locally sourced or shipped overseas. On a scale ranging from "I agree" (left) to "I disagree" (right).

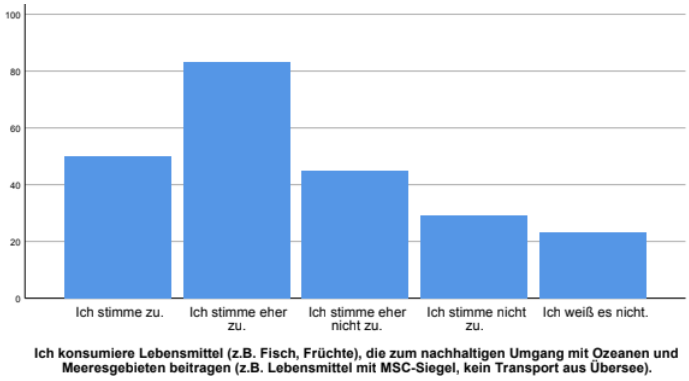

Figure 17: I consume food that is labeled (e.g. with the MSC-label) to contribute to the sustainable use of oceans. On a scale ranging from "I agree" (left) to "I disagree" (right).

After analyzing how the individual attitude impacts reported protective action, we focused on the impact of perceived collective behavioral intention on the degree of action being taken by individuals (RQ3b).

Our data revealed that although 81.8% report high self-efficacy (Fig. 13), only 37% of participants believe that their local community would be willing to adapt their lifestyle as well, therefore reporting low levels of perceived collective efficacy (Fig. 18). The majority of participants who reported high levels of perceived collective efficacy also report high self-efficacy whereas low levels of self-efficacy are related

to low levels of perceived collective efficacy (Table 5). These low levels of perceived collective efficacy clearly contradict the high levels of reported self-efficacy. Consequently, our data suggests a misconception in the perception of self-efficacy and collective efficacy.

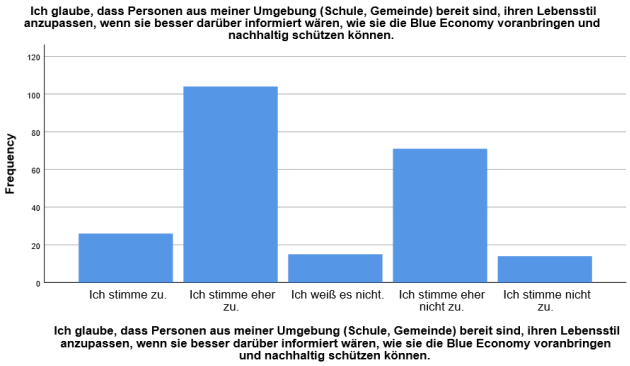

Figure 18: People in my local community would be willing to adapt their lifestyle in order to protect the Blue Economy. On a scale ranging from "I agree" (left) to "I disagree" (right).

Table 5: Percentage of participants that perceive collective efficacy to be high within percentage of participants reporting high levels of self-efficacy.

	high self-efficacy: participants willing to adapt their lifestyle	**low self-efficacy**: participants not willing to adapt their lifestyle
high collective efficacy: participants expect local community to be willing to adapt their lifestyle	**62.6%**	**24.1%**
low collective efficacy: participants expect local community to not be willing to adapt their lifestyle	**30.8%**	**72.4%**

Concluding the data analysis for the two final research questions our data reveals two significant contradictions and gaps: Firstly, the gap between awareness and initiated protective action including the gap between self-efficacy and initiated protective action. Secondly, the difference in perceived self-efficacy and perceived collective efficacy which clearly represents a contradiction. The data suggests a correspondence between both the gaps and the contradiction, and the degree of protective action being taken by young Germans. Potential mechanisms behind this will be discuss in the following section.

Discussion and conclusion

Our findings suggest that awareness of the importance of the Blue Economy can have a profound impact on the attitude, policy support and behavior of individuals. Therefore, returning to our first research question investigating to what extent young people believe that climate change affects the Blue Economy (RQ1a) we found that nearly 98% of participants agree that "climate change is affecting seas and coastal regions strongly" (Fig. 1). This unambiguous distribution of answers suggests that young Germans in our sample are aware of the consequences of climate change. Furthermore, this distribution is also reflected in the statements about energy resources.

The Blue Economy plays an essential role in providing renewable energy sources. There are different approaches to gaining energy out of the marine resources provided by the Blue Economy. With the help of new technology, it is possible to generate energy from waves. These so-called "wave power plants" are currently tested in the North Sea [25]. Another possibility to supply energy in the future is offshore wind energy, although these approaches would only cover a small part of Germany's domestic energy demand.

The German government intends on setting new standards to reach the 'net zero' objective: In 2023, more than half of consumed electricity, almost 52%, were sourced renewably for the first time [26]. In the long run, Germany wants to cover at least 80% of electricity consumption with renewables by 2030 and become climate neutral by 2045. All of these plans were made by the current government, elected by Germans in 2021, who were 18 years or older at that time. A study of Greenpeace showed that 90% of German people aged 15 to 24 support the transition in the energy policy [27]. The young generation is even more willing to rely on renewables and step away from fossil fuels. Therefore, we expected the influence of this belief, that climate change affects the Blue Economy, on policy support for different marine energy resources (RQ1b) to be clear: Participants want the government to promote renewable energy sources like wave or wind energy and no longer support fossil fuels like oil or LNG.

According to our data more than 80% of the participants want the German government to promote offshore wind energy (Fig. 2), around 75% favor the promotion of wave energy (Fig. 3). The promotion of fossil fuels however was significantly less popular: Only approximately 15% of the participants were in favor of the government promoting offshore oil (Fig. 4), around 25% support the promotion of LNG/gas. Interestingly, 41% of participants chose not to give their opinion on the promotion of LNG/gas at all (Fig. 5). This could stem from the possibility of using LNG as a more climate-friendly "bridge" fossil fuel compared to oil. Therefore, it could be used in the energy transition period when renewable energy sources alone are unable to cover global energy demands. The willingness of Germany's youth to rely mostly on renewable energy resources in the future demonstrates their desire for clean energy transition policy.

We have established that young Germans in our sample experiencing the effects of climate change are more aware of the need for climate change mitigation and hence, show more support for climate friendly energy resources. However, people experience the effects of climate change differently, depending on their temporal, physical or social distance to it. Investigating how psychological distance to the coast influences perceptions, awareness, policy support, and attitudes towards the Blue Economy (RQ2) we concluded that: (1) participants who feel psychologically closer to the coast are more likely to engage in activities that support the Blue Economy; (2) Participants who feel psychologically

distant to the coast also feel psychologically distant to climate change and other ecological issues.

These findings are scientifically supported by psychogeography, which was defined by Guy Debord in 1955, as "the study of the precise laws and specific effects of the geographical environment, consciously organized or not, on the emotions and behavior of individuals" [28]. It claims that contact with landscape can change one's attitude towards it, since all senses are involved, we connect legitimately with our environment. Likewise research on construal level theory argues that "people conceptualize things that are psychologically distant from them (in time, space or social distance) more abstractly than things that are psychologically close." [29]. The participants of our community survey have mostly not received the chance to engage with Germany's Blue Economy. Therefore, psychogeography and construal level theory claim that the participants have not formed an emotional attachment and are less likely to be informed about the current issue. This illustrates that attitudes towards climate change emerges from our participants' psychological distance to Germany's coastal areas. It is crucial that visiting German coastal areas should be widely promoted and facilitated, because this could drastically change the attitude of German individuals towards the Blue Economy and its relevance.

The importance of said attitudes becomes especially clear when investigating how the attitude of individuals towards the Blue Economy impacts their reported protective actions (RQ3a). This attitude is the combination of awareness, perceptions and opinions regarding the Blue Economy which ultimately influences self-efficacy and thus, lastly also the degree of action taken by an individual. We found that a positive attitude towards the Blue Economy is strongly related to a high degree of reported protective action. In cognitive behavioral psychology the correlation of attitude and action is explained in the Theory of Reasoned Action [30] which declares that together, attitudes and subjective norms influence one's intentions to perform a behavior, which results in said behavior [31].

As established in our data analysis the majority of participants are not only aware of the importance of the Blue Economy but further demonstrate the intention to take protective action towards the Blue Economy which according to the Theory of Reasoned Action derives from this attitude. Consequently, this could result in all participants, who claim to be willing to take action, actually initiating action. Our data supports the relationship between attitude and intention as 85.9% of participants who claim to be aware of the Blue Economy's importance also report willingness to initiate action. Yet our data shows that although 40% of the participants act in accordance with this theory, the third step in this chain of action does not follow the Theory of Reasoned Action, instead we can identify a gap: The majority of participants, 49.5%, who claim to be willing to adapt their lifestyle do not report initiating any protective action towards a sustainable Blue Economy.

In cognitive behavioral psychology this gap is called the Intention-Action-Gap or Intention-Behavior-Gap. It occurs mostly for two reasons: Firstly, as a direct result of low perceived self-efficacy. The Theory of Self-Efficacy was coined by Albert Bandura and claims that expectations of personal efficacy determine "whether coping behavior will be initiated, how much effort will be expended, and how long it will be sustained in the face of obstacles and aversive experiences" [32]. Concerning the participants of our survey, the data reinforces this as 88.2% of participants who report protective action, also report high self efficacy. Additionally, 69% of participants reporting low levels of self-efficacy also claim to not take any protective action towards protecting the Blue Economy. However, overall 84.8% report high self-efficacy which contradicts the number of only 42% managing to overcome the Intention-Action-Gap, contradicting the theory that the Intention-Action-Gap might stem from low levels of self-efficacy.

Secondly, it can occur as a result of a lack of knowledge about the issue. Although self-efficacy is generally closely linked to the Intention-Behavior-Gap, a lack of knowledge seems to be more likely to cause the Intention-Action-Gap regarding youth engagement toward the Blue Economy, seeing as nearly 90% of participants claim to have never heard of the Blue Economy before. The so-called Knowledge-Action-Gap explains why a lack of knowledge about the Blue Economy in general ultimately leads to a lower degree of action being taken: Understanding the Blue Economy "does not necessarily mean that we know how to solve it or that we can agree on how to implement measures to address it" [33]. Our data revealed that although participants understood the concept of the Blue Economy and mostly agreed that the Blue Economy plays an essential role in climate change mitigation, 90% had never heard of it before.

Although we were able to establish that a lack of knowledge about the Blue Economy significantly impacts reported actions, it represents the individual level only and does not account for any mechanisms or influences on a societal level. Yet, responses from participants where they were asked to presume actions of their peers, or collective efficacy, strongly suggest that there is at least one other societal mechanism also influencing participant's behavior. By adding another dimension to the model and investigating to what extent the perception of collective behavioral intention affects the degree of action being taken by individuals (RQ3b) we gain an understanding of the Intention-Action-Gap and are able to find measures to bridge this gap.

By analyzing our data, we have found that lower levels of youth engagement in the Blue Economy and this concept might occur even more dramatically: Although 81.8% of participants report high self-efficacy, only 37% assess collective efficacy to be high as well. The Theory of Collective Efficacy was created by Albert Bandura describes "a group's shared belief in its conjoint capability to organize and execute the courses of action required to produce given levels of attainment" [34]. Concerning our survey this means that only 27% of participants assume that their local community would be willing to adapt their lifestyle in order to protect the Blue Economy, while all other participants perceive collective efficacy to be low.

The occurrence of this low perception of collective efficacy is scientifically supported by the Third-Person-Effect, primarily articulated by Phillips Davison [35]. It describes how people typically assume the impact of external influences, especially mass communication, on others to be greater than the impact on themselves [36]. Seeing as 89.9% of participants had not heard of the Blue Economy prior to our survey and only very few participants who did, had come across it in the media, participants are likely to come to the following conclusion: If they themselves have not heard of the Blue Economy through mass communication, other people are even less likely to be aware of the topic. This is

also reflected in our data as only 26.7% of participants assumed that people within their local community understand the importance of the Blue Economy which, as previously established, clearly contradicts the 93.4% of participants claiming to understand the importance.

Having investigated where this effect on youth engagement in the Blue Economy might stem from, it is now crucial to discuss how it is ultimately related to fewer actions being taken by individuals. In cognitive behavioral psychology, our findings are supported by the Theory of Planned Behavior which extends the Theory of Reasoned Action by including a third variable that influences the intention of an individual which in turn leads to action. In this extension, intention is also influenced by the extent to which an individual believes they can control the outcome [37]. Since climate change mitigation is a group effort, individuals automatically perceive their control on the outcome to be significantly lower and thereby also perceive collective efficacy to be lower.

Ultimately, the attitude of an individual towards the Blue Economy determines the degree of reported protective action although strongly impaired by a lack of knowledge about the Blue Economy and protective actions which leads to an Intention-Action-Gap, or in other words to less protective action being taken by individuals. On a societal level we found that this gap is furthered by the misperception of collective efficacy because participants believe that people in their local community are unaware of the importance of the Blue Economy and therefore also unwilling to take protective action. As a direct result of this individuals take less protective action perceiving their possible impact on the outcome to be very low.

Participants clearly demonstrate the intention of protecting the Blue Economy, yet only half of intended actions are actually taken. By bridging this Knowledge-Action-Gap we can therefore decrease the gap in sustainable action and youth engagement. The media can play an essential role in bridging the Knowledge-Action-Gap. Through the use of media, perceptions of communal efficacy can be influenced by making individuals aware of the actual collective efficacy which is significantly higher than the presumed efficacy. As laid out in the previous part of our research paper increasing the perceived communal efficacy would ultimately lead to a higher degree of action being taken.

Ultimately, it becomes clear that the responsibility for implementing such measures and bridging the Intention-Action-Gap in order to increase active support for a sustainable Blue Economy lies mostly with the institutional forces of Germany. Effectively increasing youth engagement requires large-scale measures because, although protecting the Blue Economy requires individuals to adapt their lifestyle and take action individually, an increase in such action can only be achieved by encouraging all individuals to take action.

Seeing that our study was limited to the Dillmann high school community and a small group of people outside of it, we can not draw conclusions about Germany or the German youth in general from our survey data. Nevertheless, our findings generally align with previous research and literature. Our research could lay a foundation for future research and policy recommendations, and we suggest similar questions are included on large-scale surveys conducted about Germany's youth engagement in the Blue Economy in the future.

With this research we hope to increase understanding of the mechanisms behind the low degree of protective action being taken by Germany's young people in order to effectively resolve these issues as they hinder the Blue Economy from being protected and supported sufficiently. By raising awareness of the misconceptions and perceptions of Germany's youth regarding the Blue Economy, we hope to contribute to a significantly increased degree of reported protective action in the future and lay a foundation for a sustainable German Blue Economy, which prioritizes the health and longevity of marine resources.

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The Thesis

The Blue Economy significantly contributes to job creation, food security, and economic growth, however in the United States it is not sustainable in the face of climate change. This report explores the urgent need for strategies and policies to ensure the long-term viability of the Blue Economy.

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Summary

This research explores the unprecedented contribution of America's Blue Economy to the nation's overall economic landscape, revealing statistics that underscore its critical role. The study, drawing on recent data, comprehensively evaluates ten sectors operating within oceans, great lakes, and coasts. Key findings indicate that the marine-related gross domestic product experienced remarkable growth of 5.8% from 2017 to 2018, surpassing the overall U.S. domestic product growth [1]. Notably, businesses within the Blue Economy support 2.3 million jobs, emphasizing the profound dependence of the nation on its waters for daily life [2].

The research highlights the sectors making the most substantial contributions, including tourism and recreation, national defense, offshore minerals, and transportation. Furthermore, the study outlines the 2021-2050 plan released by the National Oceanic and Atmospheric Administration to advance America's Blue Economy, aiming to double its value to 3 trillion [3].

The fight against climate change and the sustainability of the blue economy are closely intertwined, and initiatives are being taken to guarantee a resilient and balanced future for our seas and coastal communities. The study also underscores the potential vulnerability of the Blue Economy to climate change, necessitating adaptation strategies to safeguard coastal communities and infrastructure. Finally, the research introduces the concept of the "New Blue Economy," positioning it as a knowledge-based economy that harnesses advances in science and technology to address societal challenges.

Keywords

United States, Tourism, Fishing Sustainability, Renewable energy, Aquaculture

1 Introduction

The blue economy, which includes all economic activities related to oceans, seas, and coastal areas, plays a significant role in shaping the economic and social environment of the United States. With the United State’s extensive coastline and maritime resources, the blue economy has a profound impact on its development, sustainability, and prosperity. The blue economy is expected to double in values to $3 trillion over the next decade. The blue economy touches everyone’s life, because 40% of the U.S. population lives in coastal countries. Blue economy supports 2.3 million jobs and contributes approximately $373 billion to the nation’s gross domestic product through activities such as tourism and recreation, shipping and transportation, commercial and recreational fishing, power generation, research, and related services [2]. In order for the blue economy to

continue to increase, it must respect ecosystem integrity, and that the only secure pathway to long term prosperity is through the development of a circular economy.

Oceans are key economic hubs for trade, transport, and tourism. This has not stopped decades of resource exploitation and the increasing effects of climate change affecting the seas well-being. The risk climate change poses goes beyond increasing temperatures and the sea's economic value is threatened which means a sustainable blue economy must be a priority. Climate change is putting this complex network at risk due to higher ocean temperatures, sea water rising due to melting ice caps, and so much more. Climate change poses challenges to achieving sustainable ocean development and threatens the billions of dollar Blue Economy.

2 Content

2.1 Tourism Sustainability

Tourism is travel for pleasure and the commercial activity for providing and supporting such travel. Tourism in the blue economy highlights the use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystems. Characterized by all economic activities related to oceans, seas, and coasts. In the blue economy tourism sector millions of dollars are brought in every year dominating the United States economy. In coastal towns all over the US jobs are provided, visitors are attracted, and spend money furling local economies. With almost 2.5 million people employed by ocean-based tourism and recreation in the US and workers earning about 66 billion in annual wages[2]. Overall, ocean-based tourism and recreation contributes approximately 143 billion in gross domestic product to the national economy each year[2].

Case Study #1 : Tourism in the Florida Keys

The Florida Keys National Marine Sanctuary plays a crucial role in supporting livelihoods along the coastal areas of Florida by safeguarding resources with significant economic value. Ocean recreation and tourism contribute to over 33,000 jobs in the Florida Keys, constituting 58% of the local economy and generating approximately $2.3 billion in annual sales [4]. During the 2007-2008 tourist season, recreational fishing attracted 400,000 participants who spent $274 million, while recreational diving and snorkeling drew 739,000 participants who spent $54 million, supporting 7,500 jobs [4]. However, scientists warn that Florida's reefs have suffered a staggering loss, with 98% of coral gone, leaving less than 2% of the original coral cover intact [4]. This decline poses a dire threat to ecosystems that are major tourist attractions, as reefs support over 25% of marine life and provide crucial shoreline protection against natural disasters [4]. Climate change-induced phenomena such as temperature-related coral bleaching and ocean acidification, coupled with water pollution and overfishing, further exacerbate the decline of coral health and resilience. Despite these challenges, coral reefs contribute significantly to the state economy, generating $8 billion and supporting over 70,000 local jobs, with additional benefits

including $600 million in infrastructure and over $75 million to the Florida Keys annually [4]. To address these issues, reforms like the Restoring Resilience Reef Act have been proposed, aiming to establish coral protection measures and strategies for management and restoration, with bipartisan support from lawmakers in Hawaii and Florida.

The Florida Keys National Marine Sanctuary (NMS) is one of only thirteen nationally-designated marine sanctuaries in the United States. However, the health of Florida Keys NMS is at risk, with the loss of coral, seagrass, and mangrove ecosystems. As well as, threats of nutrient pollution and harmful algal blooms, along with marine debris including lost fishing traps, vessel groundings and anchor injuries to seagrasses and corals. And finally intense storms and increasing ocean acidification all threaten the environment and the economy that the sanctuary supports.

Figure 1. Extent of Florida Keys National Marine Sanctuary

This creates the need to protect and restore the Florida keys fragile habitats in order for a healthy economy and obtain a balance between visiting and living in south florida/Keys with the demands placed on natural resources vital to the lives and incomes of many Floridians. Protected areas like the Florida Keys NMS are more than a vacation destination but a source of consistent economic output, jobs, and wages to many industries and people. Understanding their value and how resources of Florida Keys NMS supports a strong economy will help obtain management of the sanctuary and budget decisions that may impact the health of the environment and economy.

The analysis, based on 2015 data and impacts, highlights how spending on tourism and recreation, largely fueled by resources within and surrounding the Florida Keys NMS, contributes significantly to the creation of jobs, wages, and additions to the gross domestic product (GDP) throughout the state of Florida.

Florida Keys Economic Contributions:

Florida Keys NMS Contributions to Jobs and GDP ($2015)

	Employment	Labor Income $(000)	Value Added $(000)	Economic Output $(000)
Monroe County	34,583	1,363,502	2,402,471	3,879,632
Southern Urban Adjacent	1,353	74,723	122,649	214,011
Southern West Coast	161	9,912	20,249	41,885
Other Regions Together	249	12,615	24,956	53,928
Total Effect – FLORIDA	**38,111**	**1,460,753**	**2,570,325**	**4,189,456**

Figure 2. FKNMS contributions to Jobs and GDP[4]

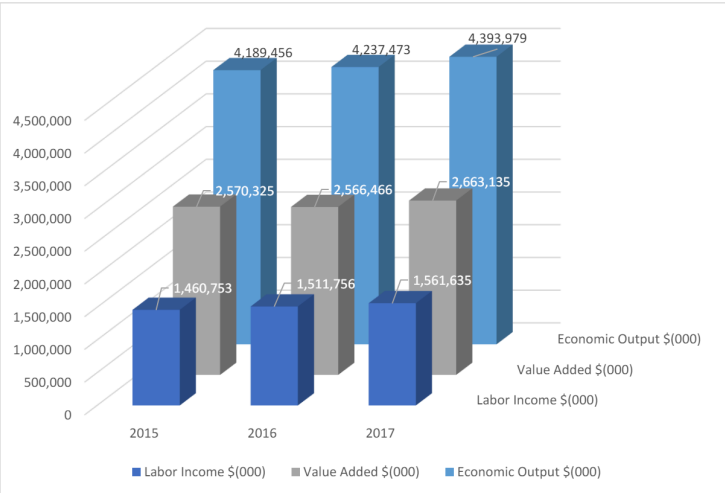

Figure 3. FKNMS Economic Contribution to Florida by Year ($2015)

[4]

Case Study #2 : Red Tide Impact on Tourism in Florida

The 2018 Florida red tide bloom inflicted staggering losses on coastal tourism, amounting to approximately $2.7 billion, highlighting the necessity of recognizing harmful algal blooms (HABs) as potential billion-dollar disasters[5]. With significant economic repercussions observed in both Southwest and Southeast Florida, where losses reached $1.27 billion and $1.35 billion, the red tide event serves as a reminder of the profound economic implications associated with environmental phenomena like red tide[5]. Red tide is a marine event characterized by the rapid proliferation of protists such as algae, resulting in extensive blooms over a 2–3 week period, during which each algal cell can produce up to one million daughter cells. The bloom's destructive effects include mass fish and marine life mortality, which leads to widespread beach closures. Even at lower levels, red tide demonstrates its capacity to cause significant economic harm, making it necessary for the public to acknowledge its substantial economic consequences.

2.2 Fishing Sustainability

Apart from providing food and 945,500 jobs, fishing in the U.S. brings in billions. The U.S. fishing industry's market size is worth about 9.6 billion dollars as of 2022. [6] However, this has decreased by over 1 billion dollars since 2022 when its market size amounted to 10.91 billion dollars. [6] This is due to not being able to sustain fisheries with climate change. Climate change creates an insufficiency of stability for this wealthy sector. Things such as fossil fuels increase carbon dioxide, it causes the water to be warmer and more acidic. This puts many species' health at risk and changes necessary migration patterns. For example, plankton are vital to the ocean as they not only recycle materials in the food chain but they also produce a lot of oxygen. [7] However, they are in great danger with climate change because it reduces carbonate which makes it hard for their shells to form. [7] Climate change puts this huge industry at risk.

Case Study #3 : Snook in South Florida

Due to climate change, the atmosphere has an increased concentration of greenhouse gasses which traps energy from the sun. [8] This leads to the ocean getting warmer which negatively impacts the fishing industry. For example, south Florida is home to the snook, a fish that is significant both economically and recreationally. [8] A study on snook's poleward expansion shows the snook's introduction into the northern Gulf of Mexico may have an impact on the ecology of the food web and the interactions between estuarine predators and their habitat. [8] They did this in the Suwannee River estuary, where monthly standardized stratified-random sampling was carried out from 1997 to 2018. They were also recording ocean temperatures regularly. They found that Increasing temperatures in the Gulf of Mexico have been linked to the northward expansion of a wide range of species. [8] Many other species have been able to spread into and endure in the northernmost regions of the Gulf due to the absence of severe frosts [8].

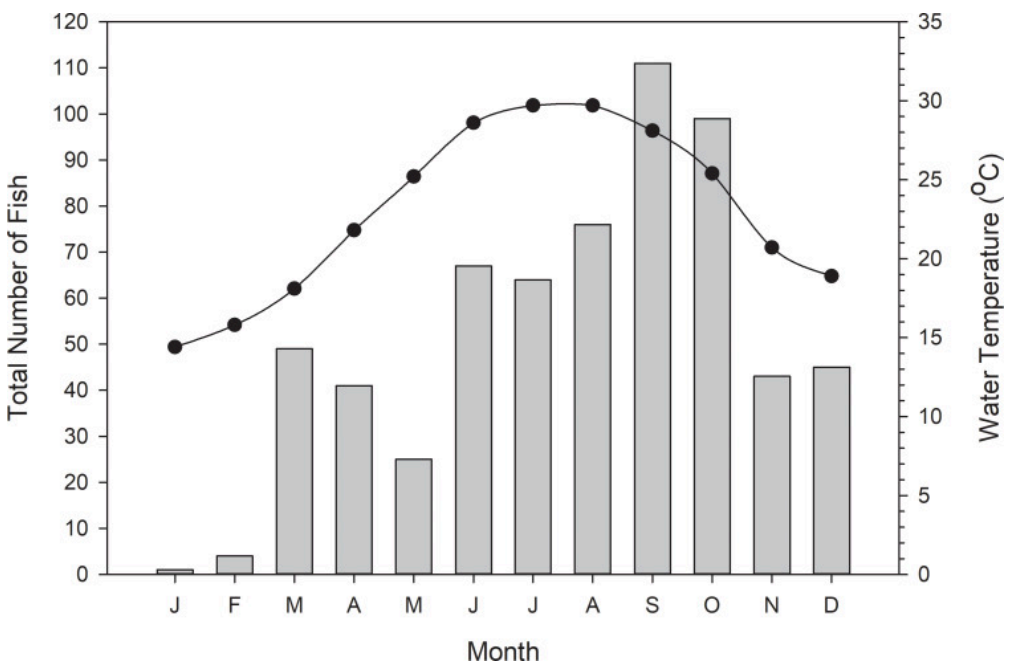

Figure 4. Combined monthly catches (1997–2018) of snook collected in the Suwannee River estuary, Florida, with all sampling gear combined.

Case Study #4 : Lobster Fishery in Maine

Lobsters play a very important role in Maine's economy as they attract millions of tourists each year, employ 3,000 lobstermen, and contribute $339 million to Maine's economy. [9] However, since the year 2000, the Gulf of Maine's rising sea temperatures have posed a growing threat to the lobster population. In a 2019 case study, they looked into the adaptive potential of fisheries threatened by fast changing climate conditions. [9] Maine lobster fishermen were interviewed to find out how they felt about the consequences of global warming on lobsters and whether they thought that lobster farming needed to change. [9] They found that the perspective of lobster fishermen on fisheries modifications was influenced by shifts in the environment. Over the course of their fishing careers, lobster fishermen have identified 39 species whose numbers have declined; eight of these species have declined as a result of warming waters. [9]

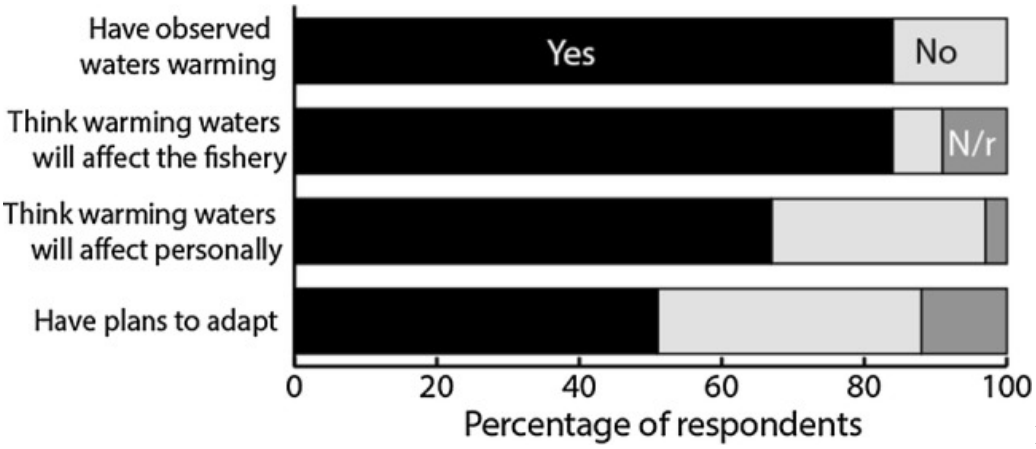

Figure 5. Warming waters' perceived effects on the lobster fishery.

2.3 Renewable Energy Sustainability

The sustainability of the blue economy in spite of climate change depends on various factors, including renewable energy. While renewable energy offers significant potential to reduce climate change impacts, its implementation within the blue economy must be carefully managed to ensure long term sustainability. Renewable energy projects such as offshore wind farms and tidal power installations can contribute to reducing greenhouse gas emissions and transitioning away from fossil fuels, aligning with the goals of the blue economy. However, there is so much research before these projects can be implemented in the United States. Wind farms are still in the early stages of development and tidal power installations requiring further technological advancements for practical use. As a result, there's potential for significant growth in renewable energy infrastructure in the United States, offering opportunities to strengthen the country's commitment to sustainability and the blue economy. These developments of renewable energy can also pose challenges to marine ecosystems,

including habitat disruption, wildlife disturbance, and potential impacts on marine biodiversity. Therefore, the sustainability of the blue economy with renewable energy relies on effective planning.

Case Study #5 : Future of Offshore Wind Energy

Offshore wind energy holds hope for the United States in transitioning towards a clean energy future. Heather Doty indicates that significant progress has been made in the development of offshore wind farms, with projects such as the Vineyard Wind 1 and South Fork Wind Farm underway[10]. In the chart below, you can see certain aspects of Vineyard Wind 1. It is evident that building a wind farm is not as easy as it may seem. The expense and length of the process shows how it is not accessible all over the United States.

Size	800 - megawatt
Construction began	November 18, 2021
Construction cost	2.5 billion dollars
Distance from Shore	15 miles

Figure 6. Factors of Vineyard Wind 1 [10]

However, there are plans for future expansion. Government initiatives like the Inflation Reduction Act and the Bipartisan Infrastructure Law have provided crucial resources to support this growth, facilitating investments in ports, vessels, supply chains, and transmission infrastructure [11]. However, despite these advancements, challenges remain in implementing renewable energy on a sustainable scale. The offshore wind industry in the United States is still in its early days [11]. While there are goals and strategies in place to accelerate its growth, there is a notable gap between current progress and the necessary scale to achieve a carbon-free power grid. Despite the promising trajectory outlined, the pace of development may not be sufficient to meet the urgent need for decarbonization.

Thirdly, the future of Renewable energy outlined in NOAA's five year strategic plan, underscores a pivotal shift toward sustainability [12]. Offshore wind projects play a crucial role in the nation's energy transition from fossil fuels to renewable and sustainable sources. This shift not only reduces reliance on finite resources but also mitigates the environmental impacts associated with traditional energy extraction and consumption. The promotion of cleaner energy production is essential in the blue economy's initiatives directly addressing the pressing need to battle climate change. By decreasing carbon emissions, a primary driver of global climate change, these efforts contribute to broader mitigation strategies.

Case Study #6 : Future of Wave Energy

Wave energy has the potential to be sustainable, as waves are continuously generated by wind patterns across the Earth's oceans. Unlike fossil fuels, which are finite and contribute to climate change when burned, wave energy is renewable and does not produce greenhouse gas emissions during power generation. In this sense, it aligns well with efforts of the Blue Economy . However, the reliability of wave energy technology has been a

challenge. Wave energy converters are complex machines that must withstand harsh ocean conditions, which lead to many mechanical failures. Factors such as corrosion, fouling by marine organisms, and extreme weather events can all contribute to the unreliability of wave energy devices. Additionally, the wave patterns variability in different locations makes it challenging to design WECs that are universally effective. Furthermore, the development and deployment of wave energy technology have been slower compared to other renewable energy sources like wind and solar. This slower progress is due to the technical challenges associated with capturing and converting wave energy efficiently.

Dave Levitan published at the Yale School of the Environment talks about the various designs of wave energy converters, ranging from buoy based systems to devices submerged on the ocean floor [13]. This diversity reflects the complexity of capturing wave energy effectively. The mass of designs indicates that no single technology has an optimal solution, leading to ongoing uncertainty and experimentation within this industry. Operating in the ocean presents unique challenges, all of which can affect the reliability of wave energy devices. The research notes that wave energy technology is decades behind wind and solar power in terms of development and reliability [13]. The lack of an efficient design contributes to the uncertainty surrounding the technology's viability. Like any emerging technology, wave energy faces significant cost barriers. Limited funding and lack of large-scale commercial deployments hinder progress. The article mentions that wave energy projects primarily rely on small amounts of government funding and lack substantial investment from major companies[13]. Without significant financial backing, the industry struggles to advance beyond small-scale projects.

Overall, while wave energy holds promise as a renewable energy source, the challenges outlined in the article underscore why it is not yet sustainable. The lack of a proven, reliable technology, combined with high costs and technical complexities, impedes its widespread adoption and integration into the energy mix. Until these barriers are overcome through continued research, investment, and technological innovation, wave energy will remain a nascent and uncertain sector of the renewable energy landscape.

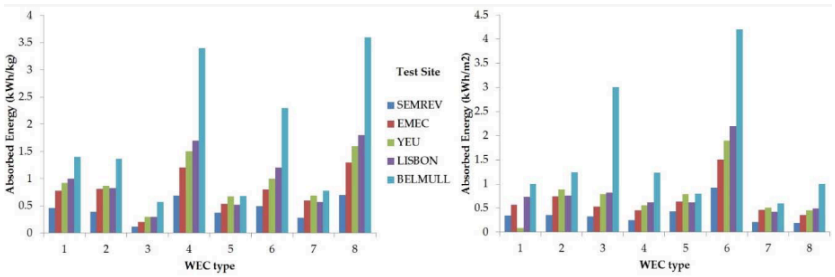

Figure 7. Energy produced by each WEC type [13]

The comparison provides insights into the efficiency of each WEC type in converting wave energy into usable power. This analysis aims to establish the performance of WECs and identify optimal designs for various wave energy potential regions in the United States. The future of WEC is huge, but there is plenty of time before it will be able to be used in the United States.

2.4 Aquaculture

Regarding American Aquaculture, the ocean is the final food Frontier. With many options , seafood can be farmed or wild caught but now with threats to ocean health and sustainability the aquaculture sector is

growing faster than any other major food sector in production has increased in volume and value since 2009 [14]. Aquaculture is any farmed aquatic species. Reports on saltwater farms replacing natural systems offshore are demonstrated as a way to supply the nation with a resource-efficient protein option while not putting additional stress on wild stocks. At the moment, the US has aquaculture thriving in state managed waters but it is in open debate whether it should and how to expand to federal waters. This could be an investment opportunity for a new offshore industry.

In recent years, the aquaculture industry in the United States has shown remarkable growth. For instance, the value of domestic marine aquaculture sales increased by an average of 2.3 percent per year from 2014 to 2019 [15]. Marine aquaculture accounts for 7 percent of total domestic seafood production by weight, amounting to approximately 658 million pounds[15]. Despite this progress, the United States currently ranks 18th worldwide in aquaculture productions, with a value of around $1.5 billion[15]. This places a considerable strain on the nation's seafood trade deficit, which reached 17 billion dollars in 2020[15]. Therefore, there;s a compelling argument for expanding domestic aquaculture to reduce reliance on imports.

Case Study #7 : Aquaculture in Alaska

Alaska's blue economy includes both mariculture and wild caught seafood. With the seafood industry expanding to include farmed seaweed and shellfish. Alaskas mariculture has made it a goal of establishing a 100 million dollar industry sustainable mariculture in 20 years as the region is a perfect place for mariculture. Currently with a team of 60 and they are enacting policies to accomplish such a goal [14].

Alaska's hatcheries play a large role in producing hatchery-born, ocean-raised, wild salmon, benefiting all user groups in the state while bolstering Alaska's economic presence in markets beyond its borders. It was established to supplement rather than replace wild stock production; these hatcheries have contributed significantly to Alaska's salmon harvests.As seen, in 2013, 2015, and 2017, three of the four highest wild stock returns in history were recorded, dating back to the late 1800s [14]. This sustainable salmon run is proof of Alaska's commitment to innovative aquaculture, which started in the 1970s as a response to low salmon abundance[14]. As of 2022, Alaska supports 30 operational hatcheries, with 11 owned by the state, 15 by the Pacific Northwest Power Supply (PNPS), and several non-PNPS hatcheries. In 2022 , around 43.3 million adult hatchery salmon returned to Alaska's waters, with pink and chum salmon leading the returns, followed by sockeye, coho, and Chinook salmon[14]. The hatchery fishery's contributions amounted to an estimated ex vessel value of $163 million, accounting for 23% of the statewide commercial harvest ex vessel value[14].

Figure 8 Alaska salmon hatchery

Figure 9 Alaska salmon offspring

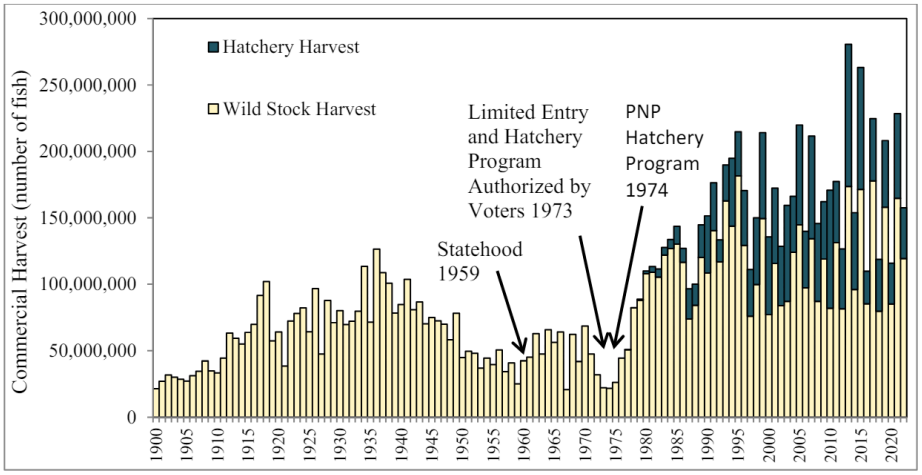

Figure 10 Commercial salmon harvest in Alaska 1922-2020 [14]

3 Conclusion

The investigation into the sustainability of America's Blue Economy amidst climate change underscores both its critical importance and its vulnerability. The Blue Economy not only significantly contributes to the nation's economic prosperity but also supports millions of jobs and sustains coastal communities across various sectors such as tourism, fishing, renewable energy, and aquaculture. Industries across the United States in the Florida Keys, Maine, and Alaska all rely on the wellness of our oceans to support their booming blue economy. However, the looming threat of climate change poses challenges, including rising ocean temperatures, sea level

rise, ocean acidification, and extreme weather events, all of which jeopardize the future viability of the Blue Economy.

The call to action to ensure the sustainability of the Blue Economy is crucial. It necessitates a multifaceted approach that integrates conservation efforts, policy reforms, and technological innovations. One key aspect of this approach involves promoting sustainable practices in industries such as tourism and fishing, which are vital components of the Blue Economy. Initiatives aimed at protecting fragile ecosystems to restore coral reefs and mitigate the impacts of harmful algal blooms are essential to safeguarding both the environment and the economic prosperity from devastating ocean events like the red tide.

Moreover, the transition towards renewable energy sources, such as offshore wind and wave energy, presents opportunities to reduce greenhouse gas emissions and mitigate climate change while simultaneously supporting the growth of the Blue Economy. However, careful planning and investment are required to ensure that renewable energy projects are implemented sustainably, minimizing potential impacts on marine ecosystems and coastal communities.

Furthermore, the expansion of aquaculture in states like Alaska presents opportunities and challenges for the Blue Economy. Sustainable practices, coupled with responsible management policies, can enhance food security and economic growth while alleviating pressure on wild fish stocks to achieve successful aquaculture industry across the US to replace the unsustainable practices as a result of fishing. However, it is essential to strike a balance between aquaculture expansion and environmental conservation to prevent negative ecological impacts.

The sustainability of America's Blue Economy hinges on collaborative efforts from government, industry, and civil society to address the complex challenges posed by climate change. By prioritizing conservation, innovation, and responsible management practices, we can ensure the resilience and prosperity of our oceans, coasts, and the communities that depend on them for generations to come. And if sustainable practices are achieved, America's Blue economy is expected to double in value to 3 trillion over the next decade.

Acknowledgements

Thank you to Dr. Llinas for guiding us through our research and formulating our paper. Thank you to Ms. Calleja and Mrs. Truby for giving us this opportunity to learn about the blue economy and research it extensively. Through Dr. Llinas' guidance we were able to extend our knowledge and participate in an enriching 5 month research on a topic we all have great interest in.

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The Impact of Climate Change on the Sustainability of Singapore's Blue Economy

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Word count: 5500

Summary

Singapore, as an island nation, has become increasingly vulnerable to climate change-induced phenomena, particularly sea level rise. It has seen great success in coastal protection with the reclamation of Marina Bay and construction of the Marina Barrage. Singapore has pioneered efforts in aquaculture to strive towards food security and sustainability. As a major hub for international maritime trade, oil refining and marine bunkering, Singapore is optimally positioned to spearhead the decarbonisation of the maritime sector. To this end, it has established significant frameworks to work towards the adoption of alternative fuels. Our research seeks to examine the driving factors behind the success of the Marina Bay reclamation project and propose it as a model for providing coastal protection whilst creating land for economic and recreational activities. We also explore aquaculture as a solution to food insecurity within the context of climate change. To transition the maritime sector towards a sustainable state, and thus foster its long-term development, the decarbonisation of maritime fuels and port operations is crucial. We will evaluate these processes and discuss how they could additionally facilitate the decarbonisation of Singapore's energy grid. In doing so, our research approaches the blue economy from the fundamental lenses of coastal protection, food security and maritime shipping, with an emphasis on Singapore's role in these aspects.

Keywords

Singapore, marine decarbonisation, aquaculture, coastal development

1 - Introduction

Singapore's position within the Blue Economy is a unique one as an island nation, it is becoming increasingly threatened by rising sea levels. Singapore is a major player in maritime shipping and is a node for maritime trade routes passing through Southeast Asia. Singapore has also taken steps to develop and make use of its limited land area, and to protect its coasts. Singapore's shortage of domestic food sources has also necessitated the importing of a vast majority of its food since independence; aquaculture is a nascent area to counteract this major flaw in Singapore's food security.

1.1 - Research Questions

1. How does the blue economy impact Singapore from a maritime trade and decarbonisation point of view?
2. Is Singapore's blue economy really sustainable with climate change using an aquaculture and Greater Southern Waterfront strategy?

2. – The Greater Southern Waterfront

2.1 - Background

The Marina Bay area is the primary financial and business district of Singapore. The 360-hectare coastal area is a culmination of 55 years of reclamation works. It has been envisioned by the Urban Redevelopment Authority as a vibrant place for recreation and work [1]. Consequently, it features some of the country's most iconic buildings, along with luxury retail shops, high-end apartments, five-star hotels, and offices. Recently, new projects such as the Gardens by the Bay and the Marina Barrage have complemented its area development, with the Marina Barrage being notable for its contributions to Singapore's coastal defence, water security and creating areas for recreation and learning.

2.2 - The Marina Bay Area

Land reclamation works began in 1969 [2], with the aim of integrating the district as part of the existing Central Business District (CBD), seamlessly creating a new, expanded downtown [3]. This area has included numerous large-scale projects contributing significantly to Singapore's tourism sector; notably, the icon of the Marina Bay skyline – the Marina Bay Sands, an Integrated Resort offering a casino, entertainment facilities, and various other amenities [4].

The Marina Bay Sands has been a financial success, bringing in USD 859 million in revenue in Q1 2024 [5]. Further expansion of the project is expected, with plans for a fourth tower consisting of a 15,000-seat entertainment arena and 587 new hotel rooms [6]. Events are commonly held in the Marina Bay area, such as the annual F1 night race, which has brought about 550,000 international visitors and SGD 2 billion in tourism receipts since its inception [7].

In line with the Singaporean government's tourism efforts and vision of creating a "City in a Garden", Gardens by the Bay was completed and fully opened in 2014 [8]. The project consists of 3 waterfront gardens and has become a popular tourist attraction, with the park welcoming its 100 millionth visitor in December 2023 [9]. Furthermore, the park is entirety built on reclaimed land, serving as a testament to the efficacy of Singapore's land reclamation projects [10].

2.3 The Marina Barrage

The Marina Barrage is an effective engineering solution for coastal defence and meeting Singapore's water supply needs. Moreover, it is multipurpose, incorporating public recreational areas and frequently hosting extracurricular learning experiences for Singaporean students on water security [11]. In line with sustainability efforts, the Marina Barrage features a solar park with over 400 solar panels, which makes it one of the largest collections of solar panels in Singapore, providing electricity needed for the lighting of the barrage [12].

