AGENDA

# Living Together Committee

# *Te Komiti noho tahi*

## Friday, 29 February 2024

## *Rāmere, 29 Huitanguru 2024*

Totara Room, Whakatāne District Council
14 Commerce Street, Whakatāne
9:00am

Chief Executive: Steph O'Sullivan
Publication Date: 23 February 2024

whakatane.govt.nz

## Live Streaming - *Ka whakapāho mataora te hui*

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|---|
| **PLEASE NOTE** |
| The **public section** of this meeting will be Live Streamed via YouTube in real time. The live stream link will be available via Council's website. |
| All care will be taken to maintain your privacy however, as a visitor in the public gallery, your presence may be recorded. By remaining in the public gallery, it is understood your consent is given if your image is inadvertently broadcast. |
| The opinions or statements expressed during a meeting by individuals are their own, and they do not necessarily reflect the views of the Whakatāne District Council. Council thus disclaims any liability with regard to said opinions or statements. |

# A Membership - *Mematanga*

Mayor Dr V Luca

Councillor W B James - Chairperson

Councillor G L Dennis - Deputy Chairperson

Deputy Mayor L N Immink

Councillor N S Tánczos

Councillor T Boynton

Councillor A V Iles

Councillor J C Jukes

Councillor T O'Brien

Councillor J W Pullar

Councillor N Rangiaho

# B Delegations to the Living Together Committee - *Tuku Mahi ki te Komiti*

The purpose is to provide governance advice on community wellbeing, facilities, strategies, economic development, and associated policy and bylaws.

To promote and foster social cohesion, connection, and wellbeing.

To ensure facilities and programmes are provided that enhance and support community health and wellbeing.

**Specific functions and delegations**

a. Develop, and monitor implementation of, Council's Community Development and other related Strategies
b. Approve Council submissions to central government, councils and other organisations including submissions to any plan changes or policy statements
c. Monitor the implementation of Te Toi Waka Whakarei – Council's Māori Relationship Strategy
d. Approve all new road names in accordance with the Road Naming and Property Addressing Policy
e. Progress the sale of properties as approved in the Long-term Plan and Annual Plan
f. Consideration of proposals to change the status or revoke the status of a reserve as defined in the Reserves Act 1977 (including the hearing of submissions)
g. Receive minutes of Community Boards
h. Consider any recommendations from Community Boards and make a recommendation to the Council
i. Develop and review associated bylaws (Note: the Council cannot delegate to a Committee the "make" (adopt) a bylaw)
j. Develop, review and approve associated strategies, policies and plans (Note: the Council cannot delegate to a Committee the adoption of the policies associated with the Long-term Plan)
k. To foster and promote strengthening civic engagement
l. Receive minutes of the:
    - Whakatāne District Youth Council
    - Community Funding Committee
    - Four Community Boards

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# 1 Apologies - *Te hunga kāore i tae*

No apologies have been received at the time of compiling the agenda.

# 2 Acknowledgements/Tributes - *Ngā mihimihi*

An opportunity for members to recognise achievements, to notify of events, or to pay tribute to an occasion of importance.

# 3 Conflicts of Interest - *Ngākau kōnatunatu*

Members are reminded of the need to be vigilant to stand aside from decision making when a conflict arises between their role as an elected member and any private or other external interest they might have.

The Elected Member Register of Interest is available on the Whakatāne District Council website. If you wish to view the information, please click this Register Link

# 4 Public Participation - *Wānanga Tūmatanui*

## 4.1 Public Forum - Wānanga Tūmatanui

The Committee has set aside time for members of the public to speak in the public forum at the commencement of each meeting. Each speaker during the forum may speak for five minutes. Permission of the Chairperson is required for any person wishing to speak during the public forum.

With the permission of the Chairperson, Elected members may ask questions of speakers. Questions are to be confined to obtaining information or clarification on matters raised by a speaker.

## 4.2 Deputation - Ngā Whakapuaki Whaitake

A deputation enables a person, group or organisation to make a presentation to Committee on a matter or matters covered by their terms of reference. Deputations should be approved by the Chairperson, or an official with delegated authority, five working days before the meeting. Deputations may be heard at the commencement of the meeting or at the time that the relevant agenda item is being considered. No more than two speakers can speak on behalf of an organisation's deputation. Speakers can speak for up to 5 minutes, or with the permission of the Chairperson, a longer timeframe may be allocated.

With the permission of the Chairperson, Elected members may ask questions of speakers. Questions are to be confined to obtaining information or clarification on matters raised by the deputation.

- Representatives from Te Whatu Ora National Public Health Service

# 5 Confirmation of Minutes - *Te whakaaetanga o ngā meneti o te hui*

**THAT** the Living Together Committee confirm the minutes of its meeting, held on 7 December 2023 as a true and correct record.

# 6 Minutes of Other Committees and Community Board Meetings

## 6.1 Minutes of Other Committees and Community Board Meetings

You are able to view the minutes by clicking on the date (link).

### 1. Recommendation - *Tohutohu akiaki*

**THAT** the Living Together Committee receive the following minutes:

- Murupara Community Board 27 November 2023
- Whakatāne-Ōhope Community Board 27 November 2023
- Rangitāiki Community Board 29 November 2023
- Tāneatua Community Board 16 November 2023
- Community Funding Committee 8 December 2023

# 7 Reports - *Ngā Pūrongo*

## 7.1 Better Off Funding Programme Update

| | |
|---|---|
| To: | **Living Together Committee** |
| Date: | **Thursday, 29 February 2024** |
| Author: | **Better Off Funding Programme Manager** |
| Authoriser: | **S Perdia / General Manager Strategy & Transformation** |
| Reference: | **A2619147** |

## 1. Reason for the report - *Te Take mō tēnei rīpoata*

The purpose of this paper is to provide Elected Members with an update on the progress of Council's Better Off Funded projects.

## 2. Recommendations - *Tohutohu akiaki*

**THAT** the Living Together Committee **receive** the Better Off Funding Programme Update.

## 3. Background - *He tirohanga whakamuri*

The Better off Funding (BoF) Programme has been underway since the Funding agreement with the Department of Internal Affairs (DIA) was signed in January 2023.

The programme consists of the seven projects listed in the table below. Project managers have completed individual project level reports which have been reviewed and approved by the project sponsors and are now summarised in this Governance level programme report.

| Project Name | Funding |
|---|---:|
| Collective Iwi Policy Hub | $1,000,000 |
| Building Civil Defence Capability and Community Resilience | $1,360,000 |
| Hono Hapori – Community Outreach for Council Services | $500,000 |
| CCTV Upgrade | $1,000,000 |
| Accelerating EBOP Spatial Plan Project | $200,000 |
| Active Whakatāne - Edgecumbe to Thornton project | $900,000 |
| Southern District Towns Regeneration – Murupara and Minginui | $700,000 |

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## 4. Discussion - *Kaupapa*

This section provides a summary of the BoF project progress as well as additional programme level commentary to provide Elected Members with a sense of the overall status of the programme.

### 4.1. Programme Manager Summary

The Programme is progressing well with the majority of projects into development and delivery phases. Rebaseling several of the project's completion dates with DIA has been approved and the process for this was straight forward.

Better off Funding's first project, Acceleration EBOP Spatial Plan Project, is completed and the CCTV project has successfully delivered the project milestones with an underspend and is now in its final stages.

### 4.2. Project Level Summary

The table below provides a high-level dashboard outlining each project's status, as per project reporting received in January 2024.

**4.3. Project Dashboard Notes**

**Risk category ratings**

The highest of all risk category ratings from the project report is used as the project's overall risk status. A project may have three risk categories rated Green, and one at Amber – the overall status will be Amber.

- A GREEN rating means there is no current risk to delivering the project within the parameters agreed in the project plan.
- An AMBER rating means there is some risk, or potential risk, to the delivery of the project in line with the parameters agreed in its project plan. There is a viable plan to manage the risk.
- A RED rating means there is significant risk to the delivery of the project in line with the parameters agreed in the project plan, and escalation is required.

**Project phasing timeline**

Project phases for this programme are as follows:

- **Concept:** Seeking approval in principle or securing a funding stream for an idea
- **Initiation:** Project planning, assembling project team and setting the foundations for successful delivery
- **Development:** Developing the proposed way forward and ensuring relevant stakeholders are on board
- **Delivery:** Executing the proposed way forward
- **Closure:** Handing over to BAU, closing out all financial obligations, documenting lessons learnt and successes achieved.

Key:

**Green:** Complete
**Pattern:** Underway
**White:** Not Started

| Project & Risk Rating | Project Details | Funding Details | High Level Commentary |
| --- | --- | --- | --- |
| **Collective Iwi Policy Hub** | **Sponsor:**<br>Paul Warbrick<br><br>**Completion date:**<br>August 2025 | **Funding:**<br>$1,000,000<br><br>**Spend to 30 Jan 24**<br>$11,000 | A Hub Programme Manager has been appointed and initial engagement with four of the District's Iwi CEOs has taken place. Drafting Terms of Engagement, determining resourcing needs, recruiting support staff and forward support plans for the Hub are progressing.<br>The Hub's first priority is ensuring Iwi contributions to the EBOP Spatial Plan and Climate Change projects with planning underway to define scope for these projects. |
| |  | | |
| **Natural Hazard Resilience** | **Sponsor:**<br>Georgina Fletcher<br><br>**Completion date:**<br>December 2025 | **Funding:**<br>$1,360,000<br><br>**Spend to 30 Jan 24**<br>$335,000 | Upgrade works have been completed for Waimana Hall and the Waiewe Street Building; Te Teko Hall works are ahead of schedule, due for completion in May 2024.<br>Modifications to the Waiewe Street building are ongoing to facilitate it's use as an alternate Emergency Operations Centre for Emergency Management Personnel in the event of an activation. Council's Emergency Response Trailer carrier and storage fit out has been completed.<br>An adjustment of the project completion dates with DIA from June 2024 to December 2025 has been approved. |
| |  | | |

<table>
<tr>
<td rowspan="2">Hono Hapori – Community Outreach</td>
<td>Sponsor:<br>Georgina Fletcher<br><br>Completion date:<br>December 2024</td>
<td>Funding:<br>$500,000<br><br>Spend to 30 Jan 24<br>$1,000</td>
<td>Following extensive research, the decision was made to purchase two VW Crafter vehicles equipped with all-wheel drive to effectively service rural regions within our district. The vehicles are expected to arrive in early May.<br>Planning for the vehicles external design and internal fit out is progressing and work will begin once they have arrived with initial deployment planned in late June.<br>Project timelines were extended due to delivery constraints, prompting an adjustment of the project completion dates with DIA from June 2024 to December 2024.</td>
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<tr>
<td rowspan="2">CCTV Upgrade</td>
<td>Sponsor:<br>Steven Perdia<br><br>Completion date:<br>June 2024</td>
<td>Funding:<br>$1,000,000<br><br>Spend to 30 Jan 24<br>$503,000</td>
<td>This project is nearing closure and handover to BAU with the installation of new cameras successfully completed along with upgrades to existing ones. The monitoring contractor has been appointed and is currently operational. A workshop briefing with the Council to commemorate the conclusion of the project has occurred, Police were in attendance and provided insights into the early effectiveness of the system and gave a demonstration of the monitoring systems.<br>This project has delivered with an underspend and a request to add an additional milestone 'deliver further CCTV cameras' has been approved and work is underway on this.</td>
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|---|---|---|---|
| **Accelerating EBOP Spatial Plan Project** | **Sponsor:** David Bewley<br><br>**Completion date:** 30 September 2023 | **Funding:** $200,000<br><br>**Spend to 30 Jan 24** $200,000 | All acceleration Better off Funding has been exhausted, external funding requirements have been fulfilled and the project, as part of the Better off Funding Programme, has been closed.<br>The acceleration funding contributed to the launch of the EBOP Spatial Plan website, Population and Land Needs assessment, Three Waters preliminary assessment and changes to mapping to reflect the change to a sub-regional scale for the project. |
| | Concept → Initiation → Development → Delivery → Closure | | |
| **Active Whakatāne–Edgecumbe to Thornton Awa trail** | **Sponsor:** Steven Perdia<br><br>**Completion date:** December 2025 | **Funding:** $900,000<br><br>**Spend to 30 Jan 24** $40,000 | The project is facing slight risk related to security concerns expressed by some landowners situated within 'phase two' of the shared pathway between the Kart Club and Thornton Road. Ongoing discussions are being held with these landowners to address their concerns and work on a solution.<br>Construction of the 'first phase' of the track is scheduled to begin in May.<br>Bay of Plenty Regional Council are undertaking stop bank works within the 'phase two' section of the pathway and work cannot commence until this work has been completed.<br>To accommodate this an adjustment of the project completion dates with DIA from April 2024 to December 2025 has occurred. |
| | Concept → Initiation → Development → Delivery → Closure | | |

| | | | |
|---|---|---|---|
| **Southern District Towns Regeneration** | **Sponsor:** David Bewley<br><br>**Completion date:** June 2025 | **Funding:** $700,000<br><br>**Spend to 30 Jan 24** $- | Murupara Community Board and Ngāti Manawa are undertaking community engagement for the community plan. Initial outcomes and project activation options are anticipated mid-February 2024.<br>Ngāti Whare and Minginui Village Incorporated Society (MVIS) will commence a Vision and Master Plan with the support of external consultants. The activation project for Minginui will follow the completion of this work.<br>The project had experienced slight delays and it was decided to adjust the project completion dates with DIA from June 2024 to June 2025. |

### 4.4. Strategic alignment

No inconsistencies with any of the Council's policies or plans have been identified in relation to this report.

### 4.5. Legal

Council has a legal obligation to deliver the Better Off Funded projects within the parameters outlined in the DIA Funding agreement for this project. This is currently on track with no risk to compliance identified.

## 5. Options analysis - *Ngā Kōwhiringa*

No options have been identified relating to the matters of this report.

## 6. Significance and Engagement Assessment - *Aromatawai Pāhekoheko*

The decisions and matters of this report are assessed to be of low significance, in accordance with the Council's Significance and Engagement Policy.

### 6.1. Engagement and community views

Engagement on this matter is not being undertaken in accordance with Section 4.2 of the Council's Significance and Engagement Policy. This states that the Council will not consult when there is already a sound understanding of the views and preferences of the persons likely to be affected or interested in the matter.

Engagement will be progressed at a project level as required, following internal protocols, and if of significance, guidance sought from governance groups or Elected Members as appropriate.

## 7. Considerations - *Whai Whakaaro*

### 7.1. Financial/budget considerations

There are no budget considerations associated with the recommendations of this report.

The Better Off Funding programme is fully grant funded by the Department of Internal Affairs with no co-funding requirements.

### 7.2. Climate change assessment

Based on this climate change assessment, the decisions and matters of this report are assessed to have low climate change implications and considerations, in accordance with the Council's Climate Change Principles.

Each project under this programme will have to consider its own climate change impacts as part of its planning and design and take any mitigation steps where appropriate.

### 7.3. Risks

There are no risks associated with the decisions required under this report. Risks to projects and the Better Off Funding Programme as a whole are described in section 4.2.

# 7.2 Whakatāne Accessible and Inclusive Trust Memorandum of Understanding Report

| | |
|---|---|
| To: | **Living Together Committee** |
| Date: | **Thursday, 29 February 2024** |
| Author: | **K Summerhays / Senior Community Development Advisor** |
| Authoriser: | **E Hatch / GM People and Engagement** |
| Reference: | **A2606434** |

## 1. Reason for the report - *Te Take mō tēnei rīpoata*

The purpose of this paper is to advise the Committee of the intention to enter into an operational Memorandum of Understanding with Whakatāne Accessible and Inclusive Trust.

## 2. Recommendations - *Tohutohu akiaki*

1. **THAT** the Whakatāne Accessible and Inclusive Trust Memorandum of Understanding Report be received;
2. **THAT** the Living Together Committee note the following:

- **THAT** the Living Together Committee note the following:
- The Chief Executive will sign an operational Memorandum of Understanding with Whakatāne Accessible and Inclusive Trust, dated 29 February 2024
- The Memorandum of Understanding commits Council to develop a Diversity and Inclusion Policy
- A paper on the development of that policy will be presented at an upcoming Living Together Committee meeting.

## 3. Background - *He tirohanga whakamuri*

Whakatāne Accessible and Inclusive Trust (WAI - formally known as Inclusion Eastern Bay) was originally set up in 2018 and is a group of people with diverse experience of disabilities and ageing in the Whakatāne District.

On 31 January 2020 members of WAI met with Councillor Andrew Iles, Chief Executive Steph O'Sullivan, and staff to discuss support for the disability sector. It was agreed that a general agreement between the two parties by way of an MOU would be advanced as a way to enhance the working relationship between the two parties.

The development of the MOU was interrupted by Covid-19 and following legal advice, the requirement for WAI to become a registered entity.

WAI is offering to advise Council on ways to ensure accessibility for all. This aligns with the Long-Term Plan's strategic priority of improving community wellbeing and vibrancy. It also fits in with the social sector's identification of community safety and access to services as key focus areas within the Community Wellbeing Project.

WAI has now established itself as a Trust and is presently seeking charitable status; their Deed states the following:

*Our Vision: Accessible, inclusive Eastern Bay of Plenty communities that meet everyone's needs.*

*Our principles are based on Te Tiriti o Waitangi, the UN Convention of the Rights of Persons with Disabilities.*

*We are committed to:*

- *Policies and practices that respect and implement the dual cultural practices and aspirations of the partners of Te Tiriti o Waitangi;*
- *Providing opportunities for disabled people/tangata whaikaha, whanau whaikaha, and seniors/pakeke to use their skills, time and talents to contribute to our kaupapa and their communities;*
- *The principle of "Nothing about us without us";*
- *Working cooperatively with other organisations and government agencies;*
- *Engaging in continuous learning, reflecting on experience and*
- *Maintaining high standards of honesty and integrity.*

*Our Mission:*

- *To enable disabled people/tangata whaikaha, whanau whaikaha and seniors/pakeke in the Eastern Bay of Plenty to address issues around inclusion and access for all*
- *To give guidance to local and regional government, the business community, non-government agencies, marae and rūnanga, recreational groups and clubs*
- *To support government and non-government agencies to develop disability and age friendly strategies.*
- *To ensure disabled people/tangata whaikaha, whanau whaikaha and seniors/pakeke know their rights and have access to services that promote their autonomy*
- *To challenge instances of discrimination against disabled people/tangata whaikaha, whanau whaikaha and seniors/pakeke*
- *To network, share information, provide training, and promote issues of inclusion and access for all.*

The attached MOU has been co-written with WAI. The final iteration was approved by WAI on 2 February 2024 and Council's Executive Leadership Team on 20 February 2024 and is now ready for signing.

Members of WAI will be attending this meeting, providing an opportunity for the two parties to sign the MOU.

## 4. Issue/subject - *Kaupapa*

This MOU provides Council staff with clear guidelines to follow when engaging with WAI and vice versa and aims to enable the ethos of 'nothing about us without us'. While there are other groups and organisations that work and advocate on behalf of people with disability (e.g. Disability Resource Centre, Hearing Support BOP), WAI is unique in that the members are predominately those with lived experience of living with a disability. This provides Council access to specialised advice.

The MOU commits Council to develop a Diversity and Inclusion Policy that "reflects this agreement and, in consultation with WAI, provides guidance for the Council." The details of this policy development process will be presented to a future Living Together Committee meeting.

## 5. Options analysis - *Ngā Kōwhiringa*

No options have been identified relating to the matters of this report.

## 6. Significance and Engagement Assessment - *Aromatawai Pāhekoheko*

### 6.1. Assessment of Significance

The decisions and matters of this report are assessed to be of low significance, in accordance with the Council's Significance and Engagement Policy."

### 6.2. Engagement and community views

Engagement on this matter is not being undertaken in accordance with Section 4.2 of the Council's Significance and Engagement Policy. This states that the Council will not consult when there is already a sound understanding of the views and preferences of the persons likely to be affected or interested in the matter.

## 7. Considerations - *Whai Whakaaro*

### 7.1. Financial/budget considerations

Going forward there is budgeting consideration of up to $20K for the development of the policies that can be met through existing operational budgets.

### 7.2. Strategic alignment

No inconsistencies with any of the Council's policies or plans have been identified in this report.

### 7.3. Climate change assessment

Based on this climate change assessment, the decisions and matters of this report are assessed to have low climate change implications and considerations, in accordance with the Council's Climate Change Principles.

**7.4. Risks**

There could be a perception that WAI is the only organisation that WDC will consult on matters requiring input from the disability sector. This MOU does not preclude any working agreements or service agreements with other organisations.

**Attached to this report:** Appendix 1 - Memorandum of Understanding – WAI-WDC 2023-25

# 7.2.1 Memorandum of Understanding - WAI-WDC 2023-25

Memorandum of Understanding

# MEMORANDUM OF UNDERSTANDING

**between**

**Whakatāne District Council**

**and**

**Whakatāne, Accessible and Inclusive Charitable Trust**

**For an inclusive and accessible Whakatāne District**

**29 February 2024 – 28 February 2026**

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This **MEMORANDUM OF UNDERSTANDING** is dated this twenty-ninth day of February 2024.

### Purpose

The Purpose of this Memorandum of Understanding is to formalise the relationship between Whakatāne District Council and Whakatāne, Accessible and Inclusive Charitable Trust.

### Goals and Objectives

Whakatāne District Council (WDC) and Whakatane, Accessible and Inclusive Charitable Trust (WAI) acknowledge that it is important to provide accessible and inclusive places and services to all people in the Whakatāne District. This makes it easier and safer for people with disabilities and their families/whānau and seniors/pakeke take part in our communities.

WAI's participation will ensure people with a disability have a voice and the principle of 'nothing about us, without us' is recognised.

By signing this memorandum both parties express a shared intention to work together to meet our shared goals and on future projects as outlined below:

# Memorandum of Understanding

| **Whakatāne, Accessible and Inclusive undertakes to** |
|---|
| Provide advice to WDC on the impact of plans and projects on people with disabilities.<br><br>Seek involvement in Council placemaking activities and design. |
| Be proactive when WAI becomes aware of an accessibility or inclusiveness situation in a WDC project that requires WDC's consideration. |
| Provide advice to WDC throughout the development of the Council's Diversity & Inclusion Policy. |
| Support WDC with advice on:<br>• The many different experiences of disability and age and people's varied accessibility needs<br>• Easy-to-read and plain language<br>• Language to use when communicating about and to people with disabilities and seniors/pakeke<br>• Suitable signage/symbols and other communication tools for public places |
| Initially raise any issues or concerns about WDC policy, plans or actions directly with the relevant Council staff.<br><br>Where a dispute arises that is not resolved by discussion with WDC within a reasonable time, engage in an informal dispute resolution process (if requested by WDC) prior to taking any other formal or public action in relation to it. |
| Invite WDC to meet with the WAI members/trustees three times annually. |
| Advocate on behalf of disabled people of the district. In the spirit of this agreement, WAI will always advise Council on a 'no surprises' basis before taking any action that might affect or involve the Council. |
| WAI will report annually to an appropriate Council Committee on matters related to this MOU and provide advice as to the effectiveness of it. |
| WAI will maintain a minimum general membership of ten people |

| **Whakatāne District Council undertakes to** |
|---|
| Recognise WAI as a key stakeholder when setting accessibility priorities, and when starting new plans and projects that may be relevant for people with disabilities |
| Reflect the diversity of the district in policies and procedures, including people with disabilities and seniors/pakeke. |
| Develop a Diversity & Inclusion Policy that reflects this agreement and, in consultation with WAI, provides guidance for the Council. |
| Provide accessible and plain language communication, including easy read translations, where applicable, and always use respectful language. |

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Commerce St, Private Bag 1002, Whakatāne 3158, New Zealand

WHAKATĀNE District Council Kia Whakatāne au i ahau

# Memorandum of Understanding

| |
|---|
| Use suitable signage and other communication tools where appropriate. |
| Provide a pathway to resolve concerns and complaints raised by WAI by allocating a single point of contact within Council and an alternative (both of which are to be a position not person).<br>Where a dispute arises that is not resolved by discussion with WAI within a reasonable time, engage in an informal dispute resolution process (if requested by WAI) prior taking any other formal or public action in relation to it. |
| Accept the invitations to meet with the WAI members/trustees three times a year |
| Consider people with disabilities within future social and social procurement policies and existing policy updates and when revising HR policies. |
| Arrange for WAI to report annually to an appropriate Council Committee on matters related to, and the effectiveness of, the MOU. |
| Use the principles of Universal Design as a guideline for thinking about design from an inclusive perspective noting that the Council must provide services that are accessible to all according to current legislation. |

**Notes:** This is not a formal agreement, with legal relationship, obligations, or rights, but rather expresses our mutual understanding.

This memorandum does not require the Council nor WAI to do anything beyond their powers or ability.

**Review:** This memorandum will be reviewed every two years starting 2026. This Memorandum of Understanding may be amended or expanded by mutual agreement.

**Termination:** Either party can give three months' notice in writing if they wish to end the MOU.

## SIGNATORIES

**Whakatāne District Council**

Signed…………………………………………………………………………………………..

Name ………………………………………………Position…………………………………………………

**Whakatāne, Accessible and Inclusive:**

Signed…………………………………………………………………………………………..

Name ………………………………………………Position…………………………………………………

# 7.3 Rex Morpeth Recreation Hub Master Plan Update – February 2024

| | |
|---|---|
| To: | **Living Together Committee** |
| Date: | **Thursday, 29 February 2024** |
| Author: | **S Evans / Senior Reserves Advisor** |
| Authoriser: | **G Fletcher / General Manager Community Experience** |
| Reference: | **A2619718** |

## 1. Reason for the report - Te Take mō tēnei rīpoata

The purpose of this report is to provide the Living Together Committee with an update report on the Rex Morpeth Recreation Hub Master Plan component of the "Mā Koutou, Mā Tātau - Our People, Our Spaces" project, ahead of and in preparation for consultation on Council's Long Term Plan 2024/34. This update provides detail on the background to the project, community consultation completed to date, the master plan option recommended by the consultant team and a schedule of works that will be necessary to carry out if the larger scale master plan project does not proceed.

## 2. Recommendation – *Tohutohu akiaki*

1. **THAT** the "Mā Koutou, Mā Tātau – Our People, Our Spaces, Rex Morpeth Recreation Hub Master Plan Update – February 2024" report be **received**;
2. **THAT** the Living Together Committee note that the decision to include the Rex Morpeth Recreation Hub Master Plan project in the draft 2024/34 Long Term Plan budget for community consultation will be made by Council as part of the Long Term Planning process.

## 3. Background – *He tirohanga whakamuri*

The **Rex Morpeth Recreation Hub**, which includes the Whakatāne War Memorial Hall (WWMH), Rex Morpeth Park, Rugby Park, Whakatāne Aquatic and Fitness Centre, and the Whakatāne Arts and Craft Centre, is one of the district's most loved and used community assets. The Rex Morpeth Recreation Hub is a place where many memories are made and lifelong friendships and skills are developed. It has served us well; however, significant upgrades, expansion, or maintenance investment is now required to respond to changing uses and modern challenges. This is a unique opportunity to ensure that the current and future needs of the community are met throughout the district and to develop a multipurpose facility and recreational activities in Whakatāne to help address social, cultural, and sporting needs across our communities.

Council identified the need for significant upgrades to the WWMH some time ago, and for the past ten years has been in the process of planning its redevelopment. A commitment was made to upgrade the WWMH and the recreation precinct (Rex Morpeth Recreation Hub) in the 2021/31 Long Term Plan.

In September 2022, the Rex Morpeth Recreation Hub Master Plan project was put out as an open tender, together with the Whakatāne Open Spaces Strategy. In November 2022, the tender for both projects was awarded to Veros (led by Adele Hadfield), with partners with DCA Architects (Darryl Church) and GHA (Kererua Savage).

In 2023, a long list of redevelopment options were developed and considered with three master plans shortlisted. These provided redevelopment options which aligned with previous findings and were informed by a new round of community and key stakeholder engagement. The three options and an 'enhance status quo' option were put out for community consultation in October 2023.

The input from the key users workshops and community engagement in September and October 2023 was used to refine the consultants recommended master plan option. This option was presented to the Living Together Committee in December 2023 and is based on the consulted Option 1, 'Optimising for Now and the Future'. It is proposed that development of the Rex Morpeth Recreation Hub is delivered in three stages over a 10-year period, that the existing War Memorial Hall is renovated and extended with flexibility available for certain works, depending on available funding and timing.

## 4. Issue/subject – *Kaupapa*

Rex Morpeth Park, Rugby Park and the WWMH are facilities of district importance which also serve the wider Eastern Bay of Plenty communities. The WWMH in particular is critical as it is the district's primary indoor courts space, event/function facility, and theatre.

The Rex Morpeth Recreation Hub Master Plan outlines the future use of the 17-hectare recreational and sporting space of Rex Morpeth Park and Rugby Park. The Master Plan is intended to be a 30 year plus vision for this significant community asset and how it may be developed over a 10 year period.

The last significant upgrade to the WWMH was in the 1970s. The facility is no longer fit for purpose for the growing wider Whakatāne District community sports groups and arts and culture needs. Numerous studies have been undertaken since 2015 with regard to upgrading the WWMH, and this is the short-term investment focus of the recommended master plan.

### 4.1. Key Considerations

Key considerations for the Rex Morpeth Recreation Hub and associated facilities include:

- A master plan that will provide for the redevelopment of existing facilities to meet the community's needs, wellbeing and aspirations now and into the future.
- Rex Morpeth Park, the Aquatic Center and WWMH are well utilised and are crucial community assets.
- In general, the WWMH is no longer fit for purpose and will not meet the communities' needs in the future. In some aspects it doesn't meet current needs. Its continued use despite its condition is evidence of its importance.
- The site's flexibility and user experience are compromised in some respects by the location of activities, the availability of spaces and the number that can be accommodated within the WWMH in particular.
- Parking, access, and traffic are key issues within the full Rex Morpeth Hub site. Parking is regularly at capacity and Traffic Management Plans are required for events of over 300 people.

- The majority of existing facilities are old and in need of a variety of repairs and upgrades. This degrades the user experience and the number and types of bookings for spaces such as the reception lounge and Little Theatre.
- Rugby Park is fenced off and is disconnected from the rest of the Recreation Hub. This compromises user experience, safety, and access and movement of all kinds through the park.
- The rugby grandstand requires earthquake strengthening; a decision must be made on its future.
- The croquet club's playing surface is negatively impacted by the large, protected trees to the east and other field surfaces have at times been compromised and damaged from different users.

### 4.2. Design Principles

The key design principles, determined through engagement and analysis, are:

- Functionality
- Accessibility
- Flexibility
- Community
- Leverage

### 4.3. Investment Objectives

A set of investment objectives were developed to provide an overarching test for the master plan options. The investment objectives of the master plan project are:

- Maximise use of the Recreation Hub by ensuring it is fit for purpose and flexible.
- Enhance user experience of the Recreation Hub.
- Ensure the Recreation Hub is future proofed for growth and change.

It is proposed that key investment moves are made over time to deliver on the agreed master plan once a final version is agreed. It is unaffordable for our community to invest in the full master plan delivery at this time, nor can we fund this alone as a community.

Council have started initial conversations to progress partnership funding discussions with Community Trusts, Corporate Sponsorship, Community Fundraising, and Trust Funding options. Conversations will also be initiated with Central Government and Philanthropic individuals and organisations. Typically, community facilities such as this can attract a significant portion of funding to match that of the direct ratepayer and community contribution.

## 5. Progress

### 5.1. Consultants Recommended Master Plan Option

Input from the key users workshops and community engagement in September and October 2023 was used to refine the recommended master plan option, as presented to the Living Together Committee on 7 December 2023.

The recommended master plan is based on the consulted Option 1, 'Optimising for Now and the Future', and is proposed to be delivered in three stages over a 10-year period. There is some flexibility with certain works, depending on available funding and timing.

The recommended master plan provides for the redevelopment of the existing WWMH to provide for upgraded facilities and four full-sized indoor basketball courts together with improvements over the Rex Morpeth Recreation Hub area. The master plan does not include any changes to the existing tennis courts and club or the Whakatāne Fitness and Aquatic Centre, although an area is left reserved for a future extension to the Aquatics Centre. The Arts House remains as part of the master plan, in the existing location, until such time that a decision is made on an arts hub as part of Councils Arts, Culture and Creativity Strategy.

The master plan recommended by the consultant team has not been adopted by Council or the Living Together Committee at this point in the process. Further engagement through the Long Term Plan 2024/34 consultation process will be undertaken before any decision in relation to a preferred master plan option is sought from Council or this Committee.

## 6. Options analysis – *Ngā Kōwhiringa*

A decision to include the Rex Morpeth Recreation Hub project into the draft 2024/34 Long Term Plan/10 year budget that will go out for community consultation will be made at Council's Environment, Energy and Resilience Committee meeting on 6 March 2024.

If the project is included in the draft budget that goes out for community consultation then input from our communities will be sought on the extent of the maintenance and improvement work to be carried out, the strategy and timing of delivery and the level of external funding required for the project to get the green light. Noting that a project of this scale will have many stop/go decision making points as part of the project delivery process.

## 7. Significance and Engagement Assessment – *Aromatawai Pāhekoheko*

### 7.1. Assessment of Significance

The decisions and matters of this specific report are assessed to be of low significance in accordance with the Council's Significance and Engagement Policy. However, future decisions in relation to the redevelopment of Rex Morpeth Recreation Hub, particularly regarding the extent of works, timing of works and budget approval are likely to be of high significance. Assessments of significance will be made and provided to the Council at the time of these decisions.

For future decisions relating to this project, information will be provided about applicable decision-making requirements under the Local Government Act.

### 7.2. Engagement and community views

Engagement on this matter is being undertaken in accordance with Section 4.2 of the Council's Significance and Engagement Policy. Engagement has been undertaken, and is continuing to be undertaken, to gain an understanding of community views in relation to the use and long-term development of the Rex Morpeth Recreation Hub.

Collaborating with tangata whenua throughout the engagement, planning and design phases is fundamental to the success of the overarching project. Council is working alongside Te Rūnanga o Ngāti Awa in relation to the Rex Morpeth Recreation Hub project. Our other Iwi partners are aware of the project but are not actively involved at this stage.

Previous engagement has been undertaken through previous Long Term Plan engagement processes, with budget provided for enhancement of the WWMH and surrounding hub in the current 2021/31 Long Term Plan.

## 8. Considerations – *Whai Whakaaro*

### 8.1. Financial/budget considerations

There are no budget considerations associated with the recommendations of this report. Commentary on the inclusion of this project in Council's 2024/34 Long Term Plan is set out in paragraph six. If the project is included in the final 2024/34 Long Term Plan a specific "funding plan" will be developed which will include a strategy to attract external funding.

Set out below is the current 2021/31 LTP budget for the Recreation Hub:

| | Total budget | 2020/21 AP | 2021/22 LTP | 2022/23 LTP | 2023/24 LTP | 2024/25 LTP | 2025/26 LTP | 2026/27 LTP | 2027/28 LTP | 2028/29 LTP | 2029/30 LTP | 2030/31 LTP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Expenditure | 10,497,002 | 195,500 | 50,000 | 101,900 | 103,632 | 3,948,391 | 6,097,579 | - | - | - | - | - |
| Subsidies & Grants | 5,875,607 | 132,598 | 25,000 | 50,950 | 51,816 | 2,566,454 | 3,048,789 | - | - | - | - | - |

### 8.2. Master Plan Cost Estimates

A first round of cost estimates was completed by Quantity Surveyors, Kingstons and further reviewed by Veros and Council staff for the four options put forward for community consultation. The costs were further refined by Veros in relation to their recommended master plan option, with the estimated cost confirmed as between $84.5 million and $110 million depending on the extent of works and inflation.

### 8.3. Recommended Essential Works

Certain works within the Rex Morpeth Recreation Hub are required by legislation or considered necessary to continue to provide certain facilities on the site. The table below outlines these works and potential options if the master plan does not progress in line with that recommended by the consultant team. The outlined costs are an estimate and do not include inflation.

**7.3 Rex Morpeth Recreation Hub Master Plan Update – February 2024(Cont.)**

| Work/Project | Status | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|
| Rugby Grandstand – seismic work | Required under the Building Act 1994 to carry out seismic work by 1 July 2036 | Demolish building and provide no facility here.<br><br>Cost: under $80,000 | Carry out required earthquake strengthening only.<br><br>Cost: $600,000 | Earthquake strengthen and upgrade building. This would include replacing broken glass, seating etc, making female and male changing spaces and new kitchen/clubroom facilities.<br><br>Cost: $1 million minimum | Demolish existing and build new sports pavilion.<br><br>Cost: $3-5 million (depending on design and scale of new building, this could be more) |
| Childrens Play Space | Must do.<br><br>Existing playground structure (excluding swing set) requires replacing. | Demolish and provide no playground here.<br><br>Cost: $10, 000 | Replace with a similar playground structure.<br><br>Cost: $80, 000 | Remove existing and create a small, children's accessible play space.<br><br>Cost: $450,000 | Remove existing and create a new, larger, accessible play space.<br><br>Cost: $1 million minimum |
| Safety enhancements and minimal upgrades to Little Theatre | Considered critical to do more than maintenance.<br><br>Risk is closure of the Little Theatre. | Maintenance and safety improvements only.<br><br>Cost: Existing maintenance budget and up to $100,000 for critical works | Small upgrades (including some lighting and sound improvements and new stage curtain) and safety improvement.<br><br>Cost: $1 million approx | Full refurbishment of Little Theatre.<br><br>Cost: $3.5–5 million approx | Full refurbishment and extension as part of WWMH upgrade and extension total cost. |

| Work/Project | Status | Option 1 | Option 2 | Option 3 | Option 4 |
|---|---|---|---|---|---|
| WWMH reception lounge and kitchen upgrades | Considered critical to do more than maintenance.<br><br>Kitchen is unusable for most events and space is rarely booked for events. | None – only maintenance when required.<br><br>Cost:<br>$0 (existing maintenance budget only) | Minor kitchen and reception lounge upgrades (tidy up). No structural works.<br><br>Cost:<br>$1 million | Commercial kitchen, minor alterations, new ceiling materials, new bathroom facilities and upgrades to reception lounge area.<br><br>Cost:<br>$4 million approx | Full refurbishment and extension as part of WWMH upgrade and extension total cost. |
| WWMH Sports hall upgrades | Considered critical to do more than maintenance.<br><br>Safety improvements are needed to mezzanine area and bathroom upgrades are overdue (this includes asbestos removal works) | Maintenance and safety improvements only.<br><br>Cost:<br>Existing maintenance budget and up to $500,000 for other works | Upgrade existing sports hall area – flooring, bathroom, kitchen, mezzanine etc.<br><br>Cost:<br>$5 million | Extend and upgrade sports hall area only.<br><br>Cost:<br>$12 million minimum | Full refurbishment and extension as part of WWMH upgrade and extension total cost. |
| Additional car parks | Considered essential to provide improved car parking within Recreation Hub. | No additional sealed and marked parking spaces provided.<br><br>Cost:<br>$0 (existing maintenance budget only) | Minor improvements to Domain Road entrance and parking and one small additional car park area (up to 50 additional parking spaces).<br><br>Cost:<br>$150,000 approx | Access and parking improvements (50 to 100 additional spaces and designated bus parking).<br><br>Cost:<br>$1 million | Car parks, lighting, new roading and footpaths and replacement landscaping. As outlined in recommended master plan Option 1.<br><br>Cost:<br>$5 million approx |

## 8.4. Strategic alignment

No inconsistencies with any of the Council's policies or plans have been identified in relation to this report.