The Marina Barrage is vital in its role of coastal defence. Due to climate change, Singapore will experience increasingly extreme and unpredictable weather. The Marina Barrage addresses this by alleviating flooding in low-lying areas, a persistent issue given the country's high annual precipitation. It is designed to be capable of handling large storm discharges through 7 powerful water pumps with a total pumping capacity of 280 m^3/s and nine hydraulically operated "fish-belly" crest gates [13]. Under typical circumstances, the crest gates remain closed to isolate the reservoir from the ocean. This changes during extreme storm events. When the tide is low, these gates will open to release excess water from the marina. When the tide is high, the pumping station and its seven vertical shaft drainage pumps will activate. Therefore, the barrage and pumping station will coordinate to manage storm flows and tide levels [14]. This stable water level, coupled with the Marina Reservoir's freshwater, ensures that the Marina Reservoir is ideal for recreational activities such as boating and sailing.

The Marina Barrage contributes to Singapore's water security. As a densely populated island nation, Singapore has been working towards being self-sufficient in its supply of water. This is a challenging goal as Singapore lacks natural water sources. However, as a tropical nation, Singapore experiences heavy rainfall year-round. The construction of the Marina Barrage has resulted in the formation of the freshwater Marina Reservoir, which collects rainwater which is then treated to form potable water [15]. The Marina Reservoir is Singapore's largest water catchment, at 10,000 hectares. It provides sufficient water to meet 10% of Singapore's needs, greatly contributing to Singapore's water security [16].

The Marina Barrage also serves as a recreational area for the public. It is integrated with nearby parks and features a large open-air green space on its rooftop. This rooftop is popular for recreational activities, being commonly used for flying kites or picnics. Over the past decade, 15 million people have visited the Marina Barrage for tourism, picnics, water sports and other activities [17].

The Marina Barrage serves as a potential case study for multipurpose coastal defence and water management infrastructure. Its careful planning and construction have ensured that its completion not only helps to achieve the practical goals of mitigating flooding and providing a source of freshwater through the Marina Reservoir, but also provides commonly used recreational spaces that are enjoyed by the public and tourists alike. This holistic and innovative approach sets a clear example for countries who seek to make their blue economy more sustainable, in light of growing populations and climate change.

3 - Maritime trade and decarbonisation

3.1 - Background of the Port of Singapore

Singapore has been an established hub for trade and seaport in Southeast Asia ever since its prototypical mentions in recorded history [18-20], and has adopted an entrepôt, transshipping, and value-adding role in the modern day [21], which is facilitated by market access provided by the World Trade Organization and Singapore's signing of 27 free trade agreements [22-23].

In the modern day, Port of Singapore is the world's busiest container transshipment port (ship arrival tonnage of 2.83 billion gross tonnage in 2022 [24]) and largest bunkering hub (supplying ~50 million tonnes of marine bunker fuel to ships along international maritime trade routes in 2021 [25-27]).

3.2 Adoption of Alternative Fuels

Our research into Singapore's role in the Blue Economy vis-à-vis the MSI revolves around the adoption of Alternative Fuels (AFs), which have lower GHG emissions than current fossil bunker fuels, such as heavy fuel oil.

51.3% of ships currently on order utilise alternative fuels, though this is disproportionately comprised of Liquified Natural Gas (LNG), at 40.3%, and methanol, at 8.01% [28]. While this augurs well for the MSI's willingness and readiness to switch away from conventional, pollutive fuels and adopt AFs, it should be noted that LNG is nevertheless a fossil fuel and emits substantial amounts of GHG when utilised as a bunkering fuel [29-30].

The adoption of AFs face several challenges, which are major impediments to the large-scale decarbonisation of the MSI. Current and expected alternative fuels are less energy intensive than fossil fuels, thus requiring more frequent bunkering and increasing concomitant costs of operation [31].

There is a high level of uncertainty around the adoption of AFs. Further investment of $8-28 billion annually is required to decarbonise the world's shipping fleet by 2050, and $28-90 billion annually to develop infrastructure for carbon neutral fuels by 2050. In addition, more expensive alternative fuels could cost 70-100% more than existing fossil fuels [32]. Shipowners and shipping companies remain sceptical of the development and provision of current alternative fuels, including the prevalence of bunkering infrastructure along major shipping lanes. Decarbonising shipping would increase maritime logistics by up to 0.08%, which approximates to $104 trillion annually and could cost $80 billion in losses globally by 2050 [33]. Furthermore, decarbonisation may cause disparate impacts on different countries: less developed economies or economies that are heavily reliant on maritime transport — such as Singapore — are disproportionately affected by increases in maritime logistics costs. As such,

decarbonisation must be carried out in an equitable manner to avoid hindrances to specific players within the MSI [34].

3.3.1 - Decarbonisation efforts within the Singapore Maritime Shipping Industry

In line with its emergent role as a hub for green shipping, Singapore has adopted several key decarbonisation efforts to reduce the environmental impact of its MSI, and to ready it to leverage future decarbonisation trends and efforts.

3.3.1.1 - The Maritime Singapore Green Initiative

The Maritime Singapore Green Initiative was launched in 2011 and is currently extended till 2024 [35]. It consists of the Green Ship Programme, Green Port Programme, Green Energy and Technology Programme and Green Awareness Programme. These programmes currently operate through the provisions of incentives to shipowners and operators that voluntarily adopt climate-friendly policies and are concretised through the MPA's thrust for greener maritime trade operations [36].

The Green Ship Programme fundamentally aims to incentivise ship owners to exceed environmental regulatory standards set by the International Maritime Organization (IMO). It provides incentives to Singapore-flagged ships that meet any 1 of the following criteria [37-38]:

1. Exceeding the IMO's MARPOL 73/78 (MARPOL) Annex VI Phase 3 EEDI requirements by ≥10%.
2. Adopting engines capable of utilising alternative fuels that produce equal or less greenhouse gas than LNG, noting (bio)-LNG, (bio)-methanol and (bio)-ethanol as examples.
3. Adopting engines capable of utilising zero-carbon fuels.

The Green Ship Programme is a good catalyst of investment and research into MSI decarbonisation policies, utilising incentives such as reductions in Initial Registration Fees and Annual Tonnage Taxes enforced by the MPA. However, as the Green Ship Programme currently does not effect wide-ranging action throughout the maritime shipping industry, the MPA could look into making the programme's requirements mandatory for ships calling at the Port of Singapore, thus ensuring greater compliance amongst shipowners seeking to utilise Singapore's port facilities.

The Green Port Programme also provides incentives for vessels calling at the Port of Singapore, and differs from the Green Ship Programme in that its incentives take the form of reductions in port fees to ship operators, and also utilises different criteria to award incentives [39]. It provides a 30% reduction in port dues for vessels that use zero carbon fuel [40]. It provides a 20% reduction in port dues for vessels that use low carbon fuel or whose Energy Efficient Design Index reduction exceeds the IMO's MARPOL Annex VI Phase 3 Energy Efficient Design Index requirements by ≥10% [41]. It also provides a 5-year waiver of craft port dues for low or zero carbon fuelled harbour craft [42].

Despite its demonstrated and internationally-recognised success [43, 44], it is clear that the MSGI is not fully utilised to incentivise ship owners and operators to decarbonise their operations, and carries significant potential for future development. It could better utilise its "existing" programmes and modify its incentive-based approach to a punitive one if MSI decarbonisation were to become a more urgent priority, thus placing pressure on the MSI to adopt climate-friendly policies.

3.3.1.2 - Singapore's First Mover Advantage

Cognisant of the nascent nature of AF adoption and the development of AF-compatible infrastructure within the global MSI, Singapore is able to leverage its status as a global MSI hub and sizeable entrepôt in oil refining [45], strategically target this gap in the adoption of alternative fuels, notably in production and distribution, and gain a first mover advantage in doing so [46].

Singapore, through its National Hydrogen Strategy, has committed to adopting ammonia as a bunkering fuel due to its projected success [47-49], notably by the Det Norske Veritas's Maritime Forecast (2022) and the International Energy Agency's Global Hydrogen Review (2021). It, through the MPA, has taken major steps to establish Singapore's first or early mover advantage in the MSI's adoption of AFs, including accelerating research & development into ammonia as an AF, accelerating ammonia's deployment, increased investment and safety regulations, and establishing various international platforms, among others [50]. The MPA and PSA International have taken additional steps to realise the adoption of AFs in Singapore's port operations. The MPA has begun transitioning domestic harbour crafts towards electric and net zero fuels, has committed to achieving net zero carbon emission by 2050 and has partnered with Pacific Island Lines to trial a blend of biofuel on its shipping line between Singapore and Qinzhou [51].

Singapore bunker sales in 2022 included~140000 tonnes of biofuel blends and 16000 tonnes in LNG [52]. Overall, Singapore has demonstrated a strong willingness to take significant steps to research and develop AF infrastructure and adoption mechanisms in the Singapore MSI, and thus leverage a first mover advantage in AF adoption.

3.3.1.3 - Benefits to Singapore's Energy Grid

Singapore's electricity is nearly-exclusively generated by natural gas, which hinders its progress towards reducing its GHG emissions. However, the decarbonisation of the MSI presents an opportunity for Singapore to adopt an AF for generating electricity — surplus bunkering fuels (such as Hydrogen) can be re-directed instead into generating electricity for the local energy grid, thus decreasing demand for fossil fuels in electricity generation. The aforementioned

National Hydrogen Strategy expedites research into hydrogen technologies to decarbonise Singapore's energy grid, and the MPA and Energy Market Authority of Singapore launched a call for Expressions of Interest for companies to build, own and operate facilities to provide low/zero carbon bunkering and energy production [53-60]. This allows Singapore to contribute to strengthening alternative fuels provisions while also benefiting from the supply chain for alternative fuels (such as ammonia) that can be used to decarbonise Singapore's energy grid, thus allowing for a more adroit mix of fuels for energy generation and decreased GHG emissions overall.

4 - Aquaculture

4.1 – Background

In light of climate change and rampant overfishing, global fish stocks are being depleted at alarming rates [61]. Between 1974 and 2017, the percentage of fish stocks being fished at unsustainable levels rose from 10% to 34%[62]. The aquaculture industry is a possible solution to meet the rising demand for aquatic products, with capture fisheries becoming increasingly unsustainable. According to the NOAA, the term "aquaculture" refers to the cultivation of aquatic organisms in a controlled environment for any commercial, recreational, or public purpose, which includes the production of food for human consumption.

Presently, aquaculture is experiencing widespread adoption in many countries worldwide, becoming one of the fastest-growing food sectors in the world. World aquaculture has grown rapidly from a production of less than one million tonnes in the early 1950s to 48.1 million tonnes in 2005, with an average annual growth of 8.8% [63]. Several advances in aquaculture have driven this growth over the past few decades, such as improvements in breeding, nutrition, and disease management, which significantly increased productivity and efficiency [64]. Consumer demand for aquaculture is also rising and is estimated to reach 62% of the total global production by 2030, further driving investment in aquaculture [65].

In Singapore, aquaculture is being swiftly embraced to enhance its food security. As a land-scarce nation with limited capacity for food production, Singapore imports over 90% of its food [66]. Aquaculture plays a crucial role in the country's plan to meet 30% of its nutritional needs locally by 2030. The Singapore Aquaculture plan aims to achieve this through:

1. Investing in research and innovation for aquaculture
2. Increasing and optimising spaces for aquaculture
3. Helping the industry adopt technology and better farm practices

4.2 Benefits of Aquaculture

A substantial amount of wild fish stocks has been overexploited due to the increasing demand for seafood worldwide. By 2050, global seafood consumption is forecast to double across all seafood categories [67]. However, current levels of seafood production are already putting a significant strain on the world's fishery resources. The FAO states that the percentage of stocks fished at biologically unsustainable levels increased from 10% in 1974, to 35.4% in 2019. Major fishing areas such as the Southeast Pacific had 66.7% of stocks fished at unsustainable levels [68]. Overexploited fish stocks may eventually deplete, causing irreversible harm to the ocean ecosystem. Aquaculture can alleviate this pressure by providing an alternative source of seafood, and allowing overfished species to recover and repopulate. Furthermore, aquaculture is crucial in meeting the rapidly growing demand for seafood in the future, which cannot be supported by capture fisheries.

Year-round aquaculture is possible in indoor systems where aquatic animals are produced under controlled conditions, which offers a consistent and reliable supply of seafood throughout the year. On the other hand, capture fisheries are subject to seasonal variations and other factors. Seasonal losses have challenged capture fisheries, making it difficult for them to maintain production, and for consumers to obtain quality fish year-round [69].

Aquaculture is thus able to meet the year-round consumer demand for seafood, stabilising food prices and availability. This also contributes to global food security by diversifying the world's sources of seafood. The director-general of FAO stated that "while capture fisheries will remain relevant, aquaculture has already demonstrated its crucial role in global food security, with its production growing at 7.5% per year since 1970" [70-77]. In countries with a lack of arable land to support commercial farming, high-intensity aquaculture systems can supplement local food production and increase food security.

4.3 Potential of Aquaculture in Singapore

The Singapore government is making tremendous efforts to promote local food production through scaling up aquaculture. As of today, the aquaculture industry is small but significant, contributing to 10% of local food-fish consumption in 2018 [78]. Singapore's aquaculture comes mainly in open-systems, with 110 small-scale sea-based fish farms using traditional floating net cages. However, challenges including higher ocean temperatures and lower oxygen levels induced by climate change can affect open-system aquaculture, and global conflicts have significantly increased costs for fish farmers. Furthermore, farms will soon have to pay for the use of sea spaces, with those in the Straits of Johor having to pay $3600/half hectare [79]. This also comes as Singapore's sea becomes increasingly crowded for purposes including maritime, infrastructure, and utilities.

The Agri-Food and Veterinary Authority of Singapore (AVA) is the main statutory board overseeing local aquaculture production. It plays a central role in helping fish farmers improve their technologies and yields. In 2009, $8.2 million was awarded to fish farmers to improve their production and engage in R&D efforts with local institutions [80]. A $63 million fund was launched to

subsidise up to 70% of fish farmers' investments in technology [81]. By continuing to invest in aquaculture, its practices and technology can continually be refined, increasing its yield and allowing it to become more economically sustainable. To combat changing conditions caused by climate change, farms in Singapore have been fitted with high-tech equipment, including monitoring systems which sound alerts when oxygen levels are low, initiating aerators to ensure adequate oxygen. This improves the environmental conditions for the fish and increases yield.

There are other aquaculture systems that Singapore can invest in, to address some of the challenges faced by open-system aquaculture. Aquaponics and Land-Based Recirculating aquaculture systems (RAS) are land-based farms, of which Singapore currently has 22. With land-based aquaculture, environmental conditions can be controlled and are no longer subject to the ocean and climate change. Land-based farms also frees up Singapore's crowded sea space.

Aquaponics is a combination of aquaculture and hydroponics, where fish and plants are grown together in a closed-loop and self-sustaining system. Aquaponics is feasible due to its high efficiency and resource recycling from combining fish farming with plant cultivation. In the context of Singapore, where land space for large farms is limited, aquaculture can be integrated into many urban settings, including the rooftops of residential buildings. This has been demonstrated, with an aquaponics farm being installed in Fairmont and Swissotel's rooftops, producing 1200kg of vegetables and 350kg of fish monthly [82]. However, being a small-scale operation, aquaponics would not have much production capacity as compared to a traditional setup.

RAS allows for intensive tank culture on land and has been one of the aims of investment and development of aquaculture in Singapore [83]. it has similar benefits to aquaponics, being a closed-system where environmental conditions can be precisely monitored and controlled. RAS is also suitable for countries or cities like Singapore with limited space for aquaculture, as it is intensive, and can be integrated into a vertical system. Apollo Aquaculture Group currently has an RAS in Lim Chu Kang with three stories, each holding two 135m^2 ponds [84]. This system has cultured Asian seabass, hybrid groupers, and shrimps successfully [85].

Finally, Singapore is well positioned to serve as an R&D and educational hub for aquaculture. With active government support in its research and development, Singapore contributes to many innovations and advancements regarding aquaculture. As a country with strong infrastructure and technological capabilities, research and implementation of advanced systems and technologies in aquaculture is possible. Aquaculture development is also accelerating rapidly in Southeast-Asia [86]. Being in close proximity to major aquaculture markets, Singapore can easily collaborate and exchange knowledge and technology with neighbouring countries, anchoring itself as a hub for aquaculture which contributes to global food security and sustainable aquaculture practices.

5 - Methodology

We conducted an online survey, targeted towards youths our age, on their views of aquaculture and the GSW. We received 23 valid responses, of which 17 were from junior college or pre-university equivalent students, and 5 were secondary school students. We focussed our response-gathering on peers and students around our age group, cognisant of the salience of this demographic group's perception of the usefulness of the GSW for their learning and Singapore's future development.

5.1 - Respondents' perceptions of Aquaculture

We delved into our respondents' understanding and perception of aquaculture, as shown in Fig. 1. Overall, respondents tended to be less familiar with aquaculture, with only 6 (26.1%) of respondents stating that they were "not familiar at all" with aquaculture, and none stating that they were "very familiar" with it.

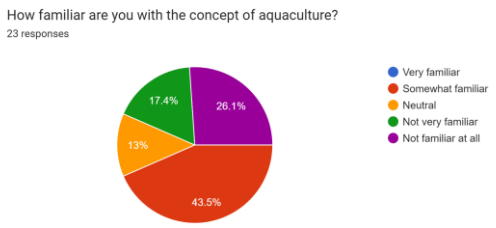

Figure 1: Respondents' familiarity with aquaculture

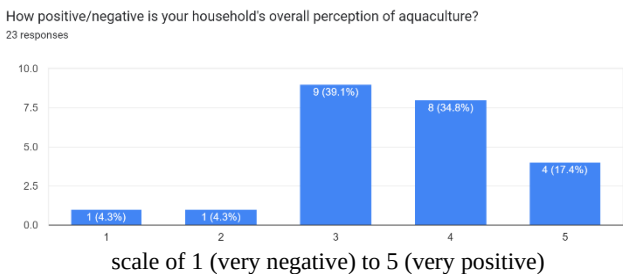

Figure 2: Respondents' perceptions of aquaculture.

Nevertheless, respondents indicated that their households tended to view aquaculture positively, with 16 (52.2%) indicating that their perceptions of aquaculture were somewhat or very positive, and only 2 (8.6%) indicating the opposite, as shown in Fig. 2.

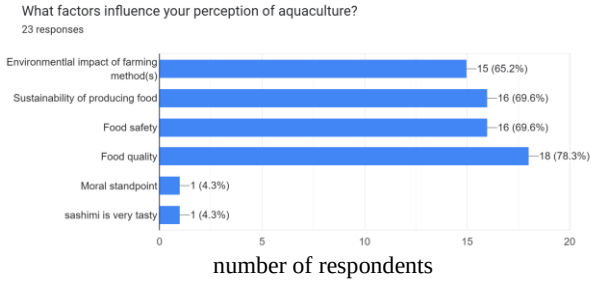

Figure 3: Factors influencing respondents' perception of aquaculture.

Regarding factors influencing the perception of aquaculture, practical considerations were the most common amongst respondents. Specifically, food quality was a consideration for 78.3% of respondents (18 individuals) while food safety was a concern for 69.6% of respondents (16 individuals), as shown in Fig. 3. Additional factors were also responsible for consumers' decisions, with sustainability of production being an aspect of decision-making for 69.6% of respondents (16 individuals) while environmental impact of farming method(s) being a similarly common consideration for 65.2% of respondents (15 individuals).

In examining the frequency of aquaculture produce purchases amongst respondents, the largest group of respondents, 39.1% (9 individuals), indicated that they were unsure, as shown in Fig. 4. This data suggests a potential lack of consideration for the source or farming methods of seafood among Singaporean consumers. In general, the purchase of aquaculture produce tends to be uncommon, with 30.4% (7 individuals) reporting they bought it a few times a month, while 13% (3 individuals) indicated they never purchased such products.

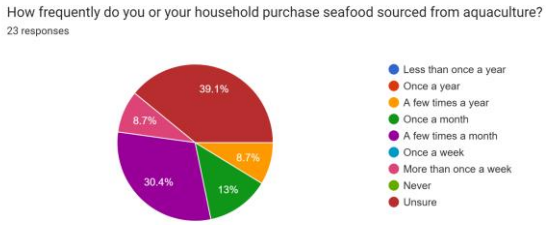

Figure 4: Frequency of respondents' purchases of aquaculture-produced seafood.

In the survey of the preferences for aquaculture versus natural produce as shown in Fig. 5, most respondents, comprising 52.2% of respondents (12 individuals), indicated no preference for either option. Nevertheless, 34.8% of respondents (8 individuals) preferred wild-caught seafood, while 13% of respondents (3 individuals) preferred farmed fish.

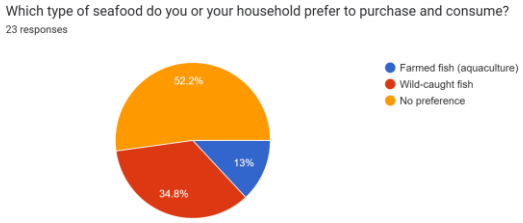

Figure 5: Respondents' preferred seafood purchase type based on production method.

Surveying factors accounting the preference for aquaculture versus natural produce, practical considerations were once again prevalent. According to Fig. 6, food quality was a critical factor for 91.3% of respondents (21 individuals), making it the most significant consideration. Moreover, food safety and cost were significant for 73.9% of participants (17 individuals), indicating that it is also an important factor in consumers' decision-making. Additional considerations were much less prevalent among respondents. Ethical concerns influenced 21.7% of respondents (5 individuals), while the sustainability of farming methods was a factor for 34.8% of respondents (8 individuals).

Even though consumers' perceptions of aquaculture are shaped by broader considerations like sustainability, their personal decisions are ultimately undergirded by practical concerns. Hence, further expansion of the aquaculture industry must cater to consumers' practical concerns.

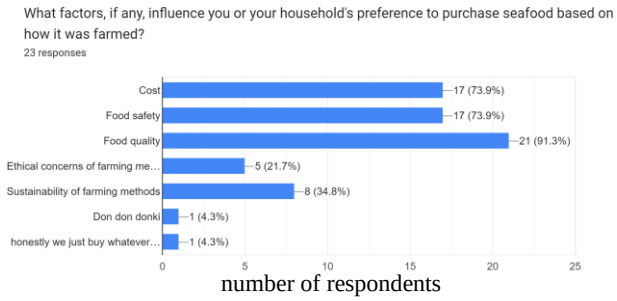

Figure 6: Factors influencing respondents' preferences to purchase seafood based on farming methods.

In the study on perceptions of aquaculture regarding food security and self-sufficiency, a broad majority of respondents believed that aquaculture would enhance these aspects. Specifically, 30.4% (7 individuals) strongly agreed with this statement, while 52.2% (12 individuals) agreed, as shown in Fig. 7.

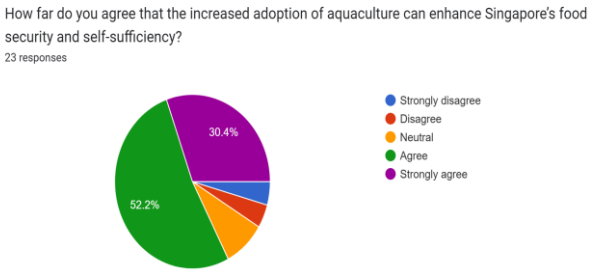

Figure 7: Perception of aquaculture vis-à-vis Singapore's food security and self-sufficiency.

Participants highlighted several advantages of aquaculture in favour of this belief, including increased efficiency of production leading to lower costs, and reduced reliance on international imports for food. Additionally, sustainable food production and logistical simplification for the seafood supply chain were noted. They pointed out that aquaculture could diversify sources of food and decrease land use, suggesting awareness of the practical concerns facing food security in Singapore.

However, concerns were also raised. Logistical constraints and potential land scarcity were mentioned as challenges. Moreover, unsuitable conditions for aquaculture might necessitate continued reliance on food imports for Singapore. However, these were not viewed as primary obstacles to the growth of aquaculture, nor were they strongly related to the core benefits perceived by the majority.

In the study on perceptions of aquaculture in relation to climate change, as shown in Fig. 8, a broad majority of respondents expressed agreement with the positive impact of aquaculture. Specifically, 17.4% (4 individuals) strongly agreed, and 60.9% (14 individuals) agreed. Notably, no respondents disagreed or strongly disagreed.

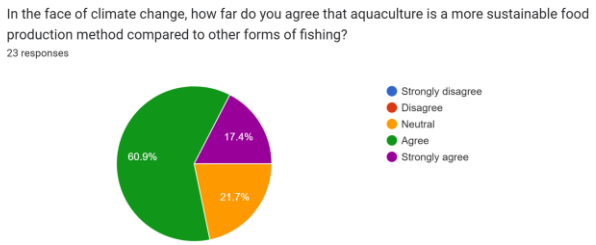

Figure 8: Perception of aquaculture vis-à-vis Singapore's climate change and sustainability goals.

Supporters of aquaculture highlighted several advantages, such as its role in mitigating the need for harmful fishing tactics and overfishing. Aquaculture was seen as a more sustainable and environmentally friendly alternative that does not affect wild ecosystems. Additionally, it was noted that aquaculture results in lower greenhouse gas emissions and relieves pressure on already-depleting fish stocks. The concept of a circular economy was also mentioned as a benefit. However, some concerns were acknowledged, primarily the more energy-intensive nature of aquaculture in the short-term. Despite this, the overall perception remained positive regarding its potential to combat climate change.

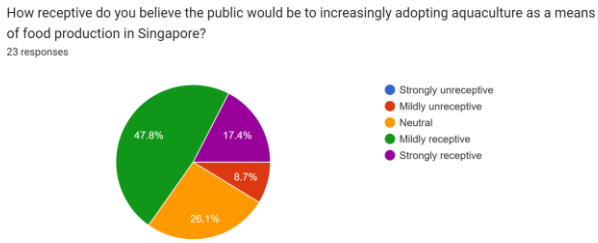

Figure 9: Respondents' views of public perception towards aquaculture.

In the study on perceptions of public reception of aquaculture, a broad majority of respondents believed that the public would be receptive. Specifically as shown in Fig. 9, 17.4% (4 individuals) felt the public would be strongly receptive, 47.8% (11 individuals) believed they would be mildly receptive, and no respondents felt the public would be strongly unreceptive, an indication that public sentiment towards aquaculture is mostly positive.

Supporters cited that consumers primarily base their purchasing decisions on cost and convenience, which could favour aquaculture products. Additionally, the promotion of aquaculture by Singaporean media and the absence of significant negative stigma around aquaculture were seen as positive factors.

However, several concerns were noted, including preconceived notions that farmed fish are inferior, a perception that overseas and wild seafood is of better or higher quality, and concerns about the quality and taste of aquaculture products. Furthermore, there was a general sense that people either do not care or lack awareness about aquaculture, indicating a need for more education and outreach.

5.2 - Respondents' Perceptions of the Greater Southern Waterfront in Singapore

According to Fig. 10, most respondents, comprising 69.6% (16 individuals), expressed the belief that visiting the GSW would be beneficial for students. There were multiple reasons cited for this positive perception. Respondents highlighted the educational opportunities found in the GSW. Students can learn about topics such as Singapore's land use, sustainability efforts and government planning, gaining valuable beyond-classroom insights.

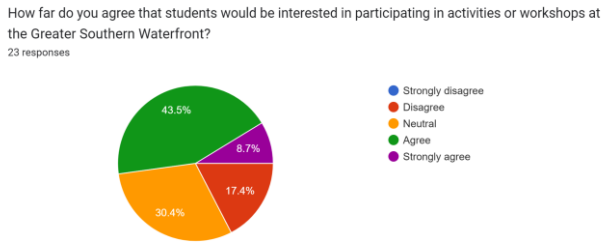

Figure 10: Respondents' perceptions of students' interests in participating in GSW-held activities.

Some concerns were raised regarding the significance of learning from GSW visits and students' interest. Despite these concerns, the perception remained largely positive, with 52.2% (12 individuals) agreeing or strongly agreeing that such visits would be beneficial, and none strongly disagreeing

Respondents suggested integrating GSW visits into the school curriculum, with a focus on sustainability education and workshops. Respondents expressed interest in exploring aspects of the GSW, such as the integration of residential and mixed-use development.

One respondent noted the importance of understanding the planning process and the specific considerations and data collection methods employed by key players in the construction of the GSW. This, they suggested, could help students see the practical applications of what they learn in humanities classrooms.

However, several challenges were identified. Some respondents pointed out potential time and logistical constraints in planning meaningful LJs. The distance to the GSW was also mentioned as a possible challenge. One respondent expressed uncertainty about the extent to which students could gain insights from the GSW if it is still under development and might not yet showcase the intended outcomes.

A majority of respondents (78.2%, 18 respondents) believed that the GSW would benefit Singapore, citing reasons such as increased environmental and marine life conservation, integration of nature into urban housing, strengthened coastal defences, and economic benefits through infrastructure development for offices, commercial activities, and tourism. These benefits were seen as long-term, contributing to better land use and providing more space for housing. Additionally, the GSW was viewed as a potential educational and tourism destination, setting a precedent for future coastal developments.

6 – Limitations

Due to the short timeframe of our research, we encountered multiple challenges during our data collection process. Thus, our research suffers from potential limitations. Notably, our survey has a small sample size (n=23). Relying on a small sample size could have resulted in false conclusions due to inaccurate inferences made from unreliable data collected. Our small sample size may not have provided us with sufficient information to detect differences between groups, potentially causing type II error in our conclusion. This is further compounded by the limited population demographics surveyed, with our survey comprising almost entirely of teenage Singaporean students (95.7%). Data collected is only representative of the student population in Singapore through a perspective study and may not be generalisable to other Singaporean demographics or demographics in other countries.

7 - Conclusion

Singapore, as an island nation, provides both challenges and opportunities within the blue economy. Its status as a maritime trade hub allows it to serve as a stepping stone for the utilisation of sustainable fuels in maritime trade globally. Addressing its food security concerns, Singapore's advancements in aquaculture are pivotal, offering a model that can be emulated worldwide to combat the depletion of fish stocks and ensure the sustainability of the seafood industry. Furthermore, as a low-lying nation vulnerable to sea level rise, Singapore's comprehensive coastal defence strategies, exemplified by the Marina Bay area, demonstrate how integrated approaches in coastal defence not only supports local economic sectors but also provides recreational benefits. Singapore's initiatives in the blue economy underscore the importance of strategic planning and innovation in achieving sustainability and resilience of the blue economy in the face of climate change challenges.

Acknowledgements

We would like to thank our teacher-mentor, Dr. Tan Guoxian, for his invaluable guidance and patience throughout our research journey.

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Gabiroba Trees: from environmental and biotechnological applications to affective memories recall

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Brazil has a significant percentage of the planet's biodiversity and diverse biomes. Brazil has six biomes: Amazon, Atlantic Forest, Caatinga, Cerrado (Brazilian Savannas), Pantanal, and Pampa. Due to the country's dimensions and climates, these biomes occupy a specific geographic space. The biggest biome in Brazil is Cerrado. As we do not have infinite labor nor unlimited time to analyze in detail the diversity of a place, it is impossible to know all the richness of species. Therefore, it is common to select groups of flora and fauna as indicators of events in a given area of interest. The biodiversity study is usually carried out by cataloging the species found locally. It is an initial way to know them, the ecological niche in which species need to receive greater attention, both for research and conservation action, environmental management, or monitoring. In this research, Guabiroba trees (*Campomanesia dicothoma* -purple guabiroba, *Campomanesia guaviroba* -arboreal orange guabiroba), medium-sized trees, ranging from 10 to 20 m in height, a native species, but not endemic in Brazil, which occurs in the Atlantic Forest and Cerrado were studies due to their diverse applications in reforestation, and pharmaceutical, popular appreciation and affective memory. New generations do not know the Gabiroba fruits and the sense to go to the field to collect their fruits was missed over generations. So, in this research seeds were collected, planted, and planted seedlings will be planted in specific areas to recover riparian forests, bring up affective memories, ornamentation, and compose green areas inside Varginha city.

1 Introduction

Urban green spaces play an important role in providing ecosystem services that directly or indirectly benefit people. However, urban growth usually leads to the loss of these green areas and, consequently, their benefits, such as regulating the hydrological cycle and the local climate. Such spaces play a crucial role in reducing the effects of urban heat islands, improving air quality, creating habitats for biodiversity conservation, providing cultural services, and preventing floods and groundwater recharge [1]. For example, Varginha City, located south of Minas Gerais, has great water resources in its urban and rural regions. In previous studies, a research group identified more than 21 urban springs [2]. However, the continuous process of urban expansion is resulting in the disappearance of these springs and the surrounding areas that have ecological relevance and are essential for urban resilience. Given this scenario, it becomes a priority to implement environmental compensation measures at the same moment "providing man with the landscape that the urban environment steals from him" [Burle Marx©]. Roberto Burle Marx was a Brazilian landscape architect. He was one of the professionals who first used native plants in public garden projects in the 30s. He recognized the diversity of Brazilian flora, its beauty, and its importance for ecosystems [3]. Burle Marx made an urban project of Varginha downtown, despite the city hall not keeping it and maybe it was not executed, probably some native trees found in the Varginha downtown could be planted following his advice. This Varginha urban project was found in the Burle Marx Museum in Rio de Janeiro city and has to be digitalized to be analyzed because it is in a big old format. Among native plant species identified in Varginha downtown, we highlight two Gabiroba trees, *Campomanesia dicothoma* -purple gabiroba and *Campomanesia guaviroba* -arboreal orange gabiroba. They are medium-sized trees, ranging from 10 to 20 m in height, a native species, but not endemic in Brazil, which occurs in the Atlantic Forest, Brazilian Savannas. Furthermore, between September and November, the tree blooms abundantly and is therefore widely used as an ornamental tree. Their fruits feed several animal species and are used for human nutrition and biotechnological applications. The seedling of bush Gabiroba (*Campomanesia xanthocarpa*) is widely sold in Brazil, however the arboreal species (C. *dicothoma* and C. *guaviroba*) are not easily found in the market. Currently, the city lacks a greenhouse nursery that could subsidize reforestation projects and the expansion of green areas, gardens, and parks. Therefore, the current project aimed: a) to reproduce the arboreal gabirobas via seedlings; b) study the natural habitats of the Gabiroba species, Brazilian Savannas, and Atlantic Forests and their role in these areas and biotechnological applications; c) study an area to plant the trees in the city Varginha.

2 Methodology

2.1 Gabiroba seedling

Studies of the behavior of guabiroba (*Camponesia spp*) seeds indicate that the species can be classified as recalcitrant, as it does not withstand storage at low temperatures and is intolerant to desiccation [4]. Therefore, the fruits were collected as soon as they fell in the ground. As the tree is too high it was unable to collect the fruits directly from it. All fruits were collected from a single tree of each species. Trees

are located in the square of Divino Espirito Santo Church (21°33'23.57"S 45°26'3.08"W) (Figures A and B).

Figure A: Localization of Gabirobas trees in Varginha downtown.

Figure B: Gabirobas tress – square of the church. Right: *Campomanesia dicothoma* -purple gabiroba and Left: *Campomanesia guaviroba* -arboreal orange guabiroba and fruits at the bottom

Seeds were planted in seedling bags or buckets about 10-15 cm deep with holes for water drainage. Bags were filled with a layer of about 1 cm depth of stones, 1 cm depth of sand, and 10 cm depth of commercial garden earth. Four seeds were added to each bag, which was covered with earth and water. The propagation environment is an open area where seedlings grow outside in an area with plenty of sunlight but protected from the wind. Weeds and insects are manually removed. Seedlings are watered once or twice a week.

2.2. Arboreal Gabirobas natural habitats and their roles.

Intensive research in a scientific database was performed to collect information about the role of arboreal Gabirobas in their natural environment. Basic information about species localizations and the main characteristics of the biomes were mentioned. We searched Scopus, Web of Science, PubMed, Directory of Open Access Journals, Portal CAPES, and Science Direct with the keywords "*Campomanesia dichotoma* or *Campomanesia guaviroba*".

2.3. Investigation of potential areas to plant the trees in Varginha city

The Santa Luiza neighborhood, in Varginha city was investigated to be a site to receive the Gabirobas trees. Studies using Google Earth and site evaluation were performed. Polygonal was traced in each green area of the Santa Luiza neighborhood by year and used to calculate total o green area in square meters. The loss of green area per year was represented in percentage.

3. Results and discussion

3.1 Seedling of Arboreal Gabiroba

Sixty-eight seeds of each Gabiroba species (C. dichotoma and C. guabiroba) were planted, four seeds in each plastic bag or bucket. Orange gabiroba were planted in October 2023 and purple ones were planted in November. Germination starts about 15 days after seedling, however, some purple ones take more them a month to start growing. As more than one plant grew in the same bucket or bag, they were separated after two months of growth. However, this procedure was unsuccessful and many plants died decreasing the number in the nursery. The nursery currently has 22 plants of *C. dicothoma* and 28 plants of *C. guaviroba* (Figure C).

Figure C: Plant nursery, January, 2024.

3.2 Brazilian savannas

The Brazilian savanna, also known as Cerrado, is the second biggest biome in Brazil. Originally occupying 22% of Brazil's territory (204 million hectares), the Brazilian savanna currently covers only 43% of this area [5]. In addition, the remaining area is fragmented into modified areas, of which only 0.85% is officially in preservation areas. The biome is threatened mainly by intensive grain monoculture, primarily soy, and extensive low-tech

livestock farming. Intensive land use leads to the depletion of resources. In addition, pesticides and fertilizers contaminate the soil and water. The main effects are the loss of diversity and the extinction or alteration of the dynamics of springs and bodies of water. The degradation lies above in agricultural expansion and irresponsible mineral extraction benefits. Around 80% of the Brazilian savanna has been altered by human activity [6]. These figures are alarming and provide a glimpse of the extent and seriousness of the damage caused to the biome, as well as the challenges faced in preserving it. The Brazilian savanna is the cradle of one-third of the Brazilian biodiversity and 5% of the world's fauna and flora, and this is why this biome is considered the most biodiverse savanna in the world [5]. Its climate is seasonal, that is, the year is split by two different seasons: from October to March, the climate is rainy, and after, from April to September, it's dry, without any rain [7].

The vegetation of the Brazilian savanna is characterized by a rich diversity of vegetative forms, including grasslands, scrublands, rocky fields, gallery forests, and woodlands. Some of the most notable species include Copaíba (*Copaifera langsdorffii*) - A tree known for its medicinal properties, Pau-santo (*Kielmeyera coriacea*) - Used in folk medicine and by the cosmetics industry, Pequi (*Caryocar brasiliense*) - A highly nutritious fruit of cultural and economic importance to the region, Gabiroba (Campomanesia spp.) - Native fruits of great dietary importance and economic potential, used in the production of juices, liqueurs, and sweets [5][7]. The Brazilian savanna harbors around 12,000 plant species, of which approximately 4,400 are endemic. This diversity is supported by nutrient-poor soils, rich in aluminum, and a season of rains followed by a dry period, creating a unique environment for the development of these plants [5] [7].

3.3. Atlantic Forest

The Atlantic Forest, one of the most biodiverse areas on the planet, is a biome that stretches along the eastern coast of Brazil and parts of Argentina and Paraguay. Originally, it covered about 1.3 million square kilometers, but today less than 12% of its original forest cover remains, mainly due to urbanization, agriculture, and natural resource exploitation activities. This biome is a biodiversity hotspot, harboring thousands of endemic species of flora and fauna, many of which are threatened with extinction due to habitat fragmentation and degradation. Research indicates that the Atlantic Forest plays a crucial role in regulating regional climate, nutrient cycling, and maintaining ecosystem services essential for human quality of life [8].

Conservation efforts have been intensified through public policies, the creation of protected areas, and ecological restoration initiatives. Reforestation projects, such as the Atlantic Forest Restoration Pact, have gained prominence, promoting the recovery of degraded areas and the connectivity of forest fragments. Furthermore, implementing sustainable agroforestry systems is a promising strategy to integrate biodiversity conservation with the economic needs of local communities. Recent studies highlight the importance of integrated and participatory policies that consider the socioeconomic and cultural dimensions in managing and conserving the Atlantic Forest, emphasizing the need for greater community engagement and government support to ensure long-term sustainability [9].

3.4 Geographic distributions *C. dicothoma*

Geographic Distribution - Confirmed occurrences: Northeast (Alagoas, Bahia, Ceará, Paraíba, Pernambuco, Rio Grande do Norte, Sergipe), Southeast (Espírito Santo, Minas Gerais, Rio de Janeiro)

Phytogeographic Domains: Atlantic Rainforest
Vegetation Type: Ombrophyllous Forest (Tropical Rain Forest).

Figure D: Geographic distributions C. dicothoma
Source: [9]

3.5 Geographic distributions *C. guaviroba*

Geographic Distribution- Confirmed ocurrences: North (Amazonas), Northeast (Alagoas, Bahia, Ceará, Sergipe), Central-west (Distrito Federal, Mato Grosso do Sul), Southeast (Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo), South (Paraná, Rio Grande do Sul, Santa Catarina).

Phytogeographic Domains Central Brazilian Savanna, Atlantic Rainforest.
Vegetation Type Cerrado (lato sensu), Seasonally Semideciduous Forest, Ombrophyllous Forest (Tropical Rain Forest), Mixed Ombrophyllous Forest.

Figure E: Geographic distributions *C. . guaviroba*.
Source: [10]

3.6 Role of arboreal gabirobas in their natural biome and biotechnological applications

The genus *Campomanesia* (Myrtaceae) comprises species with broad economic and scientific interests. They produce essential oils (EO) extracted from leaves, fruits, seeds, roots, and bark. Compounds with potential biological activities include monoterpenes as the main constituents of the volatile oils from fruits, while sesquiterpenes are major compounds in the remaining parts of the plants. Thus, EOs from *Campomanesia* provide potentially interesting and viable alternatives for food and therapeutics [11]. There are few scientific reports of *Campomanesia dicothoma* and *Campomanesia guaviroba.* The majority of information available on plants of genus *Campomanesia* belongs to the species *C. xanthocarpa, C. adamantium* and, *C. pubescens*. However, an intensive search in scientific database was performed and some important information was described in this paper.

3.6.1 *Campomanesia dicothoma*

Correia (2014) [12] found that C. dichotoma is important feeding a group of to the monkey *Callicebus coimbrai* (Guigó). This association of the Gabiroba and Monkey is a key factor for seed dispersal and habitat regeneration in a fragmented forest of the Atlantic Forest in the state of Sergipe. The group visited C. dichotoma trees 52 times in two years of study and analyses of monkey 60 fecal samples showed the presence of C. dichotoma seeds. Fecal samples were collected far from the tree sites demonstrating the power of monkey-tree association on seed dispersion and consequently regeneration of habitat.

Souza (2018) [13] described the presence of *C. dichotoma* in natural areas of beach sandbanks and revegetated dunes of the seashore of Paraíba estate. The trees have weak association with arbuscular mycorrhiza fungi (AMF). Canejo et al. (2023) [14] recorded that the fruit flies *Anastrepha fraterculus, Anastrepha sororcula, Ceratitis capitate,* and *Neosilba pendula* emerging from C. dichotoma in the northernmost limit of Atlantic Forest in the state of Rio Grande do Norte, Brazil. The flies emerged from fruit samples obtained at the conservation area at Parque Estadual Dunas do Natal. These records are of importance for monitoring and further understanding of the cycles on alternative hosts especially where these species are considered agricultural pests. Oliveira et al. (2009) [15] found C. dichotoma as a predominant tree of a riparian forest fragment, Capibaribe Mirim River, Aliança, Pernambuco.

3.6.2 *Campomanesia guaviroba*

Pascoal et al. (2011) [15] describe the essential oil from the leaves of *C. guaviroba* (DC.) obtained by hydrodistillation. Sixteen compounds could be identified, representing around 94% of the total oil. The major components were myrtenal (27.0%), myrtenol (24.7%) and trans-pinocarveol (15.7%). The essential oil was evaluated for antioxidant activity and its capacity against leukemic cell lines was demonstrated. Some studies [16, 17] described the pollen of *C. guaviroba*, for taxonomic purposes, no ecological association was done in these researches of pollen. The flammability of *C. guaviroba* in the Brazilian Savanna in southern Tocantins state was studied, as this biome is an ecosystem associated with wildfires as responsible for its formation and shaping for thousands of years. However, due to climate change and urban sprawling, anthropic action has become the main cause of forest fires. Characteristics of this species can contribute to fire proliferation [18]. So far *C. guaviroba* has no medicinal uses, but is very similar to *C. xanthocarpa* and, therefore, it is important to carry out more complete descriptive studies on this species.

3.7 Investigation of potential areas to plant the trees in Varginha city

Santa Luiza neighborhood is one of the greenest areas of Varginha city and harbors many water springs. However, due to the urbanization process, many springs were channeled and impermeabilization occurred triggering flood events. Investigated green areas of this neighborhood are shown on Figure 7, and Table 1 displays, losses (minus symbol) and gains (no symbol) of green area since 2003. Supplementary material with imagens where polygonal was traced are available at https://drive.google.com/drive/folders/1CnAZzC4gwSpe8pLu9CnWe3gp1pGVoKkb.

Despite urbanization, an increase of total o green areas was observed, however, the most vulnerable and important ones decreased. The losses were observed mainly in areas associated with waterbodies (springs and streams). It makes the region for regeneration. An action of environmental bureau of city hall planted 300 trees around a remaining spring in the area. Nevertheless, most of them were unable to grow or died due to distinct reasons. Despite the importance of the area providing with water volume and quality for the watershed and flood prevention, actions of this nature should be performed with the community participation, who could contribute on plant care.

Figure F: Polygonal of green areas of Santa Luiza Neighborhood, Varginha city, Minas Gerais state.