**8.5. Climate change assessment**

The detailed design and development of the master plan will consider Council's Climate Change Strategy. The effects of climate change and natural hazards have already impacted Council's open space network and highlights the need for careful consideration of climate change as part of the development of Rex Morpeth Recreation Hub. A key consideration will be any sustainability initiatives that could be undertaken with any building works, including examples such as the use of solar panels, the disposal or re-use of demolition materials and the types of construction materials used.

Based on this climate change assessment, the decisions and matters of this specific report are assessed to have low climate change implications and considerations, in accordance with the Council's Climate Change Principles. Detailed assessments will be provided in future reports, this will include assessment of any changes to green spaces and building and infrastructure works.

**8.6. Risks**

In addition to the risks identified in the options analysis the following key risks have been identified:

- Publicity/public perception of Council undertaking master planning and strategy development for a project that has been consulted on previously but not taken forward into the delivery and build stage.
- Publicity/public perception of costs associated with completing the master plan.
- Publicity/public perception of costs and development timeframes associated with the recommended Rex Morpeth Recreation Hub master plan option. This includes the financial impact of any option and security of obtaining funding to complete the physical site and building works.
- Timing of each stage of development and effects on existing users.

## 9. Next steps - *Ahu whakamua*

1. Council to make a decision on whether the Rex Morpeth Recreation Hub project is included in the draft 2024/34 LTP budget that will go out for community consultation in March 2024.
2. If the project is included in the draft 2024/34 LTP budget then we will further our discussions with potential partners, stakeholders and funders to help inform the final LTP 2024/34 decision making process.
3. Await the outcome of Long Term Planning process before proceeding with any further detailed design work in relation to the project.

# 7.4 Awatapu Lagoon, Sullivan Lake and Matatā Lagoon Recommended Environmental Improvements

| | |
|---|---|
| To: | **Living Together Committee** |
| Date: | **Thursday, 29 February 2024** |
| Author: | **I Molony / Manager Open Space Operations** |
| Authoriser: | **G Fletcher / General Manager Community Experience** |
| Reference: | **A2617127** |

## 1. Reason for the report - *Te Take mō tēnei rīpoata*

The purpose of this report is to provide the Living Together Committee with an overview of the history, current situation, and the recommendations made by an independent consultant to improve the environmental condition of Awatapu Lagoon, Sullivan Lake and Matatā Lagoon.

There is significant community interest in the improvement of the quality of these water bodies as they are located within areas of public open space and provide amenity, recreation opportunities and flora and fauna habitats. Each waterbody is also part of Council's stormwater network.

## 2. Recommendation - *Tohutohu akiaki*

1. **THAT** the Living Together Committee receive the "Awatapu Lagoon, Sullivan Lake and Matatā Lagoon Recommended Environmental Improvements" report and note that a decision regarding the funding required to carry out further maintenance and improvements to these water bodies will be made by Council as part of the Long Term Plan 2024/34 budget and work programme process.

## 3. Summary

Details in relation to Awatapu Lagoon, Sullivan Lake and Matatā Lagoon are provided below. Awatapu Lagoon and Sullivan Lake are owned and managed by Council, whilst Matatā Lagoon is owned by The Crown as a Government Reserve (Wildlife) under the Ngāti Rangitihi Claims Settlement Act 2022. All three waterbodies suffer from poor ecological conditions, including poor water quality. Council made a commitment to investigate measures to improve the quality of urban lakes and lagoons through the Long-Term Plan 2021/2031 and engaged River Lake Environmental Consultancy Limited "River Lake Limited" to undertake an assessment of the water quality, ecology and options for improvement of these water bodies. The recommended management interventions information provided by River Lake Limited is crucial to consider for the future management of each waterbody.

## 3.1. Awatapu Lagoon

### *3.1.1. Background - He tirohanga whakamuri*

The Awatapu Lagoon was created in the 1970’s by the Bay of Plenty Catchment Commission following diversion works undertaken on the Whakatāne River. The diversion eliminated a meander in the Whakatāne River, provided an area for housing (Ōtamakaokao/Awatapu) and improved flood protection by the creation of a flood storage basin and flood banks.

The lagoon is an intermediary receiving environment for stormwater and receives a minimal inflow of fresh water from the Wainui te Whara Stream (from the east) and from the Whakatāne River via floodgates during high tide. There are several stormwater outlets into the lagoon from the surrounding urban area.

Awatapu Lagoon experiences heavy nutrient and macrophyte loads, leading to a poor ecological environment as flushing only occurs during periods of heavy rains.

The Ōtamakaokao Kaitiaki Trust, HALO Whakatāne, Whakatāne Intermediate School Environmental Science department and local residents have been very active in advocating for the restoration of the Awatapu Lagoon. The Awatapu Ōtamakaokao Community Plan 2022-2032 highlights the ecological importance of the Awatapu Lagoon and the linkage of the lagoon to the wellbeing of the community.

### *3.1.2. Issue/subject - Kaupapa*

There are a number of factors contributing to the poor quality of the water at Awatapu Lagoon:

- Limited inflow of freshwater from the Wainui te Whara Stream
- Stagnation of water in the southern section of the lagoon
- Proliferation of undesirable aquatic weed species
- Siltation of the Awatapu delta area at the inlet of the Wainui te Whara Stream

There is currently no ongoing structured management of the Awatapu Lagoon water body and no specific budget allocated to the Lagoon.

The spraying of submerged aquatic weed has been undertaken in the past but has ceased due to the negative effects this has on increasing the nutrient loading within the water body, which affects the quality of the water.

A trial harvesting of macrophytes using a lake weed harvester was undertaken in the southern section of Awatapu Lagoon during 2019 at a cost of $21,600. This proved successful in the short term with 200 tonnes removed but requires ongoing maintenance to maintain control.

The control (spraying) of Parrot’s Feather, a perennial floating and emergent pest plant is required on an ongoing basis.

Ongoing silt removal is required from the Awatapu delta area at the inlet of the Wainui te Whara Stream. These works are carried out by Council’s Three Waters team as part of their stormwater management.

Costs for removal are approximately $130,000 per event and drawn from the Whakatāne Green Stormwater budget which is allocated to the maintenance of non-physical assets across Whakatāne and applied where there is a need.

Council has recently received the 'Awatapu Lagoon Water Quality, Ecology and Options for Improvement' report by River Lake Limited, attached at Appendix 1, which provides details on the water quality, ecology and options for improving Awatapu Lagoon.

This report outlines the following potential management options to address ecological and water quality issues at Awatapu Lagoon:

| Ecological issues | Causes | Potential mitigation options |
|---|---|---|
| Supertrophic high concentration of nutrients, algae, poor clarity. Cyanobacteria blooms. | External nutrient load | ○ Create treatment wetlands in vicinity of Wainui Te Whara delta.<br>○ Floating wetlands for N removal and habitat.<br>○ Sediment detention bunds in upper catchment<br>○ Educate to reduce nutrient use in catchment |
| | Internal nutrient load via sediment resuspension or anoxia | ○ Harvest aquatic macrophytes / azolla and remove from the lagoon.<br>○ Phosphorus-locking of sediments with focus on deep areas the develop halocline (west and central lagoon). |
| | Bottom water anoxia | ○ Harvest macrophytes to reduce load of organic matter. |
| Poor oxygen conditions | Floating macrophyte mats | ○ Harvest aquatic macrophytes. Option of using spray to managing biomass between harvesting. |
| | Halocline stratification in Western lagoon | ○ Naturally occurring but may have limited impact if brocken only during high flow events. |
| | Negligible flow in South lagoon | ○ Divert WTW Stream to flow via South Lagoon in conjunction with creating treatment wetlands.<br><br>○ Pipe or syphon water from Whakatāne River to Awatapu south using tidal head. |
| Excessive aquatic pest plant cover affecting WQ, biodiversity, recreation and aesthetics. (contribute C and N) | Pest plants of hornwort and parrots feather as floating rafts and rooted in shallow areas | ○ Harvest aquatic macrophytes<br>○ Herbicide spray of aquatic macrophytes to maintain low biomass between harvests (risks worsening low DO and high nutrients). |
| Pest plants on riparian zone | *Glyceria maxima* near the foot bridge | ○ Targeted herbicide spray of reed *Glyceria* sp.<br>○ Remove weeds on floating wetlands |
| Siltation | Stream inflow. WTW delta, Sullivan Lake footbridge | ○ Continue sediment removal from WTW delta<br>○ Extend WTW delta to create a wetland area.<br>○ Silt traps at source. Sullivans - floculation at footbridge stream. |
| Litter | Rubbish directly and via stormwater | ○ Street sweeping<br>○ Litter traps<br>○ Regular "pick-ups" |
| Riparian management restricting development of marginal wetlands | | ○ Plant native riparian vegetation to optimise habitat values.<br>○ Create shallow sloping banks into water and plant with wetlands. |
| Poor access to the water | Lack of structures in water | ○ Construct jetties and boat launching areas in western lagoon |
| Enhance biodiversity | | ○ Create wetlands and floating wetlands for birds, fish and invertebrates.<br>○ Harvest pest aquatic macrophytes to assist natives.<br>○ Establish native macrophytes (e.g. *Ruppia* sp. in Western Lagoon). Animal pest control (Halo) |

### *3.1.3. Next steps - Ahu whakamua*

Works are required to improve the flow of water through the southern part of the lagoon and to manage the infestation of aquatic weed within the lake on an ongoing basis. The following workstreams are in in place to aid this effort:

- Council is working on a project to rejuvenate the southern section of the Awatapu Lagoon (from Awatapu Drive south towards the Whakatāne River), as this section experiences significant stagnation and extremely poor water quality. Council engaged with the community to investigate 14 options to improve this part of the lake and agreed that the best option is to turn the southern leg of the lagoon into a wetland. The project has been estimated to cost $2.1M to complete and funding for this approved through the 2021/31 Long Term Plan. Project and concept plans have been created, with final engagement due to commence soon.
- The existing 'Awatapu Reserve Management Plan' is outdated and requires a review. A new Reserve Management Plan could provide a planning framework to ensure the improvements provided by 'River Lake Limited' are implemented and are aligned with the outcomes of the Awatapu Ōtamakaokao Community Plan. We plan to commence work on the Awatapu Reserve Management Plan this calendar year.
- Council will continue to support external agencies working towards the restoration of Awatapu Lagoon and implementation of the Awatapu Ōtamakaokao Community Plan 2022-2032
- Council's Three Waters team will continue to desilt the Awatapu delta area at the inlet of the Wainui te Whara Stream through existing stormwater maintenance budgets (Approximate cost $130,000 per event). Silt removed from this area will be used to establish the wetland in the southern part of the lagoon.

Further options for consideration include the following:

- Create wetlands in the vicinity of the Wainui Te Whara delta to improve water quality and biodiversity.
- Consider diverting Wainui Te Whara flow to Awatapu south to help flush this lagoon – but note this may worsen water quality in the rest of the lagoon if other actions are not undertaken.
- Further investigate syphoning water from the Whakatāne River to Awatapu south.
- Further investigate Phosphorus locking of Awatapu west and parts of Awatapu central to reduce nutrient release during periods of bottom water anoxia.

The key management intervention recommended by River Lake Limited for Awatapu Lagoon is harvesting of macrophytes biennially. The associated total cost over 10 years is $375,000, for which funding would be required as part of the 2024/34 Long Term Plan as this is not currently provided for in the Long Term Plan 2021/2031.

## 3.2. Sullivan Lake

### *3.2.1. Background - He tirohanga whakamuri*

Sullivan Lake is an ox-bow lake from the Whakatāne River, formed when the river cut a new channel at a tight bend to the west of the lake and created a wetland. The area of the present lake remained a swampy lagoon until the 1960's, when it was excavated to create Sullivan Lake as part of the original subdivision of this area.

In its early days, the former lagoon contained a mixed growth of raupo, various rushes and sedges. This disappeared with the establishment of the lake, to be replaced by infestations of common lake weeds, floating sweetgrass, water lilies and algal blooms.

There is no natural inflow of water to the lake, however a limited volume of fresh water is pumped through the stormwater system from the Whakatāne River via Council’s water treatment plant in Te Tahi Street.

Sullivan Lake is an intermediary receiving environment for stormwater runoff from the surrounding urban environment and Valley Road. The inflow of stormwater, particularly from the Valley Road area introduces a significant amount of silt. The lake acts as a sediment deposition environment and provides the trap for the fine sediments as these require a large flat area in which to settle. A bund is maintained at the southern end of the lake to aid in the capture of sediment. The silt is more manageable from that location and its removal is currently scheduled on an irregular basis by Council’s Three Waters team.

The reserve also provides stormwater overland flow relief at its southern end in the form of a shallow swale connected from Douglas Street (near Mary Henry Place) which allows water to spill into the reserve during intense rainfall events when the piped network is overwhelmed.

A wastewater pump station is located at the eastern edge off Douglas Street. This pump station and associated infrastructure was upgraded in 2014 and significantly reduced the likelihood of wastewater overflows which have occurred in the reserve in the past during severe rainfall events.

The Sullivan Lake Care Group which includes members of the community who reside beside the lake was established in 2013, with the purpose of working with Council and the reserve’s community of interest. The group are actively involved in assisting with the beautification and maintenance of the reserve. They are strong advocates for the need to improve the quality of the water. The Care Group also provided input into the Sullivan Lake Management Plan which was reviewed in 2015. Many of the actions in this Management Plan required an investigation into the water quality to dictate how best to improve the lake environment.

Desilting of a section of the southern end of the lake was completed in 2018 at a cost of $100,000 to deepen the lake and contribute to reduced water temperatures and improved water quality, particularly in summer months. No further large-scale desilting has been completed since.

### *3.2.2. Issue/subject - Kaupapa*

There are numerous factors contributing to the poor quality of the water at Sullivan Lake as follows:

- Limited inflow of freshwater with present pumping at capacity.
- Shallow depth of the lake leading to increased water temperatures.
- Silt entering the lake through stormwater runoff.
- Proliferation of undesirable aquatic weed species, particularly water lilies.
- Cyanobacteria blooms during summer caused by high nutrient concentrations and warm conditions which exceed recreational use guidelines and contributes to the death of fish species.
- Occurrence of Avian botulism resulting in the death of ducks frequenting the lake.

There is currently no regular structured management of the Sullivan Lake water by the Council's Open Spaces team and no specific budget allocated for this.

Whilst spraying of aquatic weed has been undertaken in the past, this has ceased due to increased pressure from the community and the negative effects the rotting vegetation has on increasing the nutrient loading within the water body, which affects the quality of the water.

Harvesting of submerged aquatic weed has previously been undertaken however this is expensive due to the need for removal and disposal of the weed and it requires an ongoing programme to be successful. The harvesting of water lilies has recently been trialled with little success as they regrow within a short period of time.

Ongoing silt removal from the southern end of the lake before the bund is required to be carried out by Council's Three Waters team with the frequency dependent on the amount of rainfall received.

Costs for this are approximately $15,000 per annum and are drawn from the Whakatāne Green Stormwater budget which is allocated to the maintenance of non-physical assets across Whakatāne and applied where there is a need.

Council has recently received the 'Sullivan Lake Water Quality, Ecology and Options for Improvement' report by River Lake Limited, attached at Appendix 2, which provides details on the water quality, ecology and options for improving Sullivan Lake.

Section 4.1 of this report outlines the potential management options to address ecological and water quality issues in Sullivan Lake.

**7.4 Awatapu Lagoon, Sullivan Lake and Matatā Lagoon Recommended Environmental Improvements(Cont.)**

| Issue | Cause | Potential management options |
|---|---|---|
| Supertrophic high concentration of nutrients, algae, poor clarity. Cyanobacteria blooms. | External nutrient load. | o Create treatment wetlands at western and southern end of lake.<br>o Floating wetlands for N removal and habitat (risk of root attachemnt in very shallow areas)<br>o Continue to reduce risk of sewage overflows. |
| | Internal nutrient load via sediment resuspension, anoxia, plant senescence and/or waterfowl. | o Dredging of fine sediment at western end of lagoon.<br>o Harvest curled pondweed in early summer to remove nutrients and avoid collapse.<br>o P-locking |
| Poor oxygen conditions | Phytoplankton and cyanobacteria blooms | o Manage nutrient loads (as above)<br>o Ensure areas of macrophytes in lake to help suppress excess algae (i.e. maintain some areas of waterlily).<br>o Increase volume of flow augmentation during summer to increase flushing. |
| | Sediment organic matter exerting a BOD load in eastern end | o Dredging at western end (King St) where more organic muds and lower DO.<br>o Consider harvesting some waterlily prior to winter senescence to reduce BOD load. |
| Excessive aquatic plant cover affecting recreation and aesthetics | Waterlily cover dominating western end. Provides many WQ benefits but excessive cover adversely affects asethetics, recreation and possibly DO. Very few other macrophytes, but recently curled pondweed growing during spring/summer. | o Manage waterlily extent by dredging soft sediment and lily at western (King St) end (e.g. within 10m from shore).<br>o Contain lily regrowth using mats to cover sediment.<br>o Harvest curled pondweed in early summer prior to collapse.<br>o Harvesting is preferable to spraying as it avoids the risk lof releasing nutrients and oxygen demand.<br>o Grass carp are not recommended for Sullivan Lake as they risks with worsening eutrophication. |
| Pest plants in drain downstream of Sullivans Lake | Egeria, Elodia | o Direct removal<br>o Targeted herbicide spray |
| Siltation | Long term siltation from inflowing stormwater. Also biomass accumulation at King Steet end | o Silt traps for main stormwater inflows and eastern end (foot bridge) with possible flocuulation.<br>o Dredging at western end (King St).<br>o Limited opportunity for sediment control devices in stormwater catchment. |
| Occasional outbreaks of avian botulism during summer | Associated with warm water, anoxic sediments and high density of waterfowl. | o Remove carcasses of dead birds from the lake and margins. |
| Litter | Rubbish directly and via stormwater | o Operational street sweeping<br>o Litter traps<br>o Regular "pick-ups" |
| Riparian management resticting development of marginal wetlands | | o Plant native riparian vegetation to optimise habitat values.<br>o Create riparian wetlands in water with sloping banks. |
| Enhance biodiversity | | o Create wetlands, consider floating wetlands for invert., bird and fish habitat.<br>o Animal pest control (Halo) |

### *3.2.3. Next steps - Ahu whakamua*

A sub-set of options were selected from the 'Sullivan Lake Water Quality, Ecology and Options for Improvement' report based on their potential benefits and input from Council. Work towards these improvements will also resolve many of the actions within the 'Action Plan' of the Sullivan Lake Management Plan.