4 Conclusion

The sustainable use of biodiversity, combined with biotechnology, is the path to developing more natural products or compounds. Preservation of species of Campomanesia can be combined with sustainable use, and provide benefits, from table to pharmacy, from the community to the environment to into the foreseeable future. Burle Marx's projects still have to be studied to determine if the Gabiroba trees in Varginha downtown are part of his legacy. The chosen area to receive the trees still has to be determined, because it is not just plants, care is required to enjoy the shade of the trees. Therefore, maybe it will be a plant to plant the trees close to the school where students can take care of and work together with the community to improve plant growth, water them, and control plagues. It is desirable to find and purchase in the market or greenhouses seedlings of the species investigated in the present work. This seedling could be acquired to improve the genetic variability of Gabirobas populations in Varginha to avoid undesirable effects homozygous. Other native species will be cultivated by this group aiming at the recovery of the Varginha green area and supporting biodiversity. Worth mention in the past many Brazilian citizens had the hobby of going sightseeing and collecting Gabirobas in the fields, and we will try to bring back this habit and touch the heart of the community for environmental preservation concerns, and, awareness of how much we lose with decrease of biodiversity.

Table 1: Percentage range of loss and gain of green areas in Santa Luiza neighborhood in Varginha city, Minas Gerais state. Areas in square meters were calculated by Google Earth in each selected polygonal.

Green area	Name	Area (m²)					Percentage range (2003 -2024l)
		2003	2012	2016	2020	2024	
A	Novo Horizonte Park	20.354	23.868	23.395	23.856	24.753	**21,6%**
B	Zoo	43.725	56.391	51.109	54.245	55.492	**26,9%**
C	Zoo extension	34.926	42.317	42.513	40.263	46.507	**33,2%**
D	Surrounding of the Mall 1	2.293	9.863	9.912	11.100	12.206	**432,3%**
E	Surrounding of the Mall 2	318	967	961	1.526	1.349	**324,2%**
F	Surrounding of the Mall 3	3.255	3.709	4.185	4.178	4.838	**48,6%**
G	Catanduvas 1	9.015	13.672	15.301	10.887	15.627	**73,3%**
H	Catanduvas 2	10.157	17.396	13.784	9.385	11.368	**11,9%**
I	Catanduvas 3	3.405	4.420	4.110	3.322	4.740	**39,2%**
J	Catanduvas 4	7.024	8.697	7.572	6.906	7.238	**3,0%**
K	Mall area	22.983	24.989	14.772	11.173	16.462	**-28,4%**
L	Avenida Otávio Marques de Paivo - Horizonte stream	14.323	5.780	4.948	5.903	0	**-100,0%**
M	Alameda Olívio Bregalda - Lado Ímpar	19.780	22.941	23.513	15.532	25.268	**27,7%**
N	Alameda Olívio Bregalda - Lado Par	13.342	17.988	6.789	4.274	9.460	**-29,1%**

4 Acknowledgment

We are grateful for the cooperation of the professionals from the Burle Marx Institute (https://www.institutoburlemarx.org/pt) who found the Varginha projects in the large collection.

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Studies for implementation measures on farms' permanent preserved areas

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Biodiversity and water are intrinsically connected. Water resources supports biodiversity , without sufficient water there is no live thereby causing biodiversity loss. On the other hand, biodiversity supports water resources, for example biodiversity acts in nutrient cycles therefore on water quality. Delimiting permanent preservation area (PPA) is a strategy the guarantee both maintenance of volume and quality of water resources and biodiversity. PPAs (under Brazilian law) are natural protected areas, with rigid limits of exploitation, that is, direct economic exploitation is not allowed. For this, the farmer must delimit the area according to the forest code and isolate it with natural fences (native trees predominant in the region) or physical barriers (fences and wire) to avoid the entry of external animals (livestock) and human activities (cultivation, collection of firewood, hunting, etc.). For that reason, the aim of this work was to visit farms in rural area of Varginha city, Minas Gerais state, aware and advise owners to act in specific permanent preserved areas. Measures and coordinates were taken in the field to determine the PPC that should be protect with fences and wire. Estimative of fences length was determined using Google Earth. Beyond fences other measures were advised to farmers as: implement of water reservoirs for livestock drinking, water drainage system and firebreaks. The number of water reservoirs, water drainage systems and firebreaks were suggested. To stimulate implementation of this measures official documents were filled and send to "Pro-Mananciais" program that give grants to farmers to perform proper adjustments to guarantee that permanent preservation areas will be protected.

1 Introduction

Water is an essential resource for sustainable development, and is the subject of Sustainable Development Goal 6 (SDG) [1]. Population growth and human interventions in natural resources have led to numerous consequences for the environment and the humans who depend directly on them. One of these consequences is the scarcity and poor quality of water in various regions of the world [2].

In Brazil research by MapBiomas indicates that land use dynamics based on the conversion of forests to livestock and agriculture, as well as the construction of dams, contribute to the decrease in water flow. Where did the water go?" This was a recurring question that MapBiomas scientists asked themselves after analyzing satellite images of the entire national territory between 1985 and 2020. The data indicate a clear trend of surface water loss in all hydrographic regions and biomes across the country [3].

The state with the highest absolute and proportional loss of water surface in the historical series analyzed by the MapBiomas team was Mato Grosso do Sul, with a reduction of 57%. In 1985, the state had over 1.3 million hectares covered by water, but by 2020 there were only slightly over 589,000 hectares. This reduction occurred mainly in the Pantanal. In second place is Mato Grosso, with a loss of almost 530,000 hectares, followed by Minas Gerais, with a negative balance, between the water that entered and that drained, of more than 118,000 hectares [3]. Brazil has faced numerous water crises, most notably that of December 2016, which affected several cities in the country, causing supply collapses and promoting the adoption of extreme measures, such as rationing and suspension of water use [2].

The National Water Resources Policy (NWRP) is a strategy that, within the United Nations (UN) concept of water security, encompasses the human, economic, ecosystem, and resilience dimensions to reduce the impacts of droughts and floods by 2035, through integrated planning and consistent water infrastructure. In Brazil, (NWRP) was established by Federal Law No. 9,433/1997, which has the responsibility of organizing all water management, to ensure the water supply for multiple uses in quantity and quality, associated with the preservation of aquatic ecosystems [4].

In Minas Gerais state, water management is governed by the State Water Resources Policy (SWRP) determined by Law No. 13,199/1999. The SWRP was implemented through infrastructure and management actions aimed at the conservation, recovery, and sustainable use of natural resources, through reforestation practices, preservation of biodiversity, and vegetation cover, in addition to the articulation and mobilization of the population to adopt sustainable practices. This set of measures aims to guarantee water security inside the state and promote economic and social progress in all regions of Minas Gerais [5].

In Minas Gerais state, COPASA, is responsible for the supply and distribution of water in 640 cities. Besides the water supply, COPASA operates wastewater treatment in most cities when waste treatment is performed. In Varginha City, the company also operates a landfill. Therefore, the COPASA business is directly linked to water use and preservation. The company has a program called "Pró-Mananciais". It is a social-environmental Program for the Protection and Recovery of Watersheds. The main aims are: to protect and recover the micro-watersheds and aquifer recharge areas. Selected areas are connected to public supply in the cities where Copasa operates [5].

Started in 2017, Pró-Mananciais is part of the company's commitment to socio-environmental responsibility and sustainable development, seeking to prevent the worsening

effects of the water crisis in the context of climate change. The program is based on the idea of anticipating actions through the care, protection, and recovery of waters and small watercourses, from their source to their point of capitation. The financial resources of the Pro-Mananciais Program come from 0.5% of Copasa's nominal revenue. [5].

Actions are developed by establishing partnerships with local communities, city councils, representatives of public schools, state organs, and NGOs, among others, to improve the quality and quantity of water, and favor environmental, economic, and social sustainability. Among the actions carried out are the fencing of springs and other Permanent Protection Areas ("PPAs"), the planting of native seedlings, the construction of rainwater containment basins, engineering actions to prevent erosion and septic tanks. Besides developing environmental education actions for children and training for students, farmers, and other residents of the municipality, to promote a culture of sustainability and thus gain more and more partners in environmental preservation [5].

Due to the importance of water preservation, this work aims to contribute to Pro-Mananciais actions and collaborate with the local environmental group, COLMEIA (Coletivo do Meio Ambiente) to determine important areas for intervention. Collectively, these groups decided to use Pro-Mananciais financial resources in action to preserve and/or restore Ribeirão dos Tachos micro-watersheds (Figure 1A) located in the cities of Três Corações and Varginha, at the south of Minas Gerais, state. This micro watershed belongs to the Verde River watershed (Figure 1B).

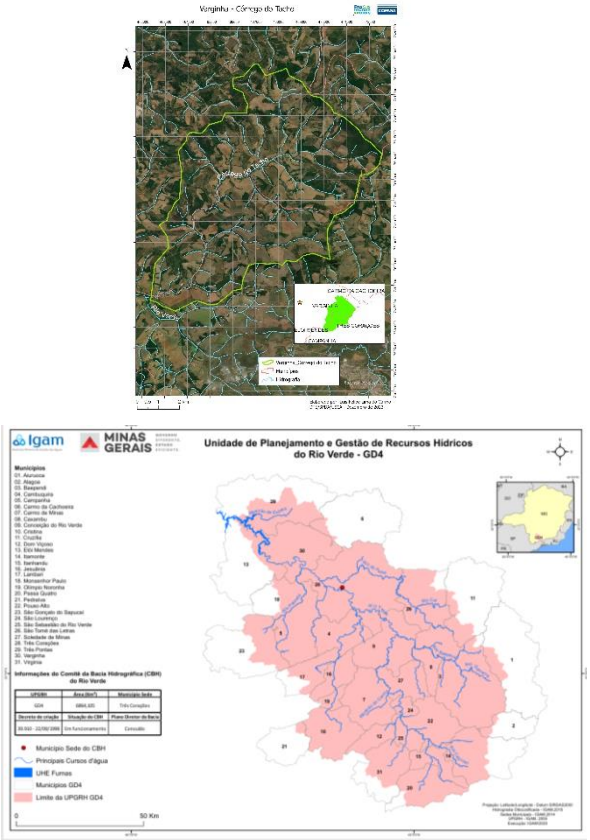

Figure 1: Site of action of Pro-Mananciais 2024. A: Ribeirão dos Tachos micro-watershed. B: Rio Verde Watershed. Sources [6, 7]

The Ribeirão dos Tachos contributes greatly to the volume and the quality of the Verde River, where it flows. Verde River water is the main source for Três Corações and Varginha cities' water supply. As shown in Figure 1A, this micro-watershed has many springs and streams so crucial for the volume and quality of the Rio Verde Watershed. The Rio Verde River Basin has an area of 6.864 km² and encompasses 31 cities (23 municipalities with headquarters in the basin) in the South of Minas Gerais estate. Responsible for supplying water for a population averaging more than 460,192 thousand inhabitants in urban and rural areas. Worth value the micro-watershed Ribeirão do Tachos is located in a rural area and is the source of inhabitants' water supply, therefore the quality of water in springs and streams is essential to guarantee the safety of household uses.

The water of Ribeirão do Tachos micro-watershed is classified as Class 1 from the springs until the confluence with the Verde River [8]. Water from Class 1 can be use waters that can be used: a) for human consumption, after simplified treatment; b) for the protection of aquatic communities; c) for primary contact recreation, such as swimming, water skiing, and diving, d) for vegetable irrigation that are consumed raw and of fruits that grow close to the ground and are eaten raw without removing the peel; and e) for the protection of aquatic communities in Indigenous Lands [9]. Consequently, the water of this micro-watershed must have a high-quality index and a great volume.

2 Methodology

Before starting working in the field, Copasa provides a 12-hour course for CEFET students. The course was based on three activities: a) study of reference terms and main characteristics and procedures of Pro-Mananciais services – e.g. type of fences, where they should be installed; plant seedling and care; engineering services: roads, rainwater containment basins, actions to prevent erosion as terracing, speed bump, and drainage systems, firebreaks, septic tank; installation of animal drink water tanks; b) Field visit to learn to use application Camera stamp and Fields area measures and fill required forms; c) practical course in computer lab to learn Google Earth tools. Important aspects of how to talk to farmers were addressed during the course. The course also focused on communication ability skills, teaching how to speak to people from different realities and convince them of the importance of applying preservation measures.

After developing technical skills, field expeditions started. Field data were collected using a Timestamp application for photo documentation and a Fields Area Measure application was used to get geographic coordinates. Google Earth tools were used to trace and calculate the perimeter of the polygonal off-investigated areas. Forms required (Appendix 1 and 2) to request grants from Pro-Mananciais were filled. They were approved for COPASA commitment and determined preservation interventions will start in August 2024. An Instagram profile was created to disclose actions performed during the work.

3 Results

According to Brazil Forest Code [10] Permanent Preservation Areas (PPA) are areas located along rivers or any watercourse; around lagoons, lakes, or natural or artificial water reservoirs; at springs; on top of hills, mounds, mountains, and mountain ranges; on slopes or parts thereof; on sandbanks, as dune fixers or mangrove stabilizers; on the edges of plateaus or plateaus; and at altitudes above 1,800 meters. The use of forest resources in PPA areas is not permitted. The vegetation removal at PPAs may only be authorized as justified for public utility or social interest.

Up to now, three expeditions have been performed in farms localized in Ribeirão dos Tachos micro-watersheds to determine required measures aiming at water resources preservation or restoration. In one farm, Areas 1A and 1B, there are many springs. In areas 1A and 1B, according to the owner, one spring has disappeared (Figure 2). As cattle, horses, and cows, are present in these areas (Figure 3) the fence will provide protection and limit the entrance permanent preservation area. Fences should be used to keep animals and avoid water contamination, besides that cattle trampling limits plant recovery and forest regeneration, and infiltration is reduced due to compression. Watering cattle directly in the spring is a problem compounded by the lack of riparian forests and the trampling of springs. In many situations, livestock farming uses water directly from streams, rivers, and springs, without any delimitation, creating large trampled areas that contribute to continuous and progressive silting and hinder the flow of smaller streams. It is a common degradation practice. Often, the poor water quality is visible. For many livestock farmers, however, there is an economic and infrastructure reason. When questioned about this practice, many say that, even though there are other possibilities (cisterns and tanks supplied by solar energy), in practice, the lower economic cost of direct watering ends up being the option chosen [11]. In Farm 2, despite the huge well-preserved permanent vegetation (Figure 4), the horses were in the PPA's surroundings. Farmers agreed to use fencing practices in Ribeirão do Tachos due to long-term benefits to land owners and communities. A total length of 5.580 m of fence will be adopted in the areas. Length was calculated using the Google Earth polygonal measure tool (Figure 5). It is worth valuing the high quality of the fence used in the Pro-Mananciais program that will last long allowing faster vegetation regeneration. Table 1 shows the coordinates of each area and describes environmental measures established with the farmer's agreement. Sites where springs were present a radius will be adopted to install the fences. Polygonal was used to calculate fence length as shown in Figure 5 using Google Earth tools. Due to the presence of livestock in the areas beside the fence, drinking water tanks will be installed to minimize cattle watering directly from springs and/or streams.

There is no sewage pipeline or sewage treatment system in several rural areas. Therefore, surface and underground water can be contaminated by wastewater. Many homeowners rely on septic systems for safe and effective treatment of their wastewater. In farms, household wastewater is treated by a septic system before it filters into the soil. Frequently, a properly installed, sited, and maintained septic system should not adversely affect water quality. One house in the visited area requires a septic tank and a system will be offered to meet proper environmental measures procedures.

Controlled drainage in rural settings aims to maintain the groundwater table regime that will provide adequate root zone aeration, soil salinity control, recharge of aquifers, and also avoid silting downstream areas. Rainwater basins are small sediment basins that catch and decrease runoff of rainwater contributing to water resource systems. Only one area required the allocation of this kind of basin (“Barraginha”).

Note: Official documents of farmers agreement are not shown due to personal data.

Table 1: Environmental Actions establish in Farms o Ribeirão dos Tachos Micro-watershed.

Environmental Actions	Farm	Coordinates (UTM)	Unit	Amount	Note
Fencing for springs and riparian forest	1A	-21.576132, -45.306099	meters	2.327	Radius springs: 50 m Width riparian forest: 15 m
	1B	-21.581641, -45.301287	meters	1.170	
	2	-21.578892, -45.292496	meters	2.333	
Total of fencing length			meters	5.830	
Animal water tank	1A	-21.575242, -45.305472	Unites	2	
	1B	-21.582647, -45.300879	Unites	2	
Septic tank	1A	-21.574481, -45.301411	Unites	1	
Rain water basin	1A	-21.575871, -45.302326	Unites	1	Besides road with erosion

Figure 2: Pro-Mananciais team investigating an area where a spring drought.

Figure 3: Left: Presence of horse feces; B: cattle trampling.

Figure 4: Overview of a permanent preservation area Farm 2.

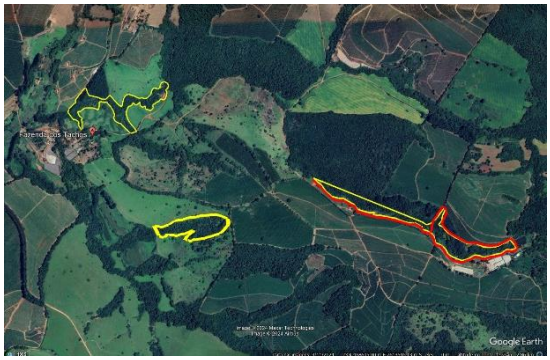

Figure 5: Polygonals to determine the fence length and width on areas 1A, 1B, and 2. Google Earth tools.

An Instagram account @colmeia_varginha the main action of Pro-Mananciais is disclosure. Instagram makes the project visible contributing to awareness and motivating the community and farmers to participate.

4 Conclusions and Future perspectives

The field expeditions started in 2024, so there is a great perspective to find vulnerable areas where effective actions will make a difference in water quality and volume in the Ribeirão do Tachos micro-watershed and consequently protect, recover, and support biodiversity. As coffee crops and livestock are the main practices in the area, this work has an important role in bringing awareness to farmers and the local community. Other environmental education actions should be taken with the community pointing out garbage discharge in rural areas. Sadly, a significant amount of trash of different origins is thrown at Tachos Avenue near the water collection point used for Varginha city supply. Citizens can consume chemicals produced from decomposition and burned garbage that cannot be identified in water routine chemical and microbiological analysis.

6. Acknowledgment

We thank Copasa professionals Marla Lima and Alexander Rocha Inácio for training practices, motivation, and assistance. Thanks to the farms that not only allowed, gently, the Pro-Mananciais team but also provided the proper environment for work. Thank Colmeia members for supporting us.

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Appendix 1

Authorization for environmental services

Pro-Mananciais forms to be filled with number, length and types of environmental services to be applied in Permanent Preservation areas, geographic coordinates data and land owner details and signatures.

COPASA

PROGRAMA PRÓ MANANCIAIS
AUTORIZAÇÃO DE SERVIÇOS AMBIENTAIS - ASA

Pro manan ciais

Página 1 / 1

Município:	Manancial a Proteger:
	Manancial Captado:

Proprietário:	
Representante Autorizado:	
Endereço da Propriedade:	
Endereço da Residência:	
Telefone de contato:	RG / CPF:

Autorizo a Companhia de Saneamento de Minas Gerais – COPASA MG a promover, por meio do Programa Pró Mananciais, a(s) ação(ões) ambiental(is) abaixo relacionadas:

Nº	X	AÇÃO AMBIENTAL	UNID	QUANTIDADE	OBSERVAÇÃO
1		Cercamento de nascentes	m		Raio:
2		Cercamento de matas ciliares	m		Largura:
3		Plantio de mudas nativas	muda		
4		Construção de bolsões	Unid.		
5		Construção de terraceamentos	m		
6		Construção de aceiros	km		
7		Adequação de estradas	km		
8		Outras			

Coordenadas (UTM)	Datum:	Fuso:	
Nº	mE / mN	Nº	mE / mN

Declaro, também, concordar com os seguintes termos:
1° - Permitir o acesso dos executores do projeto ao imóvel acima referido para nele implementar a recuperação das áreas, bem como a fiscalização e acompanhamento dos serviços;
2° - Cuidar e manter as áreas recuperadas e benfeitorias realizadas pelo Programa, nelas não exercendo atividade degradadora.

Local:	Data:
Assinatura:	

Representantes do COLMEIA

Instituição	Nome / Assinatura	Contato

Appendix 2

Sketch and photo documentation document

COPASA

PROGRAMA PRÓ MANANCIAIS
CROQUIS DAS AÇÕES AMBIENTAIS

Pro manan ciais

Página 1 / 2

Município / Distrito:	Centro de Custo:	
Manancial Captado:	Manancial Protegido:	
Proprietário / Contato (Telefone):	Informante / Contato (Telefone):	
Tipo de Ações propostas:	Coordenadas (UTM): WGS 84	Nº do CROQUI:
Quem acompanhou na propriedade:		

Responsável / (Celular):	Nº Pessoal / Lotação:	Data:

Atenciosamente,

Nome / Assinatura

COPASA

PROGRAMA PRÓ MANANCIAIS
CROQUIS DAS AÇÕES AMBIENTAIS

Pro manan ciais

Página 2 / 2

A área se localiza em "APP"? ( ) SIM ( ) NÃO	Em área inundável? ( ) SIM ( ) NÃO
A obra poderá ser executada em qualquer época do ano? ( ) SIM ( ) NÃO	
Via de acesso à propriedade:	
Acesso detalhado à locação:	
Distância em Km da propriedade à captação da COPASA MG:	

FOTOGRAFIAS REPRESENTATIVAS DA ÁREA

Legenda:	Legenda:
Legenda:	Legenda:
Legenda:	Legenda:

Coal Mining in Poland and the State of Water Resources: Challenges and Prospects for Sustainable Economic and Environmental Development

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Summary

Hard coal, historically the most important natural resource driving Poland's economy, has played a key role for many generations. Large reserves of this resource, particularly in the southern part of the country, still form the basis for the energy sector. However, due to climate change, current policies focus on reducing the use of fossil fuels in favor of developing energy based on renewable sources, particularly wind and solar energy.

Mining activities, while providing access to energy resources essential for the functioning of Poland's economy, have negative impacts on groundwater and surface water resources. The main phenomena associated with hard coal mining in Silesia include changes in hydrogeological conditions and the salinization of surface waters. The decarbonization of the country and the closure of many mines bring further changes in the context of water resources, raising the question: are these changes solely beneficial?

In our work, we examine the environmental interdependencies between the exploitation and cessation of hard coal mining and water resources in mining areas. We analyze how the management of these resources affects Poland's development and whether it is sustainable in the context of climate change. We also propose a strategy for utilizing these resources that takes into account environmental challenges.

Keywords

coal, coal mines, salt water, sustainable development

Introduction

Poland, located in Central Europe, is rich in non-renewable resources, especially in the southern part of the country. Since the 18th century, when the first mines were established in Silesia, hard coal has played a key role. To this day, Poland significantly utilizes coal in energy production and industry (Fig. 1).

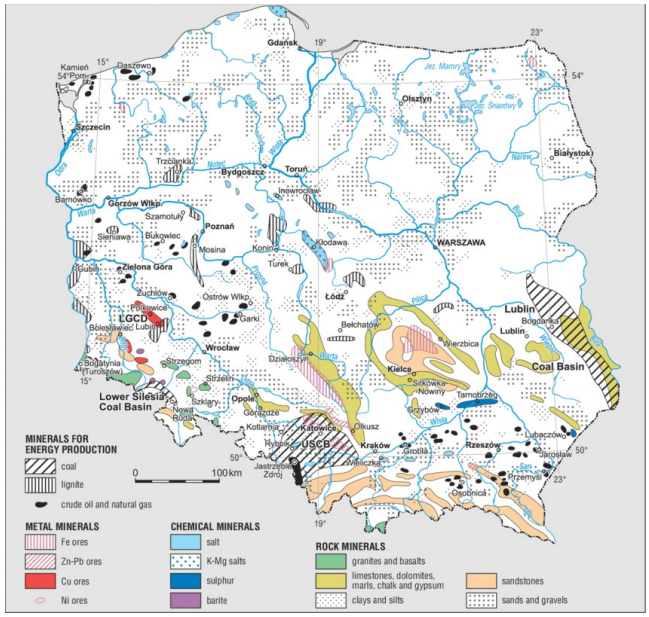

Fig. 1 Distribution of natural resources in Poland created by ResearchGate

A survey conducted in our school shows that a significant number of people have or had a miner in their family, highlighting the importance of coal in Poland, particularly in Silesia. Lignite, found in the central-western part of the country, is also an important energy source. In March 2024, hard coal accounted for 36% of total energy production, and lignite accounted for 21% [1].

Mining and coal exploitation has a serious negative impact on Poland's water resources. During coal extraction, mines are forced to dewater deposits, leading to the disappearance of groundwater, and the drying up of wells, rivers, and lakes. In recent years, environmental awareness among Poles has been increasing, prompting more people to replace non-renewable sources with renewable ones to reduce environmental pollution in households. Currently, 12% of produced energy comes from renewable sources, with wind energy accounting for 62%. Solar energy is becoming increasingly common (about 8%), along with hydro energy (2%) [1].

1. COAL RESOURCE EXPLOITATION

1.1. A Brief History of Coal Mining in Poland

The beginnings of mining date back to the 18th century, when the first mine in Szczakowa was established in 1766 with the initiative and funding of King Stanisław August Poniatowski. Coal gained popularity 20 years later in Jaworzno [2]. The society recognized the benefits of hard coal mining, which led to increased exploitation. The record production level was reached in 1979 – 201 million tons. Since the 1990s, coal production has been declining by about 2.7 million tons annually, mainly due to mine closures and decreased demand (Fig.2). In 2023, production amounted to 49 million tons [3]. Currently, mining occurs in three basins: Upper Silesian, Lublin, and Lower Silesian.

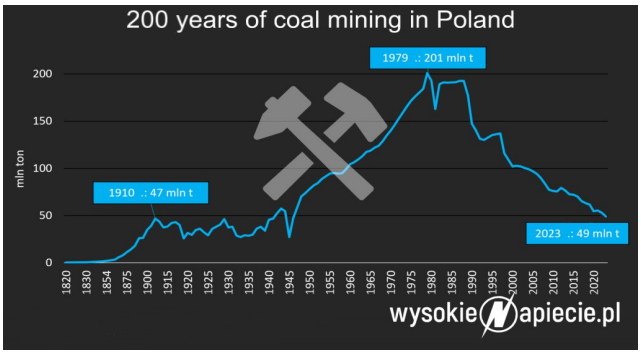

Fig. 2 200 years of coal mining in Poland created by WysokieNapiecie.pl

Coal prices have been very volatile over the years and correlated with oil prices. In 2018, the price of coal was $107 per ton, and the price of a barrel of oil was $74 (data from 2018). In 2022, the price of a ton of coal reached its peak - $430 per ton, due to high inflation. In January 2024, the price of one ton of coal was $300, and a barrel of oil was $80 [4,5].

The mining past has significantly impacted Silesian culture and social traditions. Coal is a key element in building Poland's economy on many levels, including international exports, energy production, and industry. Mines also provided jobs for thousands of Poles, contributing to reducing unemployment in the country. In 1979, the number of people employed in mining was 388,000 out of 35 million inhabitants [6]. Currently, this number has decreased to 75,000 out of 37 million [7, data from GUS].

1.2. Impact of the Coal Industry on Groundwater Resources

Water is an essential element in coal mining, which negatively affects the quality of water resources. Groundwater contains higher amounts of ions, such as iron, manganese, sodium, and chloride ions, which affects its salinity and contamination. Resource extraction requires the dewatering of the rock mass using deep dewatering systems and discharging significant amounts of groundwater outside the mining area, as water intrusion into mining excavations can be dangerous for both the mine and the workers. Pumping out water causes a lowering of the groundwater table.

Mining infrastructure is an additional factor contributing to the decline in groundwater quality. Machinery associated with coal extraction generates pollutants that harm water conditions.

Open-pit mining used for lignite extraction can lead to the formation of depression cones associated with dewatering. A depression cone can cover hundreds of square kilometers. Continuous dewatering of mines can lead to the drying up of wells or municipal groundwater intakes. The main recipients of saline mine water are the Vistula and Oder river basins in southern Poland. Due to the disappearance of underground recharge, river flows decrease, and lake and reservoir levels drop, potentially leading to land drying in crisis situations. In wastewater receiving water from dewatering, increased flows occur [8].

1.3. Impact of the Coal Industry on Surface Water Resources in Poland

For decades, mine waters have been discharged into nearby rivers, making them more saline. The total amount of mine water discharged into rivers is about 93.5 million m3 annually. About 63% goes to the Oder River Basin, and about 37% to the Vistula River Basin [9]. The Oder is the second-longest river in Poland (854 kilometers). This river has its sources in the Czech Republic, flows through southern and western regions of Poland, up to the Polish-German border (Fig. 3) [10]. The salinity of the Oder after dosing mine waters is controlled by a monitoring station in Krzyżanowice. Despite measures taken, in the summer of 2022, an ecological disaster occurred on the Oder due to salinity, causing a bloom of golden algae that produced toxins, leading to a mass fish kill (about 350 tons) and the extinction of 80% of organisms responsible for river purification. The effects of this disaster are still felt today. The disaster contributed to more thorough monitoring of the Oder. Actions have been taken to mitigate negative environmental impacts and to achieve sustainable ecological management of natural resources.

Fig. 3 The Oder River on the map of Poland.

1.4. Infrastructure Associated with Mining Activities

Another generator of pollution is the infrastructure of mining activities. The most visible effect of coal extraction is spoil heaps (Fig. 4), which are waste deposits from mining. There are 153 such objects located in the country (Fig. 5), covering an area of 11 hectares. They affect the landscape of the Silesian Voivodeship and permanently exclude the surfaces they occupy from use. The environment and people living nearby are exposed to the dangers resulting from the storage of mining waste, including groundwater contamination by leachate from heaps, dust, and wildfires. About 98% of post-mining waste is destined for perpetual storage, and only 2% has been utilized in other ways, for example, in the production of aggregates for construction. The low interest in their use is due to the physicochemical properties of this waste. Heaps are not properly supervised, which contributes to the fact that all types of waste, including hazardous ones, are dumped on them. Groundwater near the heaps is mostly characterized by high acidity levels and elevated amounts of elements such as zinc and lead, as well as exceeding permissible levels of chlorides and sulfates in surface waters [11].

Fig. 4 The heap "Szarlota" in Rydułtowy (Wikipedia)

The Supreme Audit Office (NIK) checks whether the actions of administrative bodies and entrepreneurs taken to manage coal waste landfills (heaps) are correct, effectively protect the environment, and are economically efficient [12].

Fig. 5 Location of heaps in Poland created by NIK

2. ACTIVITIES AND CHANGES IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

2.1. Actions Taken During Mine Operations

During mining operations, large quantities of saline water are pumped out, a byproduct of mining activities. In the Upper Silesian Coal Basin (GZW), facilities have been established to reduce the salinity of the pumped underground waters. The only plant recovering salt from post-mining waters is located in Czerwionka-Leszczyny. The desalination process begins in the mine workings, from which the underground water is pumped to the surface. Subsequent stages take place at the desalination plant. The brines are purified by filtration and concentrated using reverse osmosis. Then, crystallization and centrifugation of the salt occur. Finally, the salt is dried to the required parameters. In 2020, salt production amounted to approximately 67,000 tons. [13]

The "Olza" retention and dosing system is another activity aimed at desalinating waters to reduce the salinity of surface waters. Before underground waters reach the river, they are purified of suspensions, barium, and radium ions. Part of the water is used for technological purposes in mines. The "Olza" collector ensures that the discharge of saline water into the river is safe and controlled, adhering to

current norms. It also protects about 150 km of small rivers (tributaries of the Oder). Polish-Czech studies have shown a positive effect concerning the "Olza" collector system.[14] Thanks to the desalination plants' activities, the quality of the water introduced from the mines into the rivers is maintained at an optimal level for the development of aquatic fauna and flora.

2.2. Why Should Changes be Implemented?

Changes in mining, water quality control, and water management are crucial for maintaining the sustainable development of the aquatic environment. The solutions used so far are becoming ineffective in the face of observed climate changes. In many rivers, including the Oder River, particularly burdened with mine water discharges, many alarming and, as it has already turned out, catastrophic changes are being observed in recent years, resulting from many interconnected factors.

The increase in average annual temperatures and, most importantly, periods of very high temperatures not previously observed in Poland, lasting for many weeks, lead to the rise in water temperatures. This, in turn, reduces the dissolved oxygen content in the water, limiting the proper functioning of aquatic organisms. The increase in water temperature also leads to algae blooms, resulting in eutrophication and a decrease in water quality, and in particular situations, the release of huge amounts of toxins causing losses in river fauna.

Climate changes also lead to changes in rainfall patterns in Poland. Intense rainfall leads to increased surface runoff, which carries pollutants from agricultural fields, cities, and other areas, increasing the amount of chemical and biological pollutants in rivers. Droughts, on the other hand, lower water levels, reducing rivers' ability to dilute pollutants. Lower flows can increase pollutant concentrations in the water.

These climate change effects significantly increase the threat associated with the impact of mine waters and pollution runoff related to mining on river ecosystems. A key threat in this context is the emergence of "golden algae," *Prymnesium parvum*, which releases toxins lethal to fish and other gill-breathing organisms. The first mass occurrence of golden algae in Poland was in the Oder River in 2022. [15]

Using coal for energy purposes in power plants and household furnaces for heating buildings is a significant factor in air pollution and negatively impacts human health. The depletion of non-renewable deposits also necessitates changes that enable the creation of stable jobs, investment in local communities, and infrastructure development. Improving resource use efficiency through recycling and more efficient technologies will increase business profitability and positively impact the economy.

It is also essential to implement changes to adapt the economy to international standards and norms regarding sustainable development. Therefore, changes in the mining sector are necessary in the social, economic, and environmental contexts.

2.3. Mine Closures as an Element of Sustainable Development

Due to the intensive exploitation of coal over decades, its resources in Poland have significantly decreased, and mining was possible at ever greater depths. The deepest active mine in Poland is KWK Budryk, where coal is extracted at a depth of up to 1300 meters. These factors, along with the restructuring of heavy industry after 1989, led many mines to become unprofitable and unnecessary. Another reason for mine closures in Poland was the global pressure to reduce greenhouse gas emissions and develop renewable energy sources, along with the introduction of strict environmental regulations at the national and EU levels.

Over the past 30 years, the number of active mines has decreased from 70 to 20.[16] (Fig. 6) By 2049, all mines in Poland are planned to be closed. The effects of mine closures are multidimensional, encompassing economic, social, environmental, and cultural aspects. Many thousands of people lost their jobs and had to retrain, changing the employment profile in significant areas of Silesia.

Fig. 6 Transformation in coal mining in Poland (1990-2014): number of mines created by ibs

Mine closures have also brought changes and new challenges in the environmental context. In Poland, two methods are used for mine closure: ceasing dewatering and allowing the mine workings to be flooded or continuing to pump water from the closed workings to protect nearby active mines from flooding. The choice of method depends on many factors. Safe flooding of mines takes several years, but if mines are hydraulically connected and the closure method of ceasing dewatering is neglected, it can lead to flooding of nearby active mines or the entire basin. Among the most important consequences of mine flooding are the formation of floodplains or even floods caused by the outflow of water from riverbeds lowered due to surface subsidence, and the potential submergence of buildings located on previously dried-out riverbeds due to coal exploitation. The quality of water in flooded workings deteriorates significantly due to higher sulfate and metal content, such as Fe and Pb. This water is unsuitable for use, and its purification requires substantial financial resources. A safer method is continuous water pumping, as neighboring areas are not threatened by flooding or water outflow to the surface. Such underground water is less

polluted. This option brings greater environmental benefits but requires ongoing work and funding. A positive effect of mine closures for the environment is the reduction of air, water, and soil pollution, the cessation of waste storage on heaps, and the increase in usable land area. [17]

3. STRATEGY AND RECOMMENDATIONS

Implementing effective strategies for managing coal, water, and post-mining waste resources is key to limiting the negative impact of mining and ensuring sustainable economic and environmental development. Many solutions have already been implemented and are being intensively developed, while others require implementation.

3.1. Mine Water Management

The development of technologies allowing the reuse of mining and post-mining waters includes the construction of new and modernization of existing treatment plants. Mine water can be utilized as technological water in industries, such as the energy sector, municipal and industrial services, including street washing, watering urban greenery, and environmental protection. Post-mining water can also be a primary source of geothermal energy and serve for consumption. The "Ziemowit" mine in Lędziny is a source of highly mineralized water containing magnesium, sodium, and calcium. After treatment at the mine's Water Treatment Station, it meets the requirements of the ministerial regulation specifying the quality parameters of water intended for human consumption. [18]

During the desalination process, evaporated salt is also produced. Jastrzębska Spółka Węglowa is the second-largest producer of evaporated salt in Poland. Water is desalinated at the Czerwionka-Leszczyny installation, and the resulting salt is used in agriculture, municipal services, and for consumption.

In the exploitation process at the Jastrzębie mine, saline springs were discovered and used intensively for medicinal purposes. In recent years, efforts have been made to restore part of the former glory of the Jastrzębie-Zdrój spa and reuse saline springs on a large scale. A saline inhalation facility has been opened in the Zdrojowy Park in Jastrzębie-Zdrój, accessible to residents and tourists. Saline inhalations support the treatment of respiratory conditions such as asthma, bronchitis, and help alleviate stress and neurosis. [19]

3.2. Reclamation

Land reclamation is the process of restoring biological, chemical, physical properties, or terrain shape to areas previously damaged or degraded due to mining activities. Besides restoring utility value, reclamation also aims to restore ecosystem functions, such as water retention or pollution filtration. There are 138 waste dumps in the Upper Silesian Coal Basin. Reclamation and land development are planned, designed, and implemented at all stages of industrial activity. [20,21]

Reclamation applications on post-mining lands include region revitalization and the development of new investments. [22] Economic factors significantly impact reclamation effectiveness. Maintenance costs of reclaimed land can exceed the reclamation process costs. Monitoring and quality assessment systems are fundamental tools that allow controlling various indicators and parameters of a given area, such as water, soil, vegetation, fauna quality, and other environmental aspects. Restoring proper functions to post-exploitation areas is crucial for environmental protection and sustainable development.

An example of such reclamation is the dump in Libiąż, where trees were planted as part of the RECOVERY project. Another example of utilizing mining dumps is converting dumps into recreational areas. Such actions give new life to unused areas and are actively used by society. An example is the "Ajska" dump in Świętochłowice, where a motocross track was created. [23,24]

Reclamations are carried out not only in the natural aspect but also in mining infrastructure. Post-mining buildings can be converted into recreational or educational places. An example is the Ignacy Historic Mine in Rybnik (Fig. 7), located on the former Hoym mine site. In 1999, the mine was granted monument status, and since 2015, all buildings of the former mine have been renovated. Today, this well-maintained technical monument combines an interactive science center and an object popularizing the industrial culture traditions of the Rybnik land. On the site, one can find old mining machines, a water tower converted into a viewpoint, and a park with a playground and an experience garden. Various festivals, events, and educational workshops are also held there. [25]

Fig. 7 The Historic Ignacy Mine from Poznaj Śląsk

3.3. Innovative Projects and Collaboration with International Organizations for Sustainable Development

The changes taking place across the Silesian mining area require the implementation of many new solutions promoting sustainable development and economic transformation of the region. To this end, national and international cooperation is established with enterprises and scientific units in new technologies and environmental protection.

The international LIFE Brine-Mining program aims to transition to sustainable energy based on renewable sources and improve the environmental condition, including water, air, and soil. As part of the program, a four-year LIFE Brine-Mining project titled "Demonstrative Implementation of Advanced Salt Load Reduction and Resource Recovery from Saline Mine Waters" is funded by the EU. The LIFE Brine-Mining consortium comprises nine partners from Greece, the Netherlands, and Poland. The project aims to support the implementation of the Water Framework Directive and promote a circular economy, improving the efficiency of mine water management. In Poland, the project involves developing and applying an economically viable system for full resource recovery from mine brines, as well as purifying and directly recovering salt. [26]

The RECOVERY international project tested new methods of reclaiming and greening dumps. The project, carried out by Poland, Germany, the Czech Republic, and Spain, ended in June 2023. TAURON Mining experts and scientists from the Central Mining Institute planted hundreds of plants on the Libiąż mining dump (Fig. 8). The goal was to develop a reclamation method for so-called mining waste disposal sites and other degraded areas. Various soil mixtures made from by-products of TAURON Mining's mining operations and TAURON Group power plants were tested. Reclamation works were carried out variably, using innovative methods to create a soil cover neutralizing the acidity of mining waste. This action reduced the potential for generating acidic leachate on dumps. Four hectares were reforested, and the acquired knowledge will be used in future actions for sustainable reclamation of dumps for natural and recreational purposes. The RECOVERY project also developed an innovative ecosystem service valuation model, enabling planning and optimizing the reclamation and management of post-mining areas.[23,27]

Fig. 8 The Waste Dump in Libiąż (2023) from Gazeta Krakowska

The European Union established the Just Transition Fund to support regions most affected by the transition to a low-emission economy. Silesia is one of the beneficiaries, allowing financing projects related to industry restructuring and creating new jobs in green sectors. [28] According to the European Green Deal, EU member states committed to achieving climate neutrality by 2050. The revised Renewable Energy Directive, part of the "Clean Energy for All Europeans" package, aims to achieve at least 32% of energy consumption from renewable sources by 2030, including increasing the share of renewables in transport.

The National Fund for Environmental Protection and Water Management, with the support of the Ministry of Climate and Environment, launched the "Clean Air" program, aiming to improve air quality by modernizing heating sources and promoting renewable energy sources. It also supports investments in photovoltaics and energy-efficient technologies in residential buildings.

In Silesia, research and development centers focusing on new technologies in energy, materials science, and environmental protection are being established. An example is the Silesian Center for Education and Interdisciplinary Research, which supports innovations and cooperation between science and industry. Numerous pilot projects are also being implemented, such as demonstration installations for energy storage systems, using smart grids, and research on efficient natural resource use.

The Rybnik Energy Cluster is another example of regional cooperation. It is a civil agreement of five member municipalities (Rybnik City, Gaszowice Commune, Jejkowice Commune, Świerklany Commune, and Czerwionka-Leszczyny Town and Commune) located in the Rybnik district. The goal is to ensure local energy security through joint cluster investments, community integration, supporting entrepreneurs in ensuring a stable power source, and educating residents.

On December 7, 2021, the "Polish Hydrogen Strategy" was adopted in Poland. The document, developed by the Ministry of Climate and Environment, sets the framework for developing the hydrogen economy in Poland by 2030, with a perspective to 2040. The strategy aims to accelerate the country's energy transformation through hydrogen technologies development. Key projects include the Silesian-Małopolska Hydrogen Valley and the H2Silesia project. These initiatives aim to develop hydrogen production, distribution, and use in the region. Green hydrogen production will enable heavy industry power supply and emission-free transport, representing a significant step towards decarbonization. [29,30] Many initiatives are also taking place in our immediate vicinity. Rybnik initiated the ROW 2.0 project, aiming to transform the Rybnik Coal District into the Rybnik Hydrogen District. This project involves developing modern hydrogen technologies, cooperating with the Silesian University of Technology and local businesses to create a sustainable, efficient green energy hub. [31] Rybnik is one of the first cities in Poland to purchase hydrogen-powered buses. Currently, 20 such vehicles serve public transport. These buses are equipped with fuel cells that convert hydrogen into electricity, with water vapor as the only byproduct.

3.4. Strategy for Resource Protection and Sustainable Development

Sustainable use of natural resources - coal and water in Poland requires a multifaceted approach, including natural resource management, environmental protection, investment in new technologies, and cooperation at national and international levels. Poland has relied on coal for decades, which has been the primary energy source and a key industrial element. Currently, facing the need for

decarbonization and climate changes, the mining industry's liquidation and economic transformation become inevitable and challenging. Simultaneously, the long-term exploitation of coal deposits in Poland has significantly impacted water resources.

The analysis of these issues has allowed us to formulate several key points that we believe should be Poland's strategic actions in the coming years. To sustainably use natural resources in the face of climate change, it is necessary:

In the social aspect:

- Organize training and retraining programs for mining workers to help them acquire new qualifications and find employment in green sectors of the economy,
- Provide financial and psychological support for workers losing their jobs due to mine closures, including career counseling programs and assistance in finding new employment,
- Support local businesses and business initiatives that can create new jobs and contribute to the region's economic development,
- Convert historic mines and mining infrastructure into museums, cultural centers, and tourist attractions,

In the economic aspect:

- Invest in wind farms, photovoltaic installations, and other renewable energy sources. Poland has significant potential in wind energy, especially in the Baltic Sea, where large wind farms are being built. Companies Equinor and Polenergia are jointly implementing three wind farm projects: Baltic I, Baltic II, and Baltic III. These projects will power 4 million households with green energy[32],
- Invest in smart grids and energy storage systems that enable efficient management of renewable energy,
- Create funds supporting the development of small and medium-sized enterprises, which can become the basis of local economies after mine closures,
- Encourage the private sector to invest in sustainable technologies through tax incentives, grants, and other forms of support,
- Invest in eco-friendly public transport, such as electric and hydrogen buses,

In the environmental aspect:

- Invest in technologies for purifying mine water, such as reverse osmosis and membrane technologies, enabling water reuse,
- Use purified mine water in industrial processes or for irrigating green areas,
- Systematically conduct reclamation of post-mining areas to restore these areas to usability. This may include afforestation, creating parks, water reservoirs, and developing recreational infrastructure,
- Build and modernize retention reservoirs to store water during periods of heavy rainfall and make it available during droughts,
- Implement integrated water resource management that considers all aspects of water use, including industry, agriculture, recreation, and environmental protection,
- Install more modern river quality monitoring stations and conduct seasonal river studies,

In the aspect of technological innovation development:

- Invest in research and development of new technologies in energy, materials science, and environmental protection. An example is the Silesian Center for Education and Interdisciplinary Research, which supports innovations and cooperation between science and industry,
- Implement numerous pilot projects and research on the efficient use of natural resources,

In the aspect of international cooperation:

- Utilize European and international funds to finance projects related to natural resource protection and sustainable development,
- Leverage the potential of international projects such as LIFE Brine-Mining, RECOVERY, Just Transition Fund, Polish Hydrogen Strategy,
- The presented strategies can help lead the Polish economy in a more innovative way, ensuring sustainable development.

Conclusion

In the face of climate change, changes in the mining industry are crucial to achieving sustainable development that includes economic, social, and environmental needs. Implementing sustainable practices not only protects the environment and human health but also contributes to long-term profitability and economic stability. It is essential that all actions are coherent and coordinated, ensuring their effectiveness and providing lasting effects for future generations.

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word length of the report - 4558
word length of the references- 722

Securing the water resource in Colombia while recovering the páramo ecosystem,

Northern Andean region

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Abstract

Colombia is a megadiverse country that has a privileged geography. As a result, there are a lot of easily accessible water sources, the most important one being *páramos*. This study determines if water usage trends are sustainable with climate change, and analyzes how the economic and everyday activities of water-adjacent communities (rivers and *páramos*) are affected. To complete the investigation three interviews with three different experts on the topic were conducted and a number of documents from different official sources like *Ministerio de Ambiente, Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt,* among others were analyzed. The gathered information was applied to a strategy developed to aid with the prevention of further damage and recovery of the *páramo* ecosystem involving community engagement, capacity building, and responsible land use. We came to the conclusion that the current water consumption and warming tendencies are not sustainable.

Keywords: páramo, resource, climate change, sustainability, recovery.

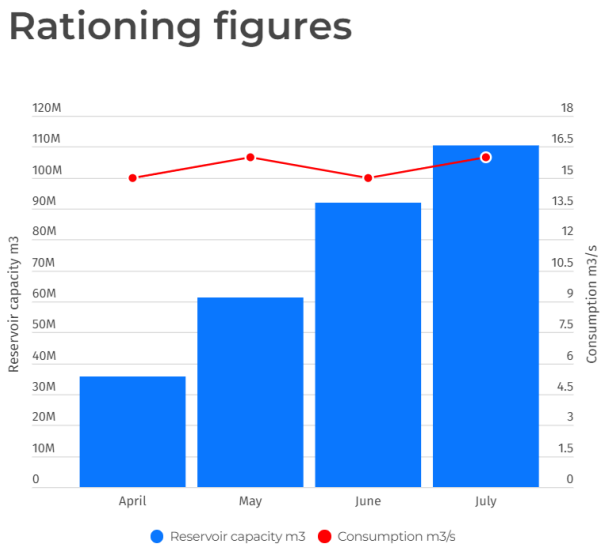
1. Introduction

Colombia is a country located in the northwest of South America between the Caribbean Sea and the Pacific Ocean. It possesses the unique geographical feature of the Andes mountain range, which due to its fractured terrain caused by the recent orographic processes that gave origin to it, creates a variety of climates, ecosystems, and biodiversity found almost nowhere else in the globe [1]. Furthermore, it also happens to have some of the highest precipitation and humidity ratings in the world, and by extension large amounts of hydric resources [2]; this phenomenon can be explained by two main physical reasons. The first one is The Hadley Cell Convergence Point, which is a high-pressure point where heat and humidity from the tropical ecosystems of lower and higher latitudes are concentrated by the surface level trade winds, rising to the higher atmosphere and condensating in heavy rain clouds [3]. The band across the globe where this effect occurs is called the Intertropical Convergence Zone (ITCZ), where the highest values of water in all of its states are measured, corresponding approximately to the Equator, although it tends to vary position slightly through the year; the ITCZ in Colombia remains consistently above the Andes range in its cycle, which is in itself the second reason, as the variation in altitude creates orographic precipitations, where the terrain forces the high-pressure air to condensate [1,3]. As such, the total precipitation value for Colombia is determined not only by the humidity of biomes like the Amazon or Darien rainforest but the addition of the Andes effect. By themselves, these factors explain the raw data of precipitation in the country, but they do not explain the distribution of water and formation of basins, such as the Magdalena or Orinoco;for this, we have to turn to ecological factors. Different types of forests have a determinant role in water sources, from the distribution of water, to the prevention of erosion, [4,5] but if there is one type of Andean forest imperative in the dynamics of water, it is the one at the highest altitudes, above the cloud forest, where these are created, where water is absorbed by the mountains and distributed in the very origin of rivers and lakes; this ecosystem endemic of the northern Andes and differentiated of common tundra due to the combination of low temperature, mountain peaks, and high humidity is known to the local people as the *páramo*. It is defined as a tropical high mountain ecosystem present between the dense humid cloud forest and the bare terrain of perpetual snow, approximately above 3000 M.A.S.L [6]. The *páramos* store water from rain and fog, which is collected by native plants adapted to the extreme conditions that use an special type of foliage such as the Espeletia, also known as the *frailejón* [7]. With all of this in mind, it would be logical to conclude that Colombia must be a country where water scarcity and droughts barely exist, and for most of history this was the case. Since pre-columbian civilizations, the inhabitants of this land have developed a culture where water is never supposed to be scarce, as Colombia also possesses one of the highest hydric demands in the world [2], and many colombians had never thought of scarcity until recently, when due to a variety of factors of anthropic origin affecting the páramo, ranging from deforestation, fires for the development of agriculture, overexploitation, industrial contamination, and droughts from climate change, various water sources across the nation have been drying out [9-8-2]. The consequences of this were highly reflected in recent months, for example, in Bogotá, which gets most of its water from the Chingaza *páramo* complex, rationing led by the state began in order to lower per capita water consumption. This was done as the reservoirs supplied by this *páramo* were beginning to show alarming data , and it became a possibility that the city would be left without water. Because of these types of scenarios, we decided to develop a strategy that, trough preserving the *páramo* ecosystem, would therefore also preserve the water resource in some capacity [10].

Table of consumption data and reservoir levels (Figure 1)

MONTH	APRIL	MAY	JUNE	JULY
CONSUMPTION m^3/s	15,67m^3/s	16,07m^3/s	15,64m^3/s	16m^3/s
RESERVOIR CAPACITY m^3	35,618,000m^3 (16,19%)	61,204,000m^3 (27,82%)	91,872,000m^3 (41,76%)	110,550,000m^3 (50,25%)

Consumption and reservoir level graph (Figure 1) [11]



This main strategy will not only aid with the prevention of further damage to the páramo, but also introduce some form of recovery for security. Lastly, for further clarification we asked to determine whether water usage trends are sustainable with climate change, to analyze how the economic and everyday activities of water-adjacent communities (rivers and *páramos*) are affected by these events, and to study the historical and economical reasons of human interference on the *páramo*.

2. Conceptual Framework

There are multiple laws in Colombia that cover up *páramos* and protect them. To mention a few:

- ***Law 99 of 1993***: The aforementioned legislation mandates the establishment of the Ministry of the Environment, restructuring the National Environmental System (SNA), and delineating territorial environmental planning as a state function aimed at overseeing and directing the planning and utilization of the country's natural resources. Its primary objective is to ensure responsible exploitation and sustainable development practices. It also states that the CARs (Regional Autonomous Corporations) are the top environmental authorities responsible for managing renewable natural resources within their areas. They are in charge of ensuring that environmental considerations are taken into account in territorial planning decisions. [13]
- ***Law 300 of 1996***: The law, commonly referred to as the Sustainable Territorial Development Law, is a Colombian legislation aimed at fostering balanced and sustainable development within the nation. It sets forth directives for territorial organization, land utilization, environmental conservation, and civic engagement in both urban and rural planning processes. The law advocates for administrative and financial decentralization, along with the establishment of tools for effective territorial governance. [14]
- ***Law 1333 of 2009***: The main functions are to regulate the sanctioning procedure in cases of alleged violations of environmental regulations, establish measures and procedures to impose sanctions in environmental matters, grant the State the power to impose sanctions in environmental matters, guarantee compliance with environmental regulations and the protection of the natural environment in the country, provide a legal framework for the application of sanctions in cases of damage to the environment, promote environmental awareness and responsibility in the conservation of natural resources. These functions contribute significantly to the preservation of the environment and compliance with environmental regulations in Colombia. [15]
- ***Law 1930 of 2018***: Called the *Páramos* Law, in Colombia, it was enacted on July 27, 2018, with the purpose of regulating the comprehensive management of *páramos* in the country. This legislation establishes key provisions for the protection, conservation, and sustainable use of these high mountain ecosystems. Among the main functions of Law 1930 of 2018 are the definition of guidelines for the preservation of biodiversity present in the *páramos*, the promotion of practices that ensure their sustainability, and the creation of a legal framework that guides the proper management of these valuable natural spaces, thus contributing to their long-term protection and environmental balance in Colombia. [16]

3. Methodology

This study requires data that describes the *páramos* characteristics, ecological role, and how these aspects have changed throughout time and due to what factors. Such research already exists in a variety of studies made by national and international preservation and surveying organizations, which were our main source of information for this paper. While such experiments could be conducted individually to gather original data, it usually takes years for results. A complex ecosystem such as the *páramo* has many different variables that describe it and cover completely different fields of science, from evolutionary analysis to climatology and geology, to mention a few. So conducting all the experiments necessary to understand the *páramo* is not feasible for a paper of this scale.

The studies chosen as references for this paper were gathered, in one part by means of academic search engines, for example, Google Scholar. By typing keywords such as "*páramo*" "biodiversity" "conservation" "water resources" "precipitation" and so; but the main method for gathering information related to the *páramo* were the publicly available papers, studies and other types of media, like map layers, published by colombian government and public agencies. To mention a few, there is the Instituto Geológico Agustín Codazzi (IGAC), Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt, Ministerio de Ambiente y Desarrollo Sostenible (MinAmbiente) and some of their international counterparts from *páramo* possessing countries like Peru or Ecuador. Even though some of the texts, infographics or papers date from a few years ago, they contain relevant information crucial for this study, and since the study of this ecosystem began only recently, the information is not yet outdated. The analysis of the studies selected was mostly qualitative, looking to establish a sort of general narrative referring to the ecology of the *páramo*, and speaking mostly in an integrated strategy that addresses correctly each of the relevant aspects, without specializing too much on one of them. Our other main source were interviews with different experts on topics related to the administration and conservation of the *páramo* and water sources. These experts were: Ana María Reyes, who we chose because of her experience as an environmental engineer; to learn about the different laws and accords for water usage in the construction and infrastructure industries and its effects on the environment. Sanitary engineer Roque Eliécer Alba González, who has over 25 years of experience on the environmental field, was interviewed so that he could give a general framework of water as a resource: how it is managed as a tool on different industries, and how pollution and global warming has affected, not only water sources, but different ecosystems too. Ministry of Environment and Sustainable Development functionary Oscar Francisco Puerta Luchini, who performs the role of Director of Integral Water Resource Managing, described the role of the government in the topics of conservation and rationing, gave a general overview on the development and approaches to the *páramo* throughout the years, and proposed ideas for the development of an integral water-páramo strategy. These people were chosen based on their experience working with water, both as a resource and as a crucial part of many ecosystems. The questions addressed to them were designed based on their field of expertise and how it could help in our objectives. We proposed the following questions as a template to help focus the answers.

- How is it being ensured that the laws protecting the *páramos* are being complied with?
- Do you think that water companies are aware of the responsibility they have over our water sources and the country?
- What are the biggest challenges facing the government in terms of *páramo* conservation?
- Is there any strategy to involve local communities in *páramo* conservation?

4. Results

Interview environmental engineer - Ana María Reyes

In the environmental approach to drainage, a motorized pump is used to control excess water, along with systems such as "Boscolver" to direct water without contaminating sources. The ministry monitors the water using a flow meter and only filters water intended for human consumption. Tanker trucks are deployed to reuse water and prevent waste. Regional autonomous corporations, such as Cormacarena in the Meta department, are responsible for protecting water sources. Permits are required to occupy the channels and studies are carried out to prevent contamination. This allows the use of surface and groundwater for different purposes, such as domestic supply and irrigation, ensuring proper management of water resources in accordance with article 2.2.3.2.12.1 of decree 1076 of 2015. [17]

Interview sanitary engineer - Roque Eliécer Alba González

Colombia is one of the greatest water powers in the world, however, it is contradictory how one of the many issues regarding this resource is the access to it and its quality (25% of the population does not have access to potable water). Approximately 400 out of 1,100 municipalities meet the requirements to have potable water. That means that the other 700 have water issues. These districts are focused on the departments of La Guajira, Cundinamarca, Chocó, Putumayo, and Guaviare. This is due to different reasons. The wrong usage and contamination of it are some of the

biggest ones. We can observe this situation in our rivers, the Bogotá River, the Magdalena River, and the Cauca River are some of the most important, yet most polluted rivers in the country. They get industrial and mining discharges, receive different toxins and pesticides used in agricultural activities, and oftentimes, mercury is found in these due to the mining and leather industries.

The expansion of the agricultural border is a big issue. The deforestation of the Amazon is directly linked to this, as it was done to support the agribusiness industry. By doing this, the availability of the hydric resource is put under big pressure, as it has a process of 'supply and demand', the supply is what we have of the water resource and the demand is what we need of the water resource. As a consequence of population growth, the demand is increasing each day and surpassing the supply. This started to manifest on our wetlands, our *páramos*. The Chingaza Dam reached critical levels regarding water reservation, which is why the rationing began in different parts of the country.

Another aspect of human activity damaging wetlands, specifically *páramos*, is urbanization. People have turned them into mining, livestock, cultivation, and residential areas. This does not allow there to be a regulation of the resource, as the intervention on the ecosystem causes different 'natural' disasters, such as floods. Juan Antonio Nieto, Director of the IGAC, said "We found a series of activities that could cause deterioration to the ecosystem. Potato crops, spring onions, free grazing livestock, legal and illegal mining, which were directly affecting the *páramos*." [18]

On the theme of natural disasters, El Niño-Southern Oscillation (ENSO), commonly known as *El Niño*, is a natural climate event that occurs in the equatorial Pacific Ocean. It is characterized by an abnormal warming of the surface of the ocean, which has significant effects on global weather patterns. It causes the lowering of precipitation in some parts of the country, including the *páramo*. The damage those received is evident. The soil is drier than it should be, and flora of the ecosystem is directly affected by that fact.

Interview Director of Integral Water Resource Managing - Oscar Francisco Puerta Luchini

In the 1950's, Colombia experienced a colonization event like no other in its history. On one side, the beginning of La Violencia, the civil war that went on for the latter half of the 20th century, which forced an enormous amount of the population to abandon their lands to escape extortion or even death, and search for new places to settle. On the other hand, the state began pushing policies to increase the productivity of the territory, which involved expanding the agrarian frontier with the promise of owning an estate, which back then and still in current times is a privilege reserved for few.

Decades later, in the 1970's, the paradigm had changed, and conservation of the environment began emerging as a concept, and as a policy through the creation of the National Institute of Renewable Natural Resources and Environment, this meant that key ecosystems had to be identified to be declared as protected zones and, as was the modus operandi at that time when it came to preservation, be completely closed off and forbidden the entrance to anyone; of course the páramo was chosen as one of these ecosystems, as even with the limited knowledge that existed before the field of ecology developed, the role of the *páramo* as essential to water sources was well documented; but there was a problem, people were already living in the páramo. Some having lineages dating back centuries, most having arrived recently searching for virgin land to settle, even if that land was below freezing temperatures and generally not prone to agriculture, or most types of life, it was their land that they fought hard for, and now the government was trying to take it apparently out of nowhere, which of course caused conflicts that still persist to this day, as people approach interactions with conservation agencies with wariness. With the passage of time other parties came to have their own interest in the páramo; mining operations from clandestine to multinationals were exploiting the soil of the páramo, and many lawsuits were filed to try to maintain them, with their only effect being wasting the time of the Ministry; and as the internal conflict continued, dissident groups found refuge in the isolated páramo, which made it even harder to approach remote communities and develop conservation strategies.

Half a century later, we have come a long way; the approach to conservation has shifted into a more socially driven effort that acknowledges the native communities and involves them in the process, many issues of disconnectivity have been solved and data on the páramo is available for almost all complexes. Unfortunately, most of the damage has already been and is being done: some *páramos* soil's have lost all vegetation, causing erosion, and by extension, the release of contamination and CO_2 to the atmosphere; some river basins have been contaminated by mining or other economic activities from their origin, or dried up entirely, leaving many municipalities without a water source; and climate change makes weather unpredictable, either causing catastrophic floods or unbearable droughts, also making the climate conditions for the existence of the páramo unattainable, and creating an imbalance in the ecosystem. Even with all the advances, society is still incapable of securing the páramo. This comes from a problem in the way we view nature in itself, sometimes as a resource, sometimes as a human right, sometimes as a reserve. What most fail to realize when making legislature or developing strategies is that water needs to be approached in an integral manner that takes into account its complete cycle, from the *páramo*, to the river; the transpiration and the so called flying rivers, all these factor influence each other and they cannot be separated, as they have been so far by the managing of different ministries.

In Colombia, *páramos* are home to many ethnic and local communities such as indigenous people, Afro-Colombians, and farmers, leading to a diversity of uses and customs in relation to the ecosystem. Of the 36 páramo complexes that exist in Colombia, 17 overlap with 31 indigenous reservations (290,360 ha), 6 territories of black communities (14,610 ha) and 2 with established Peasant Reserve Zones (ZRC). (Keys for local páramo management, pg 10). [19]

A conservation strategy is imperative to safeguard these vital areas and it must integrate community engagement, capacity building, responsible land use and early warning systems to enhance *páramo* conservation.

In 2022 the United Nations Development Programme (UNDP) adopted a policy aimed at conserving *páramo* habitats through the promotion of sustainable systems that preserve biodiversity and effectively manage socio-environmental conflicts. Over the past two years of implementation, a comprehensive analysis of the top ten risks both socio-environmental and those directly impacting the ecosystem has been conducted annually. Although these investigations were meticulously finished the year before, the degree of description and depth decreased. Out of the ten risks listed in this paper, only four will be handled since they are deemed to be significant threats. The first concern mentioned in the June 2023 report was the vulnerability of disadvantaged groups, which includes the inability of indigenous people to be linked to the project, and the possibility of receiving no benefits. The UNDP proposes mitigating this risk through a comprehensive plan involving multiple actors and participation mechanisms. This aims to assure equal recognition of all indigenous peoples, valuing their culturally significant areas and other aspects, acknowledging their decision-making processes. The report also highlights that the necessary CLPI process was not conducted at the project's inception, leading to its initiation while consultancies were being carried out for each of the four páramo regions. To address this, the project seeks to guarantee the participation of indigenous and peasant communities in the three levels of governance: Steering Committee, Indigenous Technical Committee, and Local Committees, for each prioritized páramo region. This will enable participation, monitoring of project actions, and periodic presentation of results. To further improve this, priority will be given to recognizing these communities' cultural importance, knowledge, ancestral traditions, and other aspects. The project will also comply with the due process of Prior, Free, and Informed Consent to ensure their notable presence in the participation process and enable them to benefit from the project by being well-informed. [20]

Based on various strategies taken from different articles from the *Ministerio de Ambiente, Instituto de Investigación de Recursos Biológicos Alexander Von Humboldt,* among others, we have concluded that there are different ways to address this sustainable use. However, although there are numerous options, these are limited because *páramos* are rare ecosystems. Under these criteria, the proposed strategy is divided into three goals:

The first goal to be considered will be the experience of community management of this *páramo* ecosystem. To this end, a compilation will be made to promote and evaluate general knowledge about this ecosystem and maintain strategies formulated by the *Corporación Autonoma Nacional* (CAR) for local management in distinguishing forms of ecosystem use. Additionally, an alliance is sought between the local population and the private/public sector for the development of these community activities, such as high-mountain ecotourism. This is expected to be achieved in the short to medium term (1 to 4 years). [21]

The second goal will be to promote and then implement sustainable use alternatives for *páramos*. To achieve this, the following steps must be taken: first, a rigorous environmental impact assessment of the different uses of productive systems that are used for this ecosystem. Second, monitoring of the results on the conservation of páramo fauna and flora, as well as the restoration of the current state of conservation or degradation of this ecosystem in scientific and cultural terms. Third, the identification and selection of alternative systems for sustainable production in *páramos* that are viable for areas of extensive commercial cultivation and the promotion of the use of clean technologies for existing agricultural activities. The fourth step is the use of renewable high-mountain energies, which could be photovoltaic, geothermal, etc. But these must be implemented in the country's economic activities. Finally, priority must be given to the inclusion of ecosystems known as "*Subpáramos*" in the Certificate of Economic Incentives for Conservation. This goal is estimated to take 6 to 10 years, representing a medium to long-term timeframe due to its demanding nature. [21]

The third goal aims to strengthen industrial water supply management through basic sanitation by consolidating strategic alliances for this purpose. It begins with the design of a monitoring system that can determine the environmental impact in the upper watersheds generated by reforestation. From this, an evaluation and monitoring of the acquisition of areas of vital interest for municipal water systems will be carried out, as well as the acquisition of areas or ecosystems of strategic interest for the conservation of natural resources. Project implementation will be prioritized for the integrated management of watersheds in *páramo* ecosystems, with the full participation of the local population. It is intended to concretize a strategic alliance in order to find a common good among the countries that harbor *páramos* within them. And to make this an international strategy, alliances will be formed with as many countries as possible that have páramo territory (Venezuela, Peru, Ecuador and Costa Rica). It is planned to be carried out through the UNDP, since being a United Nations agency, it has a relationship with nations in need. For this goal, an average of 4 to 7 years is estimated. [21]

5. Conclusions

The effect that modern water usage trends, along with climate change has on the hydric resource is overwhelming.

With our study, we came to know that the combination of the two is not sustainable, as it damages the resource to a critical level as seen in the last year.

In conclusion, water is essential for the economic arrangement of the country. If any of these ecosystems get affected, the economy will be affected too.

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Water Security: The Right to Access Hygienic Water for Agricultural and Basic Life Necessities.

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Keywords max 5

self-sustainability, waterways, agriculture, circular economy, accessible water

SUMMARY

This study examines the obstacles that Australian rural areas, Indigenous Australian communities, and developing nations such as Indonesia and Fiji face in getting access to clean, safe water. The study emphasises how pollution, poor infrastructure, and limited education affect the quality of water used for agriculture and bathing. It looks at effective examples such as the Western Treatment Plant in Victoria, which is vital to the circular economy since it recycles wastewater, and the nature-based solutions used in Indonesian and Fijian informal settlements by the RISE project.

Introduction

Australia's water undergoes rigorous testing to meet stringent health standards, for it to be safe to drink regardless of where it's located in your home. Australia's water comes from a spectrum of waterways, such as reservoirs, wetlands, estuaries, rivers and floodplains. The waterways support the environment, farming, habitats and social exercises. However, as you venture deeper into rural Australia and further away from urban cities, it can be found that water accessibility and quality diminishes. Examples of these communities include rural indigenous communities, rural towns and small settlements. Communities like these rely on external water sources not supported by the government, such as rainwater tanks. [15]

2 Background information:

Australia's water resources come from a mix of groundwater, surface water, and desalination. Groundwater accounts for approximately 30% of the country's water supply, while surface water, including rivers and lakes, provides the majority. Desalination plants, particularly along coastal areas, contribute around 10% of the water supply, crucial for urban centers like Perth and Adelaide. Water usage in Australia is diverse; with agriculture consuming around 70% primarily for irrigation, while residential use, including bathing and other domestic needs, accounts for approximately 9%. The remaining percentage goes towards industrial and environmental purposes. Water quality varies with urban areas generally having high-quality drinking water. However, some rural and remote regions face challenges in water quality, often relying on boreholes and rainwater. Recycled water is increasingly important, making up approximately 3% of the water supply, and is used in agriculture, industry, and urban landscaping. Access to clean water is high in urban areas, but more efforts are needed to ensure consistent quality and availability across the entire country. [1]

2.1.0 Overview, Current practices in place for water production/conservation

Throughout Australia's history water has always been a valuable resource due to the climate; there have been multiple efforts to preserve and conserve water. The nation does not just rely on one source for all its water, it relies on a diverse portfolio of water resources and production methods of both safe drinking water and agricultural water to support its growing population. [1].

2.1.1 Traditional Water Management Practices

Indigenous Australian communities traditionally use natural indicators, such as animal behaviour, plant growth, and landscape features, to locate water sources. They often extract water from roots, dig soaks and use rock holes and tree hollows for storage. Purification methods include filtering through natural materials such as sand and charcoal and using the antimicrobial properties of certain plants. In developing countries, traditional methods include rainwater harvesting, using sand dams to capture seasonal rainfall, and purifying water with solar disinfection or using seeds like *Moringa oleifera*, which help settle sediments and kill bacteria. These methods reflect a deep knowledge of the local environment.

Australia's Figure 1: Moringa oleifera [16]

2.1.2 Rainwater harvesting

In many parts of Australia, the high variation of rainfall has a significant impact on the availability of water resources. Rainwater harvesting is the third most used system in Australia. It involves collecting water runoff from roofs and filtering and then storing it in tanks for use, mainly in irrigation. Rainwater harvesting provides an estimated 274 billion litres annually. According to the ABS (Australian Bureau of Statistics) 26% of Australian houses have a rainwater tank that annually provide 9% of residential water in Australia (177 billion litres) worth $540 million. Outside of urban areas rainwater provides 63% of residential water or 109 billion litres. [2]

2.1.3 Groundwater sources

In regions where rain is limited, ground water plays a key role in supplying Australians with drinking and agricultural water. Major groundwater resources in Australia include the Great Artesian Basin, which covers approximately 20% of the country and the major aquifers (Figure 1) of the Murray–Darling Basin.[4]

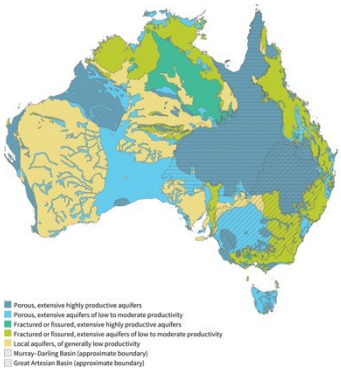

Figure 2: Map of Australia's groundwater sources [4]

Declining groundwater supply

The sustainability and continued use of groundwater is subject to change due to the current climate conditions and several other factors which include but are not limited to:

- Reductions in rain events associated with climate change
- Over-extraction
- Contamination
- Saltwater or seawater intrusion
- Mining and coal-seam gas extraction

2.1.4 Surface Water Sources

Australia's surface water sources are divided into rivers, dams and reservoirs. Australia's climate causes high variation in rainfall and streamflow, therefore, large reservoirs and dams have been built to ensure that Australia has a reliable supply of water. Australia has more than 500 major surface water storages and several thousand small ones [4]. The total accessible storage capacity is approximately 81,000 GL which is higher than many countries when compared to a nation per capita standard. For example, Australia has 3.5ML per capita, the USA has 2.26ML per capita and India has 0.185ML per capita. [5]

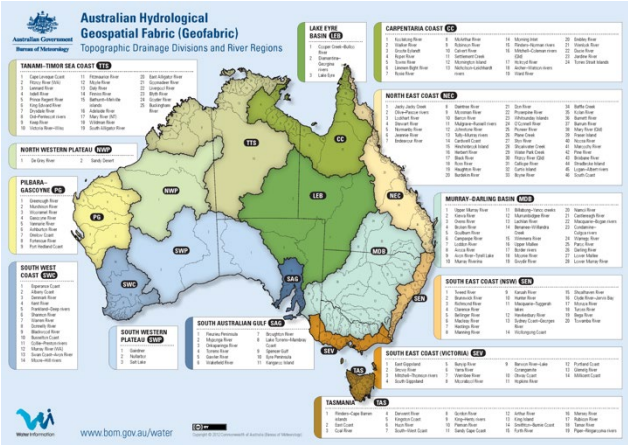

Figure 3: Map of Australia's drainage and river regions [4]

2.1.5 Recycled Water

Recycling water is the process of treating wastewater to a high standard so that it can be used for irrigation in public places and for agricultural purposes. It is used in situations where available sources cannot meet the demands of the region. It can be seen as an attractive alternative because large cities constantly produce wastewater that will be discharged into waterways. [4]

2.1.6 Desalination

Desalination is converting saline water, most commonly sea water, into fresh water. The most common desalination processes are distillation and reverse osmosis; several methods exist. [6] Australia has 270 desalination plants, however, few that are built for large-scale desalination. The total desalination capacity across Australia is approximately 880 GL of water per year [4]. The water from desalination plants is used for:

- drinking water supplies on islands or remote inland areas
- industrial processes
- irrigation of sports grounds
- agricultural purposes

2.1.7 Rain Garden/ Natural Desalination

The City of Boroondara in Victoria has implemented a raingarden as part of a broader 10-year Integrated Water Management Strategy launched in 2014. This initiative aims to enhance local water harvesting and reduce stormwater pollutants before entering waterways such as Port Phillip Bay. The rain garden at Glenferrie Oval and Grace Park collects stormwater from the Hawthorn Main Drain, treating it through bio-filtration. This treated water is stored in a 200-kilolitre underground tank for irrigation use in local parks and for broader distribution through the river system. The rain garden helps to prevent excess stormwater, nutrients,

and pollutants from contaminating natural water bodies, thereby contributing to a healthier and more resilient environment. [3]

2.1.8 Culturally Appropriate Solutions

Water holds cultural and spiritual significance for Indigenous Australians and has been respected for thousands of generations amongst communities. As stated in the 2007 Echuca Declaration by the Murray Lower Darling Rivers Indigenous Nations, "Water has a right to be recognised as an ecological entity, a being and a spirit and must be treated accordingly."[8] The development of water management has to consider these aspects, of keeping water healthy allowing Indigenous Australian communities to sustain their traditions, land, and spirituality. By involving Indigenous Australians in decision making as well as finding ways to evolve water management in a respectful manner that has a positive impact of the environment. [8]

2.3 Australian Water Usage

Australia's water usage patterns reveal a significant reliance on water resources across various sectors, with agriculture, forestry, and fishing emerging as the primary consumers. These sectors' substantial water use highlights Australia's dependence on these industries for economic and food security. For instance, between 2021-22, the agriculture sector used approximately 8,000 GL of water, maintaining its position as the largest water user. Household water consumption remains relatively stable, averaging around 1,500 GL annually, indicating consistent domestic needs. Meanwhile, manufacturing and mining, though critical to the economy, use considerably less water, averaging about 200 GL and 100 GL per year, respectively, reflecting either efficient practices or lesser dependence on water. The distribution of water usage underscores the importance of sustainable water management practices, particularly in agriculture, to ensure the long-term viability of Australia's water resources. [12]

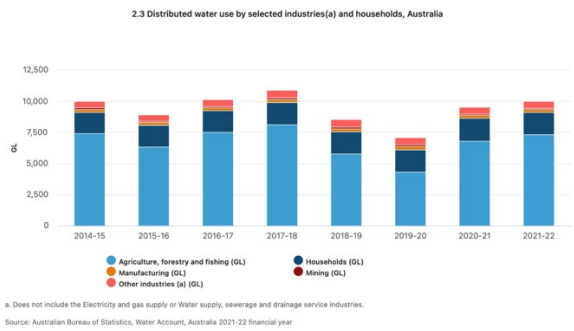

Figure 4: Australia's water use distribution by select industries [4]

	Surface water	Groundwater	Desalination	Inter-region inflow	Total
Adelaide	77,346	43,768	5,323	98,535	**224,972**
Canberra	46,667	753	0	0	**47,420**
Melbourne	344,207	18,993	125,000	0	**448,200**
Perth	170,066	519,053	116,198	1,996	**807,313**
South East Queensland	312,524	15,265	12,714	0	**340,503**
Sydney	536,576	43,826	22,480	2,184	**605,066**
Total	**1,487,386**	**641,658**	**281,715**	**102,715**	**2,513,474**
%	**59%**	**26%**	**11%**	**4%**	

Figure 5: Distribution of Australian water sources in major cities [4]

3. The scope of the investigation

3.1 Western Treatment Plant

The Werribee water plant (also known as the Western Treatment Plant) is Victoria's largest water and sewage treatment facility, being roughly the size of Philip Island. It treats over half of Melbourne's sewage providing an essential service that prevents pollutants from entering Port Phillip Bay. It treats more than 182.5 GL of sewage each year using a low-cost, low-energy sewage treatment process. [10]

The plant has a 3-stage treatment process to treat sewage via a series of large ponds, called lagoons, the largest of which can hold 600 million litres. It takes 30-35 days for all the bacteria to break down via the following system of lagoons.

Anaerobic lagoons

The first lagoons have large plastic covers which are used to create an anaerobic environment, free from oxygen, where certain bacteria thrive, these bacteria break down and decompose organic material present. As they decompose, the bacteria produce a biproduct of biogas. The most common biogas produced is methane which is captured under the plastic sheets to prevent greenhouse gas emissions. It is then used for power production in the plant, making the entire Western Treatment Plant self-sufficient.

Aerobic Lagoon

Sewage is then moved into uncovered aerobic lagoons where aerators pump oxygen into the water creating a suitable environment for another type of bacteria to thrive. These bacteria remove nitrogen from the wastewater and clump it together. Then the sewage is pumped into tanks called clarifiers which separate the solids from the liquids. These solids are called biomass and are a nitrogen and nutrient-rich fertilizer-type material.

Release or Reuse

Once the wastewater has been cleaned it is sent to the final lagoon. It may then be released into Port Phillip Bay under strict environmental guidelines, or it could be used as recycled water to maintain the surrounding wetlands and marshlands. Another possibility is that it is supplied to customers to use for irrigation and agricultural purposes.

Therefore, the Western Treatment Plant uses a self-sustaining and environmentally safe way of treating and processing wastewater that reduces pollution in its surrounding areas. It produces useful products that help maintain itself, making it fully self-sustainable. The products

also improve agriculture in the surrounding areas and reduce irrigation costs for local communities. [10]

3.2 Indigenous Australian Practices

Water has been crucial in the survival of Indigenous Australians for over 65,000 years as well as having significance in spirituality and traditions. Through nature, Indigenous communities were able to identify water sources, even in the Australian desert where birds such as zebra finch, striated pardalote and red-browed pardalote were used to locate water. Although lakes and waterways were the main sources for harvesting water, there were other places where Indigenous Australian people found water. Rock holes and tree trunk hollows were used to collect water that had accumulated after a storm. Tree roots, clay pans, moss clumps and mound springs also stored water, and these were squeezed or cut open to get the liquid. Additionally, methods such as impoundments (which are small dam constructions) and soaks (holes dug to trap water), helped in storage. [9]

3.3 Dr Karin Leder, The RISE Project

Across the developing world, over one billion people live in urban informal settlements, facing challenges from polluted water and inadequate sanitation, which lead to preventable diseases. Traditional water and sanitation systems are insufficient for these communities, which are also vulnerable to climate change and rapid urbanisation. The RISE program addresses these issues by implementing nature-based solutions like wetlands and bio-filtration gardens in informal settlements in Fiji and Indonesia, throughout 24 communities across two cities; Makassar and Suva.

These informal settlements are neglected by the government and have no access to sanitation and water services. The root of the problem is their poor sanitation systems that cause fecal contamination across the waterways and farming lands. The contamination comes from the overflowing of the unmaintained sewage systems. Most houses in these communities do not have access to toilets or the knowledge to manage their septic tanks which bubble up and explode into the environment. This microbial pollution spreads into their wells and drinking supply via the constant flooding. Furthermore, when it floods, residents are forced to walk through contaminated water, restricting daily life activities such as selling merchandise such as food, water and fresh produce and getting their children to school. The flood waters do not deplete for long periods of time due to the lack of infrastructure in the informal settlements; specifically, drainage systems. The flooding also spreads fecal matter from the unmaintained septic tanks onto the streets and into the wells forcing residents to walk in infected water up to their chests. Additionally, when young children drink the contaminated well water or play in contaminated areas, they develop chronic inflammation within their bodies affecting their growth, nutrition and limiting their life expectancy to approximately five years of age; an example of is gastroenteritis.

The RISE project aims to find solutions for these informal settlements' sewage and water management problems; this includes reducing flooding, tap water control and sanitation education. Their research and work include collecting large amounts of data and water samples from the communities to find the root of the contamination and uncover how it spreads throughout the vulnerable people. They take data from hydrology, temperature, wildlife chemicals, bug and microbe tests in water, humidity tests, blood samples, fecal samples and on-going surveys. They implement small adjustments slowly to better the daily lives of the communities. The program can achieve all of this because of its 120-150 team members which range from microbiologists, public health, infectious disease doctors, economists, ecologists, architects, engineers and more. They are funded through sponsors from Australia, Fiji, Indonesia, New Zealand and several other communities and countries from across the globe.

To date, RISE has implemented several solutions that interact with each other simultaneously to improve the lives of the locals in the informal settlements in which they work. Firstly, they installed toilets and septic tanks in many individual homes, with modernised plumbing and proper working pipes that link to their septic tanks. The water within these systems is chemically cleaned and treated with prime septic treatment. The wastewater is transferred to wetlands, also built by the RISE program. These wetlands are garden beds outside the homes and along the concrete walkways and paths between houses. The wetlands filter the water through the roots and soil of indigenous plants; a nature-based solution. The water is then released back into the environment as a cleaner alternative to what was being released previously.

Building concrete paths that run between houses and join areas within the community are another solution constructed by RISE to counteract water contamination. The elevated concrete paths with modern, simple drainage systems were constructed to counteract the flooding, thus limiting the spread of the fecal waste currently present in their environment. Wetlands run alongside these paths, so that during flooding season, the water that runs off them is cleaned before making its way towards houses. The paths are created uniquely to each settlement after in-depth discussions with local leadership on their specific wants and needs. Simple things that may not be considered in first-world nations but make such a drastic difference to these informal settlements are also implemented which differ from settlement to settlement. Some examples of these are the inclusion of play equipment for children, so that they may play in uncontaminated areas, and raised clothes lines to avoid clothing being contaminated in flooded plains.

The RISE Project's reach extends beyond fixing countless problems of water contamination, it extends to educating the local communities on the new systems and practices that they have initiated so that they can maintain the systems, supporting each of the urban informal settlements to be self-sustainable. This produces an ongoing lifelong solution and empowers those living within the settlements with the responsibility of continuing RISE's work, allowing them to feel a part of the ongoing efforts to improve their lifestyles, community wellbeing and continue living healthily with

their children with less risks of chronic illnesses and high infant mortality rates.

The RISE program intends to carry on for years, with ongoing testing of the environments within communities to measure how the conditions are improving. [14]

4. PROTOTYPING, examining how a wetland works:

'Wetland in a Bottle'

Materials:

3x 1.25L plastic bottles

1x 946ml plastic bottle

Sand

Soil

Mulch

Moss

Pebbles

Stones

Method:

1. Cut the top third of the plastic bottle and poke 6-9 holes in the cap.
2. Then place 4 layers of paper towel outside the lid and screw the cap on top.
3. Place top third of the bottle inverted inside the bottom two thirds.
4. Layer materials (2 layers of paper towel inside lid-sand-soil-hay/mulch-pebbles-stones-moss) inside the top third of the bottle).
5. Mix separate bottle of water with soil from outside.
6. Slowly poor dirtied water inside the inverted lid and allow the water to slowly filter through.

Summary: The experiment was conducted 4 times, changing the order of materials until the most effective order was found (the order in the method). The first time the water came out dark and had sediment on the bottom, the second was lighter but still had sediment, the final two were the clearest and had little to no sediment on the bottom. Although the water was not crystal clear (it was still quite murky) the main idea of a wetland was replicated which was to filter the water to make it less contaminated, although not completely clean enough to drink, similar to the RISE project. [13]

5. Conclusion

This study examines the difficulties in obtaining clean, safe water in Australia and developing nations like Fiji and Indonesia. It focuses on the obstacles that rural and Indigenous Australians, as well as urban informal settlements, must overcome. The problems include poor infrastructure, pollution, and a general lack of knowledge, all of which make health hazards and water scarcity worse, highlighting the need for a multifaceted approach that includes sustainable water management practices, educational programmes, and culturally appropriate solutions by looking at successful models like the Western Treatment Plant in Victoria and The RISE project's initiatives in informal settlements in Fiji and Indonesia. Sustainable water management techniques, such as bioremediation, decentralised systems and recycling are critical to lowering pollution and encouraging water conservation from an environmental standpoint. Socially, encouraging knowledge and instruction in local communities enables people to properly manage their water resources while honouring cultural settings and guaranteeing fair access. Financially speaking, by lowering health-related expenses and raising agricultural production, investments in resilient water infrastructure and community-based solutions, such those exemplified by the RISE program, can strengthen local economies.

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CAMBERWELL GIRLS GRAMMAR SCHOOL

Birrarung: The Yarra River, Melbourne's waterway and life source

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Summary

Flowing through the heart of the city of Melbourne, Australia's second largest city and the capital of Victoria, the Yarra River is of important in terms of culture, history and liveability for Indigenous Peoples, and residents. The Yarra River plays an essential role in the life of Melburnians, providing a source of water, as well as areas and resources for food cultivation, leisure, transport, and community culture, alongside its function as a habitat for flora and fauna – all essential for a healthy waterway. Importantly, it has considerable significance for the local Wurundjeri People of the Kulin Nation, who have been custodians of the river and the land for thousands of years.

This project explores the historical and cultural significance of the Yarra River, with a focus on indigenous perspectives and indigenous practices which help sustain the health of the river and ultimately the life experiences its local inhabitants.

Keywords

Yarra River, Birrarung, Indigenous Peoples, Indigenous practices, Wurundjeri people, sustainability, cultural heritage.

1 Introduction

The design thinking process was used to direct the research process. This process has five stages: Empathise, Define, Ideate, Prototype and Test.

In the Empathise stage, information about the Yarra River, its uses and connection to Indigenous people was researched and collated. Questions were generated to direct further research. Key insights were identified, allowing the focus of the research to be refined and defined.

The next three stages were cyclical, with proposal ideas generated and collated on a collaborative Miro board. Ideas were sorted using an Impact Matrix which considered the levels of resourcing and impact for each idea. High impact ideas with both low and high levels of resourcing were developed, with arguments for each interrogated using the Three Pillars of Sustainability Framework [1].

During the Prototyping and Testing stages, questions arising from the research and proposal generation were shared for expert feedback and input, with Murrundindi, Ngurungaeta (Head Man and Elder) of the Wurundjeri People of the Kulin Nation, a key source of information and insights.

2 Background information

2.1 What is a waterway?

A waterway, for the purposes of this investigation, is a river. The waterway selected for this investigation is the Yarra River which runs through Melbourne, Australia's second largest city. This river stretches over 200 kilometres, flowing through various landscapes, and is an essential aspect of Melbourne's geography, culture, and history.

2.1.1 Signs of a healthy waterway

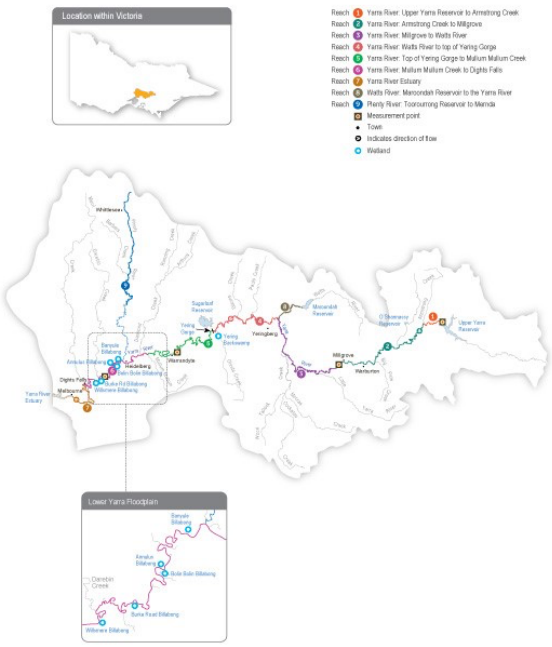
A healthy waterway features clear, unpolluted water, abundant aquatic life, and diverse plant species along its banks. It supports a balanced ecosystem, with stable oxygen levels, minimal algae blooms, and proper nutrient cycling. The water's pH remains neutral, and there is minimal human disturbance or contamination. This is an essential aspect of a healthy waterway, as an extremely acidic or alkaline pH level can impact the survivability of the ecosystem's aquatic organisms.

2.2 The Yarra River

2.2.1 Location

The Yarra River is located in Victoria, Australia. It stretches over 242km, from its source in Mt Baw Baw in the Yarra Ranges, east of Melbourne and through the Yarra Valley. The river flows through various landscapes including forests, rural farmlands, suburbs and cities, all the way to the end at Port Phillip Bay [2].

Figure 1. The Yarra River and its tributaries [3]



2.2.2 Features of the Yarra River

2.2.2.1 Source and path

The Yarra River originates in the Yarra Ranges, Victoria, near the Baw Baw Plateau. Its source is a pristine forested area at Mount Baw Baw, about 90 kilometres east of Melbourne [2]. From there, the river flows westward through the Yarra Valley, a renowned wine region, and into Melbourne's metropolitan area. The Yarra winds through the city, providing vital water sources and recreational opportunities, before reaching its mouth at Port Phillip Bay.

Along its 242 kilometre journey, the Yarra River supports diverse ecosystems and cultural landmarks, serving as a lifeline for both urban and rural communities.

2.2.2.2 Uses

Water Supply and Irrigation

The Yarra River serves as a crucial water source for Melbourne, providing 70% of the state's drinking water and supporting irrigation for agriculture, particularly in the fertile Yarra Valley [2].

Recreation and Tourism

Popular for boating, kayaking, fishing, and scenic walks, the Yarra River attracts both locals and tourists. Its riverside parks and trails offer outdoor recreation and cultural events.

Industry and Transport

Historically, the Yarra facilitated Melbourne's development, supporting industries like shipping and manufacturing. Today, it remains a vital waterway for transport and urban infrastructure.

Ecological Importance

The river supports diverse ecosystems, preserving local flora and fauna.

2.2.2.3 Flora and fauna

Flora

The Yarra River provides life for many species of flora. The banks of the Yarra are lined by unique indigenous and non-indigenous vegetation. This includes native grasses, shrubs, gumtrees, wattle trees and bushes. These plants provide habitats for the fauna living along the riverbanks. Flora throughout the river include the swamp shrub and aquatic plants such as water-ribbon and the common reed [4].