The key management interventions recommended for Sullivan Lake and associated costs staged over a 10-year period are listed below:

| Key Management Interventions | Cost |
|---|---|
| • Treatment wetland to trap sediment, nutrients and improve biodiversity. | 75,000 |
| • Dredging to remove organic sediments near waterlilies. | 125,000 |
| • Bottom-lining to contain the spread of water lily. | 40,000 |
| • Harvesting macrophytes to manage plant cover and remove nutrients. | 120,000 |
| **Total** | **360,000** |

Council's Three Waters team will continue to implement maintenance programmes within the lagoon:

- Desilting of the southern end of Sullivan Lake as required through existing stormwater maintenance budgets ($10,000 -$15,000 per annum).
- Carry out a bathymetric survey of the southern end of the lagoon every five years where silt is removed to determine the depth.

## 3.3. Matatā Lagoon

### *3.3.1. Background - He tirohanga whakamuri*

The Matata Lagoon/Te Awa O te Atua was established in 1917 after the Tarawera River was diverted directly to sea. The lagoon is divided into eastern and western lagoons by a causeway giving access to the Matata Recreation Reserve, known as the Domain Camping Ground with the sea beyond.

The Matatā Lagoon has many invested stakeholders including the Department of Conservation, Te Tatau Pounamu o Te Awa o Te Atua - The Joint Advisory Committee, Iwi and hapū.

The eastern and western lagoons form part of the Wildlife Refuge Reserve and are managed under the Reserves Act 1977 and administered by the Department of Conservation.

Following the Matatā flooding event in 2005, Council initiated a series of disaster mitigation projects around the township. One of these projects was the western Matatā lagoon (Te Awa o te Atua) earthworks and restoration project which included the establishment of two floodbays at the exit of the Awatarariki stream as it enters the western lagoon, for the purpose of managing silt before it enters the lagoon.

In 2018 a Memorandum of Understanding (MOU) was signed between Council and the Department of Conservation to define the responsibilities and ensure the effective management and ongoing maintenance of the wider Matatā Lagoon as required by the resource consent issued for the restoration works.

It is important to note the long term aspiration of Ngāti Rangitihi to reconnect the Tarawera River to the lagoon and out to sea which will change the way the area is managed in the future.

### *3.3.2. Issue/subject - Kaupapa*

Council's Three Waters team has the following responsibilities relating to the lagoon under the MOU:

- The control of pest plant species as appropriate (including but not limited to Raupo) in the lagoon.
- Ensuring that the flora growing in areas that are part of the lagoon stormwater management system within the Wildlife Refuge Reserve, are maintained to ensure they do not interfere with the function of the infrastructure. This is the access point for the Waimea into the lagoon and the culverts entering/exiting the lagoon and under the camp access road.
- Regular maintenance of the Awatarariki Stream, the floodway silt traps (Floodbay 1 and 2), culverts leading into and out of the open water and the culvert under the causeway between the eastern and western lagoons.
- $70,000 per annum is allocated specifically for this through the LTP 2021/31 with additional costs being drawn from the Matatā Green Stormwater budget which is allocated to the maintenance of non-physical assets across the Matatā scheme and applied where there is a need.

Council's Open Spaces team are responsible for maintaining the public spaces only between Arawa Street and the lagoon.

River Lake Limited has been engaged to provide a 'State of the Environment' report, which will provide vital information on the environmental health of the lagoon when the future of the lagoon is planned. Initial indications of the priorities to address are:

- Reticulation of sewage to reduce the risk of septic tank leaching contributing nutrients or microbial contamination.
- Plant pest control and native riparian planting on the northern shore of Matatā Lagoon.
- Creation of treatment wetlands in the western end of Matatā Lagoon through and directing stream inflows to pass through the treatment wetlands. This has an additional benefit of improving biodiversity values for native birds and fish.
- Improving fish access and water flow from the Tarawera River by installing fish friendly flap gates.

### *3.3.3. Next steps - Ahu whakamua*

Council's Three Waters team will continue to meet their responsibilities as outlined under the MOU through existing stormwater maintenance budgets. There are no proposed further financial requirements for Council in relation to Matatā Lagoon.

Potential management options to address ecological and water quality issues in Matatā Lagoon/Te Awa o te Atua Lagoon have been drafted by River Lake Limited as:

| Issues | Causes | Potential management options |
|---|---|---|
| Poor water quality, low clarity | External (catchment) nutrient load | o Reticulate sewage to reduced risk of leaching from septic tanks.<br>o Investigate P-locking at inflows to main lagoon.<br>o Create treatment wetlands in the western end of Matata Lagoon to treat incoming water flows (and improve habitat). |
| | Internal nutrient load via sediment resuspension.<br>Options for deepening Matata lagoon are restricted by a layer of historic contaminated sediment. | o Emergent wetlands will help stabilise sediments and provide habitat for zooplankton.<br>o Install floating wetlands near stream inflows to remove nutrients and provide habitat. |
| Siltation near stream delta | Sediment from stream inflows reducing water depth at confluence | o Direct stream flows to wetlands in the western lagoon by using a peninsular. |
| Large fluctuations in dissolved oxygen and pH | High cover of aquatic plants.<br>Nutrients causing high algae cover | o Allow more tidal inflows via the Tarawera River.<br>o Consider need for aquatic plant harvesting as required if open water areas are too affected. |
| Loss of native riparian plants and colonisation by weeds on northern shoreline | Recent removal of riparian planting on northern shore has allowed weed colonisation. | o Enhance native riparian cover with pest plant control and planting of natives. |
| Limited cover of emergent wetlands compared to original management plan | Partially due to the direct removal of raupo. | o Agree on management plan to identify areas intended for open water and areas where wetland development is encouraged. |
| Fish passage to sea restricted | Fish passage to sea restricted by flap gates | o Install fish friendly flap gates to Tarawera River. |
| High values for birds but native bird habitat reduced with loss of emergent wetlands | Direct removal of riparian plants and raupo has reduced native bird cover. | o Enhance native riparian plant cover with pest plant control and planting of natives.<br>o Enhance bird habitat with floating wetlands. |

## 4. Options analysis - *Ngā Kōwhiringa*

No options have been identified relating to the matters of this report.

## 5. Significance and Engagement Assessment - *Aromatawai Pāhekoheko*

### 5.1. Assessment of Significance

The decisions and matters of this specific report are assessed to be of low significance in accordance with the Council's Significance and Engagement Policy. However, future decisions in relation to the proposed environmental enhancement actions and management of Awatapu Lagoon and Sullivan Lake - particularly regarding budget approval - are likely to be of medium significance. Assessments of significance will be made and provided to the Council at the time of these decisions.

### 5.2. Engagement and community views

Each of the three water bodies will require a level of community consultation if environmental improvement work is to be carried out. Engagement and Communications plans will be developed for each, with iwi, hapū and wider community engagement included.

As outlines in Section 3.1 above, improvement of the Awatapu Lagoon is a strong desire of the local community. Any updates to Reserve Management Plans or physical works to the lagoon will be in consultation with iwi, hapū and the community.

Community consultation has already taken place for Sullivan Lake during consultation of the Sullivan Lake Management Plan, where the community worked with Council to create an action plan of what work should be implemented at the Lake. Scientific measures to improve the lagoon would be in keeping with the action plan of the Sullivan Lake Management Plan.

Any plan or physical work regarding Matatā Lagoon will require significant hapū, Iwi and community engagement.

## 6. Considerations - *Whai Whakaaro*

### 6.1. Financial/budget considerations

The Long Term Plan 2021-2031 includes:

- $100,000 of resourcing to develop a longer-term strategic approach to the management of these three urban lakes.
- $2.1M to convert the southern leg of the Awatapu lagoon into a wetland.
- $70,000 annually for desilting of the Matatā Lagoon Floodbays.
- Existing Three Waters Green Stormwater budgets for the purposes of maintaining non-physical assets.

There are no budget considerations associated with the recommendations of this report. A decision to proceed with and fund the recommendations made in River Lake Limited’s report will be made as part of the Long Term Planning process for the 2024/34 Long Term Plan.

### 6.2. Strategic alignment

No inconsistencies with any of the Council’s policies or plans have been identified in relation to this report.

### 6.3. Climate change assessment

The improvement of the environmental condition of our three urban lakes aligns with the Council’s Climate Change Principals and Strategy, specifically, ‘We will care for an protect our environment’ as the intended outcome is the enhancement of the lake environments, including the biodiversity, water quality and ecology. The continued enhancements of the three lakes/lagoons will have positive environmental and climate related outcomes. Based on this climate change assessment, the decisions and matters of this report are assessed to have low climate change implications and considerations, in accordance with the Council’s Climate Change Principles

### 6.4. Risks

The following key risks have been identified:

- Adverse effects on the community in relation to environmental, cultural and social matters if further restoration works are not undertaken.
- Publicity/public perception of Council not undertaking restoration works for projects that have had previous community input and but not fully taken forward into the delivery stage.
- Publicity/public perception of costs associated with recommended works.
- Publicity/public perception of costs and timeframes associated with any restoration works.

**Attached to this report:**

- Appendix 1 – 'Awatapu Lagoon Water Quality, Ecology and Options for Improvement' report
- Appendix 2 – 'Sullivan Lake Water Quality, Ecology and Options for Improvement' report

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement

RIVER LAKE

Appendix 1

# Awatapu Lagoon Water Quality, Ecology and Options for Improvement

Prepared for:

**Whakatāne District Council**

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



# Awatapu Lagoon Water Quality, Ecology and Options for Improvement

**Prepared for:**

Whakatāne District Council

**Prepared by:**

K. D. Hamill (River Lake Ltd)

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**Title:** Awatapu Lagoon Water Quality, Ecology and Options for Improvement **Project No.:** wk-1167

| Version | Date | Status | Prepared by | Reviewed by | Approved by |
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| 1 | Jan. 2024 | Draft | K. Hamill | | |
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**Cover Photo**: Floating wetlands in Awatapu Lagoon Central, Whakatāne, April 2022.

## Acknowledgements

A special thanks to:

- Ian Malony, Whakatāne District Council, who led the Project for assessing water quality of Awatapu Lagoon.
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- Bay of Plenty Regional Council for providing historical water quality data and part funded laboratory analysis of additional monitoring results used in this report.
- Halo for sharing of eDNA data from Awatapu Lagoon.

# Executive Summary

Whakatāne District Council (WDC) has responsibility for managing Awatapu Lagoon. In order to inform the management of Awatapu Lagoon, WDC commissioned science investigations to: a) provide robust information on water quality and ecology values, and b) identify key management options for improving water quality and ecological values in Awatapu Lagoon.

**Awatapu Lagoon condition and values**

*Morphology*

Awatapu Lagoon is a 12.9 ha oxbow lake created when the Whakatāne River was straightened in 1970. The lagoon is divided into three sections, the outlet is in the western lagoon (4.62 ha) which is connected to the Whakatāne River via fish friendly flap gate, the central lagoon (ca. 5.56 ha), and the southern lagoon (2.75 ha).

The water depth in the lagoon is typically about 1.7m with the deepest section about 4.3m deep. The lagoon is shallower (about 0.5m) is near the confluence of the Wainui Te Whara Stream where stream sediment has deposited.

*Hydrology*

Awatapu Lagoon has a total catchment area is 720 ha. The main flow into Awatapu is from the Wainui Te Whara Stream (median flow of 0.061 $m^3/s$), which enters the central lagoon. The southern lagoon has no baseflow and only a small stormwater catchment, it is connected to the main lagoon via a 2m culvert under Bridge Street. Water flows out of Awatapu Lagoon at its western end, via twin 1.15 m diameter culverts under Awatapu Drive, to an arm of the Whakatāne River. These have Fish Friendly Flap gates (**FFG**) to allow water exchange. Tidal water flows into the lagoon via the FFGs and cause small tidal fluctuations within the lagoon. The tidal range in the Whakatāne River near the Awatapu Lagoon outlet is between about 1m and 1.65m respectively for a neep and spring tide. When the FFGs are operating, the tidal range in western Lagoon west is about 0.05m to 0.08m.

The tidal water entering Awatapu during spring high tides is brackish when river flows are low; this causes the bottom water of the western lagoon and the deepest part of the central lagoon to periodically be brackish during summer and autumn.

The median hydraulic residence time for combined Awatapu Central and Awatapu West is about 28 days. The average residence time for Awatapu South is about 61 days – but will be much longer during summer.

*Birds*

Awatapu Lagoon provides breeding and feeding habitat for a large number of water birds. Pukeko, mallard and Australian coot (Nationally uncommon) are the most abundant waterfowl on the lagoon. Threatened species are also present including: Royal spoonbill (Nationally uncommon), New Zealand dabchick (Nationally Increasing), bittern (kotuku) (Nationally Critical).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



The bird life on Awatapu Lagoon has benefited from trapping of predators, and protection provided by floating wetlands.

*Fish*

Fish access to Awatapu Lagoon and the Wainui Te Whara Stream catchment is facilitated by Fish Friendly Flapgates (FFG) on the two outlet culverts. A wide variety of fish have been recorded in Awatapu Lagoon and in the wider Wainui Te Whara catchment, including: shortfin eel (*Anguilla australis*), longfin eel (*Anguilla dieffenbachia*), speckled longfin eel (*Anguilla reinhardtii*), inanga (*Galaxias maculatus*), banded kōkopu (*Galaxias fasciatus*), shortjaw kōkopu (*Galaxias postvectis*), giant kōkopu (*Galaxias argenteus*), common bully (*Gobiomorphus cotidianus*), giant bully (*Gobiomorphus gobioides*), redfin bully (*Gobiomorphus huttoni*), common smelt (*Retropinna retrpinna*), goldfish, brown trout (*Salmo trutta*), and gamusia (*Gambusia affinis*). Many of these fish are classified as threatened. Goldfish and common bully were most abundant in the lagoon, while shortfin eel and longfin eel are most abundant in the Wainui Te Whara Stream.

*Plants*

A narrow band of raupo (*Typha orientalis*) extends along much of the lagoon margin, interspersed in places with reed sweetgrass (*Glyceria maxima*), and patches of *Machaerina articulata*.

Aquatic vegetation in Awatapu Lagoon is dominated by hornwort (*Ceratophyllum demersum*) and parrot's feather (*Myriophyllum aquaticum*) – both are exotic pest plants. These can be rooted but in Awatapu more commonly occur as floating mats (often c. 0.5m thick) that cover large areas of the lagoon. The southern lagoon has almost 100% coverage of hornwort and parrots feather, but floating mats of hornwort are also common form large floating mats in the central and western lagoons. The growth of hornwort in the western lagoon can be limited by the brackish water. The floating fern *Azolla filiculoides* can also cover large areas of Awatapu during summer, and is easily recognised by its purple colour.

Aquatic plants are a key to maintaining good water quality in natural lakes, by regulating water quality, stabilising sediments, and providing habitat for invertebrates and fish. However, the extensive cover of hornwort and parrots feather in Awatapu causes major water quality problems with low dissolved oxygen below the thick floating mats of hornwort.

*Water quality*

Awatapu Lagoon has poor water quality. Its TLI score (5.1) is borderline between eutrophic and supertrophic. It has low water clarity (median 0.62m), high concentrations of total nitrogen (median 0.34 mg/L), total phosphorus (0.069 mg/L), and phytoplankton (median Chl-*a* 10.4 mg/m$^3$). Algae blooms are common during summer and are often dominated by potentially toxic cyanobacteria.

National bottom-line values set for lake attributes in the NPS-FM are not met for median TP, median Chl-*a,* maximum Chl-*a*, and cyanobacteria biovolume, or dissolved oxygen in the bottom waters. However, the microbial water quality of Awatapu Lagoon west appears to be in NOF Band B, which is suitable for Human Contact recreation.

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



The Western and Southern lagoons have broadly similar water quality, but Awatapu Lagoon South has considerably worse water quality compared to the rest of the lagoon. TP concentrations are considerably higher in the lagoon than in the Wainui Te Whara Stream.

A distinctive feature of Awatapu Lagoon is that the Central Lagoon and Western Lagoon experience both thermal stratification and salinity stratification. These develop with the inflow of brackish water during low river flows, but can persist for months, resulting in anoxic bottom waters and internal nutrient release.

Management interventions to improve water quality are likely to require targeting both loads for both nitrogen and phosphorus.

*Dissolved oxygen and pH regime*

When Awatapu Lagoon West and Lagoon Central are stratified the surface water is usually replete in oxygen, while the bottom water has very low oxygen. Past monitoring found that anoxic bottom waters occur on 89% of occasions in Awatapu Central and 75% of occasions in Awatapu West. During periods with high macrophyte cover the southern lagoon can have very low dissolved oxygen concentrations. When the stratification breaks down, the bottom water becomes aerated but the mixing of the bottom water reduces the DO in the surface water to about 30% to 70% saturation.

There can be strong spatial variability in surface water DO associate with the distribution of floating mats of hornwort. Thick mats block the air from aerating the surface water and partial decomposition within the mats creates an oxygen demand. In 2021, DO was measured at less than 5% saturation directly below and expanse of thick macrophyte mats floating over deep water. Furthermore, the sinking of hornwort mats to the lake bed and their subsequent and decomposition will be a major contribution to accumulated organic matter that drives the rapid decline in DO in bottom water following stratification.

**Interventions to improve water quality**

There is no single quick fix to improving water quality in lakes, there is no “magic bullet”, but there are effective actions that can shift Awatapu Lagoon towards being a healthier ecosystem. Highest priority should be given to actions that would address multiple issues in a cost-effective way, and with low risk of adverse effects.

- Harvesting and control of aquatic pest macrophytes is a priority to improve the DO regime, reduce organic matter load to lake sediments and reduce nutrients.

- Constructing treatment wetlands provide multiple benefits in removing nutrients, providing habitat for aquatic life and increasing biodiversity values. Floating wetlands provide a similar range of benefits but can be more costly in terms of nutrient removal unless carefully placed.

- Phosphorus locking of sediments has considerable potential to reduce the internal load of phosphorus from anoxic bottom waters. However, this needs to be undertaken in conjunction with actions to reduce the organic matter load from hornwort.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



- There is potential to harness tidal fluctuations to drive a flow of water from the Whakatāne River to Awatapu South via a culvert with flap gates or via a syphon system. This would improve flushing but would likely be insufficient to stop cyanobacteria blooms in the absence of other actions. It would do little to reduce excessive macrophyte growth and associated problems.
- There is potential to reducing catchment sediment and nutrient loads to Awatapu Lagoon. One option for further investigation is to use detainment bunds within the upper Wainui Te Whara catchment.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



# Contents

# 1 Introduction

## 1.1 Background

Whakatāne District Council (**WDC**) has responsibility for managing Awatapu Lagoon. In order to inform the management of Awatapu Lagoon, WDC commissioned science investigations to: a) provide robust information on water quality and ecology values, and b) identify key management options for improving water quality and ecological values in Awatapu Lagoon.

This work is being undertaken by River Lake Ltd in partnership with WSP Ltd. In this report we:

a. Describe the geographical context of Awatapu Lagoon (including hydrology, morphology).

b. Describe the current state for water quality and ecology.

c. Identify the key issues for Awatapu Lagoon with respect to water quality and ecology.

d. Describe and prioritise potential management actions to address the key issues.