Fauna

The Yarra River and its riverbanks are a sanctuary for its diverse range of fauna, providing habitats and shelter, as well as resources essential for a species to thrive. Several hundred species of birds, mammals, reptiles and amphibians can be found in and within 50 metres of the river, with both native and introduced species, such as honeyeaters and deer. Unfortunately, the Yarra River is also home to a variety of endangered and threatened species. This includes bird species such as the Diamond Firetail and the Black Falcon, mammals such as the Southern Brown Bandicoot and the Spot-Tailed Quoll, fish species such as the Macquarie Perch and the Australian Grayling [5], as well as reptiles and amphibians such as the Growling Grass Frog [4].

2.2.2.3 Name

The Yarra River's name originates from the Wurundjeri people, the Indigenous custodians of the land. The current name for this Australian waterway was mistranslated from the Indigenous term, "Yarro-yarro", which is thought to mean "ever-flowing" or "flowing water" but was mistakenly applied to the entire river system by European settlers [6]. Within the Wurundjeri community, this river is known as the "Birrarung".

2.2.2.4 Importance to the economy

The Yarra River plays a vital role in Melbourne's economy, supporting various industries and sectors. Its waters provide essential resources for agriculture, particularly in the Yarra Valley, one of Australia's premier wine regions. Tourism thrives along the river, attracting visitors to its scenic landscapes, parks, and recreational activities like boating and fishing. The riverbanks host major cultural events and festivals, boosting local businesses. Additionally, the Yarra historically enabled Melbourne's industrial growth, acting as a shipping route [7].

Today, the Yarra River remains essential for urban water management, contributing to infrastructure development and enhancing property values along its waterfront areas.

2.3 The Yarra River's Indigenous Peoples

The Yarra River, known as Birrarung by the Wurundjeri people, holds deep cultural and spiritual significance for the Indigenous groups of the Kulin Nation, including the Wurundjeri, Boonwurrung, and Wathaurong. The river and its surrounding lands provided food, water, and materials for tools and shelter, forming the foundation of their traditional lifestyle. The Wurundjeri people, as custodians of the land, engaged in sustainable practices such as controlled burning and fishing to maintain ecological balance. The river also served as a meeting place for trade, ceremonies, and storytelling, linking Indigenous communities across the region in cultural exchange and unity.

2.3 Cultural Significance

The Yarra River holds deep cultural significance for the Wurundjeri People. It has been a vital source of food, water and essential needs, that provide for life. It has also been a vital source for spiritual connection for thousands of years. The river is central to Dreamtime stories, symbolising life, continuity, and connection to the land [8].

The Yarra River's importance extends to the non-indigenous community, where it is significant for its environmental, recreational and economic value. The Yarra River well-reflects the rich indigenous heritage and remains culturally significant to many people to this day. It is a spiritual symbol of the Wurundjeri People's cultural heritage and values [2].

2.4 Indigenous Practices

The Indigenous Wurundjeri people and other Kulin Nation groups have long practiced sustainable stewardship of the Yarra River, or Birrarung, recognising its significance for both the environment and their cultural heritage. Central to these practices is a deep respect for the interconnectedness of land, water, and all living things.

One key method was controlled burning, which involved the intentional, small-scale burning of vegetation. This practice promoted the growth of new plants, reduced the risk of large bushfires, and created open areas that benefited the local wildlife. It also maintained the river's banks, preventing overgrowth and erosion that could harm the waterway's health [8].

The Wurundjeri also engaged in seasonal fishing and harvesting. By rotating their use of natural resources, they ensured that fish populations and plant life along the river remained abundant and healthy. Fish traps and weirs were built in ways that allowed for sustainable capture while still ensuring fish could reproduce and thrive [8].

Another key practice was ceremonial care, where spiritual and communal ceremonies were performed to honour the river and its significance. These ceremonies not only strengthened cultural bonds but also reinforced the belief in caring for the land, preserving the Yarra River's ecosystem for future generations [8].

2.5 How has the river changed over time?

Like all natural environments, the Yarra River has been subject to several changes through time, both through natural causes and human intervention. Naturally, the course of the river changes with time, however with human involvement, this natural process has become both slowed and accelerated. When European settlers first began inhabiting the area, factors such as agriculture and building of infrastructure has changed the landscape of the river [7].

The river's significant disruptions are primarily due to human infrastructure. Riverbanks have turned into concrete; streams have turned into drains and the significant land clearing and development which occurred in the 1800s have left the Yarra River a muddy brown colour.

2.6 What are some of the issues associated with the Yarra River?

2.6.1 Water health

The Yarra River faces several water health issues, primarily due to urbanization and industrial activities. Pollution from stormwater runoff carries litter, chemicals, and oils into the river, degrading water quality. Elevated nutrient levels from agricultural runoff can cause algal blooms, reducing oxygen levels and harming aquatic life. Sedimentation from construction and erosion destabilises riverbanks, affecting habitats. Heavy metals and toxins from past industrial practices still persist in some sections, further impacting the ecosystem. Additionally, untreated sewage overflows during heavy rainfall exacerbate contamination [9].

These issues threaten the river's biodiversity and undermine efforts to maintain it as a clean, healthy waterway. Signs of a healthy waterway include the presence of species such as platypus, frogs and indigenous vegetation [10].

2.6.2 Endangered species

The Yarra River is home to several endangered species, including the Australian Grayling, Macquarie Perch, and Murray Cod. These species face threats from habitat loss, pollution, and altered flow regimes [4]. Conservation efforts include habitat restoration, pollution control, and the implementation of fishing regulations to protect these species. Additionally, the Yarra River has been legally recognized as a "living entity," which provides it with greater protection and ensures sustainable management practices [11]. These actions aim to preserve the river's biodiversity and support the recovery of its endangered species.

2.6.3 Environmental threats

The Yarra River faces several environmental threats that endanger species like the Australian Grayling, Macquarie Perch, and Murray Cod. These threats include habitat loss, pollution, invasive species, and altered flow regimes. Pollution from urban runoff and litter significantly impacts water quality. Invasive species, such as exotic fish and weeds, disrupt the native ecosystem. Conservation actions include habitat restoration, pollution control, and the implementation of fishing regulations. Additionally, the Yarra River's legal recognition as a "living entity" ensures sustainable management practices to protect its biodiversity [11].

2.6.4 Leisure activities

Leisure activities on the Yarra River face challenges such as water pollution, which affects water quality and safety. Additionally, increased boat traffic can disturb wildlife and contribute to erosion. Managing these impacts requires careful regulation and sustainable practices to balance recreation with environmental preservation.

2.6.5 Transport

Yarra River transport faces issues such as congestion from increased boat traffic, which can lead to safety concerns and environmental impacts. Additionally, pollution from boats affects water quality. Managing these challenges requires effective regulation and sustainable practices to ensure safe and environmentally friendly river transport. This includes a law where parts of the Yarra River (south of Gipps Street) have been declared illegal for swimming [12].

2.7 What is in place to protect the Yarra River?

The Yarra River is protected in several ways including through government policies and laws and community initiatives and organisations, all focused at preserving its ecological, cultural, recreational and historical significance. These protections also acknowledge the river's importance, not only as vital natural resource, but also as a cultural and spiritual site for the Wurundjeri people.

2.7.1 Laws

A law created in order to protect the Yarra River is *'The Yarra River Protection (Wilip-gin Birrarung murron) Act 2017'*. The Act establishes the river as a living entity, establishes the Yarra River Strategic Plan and the Birrarung Council for its management, and introduces and amends legislation to ensure the protection and sustainable use of the river and its surrounding environment [11].

2.7.2 The role of councils

Several local councils are responsible for the protection of the Yarra River including the City of Melbourne, the City of Yarra, the Boroondara City Council and the Yarra Ranges Shire council [13]. These councils contribute to the development of the Yarra Strategic Plan and are responsible for the implementation of these initiatives in their local government area. The local government also provides significant funding for investments and management activities within the Yarra River. Furthermore, local councils develop planning schemes to control land use, development and infrastructure to ensure the protection and conservation of the natural environment [13].

2.7.3 The role of Melbourne Water

Melbourne Water plays a crucial role in the management of the water supply and the environment for Melbourne and surrounding regions and areas. Melbourne Water is responsible for the collection, storage and distribution of drinking water to metropolitan areas, as well as the treatment and recycling of wastewater, with the intention of prioritising and protecting public health and the environment. This is done alongside the stormwater drainage systems in place to minimise flooding, improve water quality, and the overall management of rainwater runoff. Melbourne Water is responsible for the promotion of sustainable water use practices of residents and businesses, engaging with the community through education programs, partnerships, and events to raise awareness about water issues and responsibility. Melbourne Water is also responsible for reviewing planning applications within 100 m of the Yarra River [13].

2.7.4 Community responsibility and actions

Local communities are encouraged to participate in river clean up events to remove litter and pollutants, with the aim to maintain the river's natural beauty and health. Recognition and support of the cultural heritage and significance of the river in relation to the Wurundjeri people and other Indigenous groups connected to the Yarra is vital for fostering respect and responsibility towards the river.

The Yarra Riverkeepers is a community organisation dedicated to the protection and restoration of the Yarra River and its surrounding environment, promoting advocacy, community engagement, habitat restoration, and collaboration. By promoting policies that protect water quality, biodiversity, and public access, while building community engagement with the use of events, workshops, and educational programs, Yarra Riverkeepers can raise awareness about the river's overall importance and build respect for the waterway. They also participate in habitat restoration projects, including planting native vegetation and restoring wetlands to improve biodiversity, working alongside local councils, other environmental groups, and government agencies to develop strategies for managing and protecting the river.

2.7.5 Sustainable practices

There are currently sustainable practices in place to protect and enhance the Yarra River which prioritise the protection of the Yarra River, as well as enhancing its quality. The implementation of green infrastructure, such as rain gardens and permeable pavements, assists in the management of stormwater runoff, reducing chances of flooding and pollution. Advanced wastewater treatment processes also exist to minimise the amount of pollution entering the river, and recycled water is used for irrigation and industrial purposes, minimising the demand on fresh water sources. Local organisations, including Yarra Riverkeepers, organise community clean up events to remove litter and debris, fostering a stronger sense of responsibility through the community.

3 Proposal

Our proposal is twofold:

- Raise awareness of effective indigenous practices for managing the Yarra River to broaden their use.

- Build community awareness and understanding of the cultural and spiritual significance of the Yarra River, including ways to interact with it.

4 Arguments to or for the proposal

4.1 Three Pillars of Sustainability Framework

The Three Pillars of Sustainability Framework was first used in the late 1980s. The three pillars, representing the environment, society and the economy, are used to understand sustainability. Each has a particular focus however all are intertwined. The environment pillar focuses on a commitment to protect the environment. The social pillar acknowledges social issues and aims to reduce social inequality by focusing on working together. The economic pillar considers ways to improve the standard of living and efficient use of assets for businesses and organisations to remain profitable [1].

4.2 Key proposal: Raising awareness and understanding

The key proposal for this investigation is to raise awareness of effective indigenous practices used in managing the Yarra River. A key feature is to build community awareness and understanding of the cultural and spiritual significance of the

Yarra River for the traditional owners who have safeguarded the river for thousands of years. Additionally, it is to educate and inform the community about the river's history and to promote respectful and sustainable engagement with it.

4.1 What approaches might be used?

In order to effectively raise awareness of indigenous practices for managing the Yarra River and build a deeper understanding of its significance, several approaches can be introduced and implemented. This includes social media campaigns and poster campaigns, alongside educational sessions and promotion of respectful and sustainable practices through local events.

4.1.1 Social media campaign

In our proposal we suggest creating a social media campaign to raise awareness, engage the community, and inspire action. Social media platforms such as Facebook, Instagram and TikTok are all commonly used social media that can create rapport and connect with a wide variety of target audiences.

The three key objectives for using a social media campaign would be:

1) Raise awareness about the significance of this river both culturally and historically especially for the Wurundjeri people and therefore its health and ecosystems.

2) Highlight key environmental issues concerning the river including pollution, habitat destruction and water management.

3) Promote actions in which the community can take to protect the river.

Different social media platforms would have different target audiences. Facebook is well-known to have a target focus of older generations. With a wide range of community groups, this platform would be key for community engagement, and promotion of local events, including initiatives such as river clean-ups or educational sessions.

Instagram, on the other hand, is more widely used by a younger audience. Use of this social media platform enables the spread of awareness among a larger group of people. Many Instagram-users are also heavily influenced by influencers on this social media platform. Having collaborations with local influencers and content creators on Instagram would also aid in promoting the campaign, and broadening knowledge and awareness of the river's health.

Finally, TikTok, with the content style of short videos, often involving trends, challenges or information can allow community-interaction and spread of knowledge through the implementation of challenges and eco-friendly trends or social movements.

Having a low-resource, high impact and time-effective social media campaign should result in many positive outcomes regarding the river, calling to action community members to raise awareness and promote action for the hopes of a healthier river.

4.1.2 Poster campaign

In our proposal we suggest creating a complementary poster campaign to raise awareness and educate the public about the importance of Indigenous practices in sustainably managing the Yarra River. This is the key focus and aim of the poster campaign. Good posters have clear themes, concise messages, and captivating visuals. The posters element of the campaign would send important messages and inform the audience of important facts.

Content would include the following:

1) local flora and fauna,
2) cultural significance,
3) indigenous stewardship and practices,
4) challenges to the community in terms of what they can do to implement and develop sustainable practices.

The four different posters would surface in high-traffic areas, where large numbers of people pass by. This includes picnic areas along the river, parks along the river, hiking/walking trails along the river, as well as well-visited places in the community, such as a train station or library. Along with their clear and concise message, these posters will have bright, but relevant coloured visuals and text to attract passers-by, with aspects that interact with viewers. A QR code would be incorporated with a link to either a website or a social media campaign where people can find more information. The posters could be interactive with the public, through surveys or challenges, for example, spot specific birds in particular area. This challenge would be a fun activity for participants, while also teaching them about the birds living in the area. QR codes could also link to citizen Science activities in the area.

This type of engagement with the community may foster community involvement, broaden knowledge about the Yarra River and raise awareness about the importance of Indigenous practices. This form of campaign would be a long-term project due to the number of resources needed to implement it. Money and time are both factors which would impact this form of promotion being a quick, short-term option.

5 Summary of arguments

Application of the Three Pillars of Sustainability Framework to the arguments and proposals suggests that while there is value to all proposal elements, a social media campaign (4.1.1) should be pursued in the short term.

When considering the environmental pillar of the Three Pillars of Sustainability Framework, raising awareness of indigenous practices is directly related to protecting and managing the environment. Using the lens of the social pillar, raising awareness acknowledges the importance of Indigenous knowledge and skills as well as their world view. Finally, considering the economic pillar, raising awareness of practices that improve the health of the Yarra River benefits communities living near the river and has the potential to reduce the economic impact of poor river health.

The key challenges relate to understanding and managing river health, and raising awareness and understanding of Indigenous knowledge, skills and practices in a culturally sensitive manner. A social media campaign can be wide ranging with minimal negative environmental impact. So while a campaign may have a small impact it would nevertheless be a valuable one for the environment.

As social media is easily accessible, there is more scope for individuals to learn about and acknowledge the importance of indigenous knowledge, skills, and world views, which in turn has the potential to build a sense of community spirit between different groups. Finally, it is envisaged that the simplicity of the campaign might provide more long-term benefits, including protection of neighbouring communities, the ecosystem and the waterway's health.

6 How can some of these challenges be overcome?

Understanding river health is one of the key challenges regarding a social media campaign to support the ongoing health of the Yarra River.

River health is a complex issue, due to the different aspects to river health and the many stakeholders and organisations involved. Stakeholders and organisations involved include local councils, residents of the area, the Yarra Riverkeepers and local Indigenous People. It would be important to consult with the different stakeholders to ensure information is accurate and messaging is supportive of the work currently being done.

One social challenge to raising awareness is being considerate and culturally sensitive to Indigenous knowledge and skills and world view. One way to minimise this is to actively consult with Indigenous Peoples to gain a better understanding of what needs to be known, understood and shared. If a campaign is to include an Indigenous perspective, then it is both respectful and important to ensure that Indigenous People are involved. This provides authenticity, as the campaign would be reflective of lived experiences, cultural heritage and the perspectives and the world view of Indigenous People.

7 Global Perspectives

The Yarra River, a vital waterway in Melbourne, can be compared to the Yangtze River due to its significance in shaping local economies and ecosystems. While the Yangtze is far larger, both rivers face similar environmental challenges, including pollution and the impact of urbanization on water quality.

7.1 The Yangtze River

The Yangtze River, Asia's longest and the world's third longest, spans over 6,300 km through China. It is crucial for transportation, agriculture, and energy production, particularly through the Three Gorges Dam. However, the river faces environmental threats such as pollution, habitat loss, and the effects of climate change [14].

7.1.2 Features of the Yangtze River

7.1.2.1 Source and path

The Yangtze River originates from the glaciers of the Tanggula Mountains on the Tibetan Plateau. It flows eastward for over 6,300 km across China, passing through diverse landscapes and major cities [14]. The river eventually empties into the East China Sea near Shanghai, marking its endpoint.

7.1.2.2 Uses

Transportation

The Yangtze River serves as a major transportation route, facilitating the movement of goods and people across China.

Agriculture

Its waters support extensive irrigation systems, enabling agricultural production along its fertile plains.

Energy

The river powers hydroelectric plants, including the massive Three Gorges Dam, providing crucial energy.

Tourism

Yangtze cruises attract visitors for scenic views and cultural exploration.

7.1.2.3 Flora and fauna

Fauna

The Yangtze River's ecosystem is rich in biodiversity. Key fauna include the critically endangered Yangtze finless porpoise and the Chinese alligator. The river also supports various fish species, including carp.

Flora

Flora along the Yangtze River's banks includes willow trees, reeds, and aquatic plants vital for maintaining ecological balance.

7.1.2.3 Name

The name "Yangtze" comes from the Chinese term "Yangzi Jiang" (扬子江), originally referring to the river's lower reaches. Over time, Western explorers adopted "Yangtze" to describe the entire river. In Chinese, the river is called "Chang Jiang" (长江), meaning "Long River," reflecting its immense length and importance in China.

7.1.2.4 Importance to the economy

The Yangtze River is economically vital to China, supporting agriculture, industry, and trade. Its fertile basin produces rice, grains, and fish, while its waters enable

shipping routes that connect inland regions to coastal cities. Additionally, the river powers hydroelectric plants like the Three Gorges Dam, contributing significantly to energy production.

7.2 Issues

The Yangtze River faces significant environmental issues, including severe pollution from industrial waste and agricultural runoff [15]. Habitat destruction and dam construction, like the Three Gorges Dam, have led to declining biodiversity. Additionally, climate change exacerbates flooding and droughts, threatening both the river's ecosystem and surrounding communities.

7.3 Comparison

Table 1. Comparison of the Yangtze River and the Yarra River.

Features	Yangtze River	Yarra River
Length	Over 6,300 km, known as the longest river in Asia	Approximately 242km, located in Victoria, Australia
Origin	Tanggula Mountains, Tibetan Plateau	Mount Baw Baw, Great Dividing Range
End Point	East China Sea, near Shanghai	Port Phillip Bay, Melbourne
Economic Role	Major trade route, significant role in agriculture and hydroelectric power	Major contributor towards local agriculture, tourism and recreation
Environmental Challenges	Severe pollution, habitat loss, climate impacts	Pollution, urbanisation pressures
Biodiversity	Endangered species (finless porpoise, alligator)	Native species (Australian grayling)
Cultural Significance	Central to Chinese history and civilisation	Important towards Melbourne's culture, social and economic development

7.4 Insights

The Yangtze River, over 6,300 km long, is vital for trade, agriculture, and hydroelectric power but faces severe pollution and habitat loss. It hosts endangered species like the finless porpoise. The Yarra River in Victoria, Australia, is 242 km long, supporting local agriculture, tourism, and recreation, but also struggles with pollution and urbanization. It is crucial to Melbourne's development and home to native species like the Australian grayling. Information about both rivers highlight the challenges of environmental degradation and the potential for sustainable management to preserve their ecological and economic roles.

8 Global learnings

From other countries, we can learn innovative pollution control methods, effective flood management strategies, and successful biodiversity conservation practices. Countries like the Netherlands excel in water management, while Singapore showcases advanced urban water recycling. Adopting these practices can help improve the health and sustainability of our rivers.

9 Global contributions

Investigating Indigenous practices can enrich our global perspective on waterways as vital life sources. Indigenous knowledge emphasizes sustainable management, respect for natural resources, and the interconnectedness of ecosystems. By integrating these practices, we can promote holistic water conservation strategies worldwide.

To share our findings, we can engage in different ways, including collaborations with schools and organisations nationally and internationally. Hosting conferences and workshops can also facilitate knowledge exchange. Additionally, leveraging digital platforms and social media can help disseminate insights broadly, fostering a global dialogue on sustainable water management. This approach can inspire collective action to protect our waterways.

10 Conclusion

There are several approaches that can be taken simultaneously taken to promote the awareness of the practices and significance of the Yarra River to the local community, including Indigenous People. Some recommendations offer quick, easy to implement actions. Other aspects of the proposal require long-term timelines and significant work with organisations, businesses and government.

When interrogated with the Three Pillars of Sustainability Framework, both positive and negative impacts were apparent for each argument, however the overall conclusion is that each of the proposals presented in this paper have valid reasons to be considered and implemented either in the short or long term. An ongoing social media campaign offers the possibility of a short timeframe to be implemented while a targeted poster campaign would require a longer timeframe. It would also be important to build on and connect with organisations and businesses where programs and actions are currently in place.

10 Acknowledgements

Thank you to Murrundindi, Ngurungaeta (Elder and Head Man) of the Wurundjeri people for his valuable insights and sharing of culture.

Thank you to Ms Anna Clarkson for her support and guidance with learning about indigenous practices and cultural significance.

Thank you to Mrs Debbie Henson for providing important insights into the Yarra River.

Thank you to our teacher in charge, Dr Charlotte Forwood for her mentoring.

11 Word count

5008 words

12 References

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A comparative study of water quality in the Yarra River and the River Thames

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2024

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Abstract

This research paper investigates the impact of water quality on aquatic organisms and the overall health of the Yarra River and the River Thames. The study highlights the increasing importance of addressing water quality issues, particularly in the context of the current climate crisis. Poor water quality due to water toxicity negatively affects the surrounding environment, leading to pest outbreaks, invasive species, decline of native animal population, and human health risks. Water samples were collected from three sections of the Yarra River—downstream, midstream, and upstream. Samples were tested for nitrate, phosphate, dissolved oxygen levels, temperature, pH, and turbidity. The results provided a water quality index to compare the Yarra River with other global water sources. The tests showed consistent pH levels, while turbidity and phosphate concentrations varied, indicating the complexity of water quality testing influenced by factors such as weather, temperature and rainfall. Comparisons with research on the River Thames revealed similar trends. Overall, the results demonstrate the strong relationship between water quality and aquatic life, highlighting the significant impacts of climate change and urbanisation.

Keywords: Yarra River, River Thames, water quality, pollution, health, pH, turbidity, phosphate, nitrate, marine life, conservation.

1. Introduction

A waterway is defined as a navigable body of water. In the context of this investigation, the waterway is the Yarra River, with a focus on the factors impacting the sustainability of its ecosystem. Urbanisation can be defined as the shift from a dispersed population toward one that increasingly resides in densely populated settlements in which non-agricultural economic activities are dominant [2].

1.1. Importance

Water is essential to all life, and the preservation of the water bodies is crucially important for sustaining healthy ecosystems and supporting urban development. The Yarra River starts at Mt Baw Baw in the Yarra Ranges National Park, and runs through a series of reservoirs, including the Upper Yarra Reservoir, a 750 hectare dam that has a catchment area of 33,670 hectares and can hold 200,579 megalitres of water. It is a protected area, meaning that people are not allowed to enter the reservoir, preserving the water quality. As the Yarra River stretches from rural Victoria to the city of Melbourne, it is crucial to identify the impact of human activities, specifically urbanisation, on this life source. The Yarra River, which supplies 70% of Melbourne's drinking water [1], faces increasing challenges from pollution, habitat destruction, and climate change. Understanding the relationship between water quality and the health of aquatic organisms is crucial for managing these impacts.

1.2. History

Spanning approximately 242 kilometres [3], historically the Yarra River has not only served as a crucial source of drinking water, but also continues to be a place of profound cultural and spiritual significance for Indigenous Australians. The Wurundjeri people of the Kulin Nation called it Birrarung, the river of mist and shadows. It sustained them with a valuable food source and was ingrained in their spiritual and cultural practices such as birthplaces and ceremonial and burial grounds. Green and verdant, it was the breeding ground for eels, and supported many species, such as dolphins, sharks, and stingrays [4].

In 1835, Tasmanian farmer John Batman claimed that he had purchased the river and the surrounding land. However, the Wurundjeri believed that he had been giving them these goods in exchange for passage on their lands. From then, the population boomed in Melbourne, especially when gold was discovered

along the river in 1859. The population grew to around 500,000 by 1860. This development caused problems with sewage and industrial waste contaminating the lower Yarra. Only 20 years after settlement, the river was declared undrinkable and became one of the world's dirtiest rivers, spreading diseases like diphtheria, dysentery, typhoid, and scarlet fever. It also gave rise to severe and regular flooding, the largest of which was 14 metres above normal. Currently, the impact of urbanisation on the lower sections of the Yarra is very evident. The water is a consistent muddy brown, and rubbish and litter are commonplace in and around the river. As of 2024, the river is unsuitable for swimming or drinking. After periods of heavy rainfall, sewerage overflows into the river, further polluting it. More action needs to be taken to improve the health of the Yarra River, for our health and also the animals and organisms living in and around the river.

Despite the effects of urbanisation, the Yarra is still highly diverse, thanks to the abundance of native plants and animals. One-third of Victoria's animal species are found along the river [1], including fish, birds, frogs, mammals, reptiles, bugs and insects. There is also a wide range of plant species, with 25 unique vegetation communities along the river [1].

As such, efforts to conserve, replenish and reroute the river are being made. These efforts focus on the revegetation and protection of the river, and raising community awareness. It is hoped that this will help reduce flooding and increase biodiversity. The Yarra Riverkeeper Association was founded in 2004 as part of the efforts to conserve the river. It is an independent community-based organisation that is actively involved in the conservation and protection of the Yarra River and its surrounds [3]. However, there is still much that needs to be done, and a large community effort is required to restore the Yarra to its previous state.

2. Research Aims and Objectives

The aim of this project is to assess the impact of water quality on the aquatic organisms and health of the Yarra River and to draw comparisons with the River Thames, in order to understand how urbanisation and environmental changes affect river ecosystems.

The research objectives are:

1. To collect and analyse water samples from the Yarra River (upper, middle, and lower) and evaluate key water quality indicators such as nitrate, phosphate, pH, turbidity, and dissolved oxygen levels.
2. To assess the impact of water quality on aquatic organisms in different sections of the Yarra River.
3. To compare the water quality and biodiversity of the Yarra River with the River Thames, focusing on the effects of urbanisation.
4. To evaluate patterns and link them to the local environmental factors.
5. To draw conclusions about the impact of urbanisation on water quality and provide recommendations for future river conservation.

The research questions are:

1. What is the relationship between water quality and biodiversity in different parts of the Yarra?
2. What can we learn about the relationship between water quality and organisms from a case study of the River Thames?
3. What are the similarities and differences between the organisms and chemicals in the Yarra and the River Thames?

3. Literature Review

In the study of "Microplastics in the Maribyrnong and Yarra Rivers" [5], the paper investigates the sources and impacts of microplastic pollution in Melbourne rivers. The research aims to provide an overview of how microplastics enter the waterways, their effects on the ecosystem and health, and approaches to improve our environment. To conduct this research, the author frequently references other studies and articles on microplastics and supplements this with their own experiments, such as using dried trawl samples to collect microplastics. This study highlights the seriousness of plastic pollution as a growing and urgent issue that cannot be overlooked. This study is particularly valuable as it closely aligns with our investigation and provides key insights relevant to our own research.

The study 'Escherichia coli concentrations and loads' [6] seeks to understand the relationship between E.coli concentrations and other pollutants by examining spatial and temporal patterns. Monthly data was collected between 1994-2010 from six sites, with additional weekly samples from 2005-2010 at twelve sites. The results indicated that both the median concentrations of E.coli and the variability increased moving downstream. The correlation between concentration and time was cyclical in the upper catchment due to climactic influences, but this pattern was not observed in more urbanised areas. This study contributed to our understanding of water quality trends along the Yarra River, particularly when viewed through the lens of E. coli distribution.

The YKRA 2023 Annual Report [7] and the 2022-25 Strategic Report [8] provide an extensive overview of the current state of many aspects of the Yarra River, including assessments of river health, pollution levels, fauna growth and wildlife populations. While the YKRA Annual Reports are primarily focused on actions taken to improve the health of the Yarra River, they also offer insights into river's current conditions, particularly the impact of recent floods on wildlife habitats and vegetation. Furthermore, the reports identified construction sites and the disposal of white goods as the leading contributors to polystyrene pollution in the river. These findings underscore the critical need for improved waste management practices, stricter industrial regulations and increased public involvement to protect the river's ecosystem. Restoration efforts, particularly those focusing on flood resilience, habitat recovery and pollution control, are crucial to the long-term health of the river. These reports were instrumental in guiding our understanding of the broader environmental challenges faced by the Yarra River.

In the research paper titled "Effects of climate and land use activities on water quality in the Yarra River catchment" [9], S.K. Das et al. examines how climate and land use activities affect nutrient and sediment loads in the Yarra River, aiming to inform effective catchment strategies to reduce runoff and sedimentation. Data was sourced from government agencies, such as the Bureau of Meteorology and the SILO climate database, along with measurements from sixteen statins along the river. The study utilises a relatively simple data analysis approach due to limited available data on Australian rivers. The findings show that total phosphorus, total nitrogen and total suspended solid were all higher during wet years compared to the dry years. The paper concludes that water quality and constituent concentrations are significantly influenced by both rainfall amounts and land use types, supporting similar findings in our study.

4. Methodological approach

The methodological approach in this case study involved the systematic collection and analysis of water samples from three distinct sections of the Yarra River—downstream, midstream, and upstream from Melbourne. These samples were tested for key water quality indicators, including

nitrate, phosphate, dissolved oxygen levels, temperature, pH, and turbidity, which provided a quantitative basis for assessing water quality. The data collected was used to develop a water quality index, enabling comparisons with other global water sources, including the River Thames. This approach allowed for a detailed understanding of the relationship between water quality and the health of aquatic ecosystems, particularly within the context of urbanisation and climate change.

5. Findings

Water quality testing was carried out at three sites along the Yarra River, Upper Yarra (Warburton), Middle Yarra (Warrandyte), and Lower Yarra (Studley Park). Key water quality indicators measured were nitrate (mg/L), phosphate (mg/L), dissolved oxygen (% sat.), turbidity (NTU), pH, and temperature (°C).

5.1. Nitrate and Phosphate Levels

Nitrate and phosphate levels reflect the concentration of key nutrients in the water, which are essential for plant growth but can become problematic when present in excess. High levels of nitrate and phosphates indicate nutrient enrichment (eutrophication), commonly resulting from agricultural run-off, urban wastewater, and industrial discharges [10].

From the data collected at Warburton, total phosphate levels were recorded at a relatively high 0.40 mg/L, while nitrates were measured at a normal level of 1.1 mg/L. This high value could be because of recent rains that caused an influx of fertiliser and waste from nearby farms. In Warrandyte, total phosphate levels were much lower at 0.09 mg/L, with nitrates at 0.7 mg/L. At Studley Park, total phosphate levels were similar at 0.15 mg/L, while nitrates remained consistent at a low value of 0.7 mg/L. Overall, the nutrient data across the three sites indicate varying concentrations of nitrates and phosphates.

Online data reveals that the results for the total nitrogen and phosphorus levels had similar trends, with the phosphate levels <0.1 mg/L and nitrate levels around 1-1.5 mg/L over the years 2000-2005 [11].

5.2. Dissolved Oxygen (DO)

Dissolved oxygen (DO) levels are an important measure of water quality as they indicate an aquatic resource's ability to support aquatic life. Low DO saturation levels can lead to a lack of aquatic life in the region, as many species are unable to survive on low water oxygen levels in the water. Elevated DO saturation levels can also result in the death of fish and invertebrates, from gas bubble disease [12].

From the data collected onsite, DO levels were all measured to be in the usual range, with saturation percentages of 105%, 108%, and 100% at Warburton, Warrandyte, and Studley Park respectively. As a whole, DO saturation levels remained relatively consistent throughout the three sections of the Yarra that were tested and within acceptable limits for aquatic life.

Online sources have revealed that the DO is within the range of values from 63.47%-123.01% found in the Waterwatch Data Portal. However, it is above the means found in data collected across 2017-2022 [13].

5.3. pH

The pH of a solution measures how acidic or alkaline it is. pH affects the nutrient uptake by plant roots, the solubility of heavy metals, and concentrations of dissolved solids. A pH outside of the normal range of 6.5 to 8.5 causes stress to organisms, and in extreme cases, death. Many factors affect pH, including rainfall, temperature, algal growth, and pollution [14].

The data collected onsite measures the pH levels to be within acceptable ranges. The pH was shown to be 7.85, 7.45, and 7.3 at Warburton, Warrandyte, and Studley Park respectively. Overall, the pH levels were fairly consistent and

were well within acceptable limits for aquatic plants and animals.

Data from online sources shows similar results, with ranges from 7.0 to 7.9. The Yarra River Water's water quality reports from Warburton had a mean of around 7.1 in 2023. Results from suburbs near Warrandyte such as Doncaster and Eltham showed a mean of around 7.4, and Kew (Lower Yarra) also had a mean of 7.4.

5.4. Turbidity

Turbidity is often used as an indicator of the total amount of material suspended in the water (total suspended solids). Turbidity can indicate the presence of sediment that has run off from construction, agricultural practices, logging or industrial discharges. High turbidity harms aquatic life by reducing food supplies, degrading habitat, and impairing fish activities. This high turbidity level suggests that land use activities in the catchment (e.g. agriculture, construction etc.) have a significant impact on the waterway.

The data collected onsite measured the turbidity to be excellent in Warburton and within acceptable ranges in Warrandyte and Studley Park, with values of <9, 27, and 24 NTU respectively [15]. This is consistent with findings online, where the Waterwatch Data Portal revealed a maximum of 80 NTU, with a minimum of 3 NTU, and the values to be relatively high when compared to the interquartile range of data from 2022-2023 [14].

5.5. Temperature

Water temperature significantly influences the physical, biological, and chemical dynamics of a water body. Warmer waters reduce oxygen solubility, and accelerate eutrophication, leading to species loss as certain organisms only thrive under extremely tight conditions.

Our data shows that the water temperatures were 8.7°C, 10.6°C, and 10.9°C at Warburton, Warrandyte, and Studley Park respectively. This is consistent with measurements from similar seasonal periods across the years, with measurements of the water temperature to be around 9 to 12°C [14].

Table 1 Water Quality Index Ratings

WQI Rating	
90 – 100	Excellent
70 – 90	Good
50 – 70	Medium
25 – 50	Poor
0 – 25	Very Poor

Table 2 Site 1, Warburton

Test	Results	Q value	Weighting factor	Subtotal
Temperature (°C)	8.70	57.00	0.11	6.27
pH	7.85	85.00	0.11	9.35
Turbidity (NTU)	4	97.00	0.08	7.76
Dissolved Oxygen (% sat.)	105.07%	95.00	0.17	16.15
Total Phosphate (mg/L PO_4^{3-} P)	0.40	92.00	0.10	9.20
Nitrates (mg/L NO_3- N)	1.10	73.00	0.10	7.30
Total Solids (mg/L)	445.00	42.00	0.07	2.94
5-Day BOD (mg/L)	9.40	35.00	0.11	3.85
Faecal Coliform (CFU/100mL)	140.00	41.00	0.16	6.56
			WQI RATING	**69.38**

Table 3 Site 2, Warrandyte

Test	Results	Q value	Weighting factor	Subtotal
Temperature (°C)	10.6	44	0.11	4.84
pH	7.45	92	0.11	10.12
Turbidity (NTU)	27	53	0.08	4.24
Dissolved Oxygen (% sat.)	109.07%	95	0.17	16.15
Total Phosphate (mg/L PO_4^{3-} P)	0.09	98	0.10	9.80
Nitrates (mg/L NO_3- N)	0.7	80	0.10	8.00
Total Solids (mg/L)	445	42	0.07	2.94
5-Day BOD (mg/L)	9.4	35	0.11	3.85
Faecal Coliform (CFU/100mL)	140	41	0.16	6.56
			WQI RATING	**66.50**

Table 4 Site 3, Studley Park, Kew

Test	Results	Q value	Weighting factor	Subtotal
Temperature (°C)	10.9	44	0.11	4.84
pH	7.3	92	0.11	10.12
Turbidity (NTU)	24	62	0.08	4.96
Dissolved Oxygen (% sat.)	100.07%	100	0.17	17.00
Total Phosphate (mg/L PO_4^{3-} P)	0.15	98	0.10	9.80
Nitrates (mg/L NO_3- N)	0.7	80	0.10	8.00
Total Solids (mg/L)	445	42	0.07	2.94
5-Day BOD (mg/L)	9.4	35	0.11	3.85
Faecal Coliform (CFU/100mL)	140	41	0.16	6.56
			WQI RATING	**68.07**

6. Discussion

6.1. Comparison between the three Yarra sites

Across the three sites that were tested, varying results were collected, some of which were surprising. For instance, Warrandyte, which was expected to have better water quality due to its upstream and less urbanised location, showed worse results than expected. On the other hand, Studley Park much closer to urban areas, performed better, obtaining a WQI rating of 68.07 compared to 66.50 at Warrandyte. This result challenged our initial thoughts on the changes in water quality throughout the Yarra, indicating that pollution sources and their impacts may be more complex than initially considered. The temperature of the water also could also affect results. When testing was conducted at the first site, it was early in the morning and the water temperature was 8.7°C, which changed as the day went on, increasing to 10.9°C by the last site. Temperature changes the water's ability to hold dissolved oxygen. An increase in temperature means that less organisms are able to survive in large populations, as there would not be enough oxygen.

6.2. Limitations of our methodology and study

However, upon reflection on this research, there were several areas where improvements could be made for future studies. One unexpected outcome was the water quality between the sites. Moreover, we faced challenges converting the results into Q-values, a quantitative assessment of water quality that provides a numerical score, allowing the results to be interpreted easier [16].

Different sources provided different Q-value results, making it difficult to assess which one is the accurate measurement. Furthermore, the collection of results was conducted over a single day, which presents limitations as to whether the water quality measurement was accurate or valid. This approach oversees and excludes the possible variables and external factors, such as rainfall or temperature fluctuations that might affect the water quality on other days. For example, heavy rainfall on the previous day probably led to increased runoff, which likely altered the levels of phosphate, nitrate and turbidity. By relying on data collected from just one day, the results were less accurate and reliable. To obtain a more comprehensive understanding of the Yarra's health, future studies should collect data over multiple points throughout different seasons and weather conditions. This would provide a clearer picture on the river's water quality and how various environmental factors influence the river over time.

We also encountered limitations in collecting data for certain quality indicators, which prevented obtaining complete results for every parameter at each water site. To address this, we estimated the Water Quality Index by gathering the missing values from external sources and standardising these values to all three sites. This allowed us to supplement the missing data by applying realistic and reasonable values, making sure that we could still calculate a WQI for each site. Although this solution is viable, it brings a degree of uncertainty into the results, as the estimates may not perfectly reflect the true water conditions and thus providing the true WQI along the Yarra. Future studies should aim to directly measure these missing values to obtain more accurate and reliable WQI calculations.

Another challenge we faced during the collection of our data was measuring the turbidity. The turbidity tube we were provided could only detect values as low as 9 NTU, but the turbidity at Warburton appeared lower than what our tube can measure. Therefore, we estimated the turbidity to be around 4 NTU for the best-case scenario. For the worst-case scenario, we assumed the value to be closer to 8 NTU. Future studies should implement a more reliable and accurate method to measure turbidity, such as an electronic turbidimeter, which not only provides readings below 9 NTU, but also eliminates the risk of human error in interpreting and reading the values from a turbidity tube.

6.3. Comparison of the Yarra River to the River Thames

The River Thames was chosen for this study due to its similarities with the Yarra River in terms of its geography and the impact of urbanisation. Both rivers flow through major cities, Melbourne and London, and have undergone significant industrial development, pollution, and environmental challenges. However, the River Thames, once declared biologically dead in 1957 due to the impacts of post-World War Two industrialisation and urban expansion, has since undergone incredible recovery [17]. Examining the Thames offers insight into how heavily polluted urban rivers can be rehabilitated and provides valuable lessons for the future restoration of the Yarra River.

From data collected online, the River Thames maintains relatively stable and similar pH levels around neutral (7.3 - 8.0). A neutral pH level helps ensure that most aquatic species can thrive, as extreme pH conditions could disrupt metabolic and reproductive functions in aquatic organisms. However, while the upper and lower sections of the River Thames exhibit low turbidity levels between 12-17 NTU [18], the middle section, in central London, shows significantly higher turbidity values exceeding 240 NTU. For reference, a turbidity value over 100 NTU is unsafe for most aquatic life [19]. Compared to the values collected from the Yarra River (ranging from 4 to 27 NTU), the significant difference suggests the extreme pollution or environmental challenges the River Thames is facing especially in Central London. However, such high values might vary depending on the weather conditions, especially

after rainfall, due to stormwater and road run-off. The Thames was also found to have high phosphorus levels, averaging 0.99 mg/L PO_4-P with a maximum of 6.70 mg/L PO_4-P, particularly in relation to urban areas where effluent discharge was a significant source [20] . With the data obtained from the Yarra, averaging around 0.21mg/L PO_4-P, there is a clear difference in the amount of phosphorus between the two waterways. An excess in the amount of phosphorus in a river body can lead to nutrient enrichment, which promotes the growth of algae and plants in the water [21]. This process, known as eutrophication, can have detrimental effects to the quality of the water as the overgrowth of algae consumes oxygen and blocks sunlight, leading to hypoxic conditions that threaten aquatic life. Moreover, for most fish to thrive, the water they live in must contain at least 4-5 milligrams of dissolved oxygen per litre (mg/L) [22]. Measurements taken during the 1950s showed that dissolved oxygen (DO) levels in the Thames were at just 5% saturation: the rough equivalent of 0.5 mg/l. This meant the river could only support a few aquatic lives such as midges and fly larvae [17].

Bombings across the city during World War Two destroyed parts of the network, allowing raw sewage to enter the river once again. In addition, as the Thames widens and slows through central London, fine particles of sediment from its tributaries settle on the riverbed. This created a highly contaminated aquatic environment that was inhospitable to most marine life, contributing to the river being declared biologically dead by 1957 [17]. However, the recovery of the Thames commenced soon after World War Two through a series of large-scale restoration efforts [23]. Over the following years, improvements in waste management and the construction of modern sewage treatment plants significantly reduced the discharge of untreated sewage. Additionally, the Port of London Authority and London County Council adhered to stricter regulations that were introduced to control industrial waste and limit the release of pollutants into the river [24].

Environmental groups such as Thames21 play a crucial role in restoring habitats, cleaning the river, and raising awareness about its importance. The Clean Thames Plan (2024-2030) [25] focuses on tackling key environmental challenges affecting the River Thames. It aims to reduce pollution from stormwater run-off, untreated sewage, plastic waste, and microplastics, which continue to impact the river's health. Ongoing projects such as the Thames Tideway Tunnel aims to address sewage in the Thames by capturing the sewage from these overflow points and redirecting them to pre-existing treatment plants. This project began construction in 2015, and aims to be completed by 2025, with a total cost of £4.2 billion [26]. The plan also addresses climate change, promoting nature-based solutions like wetland restoration and floodplain enhancement to fight against rising temperatures and increased flooding risks.

The Thames provides critical lessons for the Yarra River, particularly the importance of infrastructure investment such as modern sewage treatment and stormwater management systems, to prevent untreated waste from entering the water. Projects like the Thames Tideway Tunnel [27] demonstrate how large-scale infrastructure can effectively address pollution issues. Another key takeaway from the Thames is the importance of community involvement. Initiatives led by community groups like Thames21[28] have proved to be successful in raising public about restoration efforts, educating local communities on the importance of preserving the river, and organising large-scale clean-ups. Engaging Melbourne residents in similar community efforts would help foster a sense of ownership and responsibility toward the Yarra. The Thames serves as a powerful example that the Yarra River too can be preserved for future generations.

7. Conclusion

Currently, the Yarra River's health status reflects a challenging scenario: while certain indicators are within acceptable ranges, persistent nutrient enrichment and turbidity levels indicate ongoing threats to its ecological integrity. Our research has shown that the relationship between water quality and organisms in different parts of the Yarra River is significant through the variability in key water quality indicators across the Upper Yarra (Warburton), Middle Yarra (Warrandyte), and Lower Yarra (Studley Park). Nitrate and phosphate levels, dissolved oxygen saturation levels, pH, turbidity, and temperature all suggested that higher nutrient levels contribute to the risk of eutrophication, which disrupts the delicate ecological balance in the Yarra River. There is a clear connection between water quality and biodiversity. Areas with increased pollution levels impact biodiversity, underscoring the importance of efforts to protect and preserve the Yarra River as a vital waterway.

8. Acknowledgements

We would like to thank our teacher-mentor, Ms Georgia Bellchambers, our Sustainability Coordinator, Ms Jo Menzies and our student mentor, Ivan Zhang, for their unwavering support and dedication to our research, without which this project would have been impossible. We would also like to thank Mr Raphael Johns, who provided us with the devices and equipment that allowed us to conduct our research. No conflicts of interest have been declared by the authors.