Pre-feasibility assessments have been prepared for key management options. These assessed the benefits, risks, cost-effectiveness and application to Awatapu Lagoon, so as to inform prioritisation of actions to improve water quality and ecological values.

## 1.2 Location and Context

Awatapu Lagoon is a 12.9 ha oxbow lake created when the Whakatāne River was straightened in 1970. The lagoon is divided into three sections, the outlets is in the western lagoon (4.62 ha) which is connected to the Whakatāne River via fish friendly flap gate; the central lagoon (ca. 5.56 ha) between Bridge Street and the foot bridge; and the southern lagoon (2.75 ha) which was the original entrance from the Whakatāne River (**Figure 1.1**). The southern lagoon is connected to the central lagoon via a 2m diameter culvert under Bridge Street.

The Lagoon has a total catchment area of 720 ha, predominantly from the Wainui Te Whara Stream which enters the central lagoon. Tidal water from the Whakatāne River also flows into the lagoon via the fish friendly flapgates. The tidal water entering Awatapu during high tides is brackish when river flows are low; this causes the bottom water of the western lagoon and the deepest part of the central lagoon to periodically be brackish.

The water depth in the lagoon is typically about 1.7m with the deepest areas of 4.3m. There has been considerable sedimentation at the confluence of the Wainui Te Whara Stream, reducing the water depth to less than 0.5m in places. In this area **WDC** has formed a delta and settling area to manage sediment inputs.

Awatapu Lagoon is an integral part of the stormwater management network by providing live storage to attenuate peak flows during heavy rain events.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



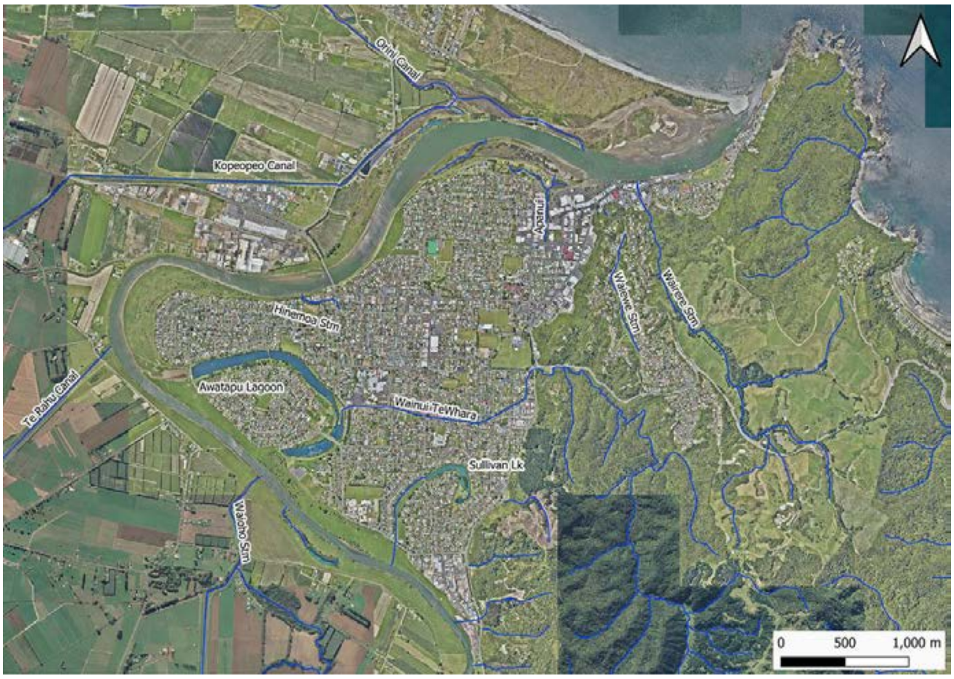



**Figure 1.1:** Location of Awatapu Lagoon and stream networks in Whakatāne township.

### 1.2.1 Historical context

Awatapu Lagoon was originally a meander of the Whakatāne River, but was formed into an oxbow lake when the Whakatāne River was straightened in 1970 as part of flood protection works. Around the same time, the Wainui Te Whara Stream was diverted to flow directly into Awatapu Lagoon instead of following its original channel that entered the Whakatāne River upstream of Landing Road Bridge via what is now known as Hinemoa drain. Historical aerial images show that sediment from the Wainui Te Whara Stream quickly formed a delta in the new oxbow lake (**Figure 1.2** and **Figure 1.3**).

The lagoon and associated parkland is surrounded by a secondary stopbank system, designed to contain flood waters from the Wainui Te Whara Stream and direct urban stormwater.

Aquatic pest plants appeared to have colonised and formed excessive nuisance cover in Awatapu Lagoon soon after its formation. A survey in 1987 found hornwort to be by far the most dominant aquatic plant in both Awatapu Lagoon and the nearby Sullivan Lake.

### 1.2.2 Management Plans

The Awatapu Lagoon Management Plan (WDC 1990) identifies values and uses of Awatapu Lagoon and set pragmatic management objectives including:

> "*1. The primary function of the reserve shall be to preserve and manage the natural qualities of the reserve in perpetuity and to provide for the usage and enjoyment of the public for recreation, and to ensure that this management does not compromise the area's integrity as a flood control area*."

The Awatapu Lagoon Management Plan recognised the value of the lagoon for flood control, recreation and wildlife. It also identified some key issues for the lagoon including sedimentation, nutrient enrichment, excessive growth of pest aquatic plants and rubbish in the lagoon. WDC has implemented one of the policies to address sedimentation by forming a delta at the inlet of the Wainui Te Whara Stream to reduce sediment deposition in the main body of Awatapu Lagoon.

More recently, the Ōtamakaokao Kaitiaki Trust led the development of the Awatapu Ōtamakaokao Community Plan (2022). The Community Plan seeks to express vision and aspirations of the community based around four pou: Pou Taiao (environment), Pou Tikanga (culture), Pou Tangata (people), and Pou Tuahu (economy). The aspirations for the Awatapu Lagoon and surrounding Ōtamakaokao area under Pou Taiao are:

- The lagoon is connected to Ōhinemataroa (Whakatāne River).
- The awa is clear and safe to swim.
- Biodiversity is present and abundant.
- The awa is a food source.
- Native plants flourish.
- Rubbish is absent.

Recent work in the Ōtamakaokao area to support these aspirations for the lagoon include:

- Riparian planting along the edge of Awatapu Lagoon near the Wainui Te Whara delta by Ōtamakaokao Kaitiaki Trust and Halo with the support of WDC and Bay of Planty Regional Council (**BOPRC**).
- Pest animal control by Halo.
- Instillation of numerous floating wetlands by Whakatāne Intermediate School and by Ōtamakaokao Kaitiaki Trust.
- Rubbish collection by Whakatāne Intermediate School and other groups.
- Instillation of rubbish bins by WDC.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 1.2**: Aerial photos of Awatapu Lagoon area in October 1962 before diversion of the Whakatāne River and of the Wainui Te Whara Stream (top); and in April 1974 after the diversions and creation of the Awatapu oxbow (bottom) (Source: Retrolens).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 1.3**: Aerial photos of Awatapu Lagoon in December 1982 showing the development of a large delta at the entrance of the Wainui Te Whara Stream (Source: Retrolens).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



# 2 Methods of investigation

The descriptions of Awatapu Lagoon water quality and ecology used in this report is a synthesis of information from existing reports, analysis of historic datasets and specific investigations and monitoring collected as part of this project.

This project undertook multiple investigations in Awatapu Lagoon to inform our understanding of the waterbody and key mitigation options, these included:

- Water quality samples of Awatapu Lagoon surface water during the summer of 2022/23.
- Dissolved oxygen, pH and temperature spatial surveys to characterise spatial variability.
- Dissolved oxygen and temperature loggers to characterise diurnal variability.
- Tidal water level for estimating potential tidal river inflows.
- Fish and waterfowl presence using eDNA in Awatapu Lagoon and Wainui Te Whara Stream.

Sites in Awatapu Lagoon used for regular water quality sampling and for logging of dissolved oxygen, salinity and water level are shown in **Figure 2.1**.


**Figure 2.1**: Location of water level and water quality monitoring sites in Awatapu Lagoon (aerial image: Open Commons, LINZ 2022).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



## 2.1 Water quality sampling

BOPRC monitored water quality of Awatapu Lagoon at the Riverside Drive monthly from January 2015 to December 2020 (n=59). Samples were analysed for: temperature (**Temp**.), pH, dissolved oxygen (**DO**), specific electrical conductivity (**EC**), total nitrogen (**TN**), nitrate-nitrite-nitrogen (**NNN**), total ammoniacal nitrogen (**NH4-N**), total phosphorus (**TP**), dissolved reactive phosphorus (**DRP**), turbidity (**TURB**), total suspended solids (**TSS**), *E.coli* bacteria (***E.coli***) and visual clarity using a clarity tube. In addition, chlorophyll-*a* (**Chl-*a***) was measured from March 2019 to December 2020.

From February 2021 to April 2023 River Lake Ltd, with sample analysis support of BOPRC, collected summer / autumn samples from the following sites: Awatapu Lagoon south at Bridge Street (n=8), Awatapu Lagoon West at Foot Bridge (n=5), Awatapu Lagoon West mid-lake (top and bottom) (n=10), Awatapu Lagoon Central mid-lake (top and bottom) (n=10), Wainui Te Whara at Hinemoa Street (n=12) and Wanui Te Whara at Valley Road (n=7) (**Figure 2.1**). These samples were analysed for the same suite of variables as previously measured by BOPRC.

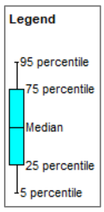
The mid-lake samples from Awatapu Lagoon West and Awatapu Lagoon Central included samples from both the top water (0.2m depth) and the bottom water hypolimnion/halocline (c. 0.6m above lake bottom, 2.2 to 2.8m depth). Depth profiles of temperature, DO, and sp. EC were measured at the same time as these samples were collected. In addition, depth profiles had been measured during summer/autumn by River Lake Ltd prior to 2021; in total 19 depth profiles were measured from Awatapu Central and Awatapu West between February 2017 and April 2023. Field measurements were made using a YSI Pro Plus multi-meter.

BOPRC also collected cyanobacteria samples from Awatapu Lagoon west during summer between February 2015 and February 2021. The frequency of sampling ranged from weekly to monthly, with a total of 30 samples collected over this time. Samples were analysed for species identification, biovolume and potentially toxic biovolume.

Water clarity was usually measured using a clarity tube. This data was converted to black disc water clarity using the formula provided in Kilroy and Biggs (2002)[1]. For the purpose of estimating the TLI, black disc water clarity was converted to TLI by multiplying by 1.25 following the approach in the Ministry for the Environment (**MfE**) water quality guidelines (1994).

The data analysis used an aggrigated dataset for Awatapu Lagoon West consisting of "top" water samples from sites: Awatapu Lagoon at the Riverside Drive, Awatapu Lagoon West mid-lake and Awatapu Lagoon West at Foot Bridge.

Water quality data was expressed using box plots show the median, interquartile range, 5$^{th}$-percentile, 95$^{th}$-percentile, minimum, and maximum, as illustrated here.




[1] Clarity tube reading (yCT) < 50cm = black disc (yBD); yCT >50cm adjusted as: yBD = 7.28 x 10^(yCT/62.5).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



## 2.2 Temporal variability of lake dissolved oxygen and salinity

The temporal variability of dissolved oxygen and temperature was characterised using dataloggers. In Awatapu Central, a Hobo U26 optical DO logger was installed from 23/2/2017 to 11/3/2017. The logger was suspended from a buoy at the mid-lake central lagoon site, with the sensor at a depth of 1.3m for the first four days, after which the sensor was raised to 0.5m depth.

In Awatapu West, DO and electrical conductivity loggers were installed on a buoy at the mid-lake west lagoon site from 9/4/2022 to 25/6/2022 (although an increase in water level and movement of macrophyte mats prevented the loggers from being retrieved from this site until November 2022). DO and EC measurements were made at two fixed depths of 0.25m below the water surface (at time of installing) and 0.6m above the lake bottom using Hobo U26 optical DO loggers and Hobo U24 EC loggers.

The DO logger was calibrated before and after deployment using 100% water saturated air. As a further check, separate measurements of dissolved oxygen were made when installing, removing and checking the logger using a calibrated YSI Pro Plus multi-meter with a polarographic DO sensor.

Atmospheric pressure was recorded near the site using a Hobo U20 logger (measuring pressure and temperature). These measurements were used to adjust DO measurements for atmospheric pressure. Measurements of temperature, DO, pH and electrical conductivity were made at the top and bottom of the water column when the loggers were installed and removed.

## 2.3 Spatial variability of dissolved oxygen and pH

Synoptic surveys were undertaken in Awatapu Lagoon to characterise the spatial variability of dissolved oxygen (**DO**), pH and temperature. The surveys were on 11 April 2022 in the late afternoon (3pm to 4pm). The early morning and afternoon surveys correspond to when diurnal fluctuations of DO and pH are respectively near their minimum and maximum values.

The measurements were collected from a kayak at a sample depth of *c.* 0.2m, using a YSI Pro Plus multi-meter with a polarographic DO sensor. The sample location was recorded using a GPS tracker and linked with each measurement using the date-time stamp. Prior to the survey the time was synchronised between devices, and the multi-meter was calibrated for both DO (at 100% saturation) and pH (three-point calibration).

## 2.4 Tidal water level for estimating potential tidal river inflows

The relative water level, tidal dynamics and salinity influence from the Whakatāne River were investigated by installing loggers in the Whakatāne River and in Awatapu Lagoon. The loggers were installed for eight weeks during December 2022 to February 2023, and for c. six weeks during April and May 2023 (**Table 2.1**).

Floods were frequent during this period (e.g. 17 December 2022, 22 December 2022, 29 January 2023, 4 February 2023, 4 May 2023, 11 May 2023), but the logging also included baseflow conditions. On 26 January 2023 the daily mean flow in the Whakatāne River was 26.7 $m^3/s$ (about 75% of median flow), and the Wainui Te Whara Stream had a median flow of 0.066 $m^3/s$ (about median flow).

Logging during April and May 2023 was a period of receding river flow; by the end of the monitoring period. On 30 April 2023, the flow in the Whakatāne River and the Wainui Te Whara Stream were respectively 45 $m^3/s$ and 0.065 $m^3/s$ (just over median flow); and on 27 May 2023 the flow in the Whakatāne River and the Wainui Te Whara Stream were respectively 83 $m^3/s$ and 0.13 $m^3/s$ – which is about twice the median flows for these rivers.

All water level loggers were surveyed into a reference point by WSP, and the level data was expressed as metres RL to Moturiki datum. Spot measurements of water level were undertaken at the same time as the datum survey.

**Table 2.1**: Deployment of water level loggers, location, period and variables measured (water level, electrical conductivity, temperature).

| Site | Latitude, Longitude (NZTM) | Logger variable | Period deployed |
|---|---|---|---|
| Awatapu West Pump Station | 1948019, 5790694 | Water level | Permanent |
| Whakatāne Rv at Awatapu Outlet | 1947977, 5790697 | Water level, EC, temperature | 11/12/2022 - 13/2/2023 |
| | | Water level, temperature | 15/4/2023 - 27/5/2023 |
| Whakatāne Rv at Awatapu "Inlet" | 1948589, 5789986 | Water level, temperature | 15/4/2023 - 27/5/2023 |
| Awatapu at Bridge St Culvert | 1949077, 5790185 | Water level, temperature | 1/5/2023 - 27/5/2023 |

## 2.5 eDNA

Waterways contain environmental DNA (eDNA) of organisms present. Analysis of eDNA shed from organism in the water give a qualitative assessment of what fish, aquatic insects, birds and plants may be present (David et al. 2021). Although used as a qualitative tool, the results indicate the strength of the eDNA signal.

Samples of eDNA were collected to supplement existing information on the presence of fish and birds in Awatapu Lake and the Wainui Te Whara Stream. Following collection, the samples were preserved and sent to Wilderlab for processing. The eDNA sample dates and sites were:

- 17 November 2022 from Awatapu Lagoon west, lagoon central, lagoon south, and Wainui Te Whara at Hinemoa Street.
- 30 September 2022 from Wainui Te Whara at Hinemoa Street and Wainui Te Whara at Valley Road.
- 28 October 2021 – a composite sample from Awatapu Lagoon central collected by Halo.

## 2.6 Assessing potential nutrient limitation

In order to accurately assess the extent to which nutrients may limit algal growth in a lake requires detailed investigations and bioassays. However, some indication of potential nutrient limitation can be

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



gained by looking at the absolute concentration of nutrients in the lake and the stoichiometric ratio of N to P and assuming the absence of other factors limiting phytoplankton or macro-algal growth. Nutrient concentrations are balanced when they equate to the Redfield ratio (i.e., 7.2 by mass). In these situations, either or both N or P may limit growth. A TN:TP value less than 7 indicates potential nitrogen limitation, and a TN:TP value greater than 14 indicates potential phosphorus limitation.

Similarly, the ratio of DIN:TP can also be used to indicate potential nutrient limitation. Assuming the absence of other growth limiting factors a DIN:TP of < 1 (by mass) indicates potential N limitation and a DIN:TP > 1 indicates potential P limitation (Schallenberg et al. 2010).

## 2.7 Lake water quality guidelines

### 2.7.1 Trophic Level Index (TLI)

Lake water quality is often expressed in terms of trophic state, which refers to the production of algae, epiphytes and macrophytes in a lake. The trophic state of each lake was assessed using the Trophic Level Index (**TLI**) (Burns et al. 2000).

The TLI integrates four key measures of lake trophic state - total nitrogen, total phosphorus, chlorophyll *a* and Secchi depth. The overall TLI score for a lake is the average of individual TLI scores for each variable. The overall score is categorised into seven trophic states indicative of accelerated eutrophication as evidence more nutrients, more algal productivity and reduced water clarity (**Table 2.2**). Regular monitoring over multiple years is usually required to reliably characterise a lake's water quality or TLI.

TLI variables have not been consistently sampled. TLI estimates prior to March 2019 are calculated using only TN and TP (TLI 2). Secchi disc depth has not been directly samples in Awatapu, instead water clarity was measured using clarity tube. Results were adjusted to be expressed a black disc and these black disc was multiplied by 1.25 to provide an estimate of Secchi depth.

**Table 2.2:** Definition of Trophic Levels based on water quality measures (Burns et al. 2000).

| Trophic State | TLI Score | Chl *a* ($mg/m^3$) | Secchi depth (m) | TP ($mg/m^3$) | TN ($mg/m^3$) |
|---|---|---|---|---|---|
| Ultra-microtrophic | <1 | < 0.33 | > 25 | < 1.8 | < 34 |
| Microtrophic | 1 - 2 | 0.33 – 0.82 | 15 - 25 | 1.8 – 4.1 | 34 - 73 |
| Oligotrophic | 2 - 3 | 0.82 - 2.0 | 15 - 7.0 | 4.1 – 9.0 | 73 - 157 |
| Mesotrophic | 3 - 4 | 2.0 - 5.0 | 7.0 - 2.8 | 9.0 - 20 | 157 - 337 |
| Eutrophic | 4 - 5 | 5.0 - 12 | 2.8 - 1.1 | 20 – 43 | 337 - 725 |
| Supertrophic | 5 - 6 | 12-31 | 1.1 - 0.4 | 43-96 | 725 - 1558 |
| Hypertrophic | >6 | >31 | <0.4 | >96 | >1558 |

### 2.7.2 Cyanobacteria guideline

The NZ guidelines for cyanobacteria in recreational waters (MfE and MoH 2009) that sets an alert level framework for assessing the health risk from planktonic cyanobacteria. The "Action (Red) mode" is triggered when either: 1) cyanobacteria biovolume is ≥10 $mm^3$/L, or 2) potentially toxic cyanobacteria biovolume is ≥1.8 $mm^3$/L, or 3) cyanobacteria scums are consistently present.

The "Alert (amber mode)" is when cyanobacteria biovolume is 0.5 to <10 $mm^3$/L, or 2) potentially toxic cyanobacteria biovolume is 0.5 to <1.8 $mm^3$/L.

The "Surveillance (green) mode" is when the total cyanobacteria biovolume is <0.5 $mm^3$/L.

### 2.7.3 National Policy Statement for Freshwater Management (NPS-FM)

The National Policy Statement for Freshwater Management (**NPS-FM 2020**) (MfE 2020) sets out objectives and policies that direct local government to manage water in an integrated and sustainable way. The NPS-FM includes a National Objectives Framework (NOF) which sets compulsory national values for freshwater including: 'human health for recreation' and 'ecosystem health'. Appendix 2 of the NPS-FM sets water quality attributes that contribute to these values, and ranks attributes into bands to help communities make decision on water quality. This includes setting minimum acceptable states called 'national bottom lines'.

Appendix 2A of the NPS-FM (2020) describes attributes that require limits on resource use, while Appendix 2B of the NPS-FM (2020) describes attributes that require action plans to be developed (**Table 2.3**).

In this report, we discuss water quality state in the context of the NPS-FM bands where possible. For most attributes, insufficient samples have been collected in recent years to accurately define the band for the purpose of the NPS-FM (e.g. *E.coli* bacteria require 60 samples over 5-years), and in these cases the bands only provide a guideline of water quality state. Arguably, Awatapu Lagoon may not fall within the scope of the NPS-FM because it is an artificially created waterbody, nevertheless the attributes bands provide a context for assessing water quality state.

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



**Table 2.3**: NPS-FM attributes and values defining different quality bands pertaining to lakes. *E.coli* bacteria and cyanobacteria relate to suitability for contact recreation while the other bands relate to ecosystem health. Bolded values are the national "bottom-lines".

**Table 2A - Attributes requiring limits on resource consents**

| Attribute | Statistic | Units | Band A | Band B | Band C | Band D | Band E |
|---|---|---|---|---|---|---|---|
| NH4-N | Median | mg/L | ≤0.03 | **≤0.24** | ≤1.3 | >1.3 | |
| NH4-N | Maximum | mg/L | ≤0.05 | **≤0.4** | ≤2.2 | >2.2 | |
| *E.coli* bacteria | % samples >260 cfu/100ml | % | ≤20% | ≤30% | ≤34% | ≤50% | >50% |
| *E.coli* bacteria | % samples >540 cfu/100 ml | % | ≤5% | ≤10% | ≤20% | ≤30% | >30% |
| *E.coli* bacteria | Median | *E.coli* / 100mL | ≤130 | ≤130 | ≤130 | ≤260 | >260 |
| *E.coli* bacteria | 95%ile | *E.coli* / 100mL | ≤540 | ≤1000 | ≤1200 | ≤1200 | >1200 |
| Phytoplankton | Median | mg *chl-a* /m$^3$ | ≤2 | ≤5 | **≤12** | >12 | |
| Phytoplankton | Maximum | mg *chl-a* /m$^3$ | ≤10 | ≤25 | **≤60** | >60 | |
| TN (polymictic) | Median | mg/m$^3$ | ≤300 | ≤500 | **≤800** | >800 | |
| TP | Median | mg/m$^3$ | ≤10 | ≤20 | **≤50** | >50 | |
| Cyanobacteria biovolume | 80%ile of potentially toxic cyanobacteria | mm$^3$/L | ≤0.5 | ≤1.0 | **≤1.8** | >1.8 | |

**Table 2B - Attributes requiring action plans**

| Attribute | Statistic | Units | Band A | Band B | Band C | Band D |
|---|---|---|---|---|---|---|
| Submerged Plants Native Condition Index) | | % | >75 | >50 | **≥20** | <20 |
| Submerged Plants Invasive Condition Index) | | % | ≤1 | ≤25 | **≤90** | >90 |
| Lake-bottom DO | annual minimum | mg/L | ≥7.5 | ≥2 | **≥0.5** | <0.5 |
| Mid-hypolimnetic depth | annual minimum | mg/L | ≥7.5 | ≥5 | **≥4** | <4 |
| *E.coli* bacteria Primary Contact sites | 95%ile (summer) | *E.coli* / 100mL | ≤130 | ≤260 | **≤540** | >540 |

# 3 State of Awatapu Lagoon

## 3.1 Morphology

Awatapu Lagoon is a 12.9 ha oxbow lake. The lagoon is divided into three sections, the outlet is in the western lagoon (4.62 ha) which is connected to the Whakatāne River via fish friendly flap gate, the central lagoon (ca. 5.56 ha), and the southern lagoon (2.75 ha).

Comprehensive bathymetry data is not available for Awatapu Lagoon, but spot measurements over about 20 transects across the lagoon estimate an average depth of 1.8m, 1.5m and 1.5m respectively in the western, central and southern sections. The maximum depth is about 4.3m, located in the north-western end of the central lagoon – an area that would have originally been the outside bend of the river. The lagoon is shallowest (<0.5m) is near the confluence of the Wainui Te Whara Stream where stream sediment has deposited.

The volume of Awatapu Lagoon, under baseflow conditions, is approximately 209,200 $m^3$, consisting of 84,000 $m^3$, 82,800 $m^3$ and 42,400 $m^3$ respectively for Awatapu west, Awatapu central and Awatapu south.

### 3.1.1 Sediment depth

Most of Awatapu Lagoon has substrate organic muds over the original river gravels. The Wainui Te Whara has deposited sandy substrate near the delta area, which is overlayed with organic muds. Measurements of soft sediment depth in Awatapu south (April 2022) found a median depth of 0.2m and a range of 0.03m to 0.4m. Decomposition of macrophytes is likely a major contributor to organic mud substrate in the lagoon.

## 3.2 Hydrology

### 3.2.1 Inflows

The main flow into Awatapu is from the Wainui Te Whara Stream, which enters the central lagoon and flows west towards the outlet. The southern lagoon has no baseflow and only a small stormwater catchment (ca. 43 ha); it is connected to the main lagoon via a 2m culvert under Bridge Street.

Awatapu Lagoon has a total catchment area of 720 ha. About 83% (598ha) of the catchment contributes to the Wainui Te Whara Stream upstream of Valley Road, *c*. 44ha contributes to the lower Wainui Te Whara Stream below Valley Road, *c*. 40 ha of urban catchment contribute directly to the southern lagoon, and *c*. 37.8 ha of urban catchment contributes directly to the western and central lagoons (**Figure 3.2**).

The upper catchment of the Wainui Te Whara (above Valley Road) consists of steep hillside predominantly covered by exotic forest, native forest (64%) and farmland (35%). It cascades steeply down Mokoroa gorge and at the base of the hill, downstream of Valley Road, the gradient flattens and the stream flows through urban area.

The median flow from the Wainui Te Whara Stream at Valley Road gauging station is 0.061 $m^3/s$; the exceedance flow of 25% and 10% are respectively 0.113 $m^3/s$ and 0.204 $m^3/s$ (BOPRC flow duration

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



calculations, period 2006-2023). Accounting for the additional catchment area below Valley Road, the median flow of the Wainui Te Whara at the entrance to Awatapu Lagoon would be about 0.071 $m^3/s$. For the purpose of comparison, the Whakatāne River, which formed the Awatapu Lagoon basin, has a median flow of 36.2 $m^3/s$ and mean flow of 57.3 $m^3/s$ (EBOP 2007).

The southern section of Awatapu Lagoon only receives stormwater inflows during rain events The average catchment inflow to Awatapu lagoon south is estimated[2] to be 0.008 $m^3/s$.

Water flows out of Awatapu Lagoon at its western end, via twin culverts under Awatapu Drive (each 1.15 m diameter), to an arm of the Whakatāne River. During flood events the water is pumped. Fish friendly flap gates (**FFG**) are installed on the outlet culverts which allow the inflow of water from the Whakatāne River during high tides. These close near the upper end of the tidal range and prevent floodwater entering during floods.

Tidal water from the Whakatāne River flows into the lagoon via the FFGs. The tidal water entering Awatapu during high tides is brackish when river flows are low; this causes the bottom water of the western lagoon and the deepest part of the central lagoon to periodically be brackish.

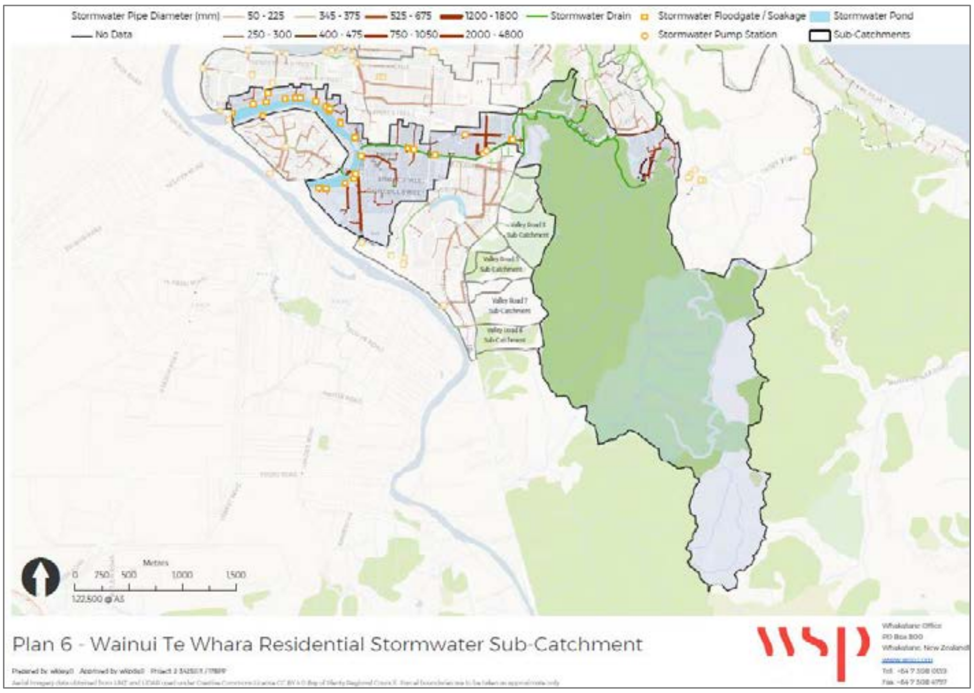



**Figure 3.2**: Wainui Te Whara Stormwater catchment including Awatapu Lagoon (WSP 2021).

[2] This was derived by multiplying the specific mean flow for the catchment (0.019 $m^3/s/km^2$) by the catchment area (0.43 $km^2$). Data modelled by NIWA River Environment Classification (REC).

### 3.2.2 Tidal water level fluctuations and salinity

The variation in water level tidal range in the Awatapu lagoon and the Whakatāne River was investigated to inform an analysis of how effective a new opening to the Whakatāne River from Awatapu south might be in providing additional flow through Awatapu Lagoon. The water level results are presented in **Figures 3.3** to **Figure 3.6**.

Key features of the monitoring are:

- During baseflow conditions, the Whakatāne River near Awatapu inlet has a spring tide range of about 1.65m (-0.45m to 1.2m RL) and a neep tide range of about 1.03m (-0.19m to 0.84 m RL) (**Figure 3.3**).
- The minimum water level in the river embayment downstream of the Awatapu outlet culvert appears to be constrained by a shelf between the embayment and the main river channel. This was seen in the water level at low tide not dropping below about -0.19m RL during spring tides in April 2023 (when river flows were 45 $m^3/s$) (**Figure 3.4**), and not dropping below -0.25m RL during spring tides on 27 January 2023 (when river flows were 26.7 $m^3/s$) (**Figure 3.5**).
- During January 2023 spring tides, Awatapu Lagoon at the outlet culvert had a tidal range of 0.039m (0.234m to 0.274m RL) with about a 2-hour delay for outgoing and a 3-hour delay for incoming tides. During May 2023 spring tides the tidal range was 0.05 to 0.08m (0.330m to 0.409m RL) (**Figure 3.5**).
- The water level[3] in Awatapu at Bridge Street culvert was about 210mm higher than Awatapu lagoon at the outlet culvert and 125mm higher than the median water level in the Whakatāne River at the outlet. This water height differential will be less at lower flows. The tidal range in the lagoon is smaller (0.04m) in at the Bridge Street culvert than near the outlet (**Figure 3.6**).
- Brackish water (e.g. spec. EC >1000 uS/cm) only reached Awatapu Lagoon outlet during a spring high tide (24$^{th}$ to 27$^{th}$ Jan 2023) and when the river flow had dropped to 26.7 $m^3/s$ (three quarters of median flow) (**Figure 3.5**).

**Figure 3.7** illustrates the measured culvert invert heights and water level tidal ranges when river flows are about median. At lower river flows, the river and lagoon water levels are lower, the tidal ranges higher and the water level gradient on the lagoon between Bridge Street and the outlet culvert is expected to be less.

[3] Measured during late May 2023 when the Wainui Te Whara flow was about 0.13 $m^3/s$.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



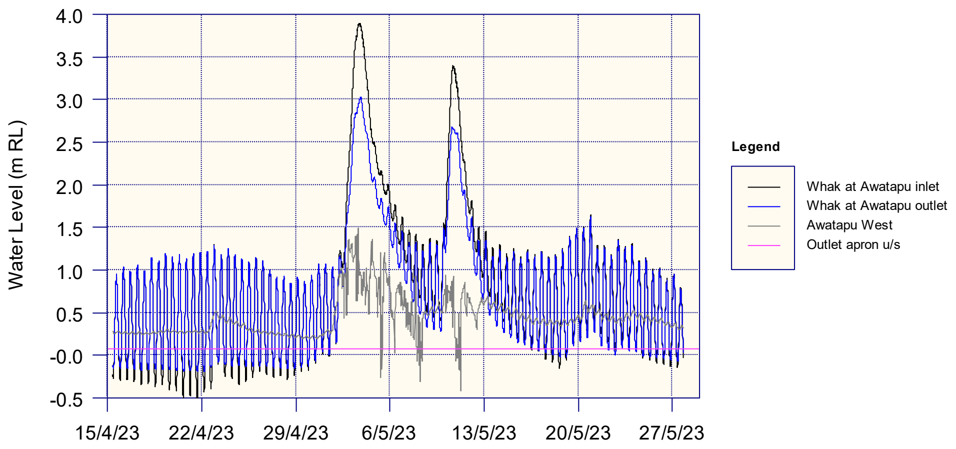



**Figure 3.3**: Water level in Awatapu Lagoon outlet culvert (west), in the Whakatāne River downstream of the outlet, and in the Whakatāne River 1.2km upstream at the original "inlet".

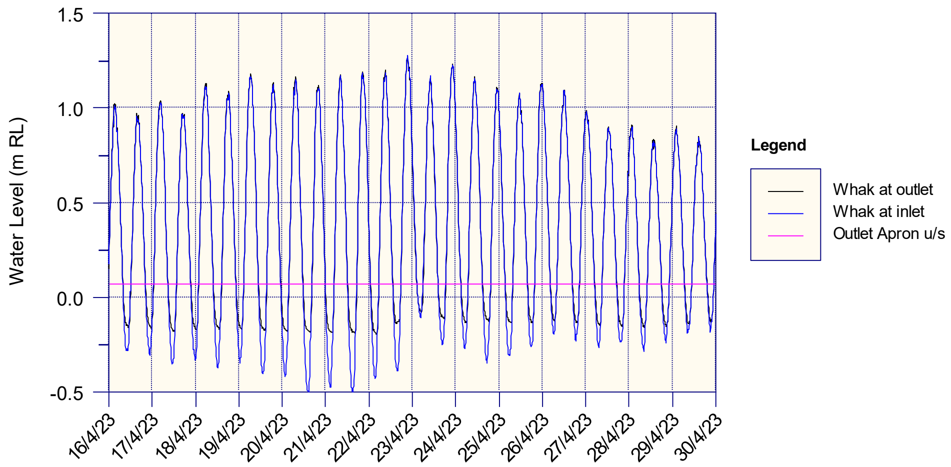



**Figure 3.4**: Water level in the Whakatāne River downstream of the outlet and 1.2km upstream at the original "inlet". At spring low tides, the minimum water level in the river embayment downstream of the Awatapu outlet culvert appears to be constrained by a shelf between the embayment and the main river channel.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



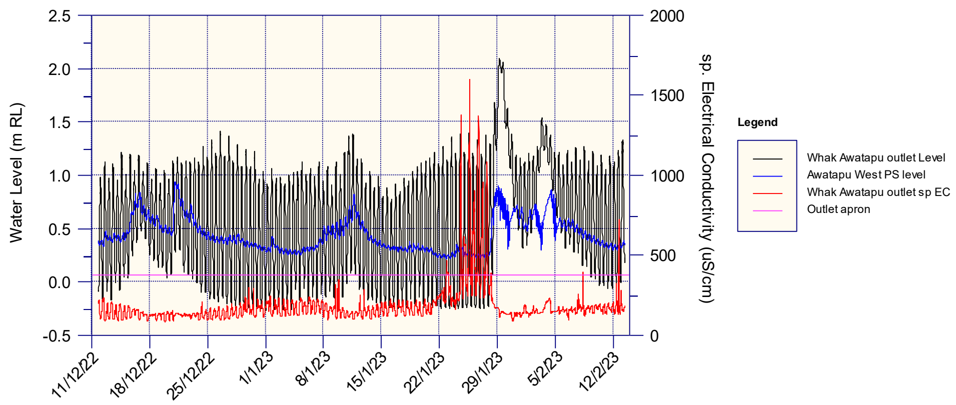



**Figure 3.5**: Water level and specific electrical conductivity (EC) in the Whakatāne River downstream of the outlet, overlayed with water level at Awatapu Lagoon outlet culvert (west). Higher salinity water only reached Awatapu lagoon during spring high tides and low flows.