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Urbanisation and the Effects of the Yarra River

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Abstract

This research investigates the environmental consequences of urbanisation on the Yarra River, focusing on its historical importance, current uses, and the pressures exerted by Melbourne's rapid population growth. Key issues explored include pollution, water scarcity, land clearing, erosion, declining water quality, and salinity. Drawing on interviews with Environmental Protection Agency (EPA) officials and an analysis of current interventions—such as litter traps, stormwater management, and government policies—the study evaluates the effectiveness of existing solutions. Proposed future strategies, framed within the Sustainable Development Goals (SDGs), include innovative urban design and the creation of man-made creeks, with attention to their strengths and limitations. This research emphasises the need for sustainable urban planning that preserves the ecological integrity of the Yarra River.

Keywords

Waterway, urbanisation, runoff, salinity, erosion.

1 Introduction

With 90% of Australians living in urban areas and a 73% increase in national migration from 2022 to 2023, Melbourne, the country's most densely populated city, faces growing environmental challenges. [1] [2] Central to Melbourne's ecosystem is the Yarra River, a waterway of significant historical and current importance. However, rapid urbanisation has intensified the strain on this critical resource, leading to issues such as: pollution, water scarcity, land clearing, erosion, and declining water quality and salinity. Existing interventions — litter traps, stormwater management systems, and various government policies — have been implemented to mitigate these pressures. This research aims to evaluate the effectiveness of existing interventions and explore future strategies, drawing on Sustainable Development Goals (SDGs), to ensure the Yarra River's ecological sustainability amidst the pressures of rapid urbanisation.

1.1 History of the Yarra River

Indigenous Australians belonging to the Kulin nation, particularly the Boonwurrung and Wurundjeri people were the first to settle alongside the Yarra River [3]. Named the Birrarung, of "the river of mists and shadows" [4], the Yarra river was particularly isolated from the outside world and was not known to have any foreign contact until the exploration of the British into Victoria. Charles Grimes, Acting Surveyor General of New South Wales in 1803, in which he named it the "Freshwater River" and stated that it was "the most eligible place for a settlement that [he] [has] seen" as it boasted some of the most environmentally rich systems of resources " [4].

Thirty-two years later, the "Rebecca" revisited the Yarra river as part of an exploration party on behalf of the Launceston-based Port Phillip Association in 1835 [5]. Surveyor John Wedge in his contact with the local aborigines questioned them about the name for the cascading waters on the lower river, in which they replied the "Yarro Yarro", meaning "it flows". However, Wedge misinterpreted the word as the name of the river, thus coining the Yarra River. In 1835 George Evans in the "Enterprise" aimed to settle alongside the Yarra and began construction along the south bank [5]. Through the 1830s, fertile land based around several waterways (with the most prominent being the Yarra River) created a large influx of immigrants, and almost 200 European farmers and sheep herders had settled on the rivers bank by the end of the decade.

The gold rush made the Yarra river the biggest hub of settlers in Victoria. Victoria was soon industrialised, though at a cost; as the city grew to house 500,000 by the late 1850s, the lack of proper sewage systems made the Yarra River one of the worst polluted rivers at the time, spreading diseases such as diphtheria, dysentery, typhoid and scarlet fever and emptied the supply of clean drinking water [6].

However, as the Victorian Gold Rush died down at the end of the 19th century and the city built around the Yarra became more of a functional city, more companies took

hold of the practical income sources of Melbourne and in 1897, the Werribee farm was created as a way to treat the sewage and waste of the river [6].

1.2 What is the Yarra River Used For?

The Yarra River is an integral part of the culture and economy in Victoria and is used for a multitude of purposes. The most predominant of which are for drinking water, transportation, leisure/recreational activity, and cultural practices.

The majority of Melbourne's drinking water is sourced from the Yarra River as the river provides on average 70% of the 1250 million litres of water supplied to Melburnian households daily. Furthermore, the Yarra River stretches all throughout Victoria as it starts from Mount Baw Baw and ends in Port Phillip Bay in the Melbourne Central Business District (CBD). Therefore, many shipments are transported along the river usually directed towards the Port of Melbourne [6].

The freshwater streams and tributaries of the Yarra River are also incorporated into irrigation systems particularly in the Yarra Valley region.

The most common use for the river is for leisure and recreational activities. Bikers, runners, and people going for casual walks utilise the Yarra River Trail, which is a path that stretches alongside the majority of the main Yarra stream through the most populated suburbs [7]. Fun runs, marathons, and a myriad of similar events occur along this trail. Large scale celebrations like the Moomba Festival/Birdman Rally, also occur adjacent to the river.

Water sports are by far the most prominent activity on the Yarra River, stand up paddle boarding, rowing, canoeing, kayaking, and even swimming in the areas clean enough are the most common sports that take place on the river. The Mercantile Rowing Club and the University Boat Club are the most well-established boating clubs in Melbourne with deep historical roots, both of which mainly operate on the Yarra River. Smaller clubs for the other water sports have also been placed either near large stretches of flatwater or by small rapids depending on their requirements [6].

Fishing is similarly a common activity on the Yarra River. Despite this, most fishing activity is independent and recreational, as there isn't large scale fishing industries connected to the Yarra.

Finally, the Yarra River has a lush history and is interconnected deeply with many Indigenous spiritual processes, stories and culture. Therefore, it is still used by the traditional custodians for numerous practices and is frequently maintained and managed by the traditional custodians as well [8].

1.3 Who uses the Yarra River?

The Yarra River underpins many communities and industries that utilise the river for various purposes. Though, the original custodians of the river have managed, maintained, and used the river for approximately seventy thousand years. The Wurundjeri, Boon Wurrung, Watha Wurrung, Daung Wurrung, Dja Dja Wurrung people, who together make up the Kulin Nation, were returned responsibility of the Yarra River in 2017 [9].

Since the Yarra River is a cornerstone of a significant portion of ecosystems throughout Victoria the river is often monitored and utilised for ecological research by numerous universities and institutes, including the University of Melbourne and La Trobe University [10].

The river also underpins many industries, such as the tourism sector which profits off the river as an attraction, with kayak tours, boat tours, and scenic river cruises, as well as waterfront activities and hotels. Small fishing businesses have been established upstream of the river, and the Yarra Valley Wine industry is a booming sector in Melbourne aided by the river's natural resources.

Although, overall, the Yarra River has a myriad of stakeholders, especially since different councils have their own policies and management plans for the Yarra River, the Banyule, Nillumbik, Whittlesea and Yarra City are the main councils that have responsibility over management of the river [11].

1.4 Urbanisation in Melbourne

This paper defines 'Urbanisation' as the process through which cities grow and expand, and the proportion of people living in towns and cities increases. This movement occurs because people move from rural areas (countryside) to urban areas (towns and cities) when a country or region is developing.

Melbourne's population in 2024 is estimated at approximately 5.3 million, and it is projected to surpass 6 million by 2030, making it Australia's fastest-growing city. This rapid growth is largely driven by international migration and is expected to continue at an annual rate of around 1.4% as migration rebounds post-pandemic [12].

The city's ability to balance growth with sustainable urban development significantly impacts its social and environmental landscape, including critical areas like the Yarra River and green spaces.

The rate at which urbanisation is occurring can be slowed down, according to Dr Melissa Neave Senior Lecturer Discipline of Sustainability and Urban Planning at RMIT. In an online questionnaire, Neave stated, "in my personal opinion it is certainly possible to slow urbanisation along the Birrarung, but this will only happen if governments (state and local) work together to implement a systematic plan to protect river-adjacent landscapes. There is immense pressure from developers to build on these areas for financial gain and people understandably want to take advantage of the natural beauty provided by the river landscape so want such buildings to occur. There needs to be legitimate land controls in place to ensure this. This can be done, and we do see it occur, but if governments are not actively invested in the process, then it will not happen."

2 Methodology

'How does urbanisation effect the Yarra River?' is the research question we based our paper around. We started the process with a Design Thinking session where we used the UN Sustainable Development Goals to guide the iteration stage. Through the workshop, our group had a greater sense of what interested us within the theme of waterways. This led to the focus on the impacts of urbanisation on the Yarra because the Yarra River is so intertwined with Melbourne's growing economy, population, and culture and we are all students living in this city, near the Yarra River. Pollution arose as a recurring focal point when discussing the main effects of urbanisation, so it naturally became a central theme in the paper.

The development of a research question aided in narrowing down our main points of research, despite being a broad question. As there was a plethora of potential solutions that could be proposed for issues relating to urbanisation, we decided to identify some groups and individuals in our community with a deep understanding of the topic. We wanted to know what realistic solutions there were for the communities to implement. We emailed questions to local councillors to get their expert advice.

September, when our last stages of research were taking place we discovered the month long event 'Birrarung Riverfest' through the Yarra Riverkeeper website, which was a source of much of our initial research. We attended a Riverfest event held by the EPA (Environmental Protection Authority) Pollution Patrol team to help with our research on potential solutions.

3 Effects of Urbanisation

Urbanisation is contributing to an array of serious issues pertinent to the Yarra River. According to the official Yarra River organisation, in the Lower Yarra the establishment of huge apartment buildings is the most obvious problem as well as the cumulative impact of many developments on single home sites [13]. Some of the consequences of properties and roads near the rivers are road run-off. This is acute after storms and floods, contributing to pollution, water degradation, altered hydrology and higher counts of bacteria found within the water [14].

In the upper bound of the river, the problem is that indigenous vegetation is being cleared to make way for expanding suburbia, infrastructure, new golf courses, which is resulting in severe problems for the waterway. This results in the destruction of native vegetation and habitat fragmentation [13]. Riparian vegetation is the ecosystem immediately adjacent to a river, and it filters runoff that would otherwise flow straight into the river. That runoff, particularly in urban areas, often contains a lot of pollutants and the riparian vegetation can help to trap those pollutants. The riparian vegetation also plays a critical role in helping to protect the riverbanks from erosion. Riparian vegetation has the added benefit of providing habitat for organisms, some of which also live in or engage with the river [15].

3.1 Run-off

Runoff is described as the flow of water across earth when there is more water than land can absorb. The excess liquid flows across the surface of the land and into nearby bodies of water like rivers, streams, or creeks [16]. Runoff can occur either through natural or human-made processes.

As Melbourne develops and becomes more urbanised with infrastructure replacing forests and meadows with buildings and pavement, runoff is becoming a large-scale issue for the Yarra River. While certain measures exist to mitigate exposure to contaminated water bodies, it has been noted that "manmade filtration systems to control runoff have not compensated for the loss" [14].

Without any vegetation the water cannot be absorbed through the soil and filtered or evaporated off leaves through transpiration. Instead, it runs off hard surfaces like roofs and driveways into the street. Runoff picks up pollutants and toxins such as trash, dirt, faecal bacteria, viruses, and other pathogens as well as nitrogen and phosphorus, oil, pesticides, toxic metals and microplastics. This makes its way untreated through storm drains and ditches to streams, rivers, lakes and the ocean where it can cause erosion, harm aquatic life and those who use the water recreationally or as a drinking source [14].

In natural environments such as forests and fields, only 10 to 20 percent of precipitation results in runoff, with the remaining water being absorbed by soil and vegetation, where it is filtered before reaching aquifers or local

waterways. In stark contrast, nearly 100 percent of rainfall on impervious surfaces generates runoff, exemplified by the fact that one inch of rain on one acre of hardened surface can produce approximately 27,000 gallons of runoff. [14].

3.3 Water Scarcity

In just the past 10 to 15 years it is projected that the amount of water flowing into various still bodies of water, such as wetlands and lakes has declined by 21%. This is linked to a global trend showing that the essential resource, water, is becoming increasingly scarce [17].

Since the Yarra River supplies most of the drinking water in Melbourne, lower water levels and irresponsible water wastage have become hot topics of discussion in recent years .

Specifically in Southern Victoria, the over-extraction of water causes environmental damage which leads to a chain reaction of negative impacts on local ecosystems further deteriorating the health of the river.

The issue of water scarcity predominantly stems from climate change. Australia is prone to periods of drought, which is natural, but dry periods have been significantly exacerbated by global warming. During the months of September to November, characterised as the 'wet season' in Victoria, waterways like the Yarra River are usually replenished naturally. However, Victoria's annual rainfall is estimated to have fallen by 11% from the 1990's [17].

Furthermore, climate change also results in intensified weather events, which causes flash flooding in the Yarra River. This in turn disturbs sediment, erodes banks, and impacts ecosystems. The floodwater is also likely contaminated by sewage and other pollutants [6].

Therefore, many of the uses of the Yarra River would have to be halted. A significant amount of pressure would also be placed on water treatment plants to ensure that clean drinking water can still be supplied to households, and for livestock.

Melbourne relies heavily on the Yarra River because it is an easily accessible, surface reservoir, of freshwater. So, if damage and pollution cause the Yarra River to continue deteriorating, Victoria's water scarcity issue would be massively amplified, and many communities could struggle to cope.

3.4 Erosion of the Yarra river

The Yarra river used to run clear, but due to the lack of proper maintenance and the increase of urbanisation destroying fine silts and riverbeds of the Yarra river; the Yarra river is now suspended with clay and other sediments [18]. Due the increase of human settlements, the Yarra river, which used to periodically flood in the "wet season" and clear sediments and precent the growth of algae in large environmental water releases onto the riverbanks, had had its ability to naturally flood and clear debris taken away by the growing population of Melbourne, making the river incredibly dirty [6].

This is problem is exacerbated by the fine sediment and rocks knocked into it through the urbanisation of the riverbanks surround the Yarra river with the middle and lower sections of the Yarra, as the use of groundwater for irrigation and agricultural uses in those sections cleared for agriculture and industrial development erodes the riverbanks even further [19] [6].

3.5 Salinity

Salinity is the measure of how much salt is dissolved is the water. The Yarra River varies distinctly in measures of salinity throughout. This is because of the sheer distance the river covers and because it flows into Port Phillip Bay.

So, in lower areas of the river the salinity levels on average are generally between 0.1 and 35 ppt. Although, a freshwater river should have an average salinity of 0.5 ppt [6].

Due to urbanisation, upstream sections of the river frequently demonstrate abnormally high levels of salinity. Contamination from stormwater and run-off causes pollutants to enter the water disrupting its natural salinity. Fertilisers, household chemicals, and road de-icing salts are the main contributors to the issue.

Periods of drought and low water levels also cause salt contents in the water to become more concentrated, so as climate continues to result in extended time periods of exacerbated drought the salinity of the river will continue to rise but also become more inconsistent throughout the year [23].

The Yarra River also plays an integral part in supporting the agricultural industry in the Yarra Valley region. Though, this has made the river more exposed to chemical pollutants from pesticides and fertilisers. Excessive irrigation practices are also becoming increasing common to cope with Victoria's rapidly increasing population, this can leech vital nutrients from the river, and causes salinity levels to increase and become unbalanced.

The rapid changes to the salt content of the Yarra River gives organisms no time to adapt. Many ecosystems are crumbling because their species cannot survive in certain areas with increased salinity anymore, and this causes a chain reaction that results in the overall deterioration of the river's health [13].

4 Current Solutions

The current solutions to promote the health of the Yarra River focus on three main areas: government policies and regulations, community engagement, and technological innovations such as litter traps and storm water drains.

4.1 Government Policies

The Yarra River Protection (Wilip-gin Birrarung murron) Act 2017, enacted by the Australian Government, recognizes the river as a living entity, acknowledging its natural, cultural, recreational, and community significance. [24] This legislation enforces strong conservation measures and involves several key actions. First, it established the Yarra Strategic Plan, a long-term framework to guide the management and protection of the river and its surrounding lands. It also introduced the Birrarung Council, an independent body responsible for advising the Victorian Government on protecting and improving the Yarra River and its parklands. The Act outlines principles public entities must follow to promote environmental sustainability, cultural respect, and intergenerational equity. Additionally, the Act recognises the cultural significance of the Yarra River to the Wurundjeri people and other Indigenous communities, ensuring their knowledge and values are respected in decision-making processes [24].

Building on this, the Yarra River Action Plan (2017) serves as a comprehensive strategic document outlining specific actions to improve the river's health in the short and long term [25]. Of the 30 prescribed goals, 15 have already been achieved, including the implementation of the Yarra River Protection (Wilip-gin Birrarung murron) Act 2017 and the creation of a 50-year community vision developed with input from thousands of Victorians.

Another significant initiative was the Stormwater Strategy (2013-2018), developed by Melbourne Water to address the impacts of urban and rural runoff on the river. When rainfall runs off hard surfaces, stormwater can enter waterways faster and in larger volumes than natural ecosystems can tolerate, harming native vegetation and habitats [21] The strategy aimed to mitigate these effects by incorporating water-sensitive urban design, developing regional drainage and floodplain infrastructure, and following environmental protocols such as the State Environment Protection Policy (Waters of Victoria).

The outcomes of the Stormwater Strategy were considerable. It resulted in improved water quality, reduced pollutants such as litter, oils, and sediments entering the river, and increased the use of stormwater for non-drinking purposes like irrigation and industrial applications. Stormwater treatment systems, including wetlands and raingardens, were implemented to filter stormwater before it entered the Yarra and other nearby water bodies. Additionally, the strategy encouraged stormwater reuse, alleviating demand on potable water supplies and managing excess runoff [21].

The strategy also improved flood risk management by upgrading stormwater drainage systems and implementing flood-sensitive urban designs, such as detention basins and constructed wetlands, reducing the risk of urban flooding, especially in areas with inadequate drainage. Erosion control efforts along the Yarra's banks helped reduce damage to riparian vegetation, supporting the restoration of native plant habitats and wildlife corridors [21].

Overall, Melbourne Water's Stormwater Strategy promoted the sustainable use of water resources and aligned with broader Sustainable Development Goals (SDGs), such as clean water, sustainable cities, and climate action. These initiatives contributed to Melbourne's efforts to create a more sustainable urban environment and preserve the ecological integrity of the Yarra River [21].

4.2 Environmental Protection Authority

The Environmental Protection Authority (EPA) Victoria is integral to protecting the Yarra River's health through a range of regulations, monitoring, and enforcement activities. [26] The primary mission of the EPA is to mitigate the effects of urban runoff and industrial discharges into natural waterways. By implementing stringent regulations and conducting regular assessments, the EPA aims to minimize ecological footprints and promote sustainability throughout the region. Their efforts are essential for maintaining water quality and ensuring the river's ecosystem thrives amid urban development pressures [27].

4.3 Community Engagement

Melbourne's community has played a vital role in improving the health of the Yarra River through initiatives like Clean Up Australia Day and the Yarra Riverkeeper Association, which focuses on litter removal and water quality monitoring. [28] Clean Up Day is an annual event designed to encourage community participation in cleaning and reducing pollution in local areas, including waterways like the Yarra River. This event mobilizes thousands of volunteers who collect litter and waste from riverbanks, parks, and streets in the surrounding catchment areas, and provides educational value, informing the public about proper waste disposal and the impact of human activities on the river.

4.4 Litter Traps

Technological innovations, particularly the incorporation of litter traps, have also been utilized along the Yarra River. Litter traps are crucial systems designed to intercept waste, particularly larger floating debris, before it enters waterways [29]. These traps generally consist of barriers, nets, or grills that allow water to pass through while retaining larger waste materials such as plastics, paper, and organic debris. Their primary role is to reduce the amount of human-generated litter that reaches natural habitats, thereby supporting the ecological health of urban rivers like the Yarra River.

The City of Melbourne manages approximately 63 litter traps aimed at preventing litter from reaching the waterway, collectively removing an estimated 100 tons of litter each year [30] The installation of these traps has contributed to a decrease in plastic and chemical pollutants entering the river, thereby improving water quality and overall ecosystem health. These innovations complement community efforts, with initiatives that educate residents about proper waste disposal and the importance of their actions in reducing litter. This holistic approach enhances the effectiveness of litter traps and stormwater management systems, targeting litter at its source.

The effectiveness of litter traps hinges on strategic placement, typically in areas prone to high runoff or where human activity leads to increased pollution, such as urban streets, industrial zones, parks, and regions prone to flooding. These high-traffic locations ensure that a significant portion of debris is captured before it reaches major waterways [29].

One notable example along the Yarra River is the floating litter trap managed by Parks Victoria at Burnley Harbour, near Herring Island [30]. This installation primarily captures large debris while allowing smaller pieces to pass through, helping reduce the burden of waste on the river ecosystem. In terms of waste removal, Melbourne Water has reported significant efforts from 2022 to 2023, including the maintenance of 170 litter traps and the removal of 15,215 cubic meters of silt and 1,220 cubic meters of litter from Melbourne's drainage system. These efforts reflect the importance of ongoing maintenance and the tangible benefits litter traps provide in waste management and pollution control [20].

Furthermore, Parks Victoria has been managing 17 Bandalong litter traps within the suburban regions that the Yarra reaches [31]. Like other models, these litter traps are floating devices that accumulate litter and debris and dispose of them in a trap to be stored until collected. Without needing any mechanical assistance, the design involves counterweights and paddles that close the entry gate when flows of water decrease or experience a change in direction and a polyethylene side skirt under the waterline to prevent debris from leaving. Though collected volume of waste changes based on the size and number of traps, an average of 1,200 cubic meters of litter and debris are collected on a yearly basis (2000-2017) [31]. Working together, Yarra Riverkeeper Association investigates the composition of litter in the Bandalong traps, thus providing an overview of what waste is the most prevalent and should be prioritized to limit in communities. A study from Parks Victoria shows that these traps can capture between 65-69% of floating litter particles released altogether [32]. However, the effectiveness of specific litter traps varies. For instance, trap 11 was predicted to be the most effective, capturing 19-27% of the particles during both regular and high rainfall conditions. However, trap 17 shows the least effective performance because of flow eddy downstream of the Webb Bridge, disrupting the trap's system.

Aside from susceptibility to overflow during heavy rainfall, the inability of litter traps to capture microplastics and the frequent maintenance of these traps to avoid blockages persist as challenges that are yet to be dealt with.

4.5 Storm Water Drains

The Yarra City Council monitors an extensive system of drainage and stormwater designs aiming to ensure safe discharge into local waterways including the Yarra River. [33] This network involves the components of pits, pipes, tanks, overland flow paths, roadways, public open systems and retaining basins. Though the council is responsible for inspecting storm water drainage systems, cleaning and maintaining their own systems and monitoring drainage flow and pipe capacity, this network requires the community to be active participants as well. Many drainage assets within a community are located on private property, making it the responsibility of homeowners to ensure that stormwater is properly directed to the council's main drainage system [33]. Property owners are liable for addressing flooding or blockages on their land, with a priority on prompt resolution to prevent excess stormwater from transporting sediments into nearby waterways, including the Yarra River.

5 Proposal of Future Solutions

Upon attending the event, the EPA staff hosts detailed the main issues surrounding pollution in the Yarra River and demonstrated some current measures in place to minimise pollutants entering the river.

When consulted about future solutions, the EPA officials proposed a myriad of ideas and innovations they would like to see implemented. Though, a standout suggestion

that inspired a lot of ideas and innovation seemed to be concept of man-made waterways.

5.1 Man-Made Waterways

The implementation of man-made waterways can significantly reduce the impacts of urbanisation and pollution on the health of the Yarra River.

Man-made waterways is a very broad term that can usually be defined as a body of water artificially constructed or significantly altered by humans.

Whilst canals, are the most popular form of man-made waterway globally, structures like bioswales, artificial wetlands and creeks, can be an incredible asset to aid a vulnerable waterway such as the Yarra River [34].

Natural wetlands are already vital for preserving water quality, are artificial wetlands can serve a similar purpose. A myriad of native vegetation that is commonly found in wetlands would greatly increase biodiversity and strengthen surrounding ecosystems. Though, the low-lying vegetation also acts as a filtration system, chemicals, run-off, and sediments would all be filtered for heavy metals, and other pollutants. This would greatly reduce the amounts of pollutants that can enter the main flow of the river [35].

Artificial basins and creeks can also be highly beneficial to catch stormwater and prevent flooding in urban areas as well as around the banks of the river [6].

So, incorporating a few man-made wetlands as wells as basins or creeks would be incredibly beneficial for the health of the Yarra River by increasing biodiversity, reducing pollution and flooding from the main river.

Conclusion

Despite progress in mitigating the impacts of urbanization on the Yarra River through policies, community engagement, and technological solutions, ongoing urban expansion still poses a threat to its ecological health. The effectiveness of measures like litter traps, stormwater management, and the Yarra River Protection Act underscores the potential for positive change when stakeholders collaborate. However, to secure the river's future, a more holistic approach is essential. Innovative strategies, such as artificial waterways, alongside stricter land use policies and increased public awareness, are needed to sustain the balance between development and environmental conservation, ensuring the Yarra remains a vital resource for future generations.

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"A Distributed Adaptive Control System Using Gossip-Based Algorithm to Alleviate CSOs and Flooding in the Saen Saeb Canal, Bangkok, Thailand"

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Abstract

The relationship between Thai people and their waterways is deeply rooted in the country's history, culture, and daily life. Waterways have significantly influenced Thailand's development, shaping its agriculture, transportation, and cultural traditions. One of the most significant waterways is the Saen Saeb Canal, which connects the Bang Pakong River to the Chao Phraya River and spans approximately 72 kilometers. However, it is heavily polluted by residents and buildings beside the canal. Despite promising attempts by the government to improve water quality, the Saen Saeb Canal remains highly contaminated.

Compared to other canals in the capital city, the area around the Saen Saeb Canal also experiences frequent flooding. During heavy rain, water is collected by the combined sewer system, one of the two drainage systems used in Thailand. The separate system, which uses distinct pipes for rainwater and wastewater, offers many benefits but requires high investment. The combined system, which uses the same pipes for rainwater and wastewater, is lower in cost and more prevalent in Thailand. However, the combined sewer system can overwhelm the Saen Saeb Canal drainage during heavy rainfall. When this happens, rainwater mixes with wastewater in the same pipes, discharging untreated wastewater into local streams in events known as combined sewer overflows (CSOs).

We propose using a distributed real-time control (DRTC) system to address this issue in Thailand. This system implements an algorithm that evaluates data collected from sensors in the combined sewers to control a network of local actuators, managing the water flow into the canal. This approach helps reduce the frequency and volume of CSOs, thereby improving water quality during heavy rainfall.

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1. Waterway Investigation

A waterway encompasses any water body that supports navigation and transportation, such as rivers, canals, lakes, and navigable streams. Bangkok's vast system of interwoven canals, which once earned it the nickname "Venice of the East," may be a largely overlooked treasure. Originally constructed as a system for transportation, trade, and defense for the old capital, these historical waterways now support communities residing along their banks and continue to be an integral part of their daily lives (So Many Canals, 2020).

The Saen Saeb Canal is a prominent waterway in Bangkok, Thailand, known for its historical significance and role in transportation. Originally constructed in the 19th century, it served as a vital route for trade and movement. Today, it still functions as a transportation corridor, with boats providing a means of commuting through the city, helping to alleviate road congestion.

However, the canal faces serious environmental challenges, particularly water pollution issues such as untreated sewage, industrial discharges, and urban runoff contribute to its declining water quality. In 2022, water quality parameters such as biological oxygen demand (BOD) and dissolved oxygen (DO) were measured, with samples collected from six locations along the canal. All samples showed DO levels less than 3 mg/L, confirming the poor water quality, while the BOD levels were still within appropriate limits. Additionally, microplastics and heavy metals, which pose severe threats to human health and aquatic life, were found in the water in alarming amounts (AM Sabilillah et al., 2023). In addition, the presence of combined sewer overflows (CSOs) and flooding further exacerbates the pollution problems especially during heavy rainfall.

Combined sewer overflows (CSOs) are caused by urban drainage systems (UDSs) designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe, often failing during heavy rainfalls (Beachapedia, 2021). When the capacity of these sewers is exceeded, untreated sewage and stormwater are discharged directly into local water bodies, leading to severe environmental degradation and posing significant public health risks (Sojobi & Zayed, 2022). As a result, combined sewer overflows are a significant cause of water pollution in rivers, lakes, and other bodies of water.

Offline storage facilities, which temporarily hold stormwater, are commonly utilized to prevent CSOs, despite their often high costs for construction and maintenance. In contrast, methods that focus on temporarily storing stormwater directly within existing UDSs have also been developed, allowing for significant cost savings. These methods leverage the fact that UDSs are typically designed with safety factors in mind. Specifically, conduits are intentionally constructed to be larger than necessary for normal operating conditions. The UDS is managed using a distributed real-time control (DRTC) system, which requires the integration of sensors and actuators into the network. All the gates are managed locally by Proportional Integral Derivative (PID) controllers, which are coordinated globally through the gossip-based algorithm. This setup enables real-time monitoring and regulation to adjust to varying rainfall events (Garofalo et al., 2017).

In this study, DRTC system is applied to UDSs of the Saen Saeb Canal, which are modeled

using the Storm Water Management Model (SWMM) simulation software provided by US EPA. SWMM simulation software has been customized in order to allow it to be integrated with an external real-time control module. This research aims to study a comprehensive analysis of how innovative water management solutions can reduce CSOs and flooding.

2. Methodology

In our solution to alleviate combined sewer overflows (CSOs) and urban flooding, The urban drainage system (UDS) was modeled as a network consisting of nodes (junctions, inlets, and outlets) and edges (conduits). Junctions represent connection points, inlets are where runoff enters the system, and outlets discharge water into bodies such as rivers and canals. Conduits, on the other hand, are the pipes through which water flows.

The UDS can be recursively divided into several interconnected sub-networks, each with its own outfall. These sub-networks are linked to a main channel through junctions, creating a hierarchical structure. This graph-based representation enables the application of optimization strategies, initially developed for simpler networks, to more complex systems, improving overall drainage management.

Our proposed solution involves two key tasks: first, creating a drainage network in SWMM, and second, running it within a Python environment while integrating a gossip-based algorithm to control weirs.

2.1 Software Storm Water Management Model (SWMM)

The drainage network in this work is created using the software Storm Water Management Model (SWMM) provided by the Environmental Protection Agency (EPA), which is an open platform for planning, analysis, and design related to stormwater runoff, combined and sanitary sewers, and other drainage systems. The study areas cover Min Buri district, where the Saen Saeb Canal is located.

The input data and parameters required for the SWMM model simulation of drainage flow include rainfall data, and sewerage network information

Firstly, the rainfall data was sourced from the National Hydroinformatics Data Center and included 12 heavy rainfall events that occurred in the Min Buri district throughout 2022-2024. The summarized version of each rainfall event is shown in Table 1. Each event was recorded in CSV format for subsequent data cleansing in Google Colab. The following steps were taken for data cleansing:

1.Removing any data points with missing values (NaN)

2.Reorganizing the columns to match the input format required by the SWMM software.

3.Deleting column headers and converting the date from the Buddhist calendar (B.E.) to the Gregorian calendar (A.D.)

4.Finally, the files were saved in .dat format and organized into a single folder for further analysis.

Table 1: Time and Hydrological characteristics of the selected rainfall events

Event	Date	Start	Finish	Total Time (hr)	Total rain Volume (mm)	Average rain intensity (mm/hr)	Max flow rate (m3/s)	Average flow rate (m3/s)
1	7/5/2022	13:25	14:40	1.25	109.5	87.6	5.99	3.27
2	20/7/2022	19:30	23:55	4.42	74	16.75	24.57	21.99
3	3/10/2022	14:30	19:10	4.67	46	9.86	18.3	15.62
4	15/8/2022	18:20	22:05	3.75	73	19.47	15.29	9.5
5	4/9/2022	13:35	14:50	1.25	31.5	25.2	10.95	8.96
6	4/9/2022	20:00	22:05	2.08	77	36.96	12.2	7.82
7	27/9/2022	16:40	17:40	1	39	39	17.86	16.23
8	9/9/2023	18:10	23:10	5	63.5	12.7	25.39	13.49
9	21/9/2023	18:40	22:35	3.92	42.5	10.85	16.97	11.81
10	21/5/2024	11:05	12:20	1.25	43	34.4	8.93	5.77
11	17/6/2024	1:15	4:55	3.67	66.5	18.14	25.55	9.81
12	23/7/2024	15:15	18:05	2.83	16	5.65	14.35	8.48

Next, the information regarding the sewerage network—including the layout of subcatchments and the physical characteristics of the conduits such as diameter and length—was obtained from Bangkok's Department of Drainage and Sewerage (DDS) as shown in Fig. 1. Specifically, the data includes the layout of the sewers, their diameters, and the locations of wastewater treatment plants, subcatchments, and pumping stations. The length of each conduit was measured individually using Google Earth Pro.

The step to draw a network is simple. Basically, nodes were placed at each junction throughout the map. The sewers, both conduits and weirs, were then connected between nodes as shown in Fig. 2 and Fig. 3, and parameters including length and depth of nodes and sewers were filled out. Lastly, weirs were added to various junction points across the network. Two different numbers were used to compare the effectiveness regarding the number of weirs: one with 8 weirs (referred to as Control 8) and another with 17 weirs (referred to as Control 17).

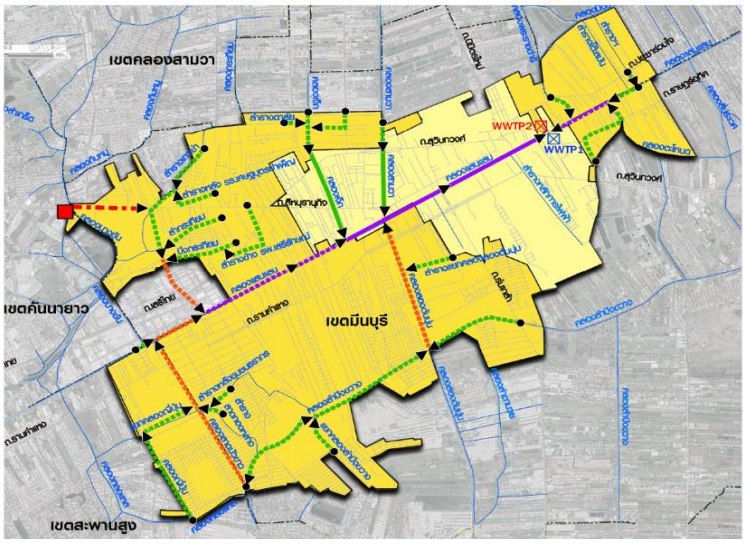

Fig. 1: Min Buri district's sewerage network from cited website (DDS, n.d.)

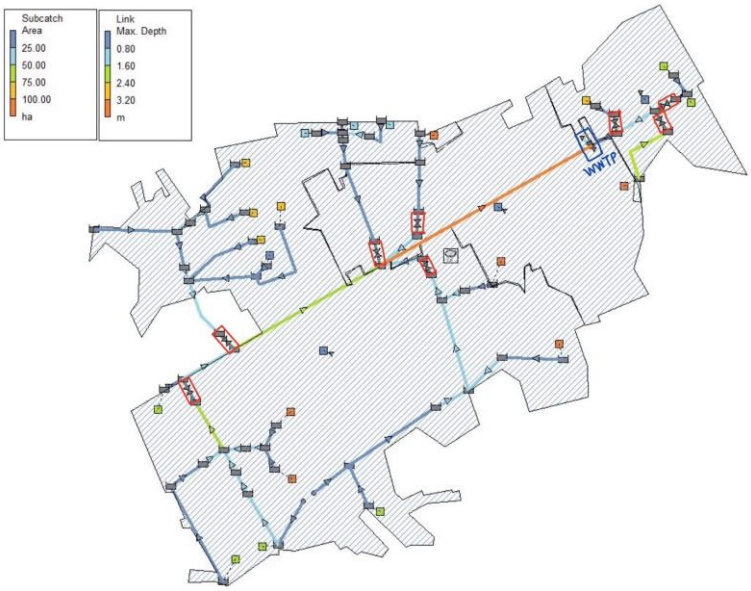

Fig. 2: Min Buri district's sewerage network in SWMM (Control 8)

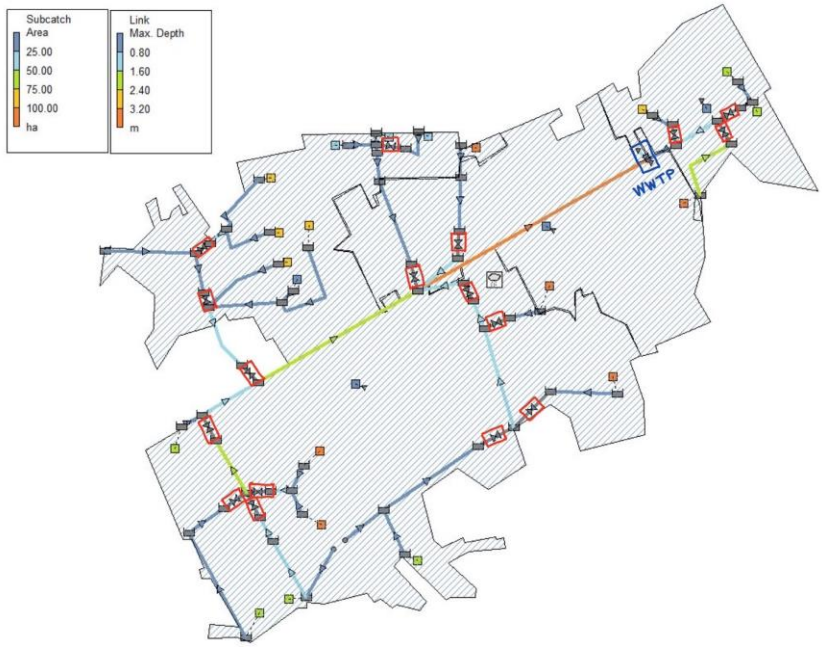

Fig. 3: Min Buri district's sewerage network in SWMM (Control 17)

2.2 Coding Implementation

The sewerage network files were then exported to be simulated in Pycharm, a python coding environment. pySWMM libraries were used to run a simulation. The simplified steps are described below.

1. A class is created to store variables for each weir, with a function to retrieve data from the SWMM file. The main variables include **node.level**, which stores the water level at that specific time, and **node.global_level**, which stores the average water level of all weirs in the network.
2. A network of weirs is constructed by linking all weirs together.
3. The **run_simulation** function is designed to initiate the simulation, retrieving data every 150 seconds.
   During each iteration, the simulation begins by updating the **node.level** of every weir. The Gossip algorithm is then executed for a total of 100 cycles, where in each loop, a node randomly selects a peer and updates their average (**node.global_level**) between each other. After 100 cycles, every node will have an equal **node.global_level**.
   Next, the water levels of all weirs are adjusted using the error between **node.level** and **node.global_level**. This error is used to calculate the percentage for fuzzy logic control:
   - If percent > 100: setting = 0
   - If percent 50-100: setting = 0.25
   - If percent 0-50: setting = 0.5
   - If percent -50 to 0: setting = 0.25
   - If percent < -50: setting = 0

   -Note that the setting for each weir ranges from 0 (fully closed) to 1 (fully open).
4. The code runs three scenarios for each event, totaling 12 events. The scenarios include: no-control, Control 8 (8 weirs), and control 17 (17 weirs). The recorded data were then saved in an Excel file for further analysis.

3. Results

Fig. 4 and Fig. 5 show a comparison of the CSO and flooding volumes for Control 8 and Control 17 against the baseline scenario with no control during 12 rainfall events between 2022 and 2024. CSO volumes represent the total overflow into the Saen Saeb canal, while flooding volumes reflect the total spilled water during each event, both expressed in cubic meters (m^3). Both Control 8 and Control 17 demonstrate reductions in CSO and flooding volumes, although the reduction in flooding is less significant. The volume of both CSO and floods varies substantially across events, likely due to differences in rainfall intensity and other influencing factors.

The effectiveness of Control 8 and Control 17 becomes more apparent when visualized in two graphs: one depicting % CSO reduction (Fig. 6) and the other showing % flooding reduction (Fig. 7), both plotted against event numbers.

As seen in Fig. 6, the % CSO reduction achieved by Control 17 is consistently about twice as high as that of Control 8 across all events. **Control 8** demonstrates a modest reduction, ranging from 1.3% to 3.6%, with the highest reduction observed in Event 5 (3.6%) and the lowest in Event 1 (1.3%). While **Control 17** does not show a dramatic reduction either, it consistently outperforms Control8, achieving reductions between 3.3% and 11.9%. The most significant reduction occurs in Event 5 (11.9%), while the smallest improvement is in Event 1 (3.3%).

In contrast, Fig. 7 reveals only minor differences in flooding reduction between the two controls, with Control 17 showing a marginally higher performance. **Control 8** has a limited impact on reducing flooding, with reductions ranging from 0.3% to 16.4%. Event 6 experiences the largest reduction (16.4%), while Event 1 shows the smallest effect (0.3%). **Control 17** provides slightly better results, with reductions ranging from 0.5% to 20.7%. Like Control 8, the largest reduction in flooding (20.7%) occurs in Event 6, while the smallest reduction (0.5%) is seen in Event 1.

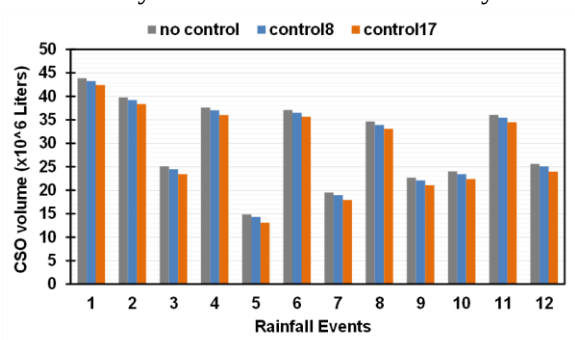

Fig. 4: CSO volume in sewage system with/without controls

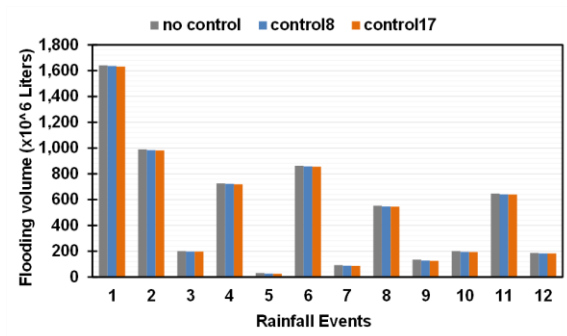

Fig. 5: Flooding volume in sewage system with/without controls

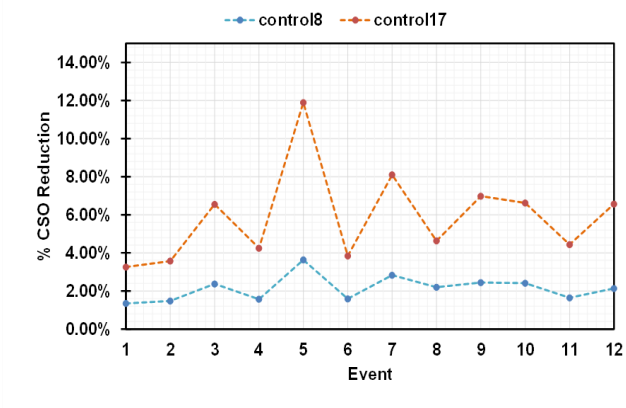

Fig. 6: Comparing %CSO Reduction between **control 8** and **control 17**

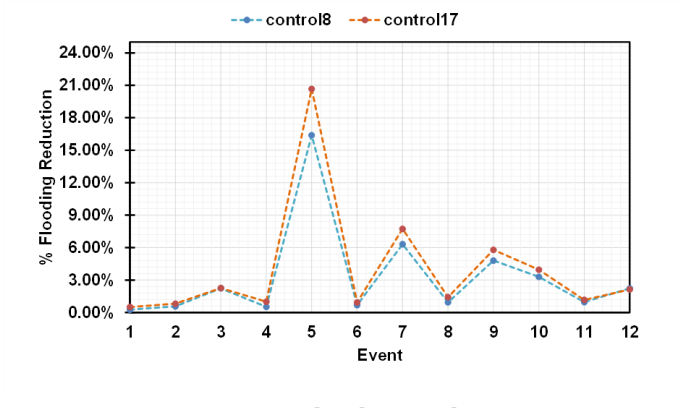

Fig. 7: Comparing %Flooding Reduction between **control8** and **control17**

4. Discussion

While Fig. 6 and Fig. 7 show that both control systems beneficially impact CSO and urban flooding mitigation, Control 17, which uses 17 weirs, is significantly more effective at reducing CSO volumes compared to Control 8, with 8 weirs. This suggests that installing more weirs can lead to better control of water flow within the sewage system. However, this assumption does not take into account the high cost of weirs or the challenges involved in installing them in the sewer network. To balance cost-effectiveness, a smaller number of weirs may be sufficient for managing less densely populated areas, such as suburbs or rural regions, while a higher number of weirs should be deployed in areas with extreme weather conditions or in densely populated urban areas, where their superior performance justifies the investment.

The experimental design of the sewage network in the SWMM model is not perfectly accurate due to the absence of certain crucial data gathered. For instance, the subcatchment areas assigned to each inlet, where water enters the system, are not explicitly shown. Instead, the model only displays the total area of each boundary. To address this issue, we manually divided the areas based on logical estimations of how much water each inlet would handle. Additionally, the two wastewater treatment plants (WWTPs) connected at the end of the main pipe were simplified into a single divider with specific flow thresholds. If these thresholds are exceeded, the excess water is discharged into the river.

Moreover, in real-world applications, data transmission is not instantaneous and typically comes with latencies ranging from hundreds of milliseconds to several seconds. Our study, however, does not account for this delay. The latency is a trade-off inherent to using a decentralized network like a Mesh network, which is highly resilient to common failures. Without a central node, this network allows all nodes to communicate, even if some become unresponsive or fail. While this adaptability is advantageous, the simplifications in our model and these network delays lead to inaccuracies in the simulation results, making them occasionally unpredictable compared to real-world values. (Iwanicki et al., 2006)

Lastly, we believe there are several opportunities for improvement in our solution, such as refining the weir control logic, gathering more detailed data to build a more realistic sewage model, or exploring alternative ways to integrate our code into the SWMM model.

5. Examination of a similar waterway in Venice, Italy

The Venice canal system in Italy shares parallels with Bangkok's Saen Saeb Canal in terms of urban functionality, flooding challenges, and pollution issues. The Venice canal system comprises over 150 interconnected canals, functioning as the primary transportation network within the city (Forrisi, 2023). Like the Saen Saeb Canal, Venice's waterways are integral to daily life, supporting both commuter transit and tourism. However, both canal systems face severe environmental and infrastructural challenges exacerbated by urban development and climate change (2023).

One key similarity between the Saen Saeb Canal and the Venice Canal system is their vulnerability to flooding, influenced by both natural and human factors. In Venice, flooding, commonly referred to as "Acqua Alta," occurs when high tides from the Adriatic Sea, intensified by rising sea levels and land subsidence, overflow into the city. These flood events have become more frequent and severe, mirroring Bangkok's struggle with seasonal flooding exacerbated by heavy rainfall and inefficient drainage systems (Carbognin et al., 2010). Both waterways also suffer from pollution due to inadequate sewage treatment and waste management. In Venice, untreated wastewater and the influx of tourists have significantly degraded water quality, similar to the untreated sewage discharge and waste accumulation in the Saen Saeb Canal (Molinaroli et al., 2009).

Despite these similarities, there are notable differences in the management approaches and challenges faced by the two waterways. Venice has implemented the MOSE project (ModuloSperimentale Elettromeccanico), a system of retractable gates designed to protect the city from high tides. This large-scale engineering project aims to address the immediate flooding risk by temporarily separating the Venetian Lagoon from the sea during high tides, thus preventing water from entering the city's canals (Antonioli et al., 2017). Moreover, Venice has shown many interesting ideas intended to improve their waterways. Without changing their historical canal system, Venice has built over 7,000 septic tanks, an effective solution yet requires plenty of space, to collect the city's sewage so that liquid waste will not pollute the water when reaching a canal (Romeo, 2020). Moreover, their MOSE project which aimed to protect the country from acqua alta could be a solution to sea level rise due to climate change for other countries as it has been causing more flooding (Horowitz et al., 2023).

Conversely, Bangkok has focused on improving its drainage infrastructure to tackle water pollution and flooding. While some areas still discharge household sewage directly into canals, the city has been implementing continuous solutions, such as building new combined sewer systems and upgrading existing ones. These efforts aim to better manage water flow and reduce flood risks, especially in key areas like the Saen Saeb Canal (Department of Drainage and Sewerage, 2020). As part of these initiatives, our project proposes a distributed adaptive control system to further optimize water management in the Saen Saeb Canal. This system uses real-time data to dynamically balance sewage transportation and treatment, reducing both pollution and flood risks more effectively. While Venice's approach involves significant structural interventions along the city's perimeter to control water flow and prevent flooding, Bangkok's strategy focuses on managing its internal waterways through combined wastewater treatment systems, which emphasizes efficiently transporting sewage from urban areas to wastewater treatment plants (Mongkolkeha, 2022).

The comparison between the Saen Saeb Canal and the Venice Canal system provides several insights and learnings. One of the primary

challenges for both cities is balancing the preservation of historical and cultural heritage with the need for modern flood management solutions. Venice's MOSE project, while innovative, has faced criticism for its high costs, maintenance challenges, and environmental impact on the delicate lagoon ecosystem (Baldin et al., 2021). This highlights the complexity of implementing large-scale infrastructure projects in environmentally sensitive areas, a consideration that Bangkok must also account for in its flood management strategies. Moreover, the focus on water quality improvement in both canal systems underscores the importance of integrated water management that addresses both flood resilience and pollution control.

From the comparison, one significant learning is the potential benefit of adopting a multi-faceted approach that combines advanced technologies with community engagement and policy reform. For instance, Venice's ongoing struggle with water pollution despite MOSE's flood prevention highlights the need for comprehensive solutions that address the root causes of water quality degradation, such as inadequate sewage treatment and waste management. Bangkok could take lessons from this by ensuring that its efforts to implement distributed real-time control systems in the Saen Saeb canal are complemented by broader initiatives to improve urban sanitation and waste disposal practices. Additionally, both cities can learn from each other's experiences in enhancing public awareness and involvement in waterway preservation efforts, as community participation is crucial in maintaining sustainable water management systems.

Nowadays, numerous flood prevention programs have been developed. For instances; sound-based system for detecting water leaks, disaster management applications, flood prediction, and IoT-based sensors and computer vision to monitor and map floods (Jeevanandam, 2022). A distributed real time control system we had developed could be the beginning to an adaptation of these programs into real use for Thailand and other countries, improving our drainage system. Using a distributed real time control system can solve the combined sewage overflow (CSO) problem, leading to clean water and sanitation, a significant life source.

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GALESS Tiltshift Conference Melbourne 2024: Life Sources – Waterways

Sustainable Solutions for Saltwater Intrusion in Singapore's Pandan Waterway

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Abstract

Saltwater intrusion into freshwater bodies is a growing global concern, worsened by climate change and rising sea levels. Singapore, a densely populated and low-lying island nation, is particularly vulnerable, with the Pandan waterway at risk due to its proximity to the coast. This study investigates the susceptibility of the Pandan waterway to saltwater intrusion by analysing historical salinity data, tidal patterns, and existing coastal defences.

The results show that current defences, including tidal gates and mangroves, mitigate saltwater intrusion but are increasingly stressed by rising sea levels. By 2100, high-emission scenarios predict up to 3,411 hours of breaches annually at the tidal gates, significantly increasing the risk of saltwater intrusion. Reduced mangrove cover due to industrialization further weakens the natural defences.

The study concludes that significant upgrades to tidal gate systems, expanded mangrove restoration, and enhanced coastal defences are crucial for protecting Singapore's waterways. A comprehensive land reclamation master plan is proposed to relocate vulnerable industrial areas and fortify coastal defences. Drawing from international strategies, advanced tidal gates and bioretention systems are recommended to enhance resilience. These findings provide essential insights for safeguarding Singapore's freshwater resources against climate change.

Keywords:

Saltwater Intrusion, Climate Change, Coastal Defences, Tidal Gates, Mangrove Restoration, Land Reclamation

1. Introduction

1.1. Water Scarcity in Singapore

Singapore, a small island city-state covering 734.3 km² with a population of 5.92 million, has a high population density of 8,058 people per km² [1]. Despite a daily consumption of 440 million gallons of water, Singapore is considered a water-scarce country due to its exceptionally high demand and limited land for natural freshwater bodies. This scarcity impacts the availability of land for water catchment and storage[2]. By 2040, Singapore is projected to be one of the world's most water-stressed countries, facing intense competition for its limited water resources[3].

1.2. Importance of Waterways in Singapore

A waterway is defined as any channel, natural or artificial, that carries water, including reservoirs, rivers, drains, canals, and roadside drains. Waterways play a crucial role in Singapore's water management strategy, which is vital for a country facing water scarcity. The government has developed an extensive network to capture rainwater, channelling it through 17 reservoirs, 32 major rivers, 990 km of drains and canals, and 7,000 km of roadside drains. This system enables Singapore to harness rainwater as one of its "Four National Taps," alongside imported water, reclaimed water, and desalinated water [4,5].

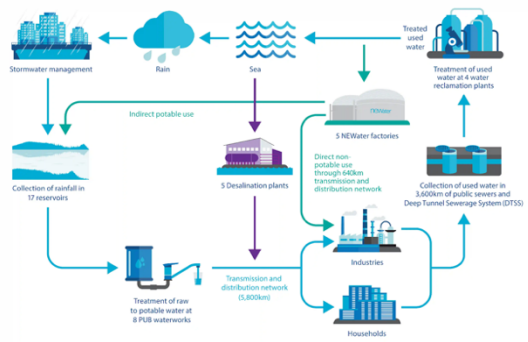


Figure 1.2.1 Singapore's Water Management Strategy[6].

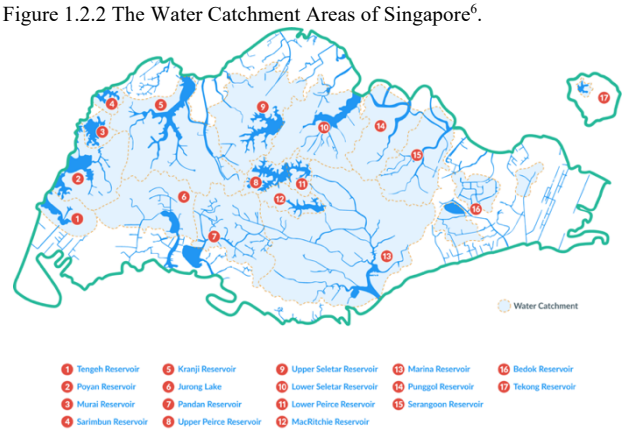
1.2.2. Local Catchment Areas in Singapore

Local catchment water, collected from 17 reservoirs and two-thirds of Singapore's land, contributes up to 20 % of the country's water needs by harvesting urban stormwater on a large scale[5]. However, this source is increasingly vulnerable to climate change, as altered rainfall patterns, extreme weather, and rising sea levels threaten both water quality and availability. Safeguarding waterways from these impacts has become essential.

In addition to supplying water, waterways play a crucial role in flood prevention. They connect to detention tanks, green roofs, rain gardens, and retention ponds to manage stormwater effectively. To enhance flood management, 1,000 water-level sensors monitor real-time conditions and provide early warnings[7].

As sea levels rise, the risk of saltwater intrusion into Singapore's freshwater sources increases, especially since Singapore is a low-lying nation with more than 30 % of its land less than 5 m above mean sea level. This could lead to the need for desalination processes before the water is safe for consumption.

Figure 1.2.2 The Water Catchment Areas of Singapore[6].



1.3. Pandan Waterway Network

The Pandan network in southwest Singapore consists of water bodies: Pandan Reservoir, Sungei Pandan, Sungei Ulu Pandan, Sungei Pandan Kechil, Sungei Perepat, Sungei Bangkong and the Pandan Straits. Sungei Pandan, also known as Pandan River, has a major tributary, Sungei Ulu Pandan, which connects to residential estates in the east[8]. As part of the Pandan water catchment, it collects rainwater and drains into Singapore's largest service reservoir, Pandan Reservoir[9].

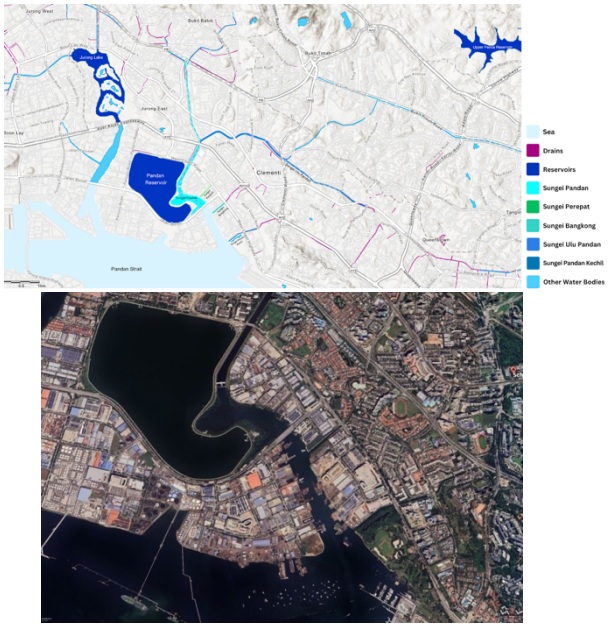


Figure 1.3.1 [Top]: Sungei Pandan Waterway Network (Data from Singapore Land Authority made with ESRI). [Bottom]: Google satellite image of Pandan Reservoir taken on September 2024.

This waterway serves two key functions: providing non-potable water to nearby industrial services, particularly the Jurong Industrial Estate, and managing rainwater drainage through the adjacent canal, which also collects water from smaller drainage channels[10].

The water table around Pandan Reservoir lies below sea level, which, according to the Ghyben-Herzberg relation, suggests an absence of fresh groundwater. Formed in 1974 by enclosing the mangrove swamps of the Sungei Pandan estuary with an earthen dyke, the reservoir was created by damming and redirecting the flow of the Pandan River[11].

Fortunately, this artificial structure raised the reservoir above ground level, surrounded by a 5 m sea wall, allowing a portion of water to be stored above sea level. Currently, the river and reservoir systems are engineered to manage water resources efficiently, aid in flood control, and prevent saltwater intrusion.

1.4. Susceptibility to Saltwater Intrusion

Over the last 15 years, the island's mean sea level has increased by 3mm yearly, and may rise by 230-1150 mm by 2100. Specifically, the west coast could see sea levels rise up to 0.74 m under the low emissions scenario (SSP1-2.6) and up to 1.39 m under the high emissions scenario (SSP5-8.5) by 2150 (relative to 1995-2014 data)[12]. Additionally, annual rainfall has also increased at 83 mm per decade, with more intense rainfall and prolonged dry spells expected. Intense rainfall could overwhelm drainage systems and cause flash floods, while prolonged dry spells could reduce water levels in reservoirs and waterways[13]. It has been estimated that should saltwater infiltrate Pandan Reservoir, it could take many years to pump out the saline water fully. This is due to the complexity and scale of the reservoir system, which makes the desalination process extremely lengthy and resource-intensive[14]. Thus, it will be important to determine if the waterway and its existing measures will be sufficient to handle the potential rise in sea levels together with the high tides while still avoiding flooding and seawater intrusion into the Pandan Reservoir.

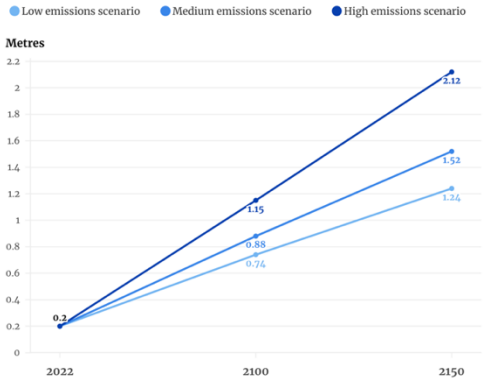


Figure 1.4.1 Prediction of sea level rise for Singapore for 3 different potential greenhouse gas emission scenarios[15].

As sea levels rise, the risk of saltwater intrusion into Singapore's freshwater sources increases, especially since Singapore is a low-lying nation with more than 30 % of its land less than 5 m above mean sea level. This could lead to the need for desalination processes before the water is safe for consumption[16].

Figure 1.4.2 Projected relative sea-level rise in Singapore at six tide gauges by 2150. The tide gauge that is nearest to the Pandan Waterway will be the West Coast tide gauge[12].

2. Establishment of the Problem

This section will examine the various coastal defence mechanisms along the Pandan waterway to assess their ability to manage potential sea level rise and prevent seawater intrusion.

2.1 Pandan Tidal Gates

The Pandan Tidal Gates is located 1.8 km from the coastline, near the mouth of the Pandan River, regulates water levels by managing tidal flows (Figure 2.1.1). The tidal gates function by opening and closing in response to water levels on either side. During high tide, when seawater rises, the gates close to prevent the influx of saltwater into inland areas (Figure 2.1.2). When the tide recedes or during low tide, the gates open, allowing excess freshwater to drain out to sea. This operation helps regulate water flow, prevent flooding during high tides and ensure adequate water levels during low tides, maintaining the balance between freshwater and saltwater ecosystems.

Figure 2.1.1 Tidal gates at Sungei Pandan with mangrove-lined riverbanks and Pandan Reservoir on the right[17].

Even as freshwater and saltwater are allowed to mix when the tidal gates are up during low tide, saltwater intrusion does not occur due to the difference in density of both. The saltwater is denser than freshwater, so when the two meet, saltwater tends to stay lower in the water column while freshwater remains on top thus limiting how much the two layers mix. The flow of the river also tends to push freshwater outwards, resisting the intrusion of saltwater. There is a zone of mixing but it does not allow the saltwater to completely replace the freshwater. As can be observed in Figure 2.1.3, the salinity outside the Pandan tidal gates is much greater than that within[10]. This indicates the gates have managed to successfully regulate the water flow between the river and the sea.

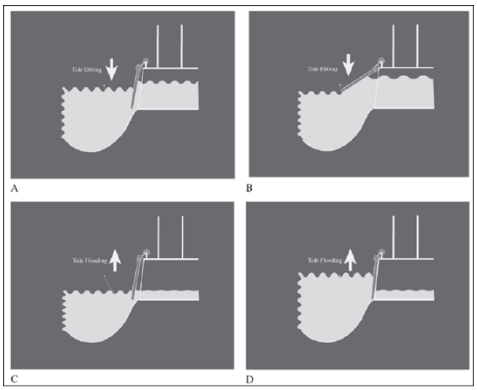


Figure 2.1.2[18] Tidal gate operation cycle. **A.** Tidal gate opens when the water pressure in the river carrying freshwater is higher than the pressure of water downstream of the river exposed to saline water during low tides. **B.** Tidal gate is wide open during low tide. **C.** Tidal gate begins to shut when the upstream water level drops and tide begins to rise. **D.** Tidal gate is shut during high tides.

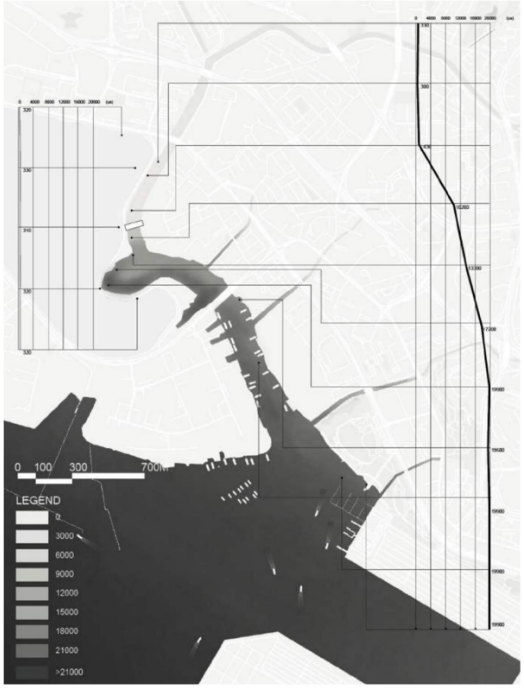


Fig 2.1.3[10] Conductivity and Salinity Levels in Sungei Pandan. Saltwater salinity ranges from 0-35 ppt with conductivity up to 40 millisiemens, while freshwater shows salinity of <1-2 ppt and conductivity <1-2 millisiemens. Measurements taken from 4-5 PM illustrate the salinity gradient in the waterway.

As sea levels rise and the weather becomes more extreme, evaluating tidal gates' effectiveness is crucial. If gates are overwhelmed by higher tides and increased tidal pressure, the incoming saltwater may push against the freshwater flow, causing more extensive mixing. This reduces the effectiveness of natural stratification, allowing saltwater to move further upstream. Larger volumes of saltwater can then flow inland, overwhelming the freshwater flow and leading to widespread saltwater intrusion. Tidal gates that are not designed to handle rising sea levels will increase the risk of saltwater intrusion into freshwater reservoirs, threatening Singapore's water security.

The team explored the tidal gates during both the low tide and high tide seasons (Figure 2.1.4). The tidal gates consist of two parallel sets of sluice gates. Upon inspection, the team found that the three older western gates can manage high tides up to 3.5 m, while the newer eastern gates can handle tides up to 3.8 m.

Figure 2.1.4 [Left] Close-up of the Older Pandan Tidal Gates (Reservoir-Facing) [Right] Height measurement of the newer tidal gate that were built higher for current tide levels.

As shown in Figure 2.1.5, which tracks hourly tidal heights for the years 2022 to 2024, the maximum tidal height over this period is 3.7 m[19-21]. This indicates that the new tide gates would be able to prevent saline water intrusion, whereas the older tide gates may be breached during high tides. However, the number of breaches at the older tide gates remained under 100 throughout the three years. The three-year cycle was analysed to account for the influence of both La Niña and El Niño phases, which can cause variations in sea levels, offering a broader perspective on how these climate conditions affect coastal water levels.

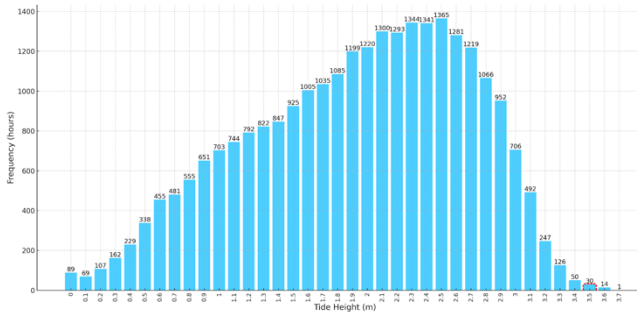


Figure 2.1.5 Frequency of Tide Heights (by hour) in Singapore from 2022-2024. The number of hourly breaches of the lower tidal gate can be calculated by summing the bars starting from the red-outlined bar onwards. Data sourced from NParks[19-21].

With rising sea levels, the tidal gates are expected to lose their control functions more frequently. A 0.7 m sea level rise by 2100 would result in 1,228 breaches for the older gates and 221 breaches for the newer ones (Figure 2.1.6). If sea levels rise by 1.15 m, the older gates could face 3,411 breaches, while the newer gates would experience 2,061 breaches. Under a high emissions scenario and without new protective measures, the Pandan waterway could be flooded around 24 % of the time by 2100.

Figure 2.1.7 provides estimates of the annual hours of breaches due to sea level rise, given the current tidal gate heights. As sea levels rise, the breach hours increase, but the rate of increase is not linear. If sea level rise is capped at 0.3m (corresponding to a global temperature increase of 1.5 °C above pre-industrial levels), the number of breaches remains relatively moderate. However, beyond this threshold, the number of breaches rises sharply, with a noticeable change in the gradient, indicating a substantial increase in the frequency of breaches at higher sea levels.

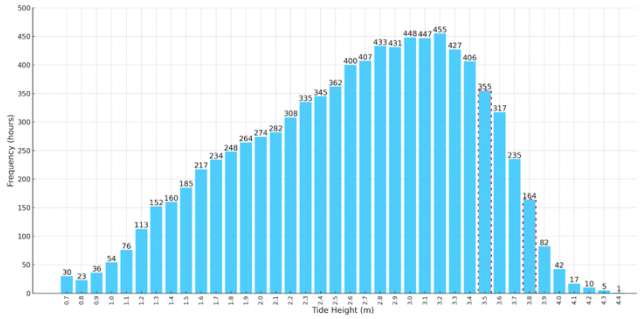


Figure 2.1.6: Predicted frequency of tide heights (by hour) in 2100 assuming the low emissions climate change scenario.

With projected sea-level rise, and extreme weather phenomena, the frequency and severity of high tides are expected to rise This could lead to more frequent overtopping of the gates, heightening flood risks in nearby industrial and residential areas. Additionally, the growing threat of saltwater intrusion could impact infrastructure, industries, and the surrounding ecosystem.

On February 9, 1979, Singapore recorded its highest extreme high tide at 3.9 m, flooding many coastal and inland areas[22]. While such events are rare, they underscore the potential impacts of high tides[23]. As sea levels rise and

weather patterns change, tides could reach 4-5 m[24,25], putting coastal reservoirs like Pandan Reservoir at greater risk of saltwater intrusion.

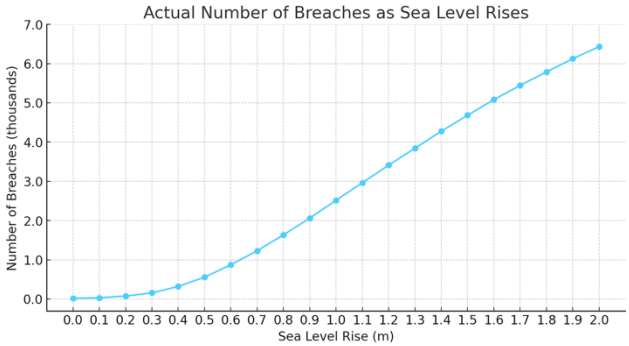


Figure 2.1.7 Projected tidal gate breach frequency by hour across various sea level rise scenarios.

Historical tidal patterns, such as the Saros, Nodal, Metonic, and Resonance cycles, suggest that extreme high tides will recur due to the moon's and sun's orbital alignments. The next peak astronomical tide, projected to be the highest of the 21st century, may occur as early as January 13, 2036 [26]. Such an event could introduce significant saltwater into reservoirs like Pandan, contaminating freshwater supplies. Removing this saltwater could take years, potentially disrupting water quality and requiring extensive engineering efforts. This looming risk underscores the urgency of strengthening flood defences before the next major high tide.

2.2 Mangroves along the Pandan Waterway

Singapore is home to more than 30 species of mangroves, which effectively mitigate saltwater intrusion in coastal and estuarine regions. The dense root system of species such as *Avicennia marina*, *Avicennia alba*, *Rhizophora stylosa*, and *Sonneratia alba* help to trap sediments, stabilising shorelines and reducing the impact of tidal waves[27]. By slowing down the movement of seawater, mangroves help maintain the freshwater balance in nearby groundwater and soil, preventing saltwater from penetrating inland and contaminating freshwater sources[28,29]. The mangroves also reduce saltwater intrusion by retaining salt within their tissues, preventing it from moving further inland.

The Pandan Nature Reserve once spanned 2,162 acres, but most of its mangroves were removed due to industrial development, the creation of Pandan Reservoir, and land reclamation in the south, leaving less than 5 % intact[30] (Figure 2.2.1 and 2.2.2). Infrastructure projects and the construction of residential and industrial areas have altered the water flow, affecting the growth and health of the mangrove ecosystems. Experts studying the mangroves in Singapore have reported that climate change has also been detrimental to the mangroves. The changing climate conditions are stressful for the trees, with many of them toppling as they cannot trap enough sediments due to erosion and low sediment supply[31]. Rising sea levels increase the risk of coastal erosion and flooding, potentially submerging parts of the mangrove habitat. More extreme weather patterns can damage the mangrove's root systems and changes in rainfall patterns and temperatures could disrupt the delicate balance of salt and freshwater that mangroves rely on, affecting their growth and resilience.

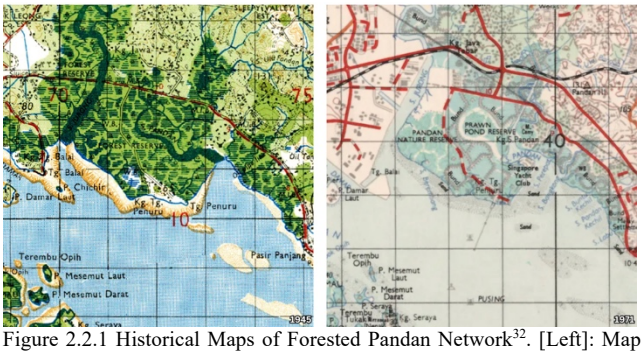


Figure 2.2.1 Historical Maps of Forested Pandan Network[32]. [Left]: Map drawn in 1945. The dark green sections in the map denote the presence of mangroves and other forms of vegetation. [Right] Map drawn in 1971.

Figure 2.2.2 Reduced Mangrove Presence along Ulu Pandan Waterway. Picture taken on 25 July 2024.

In Figure 2.2.3, it can be observed that efforts to restore and preserve mangroves have been made, but the scope of recovery has not matched the extensive losses of earlier years. The absence of vegetation to perform essential protective functions such as water filtration, habitat provision, and shoreline stabilisation would severely limit its shield against the growing threats posed by climate change and sea-level rise.

Figure 2.2.3 Satellite imagery of mangrove recovery over time (area circled in red) surrounding the Pandan waterway.

2.3 Land type and height along the Pandan Waterway

The Pandan area consists mainly of grey, fossil-rich limestone, partially metamorphosed into marble, forming part of the Pandan Facies (see appendix). The rocks are weak and heavily fractured, resulting in poor rock mass quality and intermediate permeability (10^{-6} to 2×10^{-8} m/s)[33]. The tropical climate has weathered the soils, creating deep residual layers and karstic features. Groundwater is found at 5 - 20 m depths, allowing saltwater to move quickly through the permeable soil, increasing the risk of saltwater intrusion[34].

Figure 2.3.1 Sandstone Layers from Pandan Drainage Catchment Borehole[34].

The low-lying nature of the land surrounding the waterways makes the area particularly susceptible to seawater intrusion with rising sea levels. The simulations in the image illustrate the escalating flood risks from sea level rises between 1-6m, greatly expanding the zones of impact. This occurs because the natural land gradient allows seawater to flow further upriver into areas it would not usually reach, especially during high tides and storm surges. As sea levels rise, the increased pressure and volume of seawater can overpower freshwater flow, pushing saltwater into freshwater sources.

Figure 2.3.2 displays some features of the main canals of the Pandan Waterway that would be able to hold and discharge water away in the event of extreme weather conditions and or high tides. However, it can be observed that the canals are generally around 2-3 m high with limited discharging capacities.

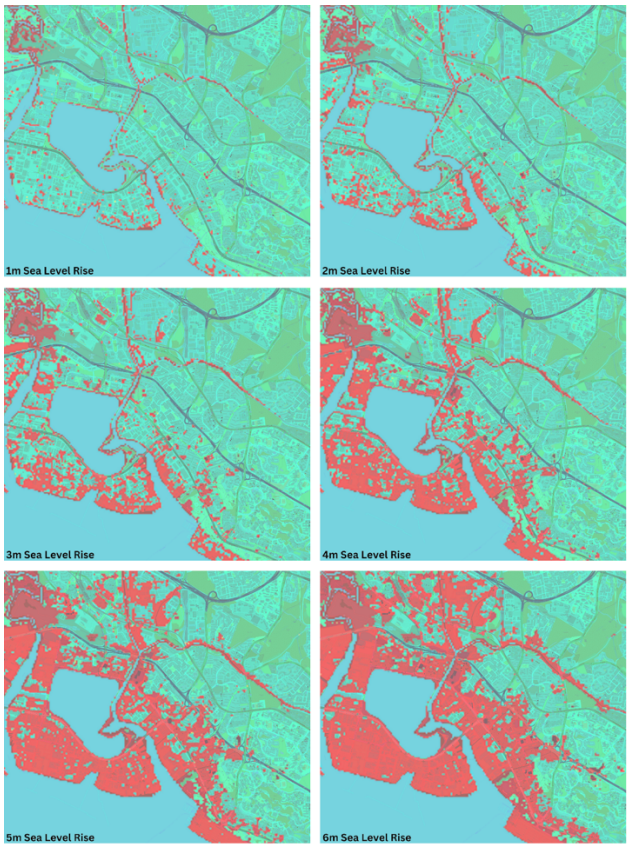


Figure 2.3.2 Effect on sea level rise (1-6 m) on the low-lying land by the Pandan waterway. Red Indicates Submerged Area. Elevation data was sourced from OpenTopography and processed with QGIS for spatial analysis and visualisation.

One example of the limited drainage capacity of the canals is the flooding of the Sungei Pandan Kechil canal. In 2013, flash floods hit Kent Ridge, east of Sungei Pandan, following heavy rainfall of 100 mm combined with high tides. The sudden influx of rainwater caused Sungei Pandan to overflow, further worsened by tidal conditions[35]. As Sungei Pandan drains into the sea, its water levels fluctuate with the tides. During high tide, the outflow of rainwater slows, leading to water backup in the river and canal, which can result in flooding during heavy rain. To mitigate this issue, the Sungei Pandan Kechil canal was expanded, and a 2-meter-tall steel gate was installed to improve drainage and prevent tidal backflow[36].

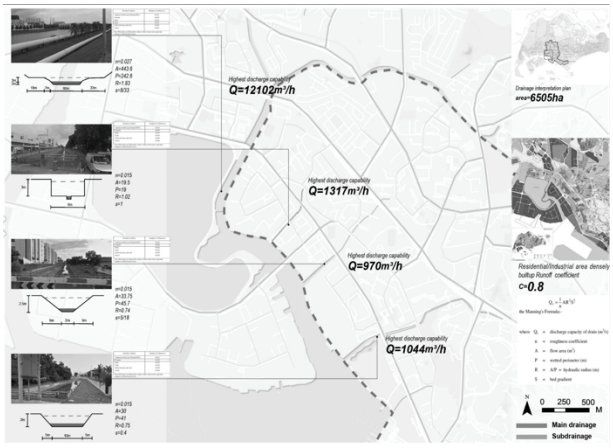


Figure 2.3.3 Canal discharging capacity of the different large canals present in the Pandan waterway[10].

Although the Sungei Pandan Kechil lies downstream of the Pandan tidal gates, protecting the main river from flooding, this does not eliminate the risk of future floods upstream. The peak rainfall during the 2013 floods coincided with a moderate tide of 1.5 m, but not the highest tide. This suggests that worse flooding could occur if heavy rain aligns with a higher tide, which would further strain the canal's ability to prevent saltwater intrusion. Therefore, enhancing the discharge capacity of other canals is crucial in reducing the risk of flooding and saltwater intrusion as climate change intensifies.

3. Impact of Saltwater Intrusion

Saltwater intrusion is defined as the movement of saline water into freshwater reservoirs or bodies of water. Businesses in the Jurong Industrial Estate near the Pandan Waterway are typically manufacturing-related (e.g. petrochemicals, pharmaceuticals, food, electronics) or provide shipping services (Fig 3.1 and 3.2). If saltwater intrudes into the reservoir, it poses a significant risk to these industries, which rely on consistent water quality for cooling, processing, and other operations. Higher salinity can corrode machinery, disrupt cooling systems, and degrade water quality, resulting in expensive maintenance and repairs. Consequently, a compromised freshwater source will require additional treatment methods, such as desalination or reverse osmosis. These added operational costs, whether borne by the companies or Singapore, would adversely impact the productivity and competitiveness of businesses in Jurong, discouraging future local and foreign investment and threatening its economic contribution to Singapore's growth.

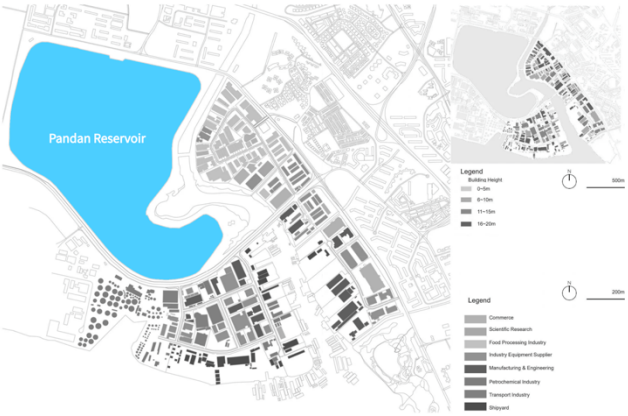


Figure 3.1 Map of Pandan Reservoir and the Surrounding Industries[10].

Additionally, saltwater intrusion into freshwater ecosystems disrupts the delicate balance of natural habitats, affecting species that are sensitive to high salinity. Freshwater fish, plants, and other organisms may experience stress, reduced reproduction, or death, leading to a decline in biodiversity. Saltwater can degrade soil quality, making it less suitable for vegetation and weakening green spaces that serve as natural flood buffers. This increases flood risk and environmental degradation. Soil salinisation also impairs natural filtration processes, undermining the sustainability of local water management systems. Saltwater that intrudes into underground structures and foundations can deteriorate it which leads to increased maintenance costs, potential damage and disruption[31].

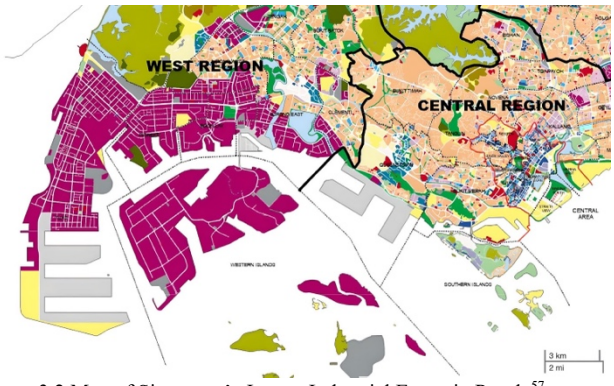


Figure 3.2 Map of Singapore's Jurong Industrial Estate in Purple[57].

The long-term impacts of such contamination can lead to complex, expensive, and prolonged clean-up efforts, especially disrupting the industrial water supply chain and aquatic life. It is clear from the above points that more than the current measures and features of the Pandan Waterway would be required to protect it from saltwater intrusion caused by climate change.

In the next section, we will draw on case studies from waterways in other countries that have implemented strategies to mitigate the risk of saltwater intrusion. These insights will guide our proposals for preventive measures and sustainable management strategies to protect Singapore's Pandan Waterway.

4. Sustainable Solutions and Strategies

4.1 Short Term Strategies

4.1.1 Replacement of Tidal Gates

Our research highlights the urgent need to replace or reinforce the existing tidal gates to better withstand climate change impacts. A relevant case study is the Santa Clara Valley Water District in the U.S., which is working with the U.S. Army Corps of Engineers to replace an ageing tidal gate structure in Palo Alto, California[37]. This structure, located along the San Francisco Bay shoreline, controls water flow from Adobe, Barron, and Matadero creeks into the bay via the Palo Alto Flood Basin (PAFB), effectively managing flood risks[38] (Figure 4.1.1).

Figure 4.1.1 Images of PAFB's Tidal Gate Structure[39,40]. [Top]: The PAFB tidal gate structure from a ground-level view [Bottom]: The gate's operation during low tide (left) and high tide (right).

The current 67 years old tidal gates, built in 1957, with a 50-year operational lifespan, have developed structural and hydraulic deficiencies over time, including leaking gates, spalled concrete, and corroded steel reinforcement. Additionally, they are ill-equipped to handle future sea level rise, with high tides already nearing the top of the gates, leaving only a minimal safety buffer[39] (Figure 4.1.1). The new project aims to replace these outdated gates with a modern structure that expands flood protection capacity and accommodates projected sea level rise, ensuring resilience against climate impacts (Figure 4.1.2).

The tidal gates in the Pandan Waterway and the PAFB share key similarities. The Pandan gates span 80 m, while the proposed PAFB gates will cover 40 m. Both ageing structures, built over 50 years ago, were designed to manage flood risks and prevent seawater intrusion during high tides, but now require upgrades to address climate change

impacts[11,39]. A key lesson gleaned is that waiting for structural corrosion before replacing these gates is inadvisable. The PAFB benefits from a marshland that serves as a natural water sink, whereas the Pandan Waterway lacks such a buffer due to nearby industrial developments and the adjacent reservoir. Both areas are sensitive ecosystems, with mangroves near the Pandan Waterway and the PAFB respectively, the latter also supporting endangered species. The proposed PAFB gate design, emphasising lower maintenance costs, is an important factor that Singapore should consider.

Figure 4.1.2 Map of PAFB with Connected Rivers and Canals[42].

The new Palo Alto tidal gate will be built upstream (basin side) of the current structure (Figure 4.1.2) and will be larger to increase hydraulic capacity and mitigate rising sea levels. The new gate will be elevated 5 feet higher than the existing one, accommodating up to 2 feet of future sea level rise. Its elevation and alignment will also align with future levee construction projects to ensure integrated flood protection[40]. Built on a concrete foundation with drilled piles, the structure will offer greater stability and durability against seismic activity and soil settlement. As with the previous design, motor-driven sluice gates will regulate water circulation, helping to maintain ecological balance in the flood basin. The four-year construction timeline is outlined in Figure 4.1.3.

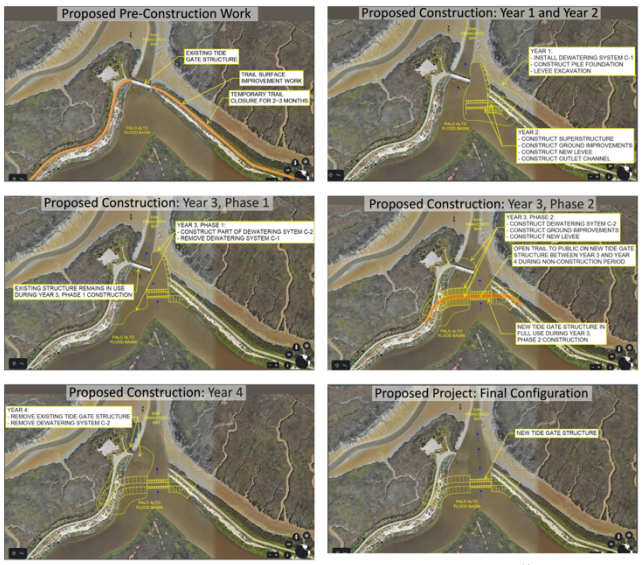


Figure 4.1.3 Construction schedule and plans over four years[40].

However, there are key differences to consider when applying lessons from the Palo Alto case study. The Pandan Tidal Gates are built to handle more frequent and extreme water level changes due to Singapore's tropical monsoon climate, characterised by heavy rainfall and high humidity. In contrast, the Palo Alto Tidal Gates address storm surges and tidal variations typical of San Francisco Bay's Mediterranean climate, which has distinct wet and dry seasons[41]. Additionally, the Palo Alto Tidal Gates are located in less foot traffic areas, allowing for a four-year construction plan. In contrast, the Pandan Tidal Gates are situated in an industrial zone where minimising disruption to operations is critical. Therefore, further research is needed to adapt Palo Alto's design and construction plans in Singapore.

Nevertheless, the insights from this project remain highly valuable, offering critical guidance for designing and implementing tidal gates that address Singapore's specific environmental and industrial needs.

Building on these lessons, we propose constructing a larger Pandan Tidal Gate slightly upstream from the existing one (see Fig 4.1.4) before dismantling the original structure. This approach ensures the current gate continues to protect the upstream from saltwater intrusion during the construction period. The new site is strategically chosen to minimise disruption to nearby mangroves and brackish habitats, while also leveraging a well-established location to reduce construction uncertainties.

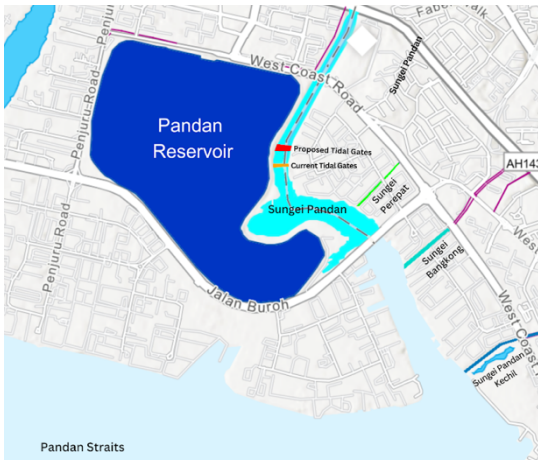


Figure 4.1.4 Proposed Location for New Pandan Tidal Gates.

Unlike the 0.6 m sea level rise accommodation for the Palo Alto Tidal Gate, the proposed Pandan Tidal Gates will be designed to handle a 1 m rise by 2100. This projection is based on mid-range CO_2 emissions scenarios and wetter climate forecasts. The 1 m allowance will also help manage the extreme high tides predicted by 2036. While raising the gate height is a critical safeguard, balancing construction costs and structural stability is essential. For context, the Palo Alto Tidal Gate, half the size of Pandan's, is already projected to cost US$40 million[43].

Given that tidal gates typically last around 50 years, a conservative approach is advised to balance climate resilience and fiscal responsibility. One consideration is a modular design, like the Eastern Scheldt Storm Surge Barrier in the Netherlands, which uses smaller, interconnected removable sections (Figure 4.1.5). The gates are modular components and can be built off-site. Thus, they can be easily replaced whenever there is a need for protection against higher tidal levels due to climate change or otherwise. This flexible design allows for easier upgrades

and cost savings while maintaining flood protection without requiring full system shutdowns[44].

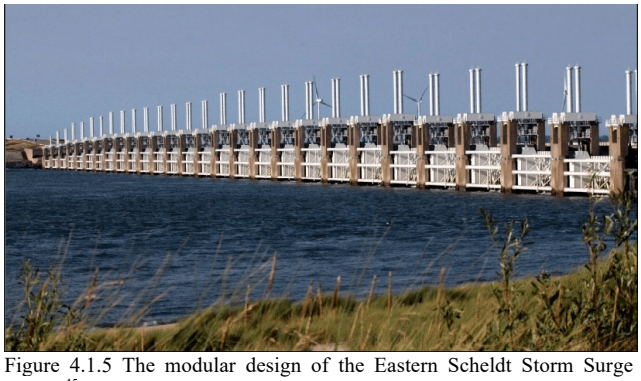


Figure 4.1.5 The modular design of the Eastern Scheldt Storm Surge Barrier[45].

However, dynamic gates designed for frequent adjustments, like Venice's MOSE Project, where gates lie flat on the seafloor and are raised as needed, are unsuitable for Sungei Pandan due to ecosystem considerations[46]. Dynamic gates can create turbulence and alter water flow, disturbing sensitive habitats like wetlands and salt marshes, which support endangered species[47]. Instead, more static gate designs are preferred to reduce ecological disruption while ensuring effective flood protection.

Following a similar design philosophy to Palo Alto's Tidal Gates, the Pandan tidal gate will be about 15 % wider to improve hydraulic capacity. Corrosion-resistant materials and self-healing concrete will enhance its durability, anticipating the harsher marine conditions expected with climate change. Additionally, the new design will integrate real-time data systems, incorporating sensors to monitor sea levels, tidal patterns, weather forecasts, and structural integrity. This will enable predictive gate management, allowing proactive responses to rising sea levels or storm surges.

This proposed design balances the need for robust flood defences with cost efficiency, allowing for adaptability as climate trends evolve.

4.1.2 Permeable Retention System

The Netherlands has pioneered water-sensitive urban design, particularly in cities like Rotterdam, where "Water Squares" use permeable pavements to allow water to seep through[48], reducing surface runoff and preventing flooding in densely urbanised areas (Figure 4.1.7).

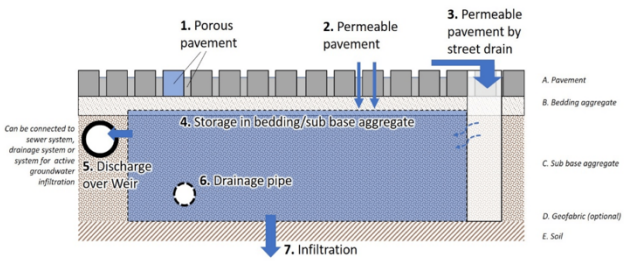


Figure 4.1.7 Cross-Section of Permeable Pavement Drainage System[49].