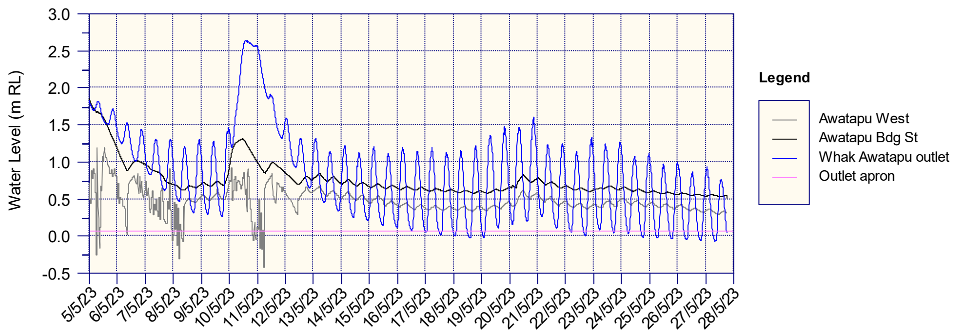



**Figure 3.6**: Water level in Awatapu Lagoon at Bridge Street culvert, outlet culvert (west) and in the Whakatāne River downstream of the outlet.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



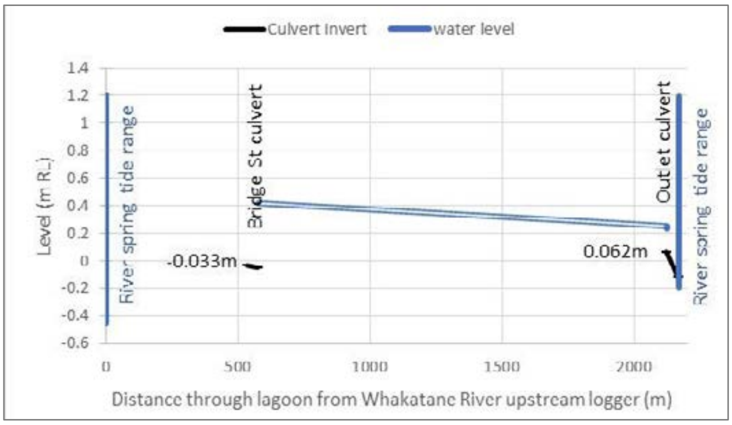



**Figure 3.7**: Schematic of culvert invert heights and water level tidal ranges when flows are about median. At spring low tides, the minimum water level in the river embayment downstream of the Awatapu outlet culvert appears to be constrained by a shelf between the embayment and the main river channel.

### 3.2.3 Hydraulic residence time

Hydraulic residence time is an important factor in determining the water quality of lakes. In large oligotrophic lakes which act as a sink for nutrients, increasing residence time can be detrimental to water quality, however in shallow eutrophic lakes with high internal nutrient loads, a shorter residence time can improve water quality by better flushing nutrients and phytoplankton biomass (Jørgensen 2002). To be effective residence time should be reduced to less than about 20 days (Hamilton & Dada, 2016; Abell et al 2020).

The median residence time for combined Awatapu Central and Awatapu West is about[4] 28 days. The average residence time for Awatapu South is about 61 days. The residence time will be much longer during summer low flows.

To completely replace the volume of water in Awatapu Central and West would require a flow in the Wainui Te Whara Stream of about 1.93 $m^3/s$ in a single day, or an average of 0.0965 $m^3/s$ over 20 days. A flow of 0.096 $m^3/s$ has an exceedance duration of 31%, and is common during winter and spring. To fully replace the water in Awatapu Lagoon South would require an inflow of about 0.491 $m^3/s$ in a single day, or an average of 0.024 $m^3/s$ over 20 days [5].

One management option to improve water quality in Awatapu may be to increase the volume of water flowing into it. Options to achieve this are discussed in the subsequent management sections of this report and include: directing flow from the Wainui Te Whara Stream to enter Awatapu South before flowing through the rest of the lagoon, and/or taking water from the Whakatāne River to the Awatapu lagoon south (via a new culvert, or enhanced syphon, or pump).

[4] Calculated as: volume of Awatapu west and central (166,800 $m^3$) / (catchment inflow (0.07 $m^3/s$) x 86,400 s/day)
[5] Equivalent to a flow exceedance duration in the Wainui Te Whara Stream of 84%

## 3.3 Birds

Awatapu Lagoon provides breeding and feeding habitat for a large number of water birds including: Australian coot (*Fulica atra*), pūkeko (*Porphyrio melanotus*), mallard ducks (*Anas platyrhynchos*), paradise shelduck (*Tadorna variegata*), Australian shoveler (*Spatula rhynchotis*), NZ kingfisher/ kōtare (*Todiramphus sanctus*), Black shag (*Phalacrocorax carbo*), black swan (*Cygnus atratus*), Royal spoonbill / kōtuku (*Platalea regia*), silver gull (*Chroicocephalus novaehollandiae*), New Zealand dabchick (weweia, *Poliocephalus rufopectus*), and occasional bittern (kotuku), and whitefaced heron (*Egretta alba)*. The presence of dabchick is notable because they are rare (about 2000 individual in NZ[6], Conservation Status of "recovering") and they have successfully bred and raised young on Awatapu Lagoon in recent years. Pukeko, mallard and Australian coot are the most abundant waterfowl on the lagoon. Threatened species are present include: Australasian bittern (kotuku) (Nationally Critical), Australian coot (Nationally uncommon), Royal spoonbill (Nationally uncommon), New Zealand dabchick (Nationally Increasing) (Robertson et al. 2021).

Bird life on Awatapu Lagoon has likely benefited from intensive trapping of rats and stoats that has been undertaken around the lagoon by conservation groups such as Halo. The floating wetlands on Awatapu provide protected nesting habitat of many of the birds.

## 3.4 Fish

Fish recorded in Awatapu Lagoon include: shortfin eel (*Anguilla australis*), longfin eel (*Anguilla dieffenbachia*), speckled longfin eel (*Anguilla reinhardtii*), inanga (*Galaxias maculatus*), common bully (*Gobiomorphus cotidianus*), giant bully (*Gobiomorphus gobioides*), redfin bully (*Gobiomorphus huttoni*), common smelt (*Retropinna retrpinna*), goldfish, brown trout (*Salmo trutta*), and gamusia (*Gambusia affinis*) (Hicks et al. 2015, eDNA records in **Table 3.1**).

Fish recorded in the Wainui Te Whara Stream include: Longfin eel (*Anguilla diefffenbachii*), shortfin eel (*Anguilla australis*), redfin bully (*Gobiomorphus huttoni*), giant bully (*Gobiomorphus gobioides*), banded kōkopu (*Galaxias fasciatus*), shortjaw kōkopu (*Galaxias postvectis*), giant kōkopu (*Galaxias argenteus*), common smelt (*Retropinna retrpinna*), and brown trout (*Salmo trutta*) are present in The Wainui Te Whara Stream flowed into Awatapu and diadromous fish in the stream need to migrate through Awatapu Lagoon (Hamill 2015, **Table 3.1**).

Hick et al. (2015) fished Awatapu using an electric fishing boat in 2005 and 2014. They caught goldfish, shortfin eel, common bully, giant bully, inanga, brown trout, smelt and gambusia. Goldfish and common bully were most abundant. The fishing confirmed that the lagoon had large goldfish but no koi carp. Sampling of the Wainui Te Whara by Hamill (2015) found shortfin and longfin eel to be most abundant – with a large abundance as elva.

Many of the fish species present in Awatapu and the Wainui Te Whara Stream have a threat classification, i.e. longfin eel, giant kōkopu, inanga are classed "At-Risk – Declining", shortjaw kōkopu is classed "Nationally Vulnerable", giant bully is classed "At Risk Nationally uncommon". Gambusia is a national pest "unwanted organism" (Dunn et al. 2018).

[6] http://nzbirdsonline.org.nz/species/new-zealand-dabchick

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



Fish access into Awatapu Lagoon and the Wainui Te Whara Stream is facilitated by the use of fish friendly flap gates (**FFG**), which remain open for a wide tidal range. The southern lagoon appears to have less diversity of fish (**Table 3.1**), which may reflect the poor water quality conditions.

**Table 3.1**: Fish present in Awatapu Lagoon and the Wainui Te Whara Stream (WTW) as identified in eDNA samples. Numbers are the eDNA sequences detected.

| Scientific Name | Common Name | 28/10/21 Awatapu central | 17/11/22 Awatapu central | 17/11/22 Awatapu west | 17/11/22 Awatapu south | 17/11/22 WTW Hinemoa | 30/09/22 WTW Valley Rd |
|---|---|---|---|---|---|---|---|
| *Anguilla australis* | Shortfin eel | ✓ 181 | ✓ 478 | ✓ 260 | ✓ 1387 | ✓ 2989 | ✓ 466 |
| *Anguilla dieffenbachii* | Longfin eel | | ✓ 13 | | | ✓ 1061 | ✓ 219 |
| *Anguilla reinhardtii* | Speckled longfin eel | ✓ 10 | | ✓ 48 | ✓ 19 | | |
| *Gobiomorphus cotidianus* | Common bully | ✓ 70 | ✓ 617 | ✓ 249 | | | |
| *Gobiomorphus huttoni* | Redfin bully | ✓ 16 | | | | ✓ 3452 | ✓ 1305 |
| *Gobiomorphus sp.* | bully (unknown species) | | ✓ 1220 | ✓ 8896 | ✓ 38 | | |
| *Galaxias maculatus* | Inanga | ✓ 211 | ✓ 8 | ✓ 158 | | ✓ 122 | ✓ 876 |
| *Galaxias fasciatus* | Banded kokopu | | | | | ✓ 101 | ✓ 47 |
| *Galaxias postvectis* | Shortjaw kokopu | | | | | ✓ 130 | |
| *Retropinna retropinna* | Common smelt | ✓ 61 | ✓ 52 | | | ✓ 618 | ✓ 141 |
| *Salmo trutta* | Brown trout | | | | | ✓ 340 | ✓ 225 |
| *Carassius auratus* | Goldfish | ✓ 3162 | ✓ 9738 | ✓ 12297 | ✓ 9357 | | |
| *Gambusia affinis* | Mosquitofish | ✓ 197 | ✓ 1103 | ✓ 416 | ✓ 804 | ✓ 10 | ✓ 15 |

## 3.5 Riparian and Aquatic Plants

### 3.5.1 Riparian plants

Awatapu Lagoon is surrounded by urban parkland consisting of mature trees and mown grass. Mature native trees are established along the northern edge of the western lagoon and parts of the central lagoon. Swamp mire (*Syzgium maire*) and willow are common near the waters edge near the southern shore. A fridge of flax (*Phormium tenex*) is also common. Where riparian restoration planting has occurred, a more diverse range of native vegetation occurs, including: manuka (*Leptospermum scoparium*), kahikatea (*Dacrycarpus dacrydioides*), *Coprosma tenuicaulis*, flaxes (*Phormium cookianum*), toetoe (*Austroderia fulvida*), rushes including *Machaerina articulata Juncus egariae, J. pallidus, leptocarpus similis*), and sedges including *Carex* secta, *C. lambertiana, Cyperus ustulatus, Bolboschoenus fluviatilis*.

### 3.5.2 Emergent and Aquatic plants

A narrow band of raupo (*Typha orientalis*) extends along much of the lagoon margin, interspersed in places with reed sweetgrass (*Glyceria maxima*), and patches of *Machaerina articulata*. Water pepper (*Persicaria hydropiper*), swamp willow weed (*Persicaria decipiens*) and creeping bent (*Agrostis* sp) are common on the bank edge and extending to shallow margins.

Aquatic vegetation in Awatapu Lagoon is dominated by hornwort (*Ceratophyllum demersum*) and parrot's feather (*Myriophyllum aquaticum*)[7] – both are exotic pest plants. These can be rooted but in Awatapu more commonly occur as floating mats (often c. 0.5m thick) that cover large areas of the

[7] First observed in about 1984.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



lagoon. The southern lagoon can have almost 100% coverage of hornwort and parrots feather during summer, but floating mats of hornwort are also common form large floating mats in the central and western lagoons. The growth of hornwort in the western lagoon can be limited by the brackish water. The floating fern *Azolla pinnata* can also cover large areas of Awatapu during summer, and is easily recognised by its purple colour. *Azolla* is often found in association with and duckweed (*Lemna minor*) **(Figure 3.8**).

The growth of hornwort, parrots feather and Azolla is seasonal, but partially decaying floating mats of can persist in the lagoon through winter until they are eventually washed out during a flood, or sink to the bottom. Epiphytic algae often grow on / within the macrophytes mats, and can be seen on the surface as a light green slime.

Aquatic plants are a key to maintaining good water quality in natural lakes, by regulating water quality, stabilising sediments, and providing habitat for invertebrates and fish. However, the extensive cover of hornwort and parrots feather in Awatapu causes major water quality problems with low dissolved oxygen below the thick floating mats of hornwort.

Extensive cover of the floating *Azolla* sp. often corresponds to clearer water as the shading and nutrient uptake reduces phytoplankton growth. However, *Azolla* can affect the aesthetics. *Azolla* also has the potential to fix atmospheric nitrogen due to a symbiotic relationship with a cyanobacteria within the plant, although this mechanism is weak when background nitrogen concentrations are sufficiently high for the plant.

The cover of hornwort and parrots feather has historically been controlled by use of herbicide sprays. This is a relatively cheap way to control macrophytes, but has can have a number of negative consequences, including decomposing macrophytes causing sediment anoxia, release of nutrients and promotion of algae blooms. Harvesting macrophytes, although more expensive, provide considerably more benefits for improving water quality and ecological values. WDC harvested macrophytes from south Awatapu lagoon in 2019, but a lack of any subsequent control allowed reestablishment of a dense cover of hornwort/parrot's feather within two years.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Figure 3.8**: Top Photo: Awatapu Lagoon west with patches of floating hornwort in (August 2022). Bottom Photo: Southern Awatapu Lagoon with 100% cover of hornwort, parrots feather and interspersed with Azolla sp. (March 2019).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



### 3.5.3 Role of macrophytes in maintaining good water quality

Macrophyte beds are a key component of healthy lakes. They help improve water quality by stabilising the sediments, absorbing dissolved nutrients, mediating the nutrient release from sediments, and providing habitat for invertebrates that consume phytoplankton (Hilt et al. 2006; Kelly and Jellyman 2007; Schallenberg et al. 2010, Wetzel 1995). Overseas studies have shown that submerged aquatic plant cover needs to be consistently >30% to 60% to ensure a clear-water state (e.g. Jeppesen et al. 1994; Tatrai et al. 2009; Blindow et al. 2002).

It is well documented that shallow, eutrophic lakes can often undergo a regime shift (colloquially called “flipping”) from a clear water, macrophyte-dominated state to a de-vegetated, algae-dominated state with turbid water quality (Scheffer 2004, Tatrai et al. 2009). At least 37 shallow lakes in New Zealand that have undergone a “flip” between clear water and turbid states and/or vice versa.

The risk of a lake flipping to a turbid water quality state increases with increasing nutrient and sediment loads, and typically corresponds to increases in epiphytes, macroalgae, phytoplankton and cyanobacteria (**Figure 3.9**) (De Wit et al. 2001, Scheffer & van Nes 2007). Flipping to a turbid, algae dominated state is more likely when a lake has a high nutrient load, where exotic macrophytes have replaced native macrophytes, and where coarse fish species (e.g. catfish, goldfish, rudd, tench, or koi carp) are present (Schallenberg and Sorrell 2009).

Re-establishing submerged macrophytes is essential for the long-term success when restoring shallow lakes. However, simply establishing macrophyte beds does not always improve water quality even when they improve fish habitat. Ecosystems are complex and often other restoration activity is also needed. Establishing aquatic plants in shallow lakes does not guarantee clear water quality, but without them good water quality is unlikely without other expensive and ongoing interventions (Gulati et al., 2008; Jeppesen et al. 2005).

Native macrophytes are much more preferable than exotic macrophytes because they provide more biodiversity, have less aggressive growth and are less likely to attain high biomass that can adversely affect dissolved oxygen or cause a nuisance for recreation. However, even exotic macrophytes can provide water quality benefits if well managed. Where exotic macrophytes are present, a common challenge for lake management is to retain the benefits of macrophytes in the lake while minimising the problems caused by excessive growth on water quality and recreation.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



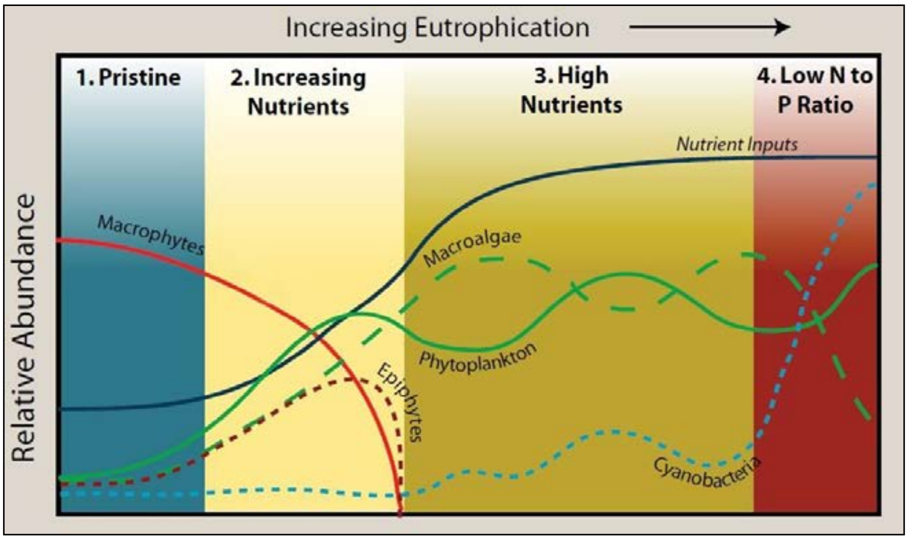



**Figure 3.9**: Generalised lake response to increasing eutrophication. Awatapu Lagoon appears to be in Stage 2 to 3 (adapted from De Wit et al. 2001).

## 3.6 Water Quality

### 3.6.1 Water quality

Awatapu Lagoon has poor water quality. Its TLI score is about 5.1, which is borderline between eutrophic and supertrophic. It has low water clarity (median 0.62m), high concentrations of total nitrogen (median 0.34 mg/L), total phosphorus (0.069 mg/L), and phytoplankton (median Chl-*a* 10.4 mg/m$^3$). Algae blooms are common during summer, and are often dominated by potentially toxic cyanobacteria (**Figure 3.10, Table 3.2, Figure 3.11**).

National bottom-line values set for lake attributes in the NPS-FM are not met for median TP, median Chl-a, maximum Chl-a, and cyanobacteria biovolume, or dissolved oxygen in the bottom waters. However, the microbial water quality of Awatapu Lagoon west appears to be in NOF Band B, which is suitable for Human Contact recreation.

Phytoplankton growth in Awatapu Lagoon appears to be more strongly limited by nitrogen than by phosphorus. The recent TN:TP ratio is about 4.8 (compared to a “balanced” ratio of 7) and the DIN:TP ratio is between about 0.16 and 0.4 (compared to a “balanced” ratio of 1). Absolute values of dissolved organic nitrogen (**DIN**) are often very low (median 0.02 mg/L), while DRP is moderate (median 0.012 mg/L). The components of the TLI in **Figure 3.10** show that TP is high relative to TN or Chl-*a*.

There is some indication that TP and DRP concentrations in Awatapu West may have reduced in the last 10 years, but the sampling has not been sufficiently consistent to have confidence in a trend. An

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



apparent decline in TLI is mostly due to including Chl-a in more recent calculations rather than any real improvement (**Figure 3.11**).

Cyanobacteria blooms during summer can be associated with large diurnal fluctuations in dissolved oxygen and pH spikes in TN, due to the fixing of atmospheric nitrogen by cyanobacteria.

The microbial water quality of Awatapu Lagoon west is likely to be in NOF Band B for Human Contact. The median *E. coli* bacteria concentration is 43 cfu/100mL and the 95 percentile 295 cfu/100mL. Microbial water quality is good during stable conditions but elevated *E.coli* can occur during high flows into the lagoon.