Similarly, Singapore's ABC Waters Program (Active, Beautiful, Clean Waters) incorporates permeable pavements, such as porous asphalt or concrete, in parks, streets, and public spaces[50]. As water infiltrates these pavements, it filters through layers of aggregates and soil, reducing immediate pressure on drainage systems and helping to mitigate flash floods that can overwhelm conventional infrastructure.

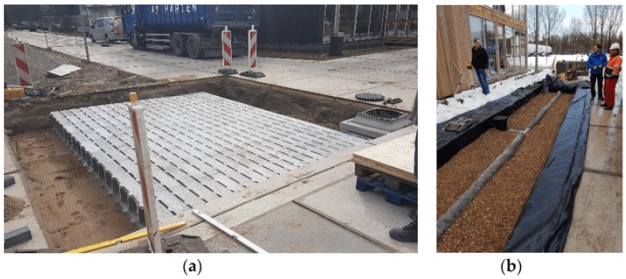


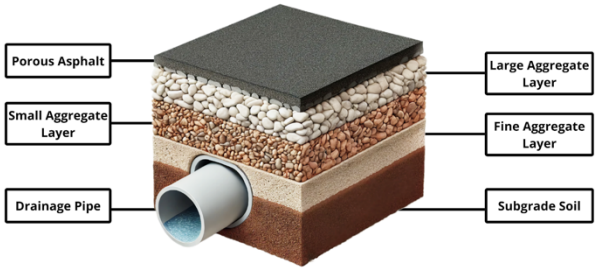
Figure 4.1.8 Installation of Permeable Pavement System in Urban Living Lab Green Village TU[49]. [Left]: The permeable pavement structure includes an underground storage space to capture and store runoff. [Right] Drainage pipes embedded in a gravel bed facilitate stormwater infiltration as part of the subsurface drainage system.

Given the fractured grey, fossil-rich limestone of the waterway banks, saltwater infiltration poses a risk of groundwater contamination. To address this, we propose a Permeable Pavement System (PPS) connected to a drainage network that redirects saltwater to treatment plants, preventing freshwater contamination (Figure 4.1.9). During coastal floods or high tides, this system would capture and manage freshwater separately from saltwater, with excess water redirected to treatment facilities like the Ulu Pandan NEWater plant, thus reducing reliance on natural freshwater sources.

The PPS design features a top layer of porous asphalt or pervious concrete, allowing rainwater to seep through and reducing surface runoff. Beneath this, larger aggregates provide structural support and facilitate water movement. A smaller aggregate layer acts as a filter, distributing water evenly and preventing clogging. A fine sand layer further filters the water, while a French pipe system at the base collects and drains excess water to prevent flooding. This system enhances existing drainage networks, particularly in managing saltwater.

For riverbank areas, we propose a Saltwater Intrusion Bioretention System using native halophytes like *Acanthus ilicifolius*, *Zoysia matrella*, and *Avicennia officinalis*. These plants naturally exclude or excrete salt, lowering salt concentrations in runoff and protecting freshwater ecosystems.

Figure 4.1.9 A Cross-Section of the Proposed Permeable Pavement System.



Beneath the plants, the bioretention layer filters salt, sediments, and pollutants (Figure 4.1.10). This layer uses a soil mix of bentonite clay, humus, and biochar, which has a high capacity to absorb sodium and chloride ions. The stratified layers with varying grain sizes slow water flow, allowing time for salt adsorption. Proper compaction and controlled permeability maintain filtration efficiency

without causing waterlogging, ensuring effective drainage while reducing saltwater intrusion.

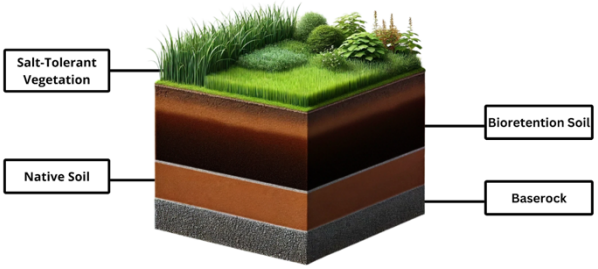


Figure 4.1.10 Cross-Section of the Saltwater Intrusion Bioretention System.

Figure 4.1.11 Grass banks along Sungei Pandan that can be converted to contain the saltwater intrusion bioretention System.

4.1.3 Rehabilitation of Mangroves

Mangroves around the river have been highly effective in supporting the broader coastal defence system by mitigating salt intrusion. By slowing water flows, mangroves encourage sediment accretion rather than erosion. Studies show that sediment accretes at a rate of approximately 10 mm per annum, effectively keeping pace with sea level rise due to climate change. To maintain these benefits, activities that cause sediment loss and hinder mangrove growth such as groundwater extraction, fossil fuel drilling, mangrove harvesting, and inland engineering projects should be avoided[51].

In the Philippines, mangroves are valued for their crucial ecological roles, including providing habitats for marine life, sequestering carbon, and offering economic benefits like fisheries, wood, and eco-tourism[52]. Despite their importance, widespread degradation due to illegal logging, coastal development, and aquaculture has occurred. Restoration efforts over the past two decades provide valuable insights that can be applied to rehabilitate the mangroves around the Pandan Waterway[53].

The choice of restoration techniques was found to be very important. Efforts with low survival rates (10 - 20 %) often focused on the monogeneric planting of *Rhizophora* species, a dominant method used for decades[54]. However, *Rhizophora* species are not natural colonisers of sandy substrates along exposed coastlines, leading to poor outcomes. In contrast, using a more diverse range of species, such as *Avicennia* and *Sonneratia* naturally adapted to these habitats yielded better success[55]. Since these species are also native to Singapore's mangroves, they should be considered in local rehabilitation efforts.

Before planting, it is important to first restore natural water dynamics, such as tidal flow and sedimentation, through hydrological rehabilitation to support long-term mangrove recovery. Additionally, planting should target the middle to upper intertidal zones, where mangroves naturally thrive, rather than the lower intertidal or subtidal zones, which are less suitable[54]. This poses a challenge for the Pandan Waterway, as much of the middle to upper intertidal area has been reclaimed for industrial use, leaving isolated strips of mangroves.

Efforts will need to focus on identifying remaining suitable intertidal zones that have not been heavily altered by industrial activities. These areas can serve as primary sites for initial mangrove planting. Where natural intertidal zones are unavailable, creating artificial intertidal zones through careful engineering and design can offer alternative habitats. This process involves reconstructing land elevations and contours to mimic natural intertidal conditions, ensuring appropriate tidal inundation and drainage.

One potential area for this is Sungai Trus Pandan, just downstream of the Pandan tidal gates (Figure 4.1.12). The small basin here presents an opportunity to expand the existing mangrove community. The considerations outlined above will be crucial in planning and executing such a planting exercise.

Furthermore, successful projects like those on Pangangan Island, Banacon Island, and in Kalibo were often community-led initiatives with modest funding, yielding high survival rates, regular maintenance, and benefiting from community co-management[53]. This indicates that involving local communities in mangrove rehabilitation, especially those benefiting from resources like coastal protection, increases the likelihood of long-term success. However, it should be noted that converting aquaculture ponds to mangrove forests is significantly easier than reclaiming land with industrial complexes, as is the case in Singapore.

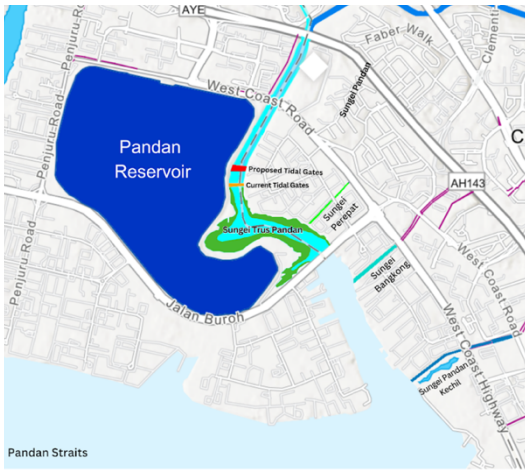


Figure 4.1.12 Mangroves Rehabilitation Sites (Green) in Sungei Trus Pandan.

Although community-led efforts in the Philippines have often proven more successful than government initiatives, the role of the government in Singapore is central and cannot be overlooked. Singapore's government, with its focus on

efficiency and zero tolerance for corruption[56], plays a pivotal role in land use planning, allocation, and enforcement[57]. The industrial estate itself was developed based on government decisions and actions, making the state the key steward in managing such projects.

4.1.4 Community Involvement Projects

Despite different socio-economic contexts, Singapore can still actively engage its citizens in rehabilitating mangroves along the Pandan Waterway. While Singaporeans do not depend on mangroves for their livelihoods, various strategies can promote community involvement[58].

Raising public awareness about the ecological benefits of mangroves is key. Public campaigns, educational programs, and community workshops can emphasise the role of mangroves in coastal protection, carbon sequestration, and biodiversity. Additionally, citizen science programs, where locals monitor mangrove health and growth, can foster a sense of ownership and responsibility.

Engaging local businesses through Corporate Social Responsibility (CSR) initiatives is another effective approach. Industries around the waterway can contribute to mangrove planting and maintenance, providing both funding and manpower. Public-private partnerships could further strengthen these efforts by ensuring financial, technical, and logistical support for long-term rehabilitation.

Addressing industrial challenges near Sungei Pandan is essential. Given the proximity of industrial buildings and shipyards, land reclamation and downstream tidal defences may be needed to create suitable areas for mangrove planting. Additionally, developing and enforcing policies that protect existing mangroves and support new rehabilitation efforts will help ensure these zones are safeguarded, while industrial activities account for environmental impacts.

Integrating eco-tourism and recreational opportunities can also boost community involvement. Building nature trails and boardwalks can create ecotourism attractions that serve as educational spaces, highlighting the importance of mangroves. These initiatives could help offset some of the costs of infrastructure development. Establishing educational kiosks along the Pandan Waterway can further raise awareness of local flora and fauna, emphasising the ecological role of mangroves in urban settings.

By adopting strategies from case studies in the Philippines, Singapore can successfully rehabilitate mangroves along the Pandan Waterway. These efforts will promote sustainability and ecological resilience, while fostering community engagement and environmental stewardship.

4.2 Long Term Strategy: Land Reclamation Master Plan

Fortunately, the Singapore government is fully cognisant of the challenges posed by climate change to its waterways and land. Several projects, such as the Long Island project, envisioned 30 years ago, aim to protect low-lying areas like the East Coast from sea-level rise[59] (Figure 4.2.1). However, no major plans have been announced for Sungei Pandan, despite earlier work done at Sungei Pandan Kechil. This report can serve as an early warning, encouraging proactive action for the area.

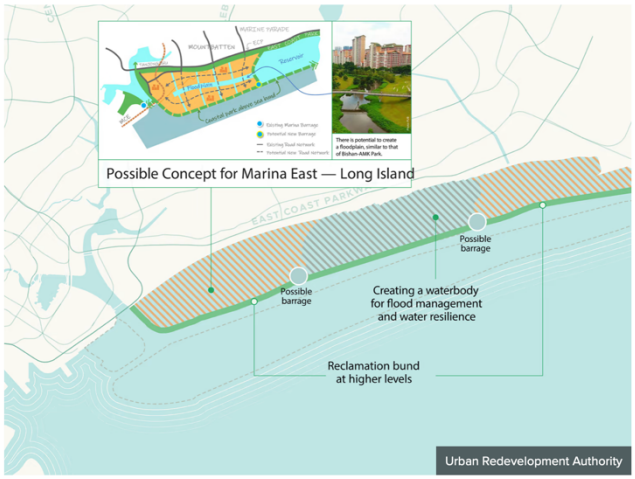


Figure 4.2.1: The Long Island Project and a possible concept plan for the area surrounding it[59].

The unique challenges faced by land-scarce Singapore will be elucidated further. Unlike other projects examined, the Pandan River and its surrounding areas lack available land for tidal defences. Additionally, the intensive anthropogenic activity, including nearby capital-intensive industries and shipping, makes planning and relocation efforts far more costly than recovering agricultural or aquaculture land elsewhere. Despite these challenges, this situation offers valuable learning opportunities for both Singapore and other land-scarce cities. Overcoming these challenges may require a coordinated effort involving government and community stakeholders.

To address the multiple constraints, a bolder long-term plan may be necessary. Given the low elevation of industrial land around Pandan Reservoir, concepts from the Long Island project could be adapted, starting with reclaiming part of the sea (see Fig 4.2.2). This would allow industries to relocate to the reclaimed land, with shipyards facing seawards. The vacated land could then be raised and fortified with tidal defences. Drawing on lessons from the Netherlands, a combination of levees and seawalls could be constructed[60].

This plan offers an opportunity for rejuvenation, integrating an "Industry in a Garden" concept where mangroves and nature trails serve both as tidal defences and recreational spaces for park workers. With proper salinity control, the enclosed water body could function as a secondary water reservoir for industrial areas like Jurong and Pandan, while also offering recreational opportunities for residents in the southwestern part of Singapore.

The brown region currently serves as the opening to the Pasir Panjang Terminals, so the plan is contingent on relocating the wharves and terminals to Tuas, a move already part of Singapore's long-term strategy to consolidate terminals in the western region by the 2040s[61]. This timeline would allow for implementation of the proposed plan by the 2050s, still in time to address sea level rise of 1 m or more[15]. While costly, Singapore has extensive experience in land reclamation and converting water bodies into reservoirs. The Pasir Panjang Terminals themselves were built on reclaimed land, and the Marina Barrage transformed the Singapore and Kallang Rivers into reservoirs supplying water to downtown

Singapore. Hydrographic charts show that the shallow waters (15 m) in the proposed industrial estate region are suitable for land reclamation (Figure 4.2.3). When comparing this expense to the consequences of incremental action or inaction such as shoreline erosion and saltwater intrusion this more proactive approach offers a viable solution for land-scarce Singapore.

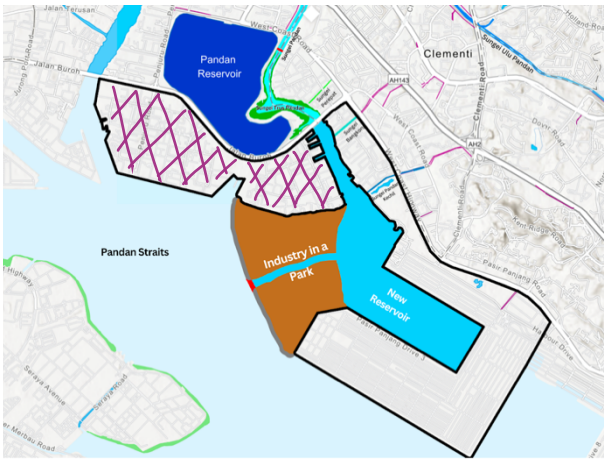


Figure 4.2.2 Proposed Master Plan for Land Reclamation and Coastal Infrastructure in the West Coast. The industries in the maroon shaded region would shift over to form the 'Industry in a park' once land (brown) has been reclaimed. The vacated land can then be raised and fortified so as to protect the reservoir from rising sea level. Light green areas indicate potential sites for mangrove relocation, where dock extensions will be designed to accommodate the mangroves. The grey zone represents seawall defences for the newly reclaimed land where docks are also built. The red barrier depicts the proposed tidal gate/barrage.

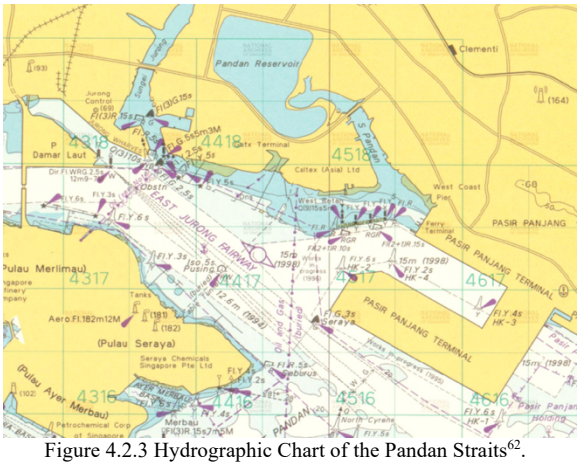


Figure 4.2.3 Hydrographic Chart of the Pandan Straits[62].

The shift to freshwater in the new reservoir may impact the existing mangroves, which will still survive, as they could face competition from other species. However, introducing and replanting mangroves at other suitable sites would have a net positive environmental effect, contributing to the fight against sea-level rise and saltwater intrusion. A key benefit would be enhanced land protection from erosion caused by open sea waves.

Like the Long Island project on the East Coast, a comprehensive master plan integrating tidal defences such as gates, mangroves, levees, and seawalls within an industrial setting is essential. The draft plan proposed here incorporates these defences, taking into account the factors discussed earlier. Against this backdrop, the slew of community-led and industry-supported projects can complement government efforts.

Figure 4.2.4 Artist impressions of the "Industry in a Garden" plan[63].

5. Conclusion

This study underscores the pressing threat of saltwater intrusion in Singapore's Pandan Waterway due to rising sea levels and climate change. By examining the limitations of existing coastal defence mechanisms—such as the ageing

tidal gates, diminishing mangrove ecosystems, and the area's geological vulnerabilities—we establish that current infrastructure may not suffice to protect this critical waterway and its adjacent industrial zones in the future.

Our research contributes to the field by integrating engineering solutions with ecological restoration and urban planning to address complex environmental challenges. The proposed strategies—upgrading tidal gates with advanced designs, implementing technologies like permeable pavements and bioretention systems, rehabilitating mangroves, and considering a comprehensive land reclamation master plan—offer a multifaceted approach to enhancing the resilience of the Pandan Waterway. These solutions not only mitigate the immediate risks of saltwater intrusion but also promote sustainable urban development and ecological balance.

The implications of this research extend beyond Singapore, offering valuable insights for other coastal cities facing similar threats from climate change. Policymakers are encouraged to adopt proactive investment in sustainable water management strategies, integrating technological innovations with nature-based solutions. Collaborative efforts between government agencies, industries, and local communities are essential to successfully implement these measures.

Future research should focus on detailed feasibility studies of the proposed solutions, including cost-benefit analyses and pilot projects to test the effectiveness of bioretention systems and mangrove rehabilitation in the specific context of Singapore's urban environment. Investigating innovative materials and construction techniques for tidal gates, as well as adaptive land use planning, could further enhance resilience against sea-level rise.

As Singapore continues to balance rapid urban development with environmental sustainability, a critical question emerges: How can the nation leverage both technological innovation and ecological stewardship to safeguard its water resources? Addressing this question is vital not only for the future of the Pandan Waterway but also for setting a precedent in global urban water management practices. Embracing integrated, forward-thinking solutions today will ensure the resilience and prosperity of Singapore's waterways for generations to come.

6. Acknowledgements

We would like to extend our heartfelt gratitude to Ms Loh Yue Yan Amelia for her invaluable guidance throughout the development of this research paper. We are also deeply thankful to Professor Wong Poh Poh for sharing his expert insights, which greatly enriched our work.

7. Appendix

Pandan Facies

The Pandan Facies is a geological term referring to a part of the broader Jurong Formation, composed of sedimentary rocks such as mudstone, shale, and sandstone, deposited in a shallow marine environment during the Late Triassic to Early Jurassic periods (235 – 175 million years ago).

Sungei

"Sungei" or "Sungai" is a Malay term meaning river, commonly used in Singapore and Malaysia to refer to natural watercourses.

Halophytes

Halophytes are plants adapted to thrive in high-salt environments like coastal areas, salt marshes, and saline soils. Some halophytes actively excrete salt through specialised glands on their leaves, reducing the salt concentration in their tissues. Others store salt in vacuoles within their leaves, isolating it to prevent disruption of normal biological functions. Many halophytes conserve water through succulence, developing thick, fleshy leaves or stems that retain moisture and minimise water loss. They often have extensive root systems that can absorb water even in saline conditions, sometimes tapping into deeper freshwater layers. Additionally, halophytes adjust their internal osmotic pressure by accumulating organic solutes, preventing water loss even in salty environments[64].

El Niño-Southern Oscillation (ENSO)

ENSO, a naturally occurring climate pattern, involves periodic fluctuations in sea surface temperatures and atmospheric pressure across the equatorial Pacific Ocean. It has three distinct phases: El Niño, La Niña, and a neutral phase[64].

During El Niño, the central and eastern tropical Pacific Ocean warms, weakening or reversing the usual trade winds that blow from east to west. This causes warmer waters to accumulate off the western coast of the Americas. In Singapore, El Niño reduces rainfall, particularly during the Southwest Monsoon (June to September). For instance, during the 2015-2016 El Niño event, Singapore experienced 35% below-average rainfall. Additionally, as cooler sea water contracts, reducing thermal expansion, sea levels decrease[65].

During La Niña, the opposite of El Niño, the central and eastern tropical Pacific Ocean cools, and the trade winds strengthen, pushing warm water further west and causing more upwelling of cold water along the eastern Pacific. This results in heavier rainfall in Southeast Asia, including Singapore, intensifying monsoons and increasing the risk of flooding. As warmer sea water expands due to thermal expansion, sea levels rise[66].

During the neutral phase, trade winds blow from east to west across the Pacific, pushing warm surface water toward Asia. This creates warm, wet conditions in Southeast Asia and cooler conditions in the eastern Pacific. The Walker circulation, the typical atmospheric flow over the equatorial Pacific, explains rising warm air over Asia and sinking cool air over South America. During this phase, normal weather patterns are observed, with no major deviations in sea surface temperatures or atmospheric conditions.

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Analysis of Water Management in the Murray-Darling Basin

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Abstract

The Murray-Darling Basin, located in the south-eastern region of Australia hosts both a highly diverse natural ecosystem and more than 2.2 million Australians, including 50 first nations groups. Furthermore, the Basin is a key agricultural region that provides over 30 billion dollars to the Australian Economy. The focus of this paper is effective water management of this valuable ecological resource. Through discussion with experts in the field, we have researched how water is allocated towards the environment, communities and farms, and attempted to resolve issues including water theft and poor water management. This research project is of relevance due to the upcoming 2026 review of the Murray-Darling Basin Plan, a government initiative aiming to improve the regulations and management of this area. Through our extensive research we first determined that increased research into the environmental science of the Murray-Darling Basin must be updated, as well as river technologies. We also suggest that the Murray-Darling Basin Authority should take into consideration the perspectives of community members and local farmers, by instating regular monthly meetings with them. In addition to this, Australia should create a national food security council, in order to prioritise and regulate the most economical and water efficient crops.

Keywords:

Waterway as a way or channel of water, such as a river or canal

Basin as the total area of land drained by a river and its tributaries

Water management as the control and movement of the water within the Murray-Darling Basin to be put to its relevant use.

Balance: acknowledging that a solution might not be perfect but considering the conflicting needs of all elements and trying our best to accommodate equitability.

Buyback scheme federal governments buying water entitlements back from farmers in the Murray-Darling Basin to have greater water resources.

1. Introduction

In this paper, we will be addressing sustainable management in the Murray-Darling Basin. We have a particular focus on the Murray River, a 2,530km river stretching across New South Wales, Victoria, and South Australia. As Australia's largest river, it supports rich biodiversity, a variety of communities, and vital industries to Australia's economy,

Figure 1: The Murray River from above

such as agriculture and tourism. The Murray-Darling Basin Authority is a current Government sponsored administration responsible for the management and protection of the Murray-Darling Basin. They are a team of professionals who aim to connect with communities, governments, industries and first Nations groups to achieve a healthy Murray-Darling Basin. They are responsible for the Murray-Darling Basin Plan, a project to improve the health of the Basin. We will examine the plan and suggest potential solutions for the upcoming 2026 review of this plan. We will scope these findings to three main categories: socio-economic, political and environmental.

2. Investigation of the Murray-Darling Basin

Figure 2

2.1 Function of Murray-Darling Basin

The Murray-Darling Basin is integral to Australia's water supply, native fauna, food production and ecosystems. It also has great cultural significance to Aboriginal people. Areas such as Coorong National Park, Ngaut Ngaut Conservation Park and the Murray River National Park have been recognised as places of cultural significance and contain rock art sites, graves and canoe trees. The Ngarrindjeri are the traditional owners of this land and river and have been living there for tens of thousands of years. Indeed, to this day, the traditional owners of the river work with the regional authority to plan, manage and protect this valuable resource and cultural site. However, the destruction of and disrespect for culture and cultural sites near the Murray River remain an issue faced by local indigenous peoples.

The river is also used extensively for farming. Farmers buy or lease water licences and entitlements, allowing them to use the water for irrigation. Due to large agricultural water demand, water theft - when agricultural water users take more than their water entitlement - is becoming a prominent issue, thus reducing environmental flows. It is difficult to monitor, and different states have large differences in penalties. This deducts equity amongst farmers in different states.

2.2 Our Research

To gather data on the Murray-Darling Basin and the issues this area faces, we used a qualitative approach to data collection, utilising interviews as our research method. We interviewed Ms Suzanna Sheed, Ms Jane Ryan, and Mr David McKenzie. Following our interviews with these experts, we were able to draw conclusions regarding the issues faced by the Basin and possible solutions we could use to improve these.

Ms Suzanna Sheed grew up in a community using water from the Murray-Darling Basin. A politician with a strong passion for water management, she represented the electorate of Shepparton for eight years. She has also been involved in many committees relating to water and rivers and is currently the Co-Chair for the Goulburn Murray Irrigation District Water Leadership Forum and a board member of the Goulburn Murray Leadership Program.

Ms Jane Ruan also grew up close to the Murray-Darling Basin. She has worked in the Goulburn Broken Catchment Management Authority, Goulburn Valley Water and Goulburn Murray Water. She was the deputy chief of staff for Lisa Neville, who was the water minister in Victoria until 2022. In 2023 Ms Ryan wrote a series of articles regarding the management and myths surrounding the Murray-Darling Basin.

Mr David McKenzie is a property valuer of agricultural supply chain assets. He was on the board of Goulburn Valley water for 6 years before becoming chair of Northeast Water and has now been a director and board member of Goulburn Murray Water. He is also Co-Chair of the Goulburn Murray Irrigation District Water Leadership Forum.

We acknowledge that each of these people may have biases which would impact the way that they approach this issue. As Victorians and as members of many of the same committees and organisations, they may also have similar biases regarding Victoria's policy, which we will consider.

3. Our findings

3.1 Socioeconomic Factors

We have concluded based on our interviews that one issue the Murray-Darling Basin faces is a lack of community involvement in management. Communities across Northern Victoria "have not felt heard"; indeed, they were the main targets of the original water buyback scheme and are again expected to complete buybacks. Jane Ryan also highlighted that disconnect between decision-making, science and communities has allowed people who "didn't know better" to damage the environment. For example, Ms Ryan suggested how large fines and greater awareness has stopped farmers putting dairy effluent into the river, which was previously a large problem. This highlighted to us how greater community engagement and awareness could potentially lower water theft and lead to a more coordinated, community-driven plan to protect the river that they depend on.

David McKenzie highlighted how the federal government is "disengaged" from the implications of policy on community. We acknowledge that efforts have already been made to incorporate community involvement such as the GMID water leadership which focuses on ensuring regional needs. However, Murray-Darling Basin Plan officials only meet once a year to discuss this and make decisions. We propose that volunteer community members are active participants in monthly policy meetings, and hold officials accountable. Community involvement "gives better outcomes" and makes governments more accountable for the implications of their policies and uses the expertise of those who live by and use the river, leading to greater cooperation and enthusiasm from the public.

Our data also suggests that the water buy-back scheme is not the most effective way to protect the ecosystem of the basin. This may have been the case in November 2012 when the plan was first implemented; but after almost 12 years, we have a greater understanding of the river, the changing science, climate change, and the effectiveness of this policy. While water buy-back is valuable and giving back water to the river is important, it is equally integral to strike "balance in our communities". Suzanna Sheed suggested the biggest problem faced by the river is achieving "balance" between "the environment" and "being able to maintain regional communities". Regional towns across the Murray-Darling Basin depend on its water for agriculture; Ms Sheed

Figure 3 – The Murray River

highlights how "no one would have [...] settle[ed] in the centre or parts of Australia if it wasn't for food production". But communities who "grew up and have been based off agriculture" in this region are now faced with water buy-backs. Indeed, Jane Ryan suggests how buybacks of water traditionally used by communities can damage regional economies and "collapse" regional towns. The basin contributes $30 billion to Australia's economy; less water will mean less food production and damage the GDP of these communities.

In addition, the basin supports 8,400 agricultural businesses, and many people in communities are employed by agriculture, or in factories dealing with Australian produce. Mr McKenzie highlights that while "it's always a good idea" to give water back to the environment, we need to be thoughtful, so we do not create "significant damage" to people and the economy. While we obviously cannot destroy the health of the river, we also cannot sacrifice our regional communities.

So how to strike a balance? One solution we have is to make water-buy backs more well-managed and localised. Currently, the government offers farmers money and buy water from anywhere; this means the areas of water which belong to the environment or farmers are scattered randomly across the basin. We suggest strategically shutting down certain areas for environmental use while other areas are preserved for agricultural and community use, which would make water transport more efficient. In fact, the Victorian government is currently suggesting to the federal government that they take out irrigation districts, allowing communities to retain their key water resources while repurposing specific areas of water on the outskirts. This could help strike a balance between the needs of community and the environment, and also help lessen the pushback on the buy-back scheme by communities in Northern Victoria who have been continuously targeted, if their key water resources are protected.

Another potential way to help balance community and environmental needs is to ensure that farms which are genuinely community run and valued by Australians are protected. Suzanna Sheed suggested we could start a National Food Security Council, which would investigate what we should "be using our very precious water to produce". For example, she discussed how in the Barmah Choke, banks are being washed away and gum trees are being ripped away by the unnaturally strong flows which are being forced down this section of river to maintain the agriculture downstream. But this agriculture is largely almond farming, which uses massive amounts of water - and makes massive amounts of money. Many of these farms are owned by huge corporations in the USA and Canada, which not only makes it harder for Australian, community run farms to find a foothold but is also, often irreparably, damaging our environment for the sake of such businesses.

We believe that if Australia were to create a National Food Security Council, they could focus more on regulating which farms and communities need water to keep communities thriving, and therefore should be protected from buybacks, and which spaces have water which could be prioritised for the environment. Furthermore, David McKenzie highlighted how some are already buying water and "instead of applying it to orange trees and almond trees and crops, they apply it to swamps and they apply it to wetlands" to maintain forest growth and stimulate fish breeding events and bird breeding habitat. Indeed, with government support of this and a coordinated attempt to determine how water can best be allocated like this, we believe a real difference can be made.

3.2 Political Factors

For many years the Murray-Darling Basin has been one of Australia's most intractable political problems and there remains many political conflicts in water management of the Basin. The politics of the Basin reflect the Australian federation itself with tensions between the federal government and the states, between the states themselves, and stakeholders competing for scarce water resources. Despite multiple initiatives and the efforts of many, these tensions have never been fully resolved. The Murray-Darling Basin Authority (MDBA) is largely responsible for managing and monitoring water resources, balancing contrasting needs and implementing policies. In 2012, the 'basin plan' was introduced which aimed to bring the basin back to a healthier and sustainable state, while continuing to support other stakeholders that rely upon the environment. Despite all this, significant political issues continue to plague management of the basin.

Water theft is one consequence that highlights the political challenges resulting from resistance to the plan's requirements. Although farmers hold water entitlements, the actual amount of water they receive varies from year to year depending on the availability of water. For example, in dry years there is less available water which leads to reduced allocations for farmers. Some farmers have been illegally extracting water over their allowance during these times and remain unpunished.

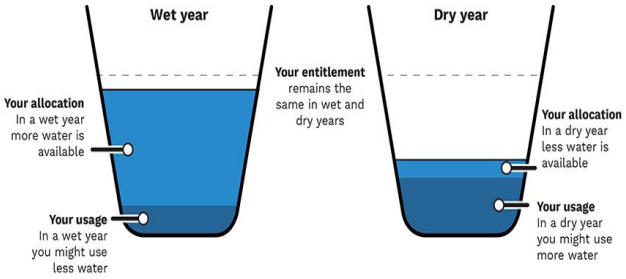

Figure 4

Suzanna Sheed highlighted the political differences between NSW and Victorian management of the Basin and how "Sometimes, decisions are not based on the best science or best management but based on politics and who is going to win the next election." As Victoria is more focused on environmental needs while NSW is invested in its economic growth, the two states have different approaches in regulating water usage. Victoria has stricter monitoring systems while NSW enforcements can be less consistent, leading to some cases where penalties are less severe. Despite having invested in satellite imaging to track water usage, NSW has been criticised for weak and unmonitored regulation of water-theft, giving farmers in NSW the opportunity to over-extract. David McKenzie stated that "each state has its own Water Act, and they don't want to give up powers over managing their own water resources, even though there's a federal Water Act as well." The rules have been developed "by the states to suit their climates, landscapes and soil types" so, for the states, harmonising the rules would not be a sensible solution.

Political tensions extend beyond the governments. There are many other stakeholders who each have different views on how the water should be utilised. The diverse stakeholders include farmers, Indigenous communities, environmentalists, recreational and other commercial interests. The requirements of each of these stakeholders' groups differs across the vast breadth of the Basin, thus further complicating the politics of their competing interests. For example, farmers upstream have first access to water before it flows downstream. The environmental impact of reduced water levels also has greater impacts on downstream ecosystems. Additionally, Indigenous communities have long been unhappy with the limited decision-making rights despite their inherent historical connection with the land.

While the Indigenous knowledge and perspectives in water management have been recognised by the MDBA, there has been criticism around the plan for not giving them rights for participation in key decision making, nor allowing control over water resources.

There is a rationale to argue that the federal government should not be taking full management responsibility. As Mr McKenzie shared, the Federal Government's "effectiveness diminishes the closer you get to the ground", the ground meaning regional communities. Despite the self-interestedness of state governments, they "represent the views of their communities" and "touch people more closely". Therefore, the current plan with the federal government overseeing the basin plan whilst coordinating with state governments who will work closely with local communities and farmers may work with "regular scientific review and socio-economic review". We also believe that greater community involvement in politics of the basin would mean a more diversified array of ideas (See Socio-Economic Factors).

In relation to water-theft, there is no easy solution. However, ensuring that the NSW government applies reasonable penalties which are consistent with the water act would be a sensible starting point. As we understand the difficulties of monitoring water theft on such a large scale, subsidising and investing in advanced technology for farming that optimises the use of water and improves efficiency may reduce the need for farmers to steal water in the first place. Financially supporting farmers who grow crops that are less reliant on water but still economically viable through grants and subsidies will encourage them to produce more of these self-sustainable crops or potentially create a shift in produce where it is more profitable to do so. Having farmers grow crops that are less water reliant may reduce the rate of water theft, allowing the MDBA to prioritise water for the environment and community.

3.3 Environmental Factors

The Murray-Darling Basin is an essential part of Australia's water supply. However, it is also an integral part of surrounding ecosystems and environments. The Basin supports hundreds of wildlife species by providing a source of nourishment and habitation. There is a reliance on the water system of the Murray to keep a balance in the environment which the Murray-Darling Basin plan aims to consider in their management. However, much water is stored by the government in dams, failing to provide the access plants and animals need. The Murray-Darling Basin Authority states that less than a quarter of the river's water goes towards the health of the river. Without access to water, increased salinity, outbreaks of algae, and loss of biodiversity can occur. Once the water is unhealthy, it is useless to communities.

Additionally, according to local politician and committee member Ms Sheed, current allocation of water is inefficient and damages local environments. When water is needed in a certain area and released from dams, it is "often flowing when the river is fairly high, in many cases is damaging the local environments." "High flows pushing through rivers and streams, [...] wash away the banks." This "degradation of the banks" leads to the destruction of the surrounding environment as soil loses quality and trees and shrubs surrounding the sites of erosion die or collapse. Ms Sheed provides the Barma choke as an example of this design flaw. The narrow part of the Murray River is a key area of flow for almond farmers who require a lot of water for their crops. This narrow waterway cannot support large amounts of water and overflows if too much dam water is released. If there was a more efficient way of delivering water from the dams to the required areas, the water would be conserved, and less damage would occur to the surrounding environments. An additional issue posed by these almond crops is that they need more water than other crops to convert sugar into protein. "Cotton and almond growing actually use very large amounts of water [but] they make a lot of money." This poses a possible area for improvement. If we made sacrifices in the type of crops grown in Australia, we could conserve our water use in a much simpler way. Growing more efficient and drought tolerant crops like herbs or grains would require less water to be taken away from the river and be more efficient for the environment's needs.

The Murray-Darling Basin authority was established after the Millennium drought with there being "a real fear that Melbourne might run out of water." Dams and irrigation systems were built "based on what had been happening in the 1990s." According to another consulted expert Jane Ryan, "some of the ways that we mined water was basically to explode rivers." These damaging methods of water management began a poor relationship with this waterway. A possible solution our research found was improving the use of science and technology in the field of managing water as "the science that was undertaken for the Murray-Darling Basin Plan was done during the first decade of this century." Outdated methods of agriculture are being used to utilise the Murray's water and could be causing wastage and damage to the environment. Ms Sheed states "the science [...] wasn't seen as being very credible." It must be acknowledged that some advancements have been made in the technology surrounding agriculture and management such as "lining channels" or "spray irrigation instead of just flooding a paddock" but "there's [still] been a lot of people calling for science to be looked at again and for a climate change lens to be put on it as well." Drip irrigation, dry farming and organic farming are all methods that have been reducing

water usage around the world. Making these more common in the Murray-Darling Basin area would greatly improve water efficiency. Jane Ryan claims "the Basin Plan hasn't really thought about climate change and its impact on the environment." She did a study in Northern Australia that showed changes in "rainfall patterns" and "the autumn break (when good farming rain falls in autumn) [dropping off] by 30%." According to David McKenzie "Climate change is already causing depopulation in some parts of regional Australia because agriculture is just too difficult to practise there anymore." This is a definite call to the Murray-Darling Basin Plan to redesign strategies or develop technologies that consider this new lens of a rapidly changing climate.

Additionally, there is a need to acknowledge that for the water to remain healthy not only for our use but the sustainable habitation of ecosystems within it, the water has to be free flowing. This means that while dams are useful for storing water, there could be more efficient methods of water transport. The Murray-Darling Basin Plan review should aim to re-consult the system they have built and see how the technology they use can be improved to better the environment they so heavily rely on.

4. Comparison

4.1 Investigation of Central Valley, California

Central Valley is the most productive agricultural region in North America. It is a structural depression of approximately 20,000 square miles. In contrast, the Murray-Darling Basin is closer to 386,100 square miles. Nevertheless, the region produces approximately 8% of the nation's agricultural output and 25% of its food. California has a Mediterranean climate, experiencing hot dry summers, and mild rainy winters. However, due to increasingly frequent drought and the effects of climate change, rain is progressively more sporadic. This, coupled with water intensive crops, is putting pressure on the water supply in the area, exposing flaws in its management, allocation, and usage.

Central Valley relies heavily on groundwater for its agricultural water supply, with it providing nearly 50% of all water for irrigation. This comes from the Central Valley Aquifer system. An aquifer system is a system of porous, water carrying rocks that can be drilled into to find water. For it to be effective, water is discharged in the summer, when there is little to no precipitation and then recharged in the wetter months with rainfall. This allows the system to have a supply of water that replenishes over time and accommodates for dry weather conditions. However, as droughts become more common, this system loses efficacy. This was exemplified in the most recent 'megadrought' that lasted from 2000 - 2021. Demand for water increased and consequently more water was pumped up. This inhibited the ability of the aquifers to replenish themselves, leading to the water table dropping until wells in Californian communities were dry or diluted with sediment. It was labelled a water emergency by Californian authorities. Now, even though the drought has passed, it is inevitable due to climate change that it will happen again in the future. Although the Murray-Darling Basin sources water from major rivers and dams, some of the key principles that affect The Central Valley in California are relevant here as well. Diminishing supplies of water due to overuse in periods of drought is an issue that Australia has been combating for years. In both California and The Murray-Darling this is exacerbated by several key factors including a) water intensive crops and b) poor or non - existent water management strategies.

4.2 Comparative analysis of the use of overly water intensive crops

Case study: almond farming

Central Valley

In the last 30 years, the almond industry in Central valley, California, has been lauded as 'lucrative', luring wealthy investors, to the region. This expansion has led to California producing approximately 80% of the world's

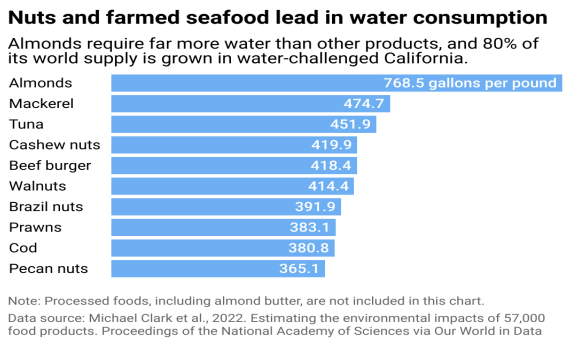

Figure 5

almonds and taking up 1.3 million acres of land. California's climate, according to *The Almond Board of California* is one of only "four other places on earth" that can accommodate the crop. However, critics argue that almonds are extremely water intensive, rendering it an unwise manoeuvre for the drought prone region. In fact, according to the *California Water Impact Network* almonds use roughly as much water yearly as total indoor water use in California. As seen in figure 5, almonds are some of the most water intensive products globally. California exports >70% of its almond crops, resulting in major economic benefits. Last year the value of California almond exports was approximately $4.5 billion. This makes farmers and

politicians reluctant to scale back on almond farming. However, rationale suggests it is not a sustainable industry in the region. Groundwater supplies are diminishing, the frequency of droughts is increasing, and almonds are still using excess amounts of water. It would be wise to move crops such as almond farming to areas with greater precipitation, for maximum environmental health, agricultural and economic productivity of the Central Valley region.

Murray-Darling Basin

In recent years the Australian Government has invested over $13 billion in the MDB Plan, involving a reduced amount of water taken from the river for agriculture. However, many sources suggest that some low priority crops with wealthy farmers use a greater amount of water than they rightly should, taking away from water used for vital crops and local farmers. This is exemplified by the rising popularity of almond farming in the Murray-Darling Basin region, an industry expected to generate more than a billion dollars in revenue in 2024. Second only to California, Australia's almond industry is rising at a fast pace, and with it the issue of its extreme water intensiveness.

Although farmers claim that almonds' water use is on par with other horticultural crops it is a year-round crop, and thus must be watered consistently all year. According to the Federal Department of Agriculture it uses up to 12.5 megalitres of water per hectare per year, more than rice and cotton. Because these crops earn so much money, the wealthy farmers that own them can buy more water, reducing the amount of water available for other crops. According to Jane Ryan a 'lot of these farms are foreign owned', suggesting that major corporations investing in almond farming can potentially cause inequities within the Murray-Darling Basin water allocations.

4.3 Summary of Current management system in Central Valley

In the Central Valley the water management system is not as formalised or legislative as The Murray-Darling Basin Plan. The Department of Water Resources (DWR) monitors and collects data surrounding groundwater levels, quality and usage statewide, as well as enforcing various government regulations devoted to its management. One major example of this management is the Sustainable Groundwater Act (SIGMA). Although this plan is government initiated, it focuses on individual communities making plans by, and for themselves with WDR assistance when needed. They offer grants to communities to assist with the management and assist in the creation of monitoring technologies and wells. As well as this, airborne electromagnetic technology and stream gauges to find data regarding where recharges are needed and other information which is then relayed to communities.

4.4 Insights and Conclusions from Comparison

The Murray-Darling Basin and Central Valley in California face unique challenges in common, as they are both highly productive agricultural regions, but in hot, often dry, climates. This leads to water shortages regularly developing in communities, and particularly in agricultural settings. Due to the rapidly increasing threat of climate change, both settings experience frequent droughts that are worsening in severity over time. As such water management is not withholding. Additionally, there is an overabundance of water intensive crops in these dry areas, often owned by major wealthy corporations and investors. There are a few notable improvements to the MDB that are identifiable when contrasting with Central Valley.

Firstly, though the Murray-Darling Basin is an extremely different water system to the Central Valley aquifer system, it could also benefit from regular advanced scientific research into river behaviour and environmental patterns. This has not been updated for a long time and would offer valuable insight into the best course of action involving the MDB plan, especially regarding the 2026 review. The MDB could also benefit from more community involvement - especially regarding the water buyback scheme. However, delegating management to just communities like in Central Valley, is unwise. When considering Australia's dry climate, water is even more of a prized commodity than it is in California, and as such negotiations and planning should remain as transparent and official as possible for the best possible outcomes. Regarding the nature of agriculture in the MDB, there are realistically far more sustainable crops that could be planted leading to greater economic benefit in the long term whilst benefiting local communities and farmers. This issue could potentially be discussed and resolved in a Food Security council, a suggestion offered by Jane Ryan, and a solution that we are proposing in this report. By prioritising sustainable, water efficient crops, legislation could also be introduced reducing the ability of wealthy investors to profit from water intensive crops.

5. Conclusion

Through this experience, we have identified several issues regarding the lack of community involvement, flaws of the water buyback scheme, the implications of water-theft, political tensions between competing stakeholders, lack of updated environmental science and accounting for climate change. From our research with our three experts in the field, we have proposed solutions that may improve management such as increasing frequency of council meetings, improved inclusion of community members, implementing a food-security council, preventing water-theft through stricter regulation, and prioritising self-sufficient crops. We believe that future studies may benefit by incorporating a more quantitative approach by closely analysing the scientific technology that is embedded in management of the waterway.

Acknowledgements

We would like to thank our mentor, Ms Hayley Kuperholz, for her continual guidance and support throughout our research. Her patience and encouragement from the start to the completion of the paper greatly motivated us along the way.

We would also like to express our gratitude to David McKenzie, Jane Ryan and Suzanna Sheed, who shared their valuable knowledge and experience in the field with us.

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Appendix- Interview Transcripts

Please see the following document for the transcripts of our interviews:
https://docs.google.com/document/d/1Q_PszR41LuC_kfNmuxKDoQbsFy1B6TxFXDdy--39M7w/edit?usp=sharing