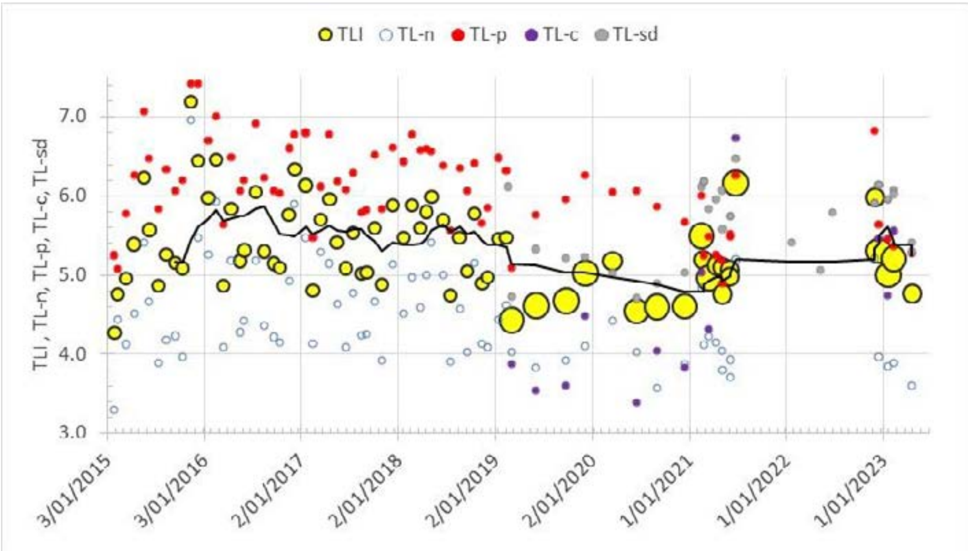



**Figure 3.10:** Awatapu Lagoon West Trophic Level Index (TLI) and its constituents for nitrogen (TL-n), phosphorus (TL-p), chlorophyll-*a* (TL-c), and Secchi depth (TL-sd). The size of the TLI circle indicates the number of components used for its calculation (range 2 to 4); and the line shows the TLI 12-point average.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Table 3.2**: Water quality summary statistics for Awatapu Lagoon west, grouped by hydrological year (July to June). Samples prior to January 2021 were sampled from Awatapu Lagoon West at Riverside Drive, TLI prior to March 2019 was estimated using only TN and TP.

| Years | Variable | n | Min | Max | Mean | Median | 95 %ile | 5 %ile | 75 %ile |
|---|---|---|---|---|---|---|---|---|---|
| 2013-2019 | TN (mg/L) | 52 | 0.20 | 3.27 | 0.64 | 0.50 | 1.40 | 0.31 | 0.81 |
| 2013-2019 | NH4-N (mg/L) | 52 | 0 | 0.42 | 0.066 | 0.01 | 0.319 | 0.002 | 0.085 |
| 2013-2019 | NNN (mg/L) | 51 | 0 | 0.32 | 0.051 | 0.007 | 0.237 | 0 | 0.037 |
| 2013-2019 | TP (mg/L) | 52 | 0.05 | 0.29 | 0.127 | 0.119 | 0.221 | 0.054 | 0.153 |
| 2013-2019 | DRP (mg/L) | 52 | 0.01 | 0.13 | 0.027 | 0.023 | 0.058 | 0.011 | 0.031 |
| 2013-2019 | CHL_A (mg/m3) | 2 | 3.3 | 4.5 | 3.9 | 3.9 | | 3.3 | |
| 2013-2019 | VS- BD | 3 | 0.48 | 1.59 | 1.01 | 0.95 | | 0.48 | 1.43 |
| 2013-2019 | Turbidity (NTU) | 51 | 1.2 | 72.0 | 14.0 | 11.3 | 30.9 | 2.6 | 18.2 |
| 2013-2019 | TLI * | 52 | 4.3 | 7.2 | 5.4 | 5.4 | 6.4 | 4.6 | 5.8 |
| 2013-2019 | Temp (degC) | 52 | 9.5 | 27.4 | 18.1 | 18.3 | 26.0 | 10.2 | 22.3 |
| 2013-2019 | pH | 53 | 6.5 | 10.0 | 7.5 | 7.3 | 8.9 | 6.7 | 7.6 |
| 2013-2019 | EC sp (uS/cm) | 53 | 110 | 4510 | 595 | 238 | 2408 | 134 | 666 |
| 2013-2019 | DO (mg/L) | 51 | 0.2 | 16.8 | 8.9 | 8.7 | 14.4 | 3.1 | 10.7 |
| 2013-2019 | E coli (cfu/100ml) | 52 | 7 | 520 | 123 | 109 | 382 | 12 | 162 |
| 2013-2019 | TN:TP | 52 | 2.9 | 11.2 | 4.9 | 4.5 | 8.6 | 3.4 | 5.3 |
| 2019-2023 | TN (mg/L) | 20 | 0.24 | 0.85 | 0.40 | 0.34 | 0.85 | 0.25 | 0.39 |
| 2019-2023 | NH4-N (mg/L) | 20 | 0 | 0.07 | 0.013 | 0.006 | 0.058 | 0.003 | 0.013 |
| 2019-2023 | NNN (mg/L) | 20 | 0 | 0.18 | 0.022 | 0.005 | 0.128 | 0.001 | 0.018 |
| 2019-2023 | TP (mg/L) | 20 | 0.04 | 0.18 | 0.08 | 0.069 | 0.151 | 0.045 | 0.098 |
| 2019-2023 | DRP (mg/L) | 20 | 0 | 0.06 | 0.019 | 0.012 | 0.052 | 0.005 | 0.03 |
| 2019-2023 | CHL_A (mg/m3) | 14 | 2.9 | 169 | 24.6 | 10.4 | 147.2 | 3.0 | 18.8 |
| 2019-2023 | VS- BD | 29 | 0.35 | 1.62 | 0.75 | 0.62 | 1.39 | 0.45 | 1.00 |
| 2019-2023 | Turbidity (NTU) | 14 | 2.5 | 10.0 | 4.9 | 4.2 | 9.5 | 2.5 | 6.6 |
| 2019-2023 | TLI * | 20 | 4.6 | 6.2 | 5.1 | 5.0 | 6.1 | 4.6 | 5.2 |
| 2019-2023 | Temp (degC) | 22 | 10.8 | 27.8 | 18.1 | 18.9 | 25.0 | 10.9 | 21.5 |
| 2019-2023 | pH | 18 | 6.6 | 9.0 | 7.3 | 7.2 | 8.9 | 6.7 | 7.3 |
| 2019-2023 | EC sp (uS/cm) | 20 | 132 | 5000 | 472 | 175 | 3099 | 137 | 207 |
| 2019-2023 | DO (mg/L) | 20 | 1.8 | 11.9 | 8.1 | 8.7 | 11.7 | 2.3 | 10.1 |
| 2019-2023 | E coli (cfu/100ml) | 20 | 8 | 420 | 69 | 43 | 295 | 9 | 59 |
| 2019-2023 | TN:TP | 20 | 2.8 | 7.3 | 5.2 | 4.8 | 7.3 | 3.0 | 6.9 |

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



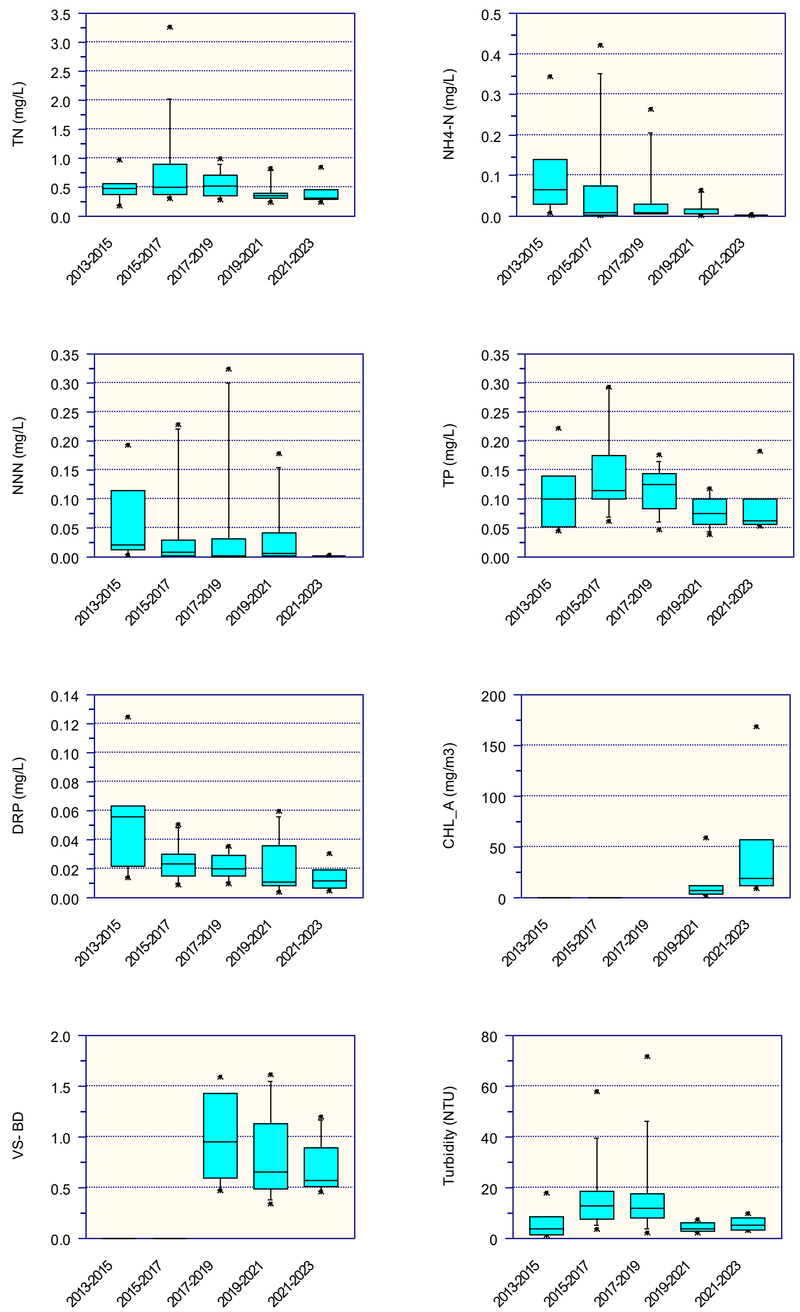



**Figure 3.11a:** Water quality in Awatapu Lagoon west (top) for two-year (July to June) periods.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



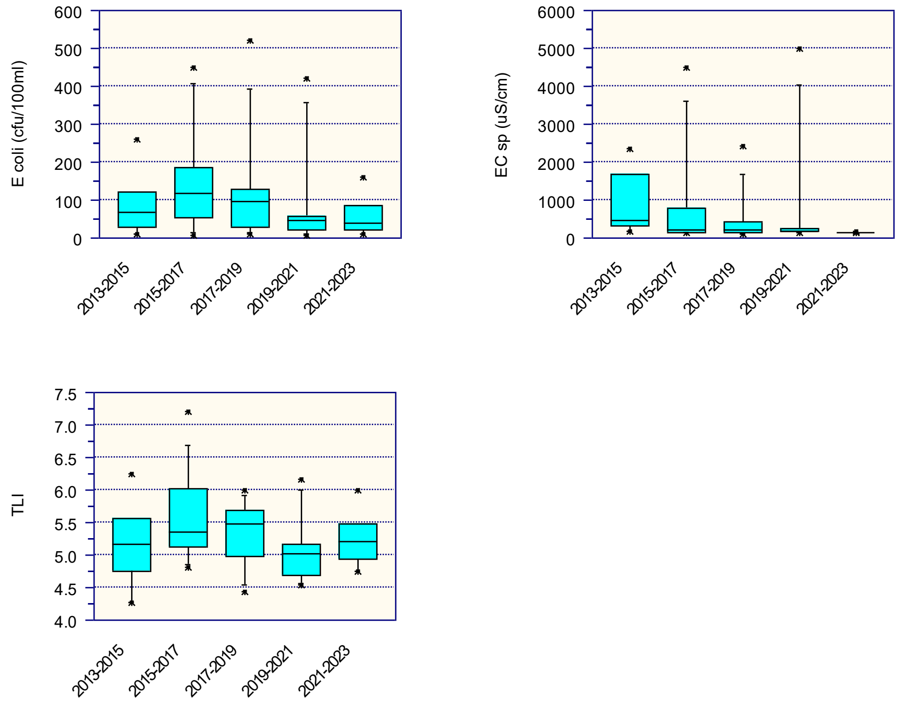



**Figure 3.11b:** Water quality in Awatapu Lagoon west (top) for two-year (July to June) periods. Samples prior to January 2021 were sampled from Awatapu Lagoon West at Riverside Drive, TLI prior to March 2019 is estimated using only TN and TP.

### 3.6.2 Cyanobacteria

Cyanobacteria are a natural part of the plankton community in lakes but can become a problem when they increase to high concentrations and form 'blooms'. Frequent cyanobacteria blooms are a feature of poor water quality in lakes and are caused by multiple factors including high nutrient concentrations, warm, calm conditions, and wind-driven accumulations of surface scums. High concentrations of cyanobacteria can also pose a potential health risk to recreational users, because they produce a range of different cyanotoxins.

Cyanobacteria blooms are common in Awatapu Lagoon during summer and autumn, often exceeding recreational use guidelines (MfE and MOH 2009). Summer monitoring of cyanobacteria in Awatapu Lagoon from 2015 to 2021 (30 samples) found that the **Alert Mode** (biovolume 0.5 to 10 $mm^3/L$) occurred on 30% of occasions, while the **Action Mode** trigger for total biovolume (≥10 $mm^3/L$) was exceeded on 23% of occasions, and the **Action Mode** trigger for potentially toxic cyanobacteria (biovolume ≥1.8 $mm^3/L$) was exceeded on 43% of occasions.

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



The 80th percentile of potentially toxic cyanobacteria biovolume for the three-year period of 2018-2020 was 8.7 $mm^3/L$. This is worse than the NPS-FM national bottom-line (i.e. threshold of 1.8 $mm^3/L$ for "D" Band).

*Anabaena* spp., were the dominant cyanobacteria present, but both *Anabaena* spp and *Microcystis* spp., were prevalent during blooms; often seen as green flocs suspended in the water (**Figure 3.12**, **Table 3.3**).

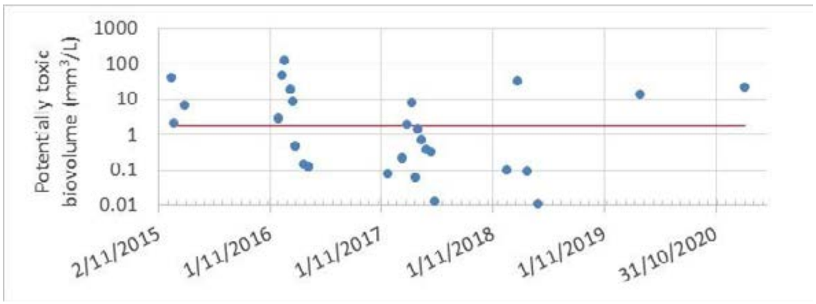



**Figure 3.12**: Biovolume volume of potentially toxic cyanobacteria in Awatapu Lagoon during summer (the red line is the 'Action' mode trigger).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Table 3.3**: Occurrence of cyanobacteria species in Awatapu Lagoon west during summer, 2015-2021 (source BOPRC). Shading groups common genesis.

| Species | Count | % occurance | % occurance when biovolume ≥10 $mm^3$/L |
|---|---|---|---|
| *Anabaena circinalis* | 13 | 19% | 11% |
| *Anabaena lemmermannii* | 2 | 3% | |
| *Anabaena planktonica* | 9 | 13% | 22% |
| *Anabaena sp* | 1 | 1% | |
| *Anabaena spiroides* | 8 | 12% | 22% |
| *Anabaena torulosa* | 1 | 1% | |
| *Aphanocapsa delicatissima* | 1 | 1% | |
| *Aphanocapsa holsatica* | 1 | 1% | |
| *Aphanocapsa sp* | 1 | 1% | |
| *Chroococcus dispersus* | 2 | 3% | |
| *Chroococcus limneticus* | 2 | 3% | |
| *Coelosphaerium kuetzingianum* | 1 | 1% | |
| *Geitlerinema sp* | 1 | 1% | |
| *Microcystis aeruginosa* | 1 | 1% | |
| *Microcystis cf panniformus* | 1 | 1% | |
| *Microcystis flos-aquae* | 2 | 3% | |
| *Microcystis panniformis* | 1 | 1% | 11% |
| *Microcystis sp* | 1 | 1% | 11% |
| *Microcystis sp.* (small) | 2 | 3% | 11% |
| *Microcystis wesenbergii* | 1 | 1% | |
| *Oscillatoria sp* | 1 | 1% | |
| *Phormidium sp* | 1 | 1% | |
| *Planktothrix sp* | 9 | 13% | 11% |
| *Pseudanabaena galeata* | 1 | 1% | |
| *Pseudanabaena limnetica* | 2 | 3% | |
| *Trichodesmium iwanoffianum* | 1 | 1% | |
| No Cyanobacteria | 1 | 1% | |

### 3.6.3 Spatial variation in water quality

The Western and Southern lagoons have broadly similar water quality, but Awatapu Lagoon South has considerably worse water quality compared to the rest of the lagoon (i.e low DO, low clarity and high concentrations of TN, TP and *E.coli* bacteria). The water quality of the Wainui Te Whara Stream has similar TN, and much lower TP compared to Awatapu Central, but more of the nutrients are in a bioavailable form. *E.coli* bacteria tend to be higher in the Wainui Te Whara compared to in the main lagoon (**Table 3.4**).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Table 3.4:** Median water quality in the Awatapu Lagoon West, Central, South and the Wainui Te Whara (2021-2023, *n*= 9 to 12).

| Site | EC sp (uS/cm) | DO (mg/L) | pH | BD (m) | TN (mg/L) | NNN (mg/L) | NH4-N (mg/L) | TP (mg/L) | DRP (mg/L) | CHL_a (mg/m3) | E coli (cfu/100ml) | TN:TP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Awatapu West - Top | 169 | 9.2 | 7.2 | 0.57 | 0.31 | 0.003 | 0.005 | 0.062 | 0.008 | 12.4 | 27 | 4.8 |
| Awatapu Central - Top | 149 | 8.9 | 7.1 | 0.62 | 0.34 | 0.005 | 0.007 | 0.060 | 0.009 | 22.7 | 57 | 6.1 |
| Awatapu South at Bridge St | 257 | 3.1 | 6.7 | 0.43 | 0.49 | 0.018 | 0.074 | 0.181 | 0.009 | 13.7 | 350 | 2.2 |
| Wainui Te Whara - Hinemoa St | 128 | 10.2 | 6.9 | 1.15 | 0.33 | 0.156 | 0.012 | 0.037 | 0.019 | 0.8 | 335 | 8.2 |

### 3.6.4 Stratification, deoxygenation and internal nutrient release

A distinctive feature of Awatapu Lagoon is that the Central Lagoon and Western Lagoon experience both thermal stratification and salinity stratification during summer and autumn. Warmer surface water separates from the relatively cooler bottom waters by a thermocline – but this is usually weak and easily disturbed by wind. In addition, brackish water enters the western lagoon from the Whakatāne River when flows are low, which drops to the bottom of the lagoon and separates from the overlaying freshwater by a halocline – this is stratification is persistent. In the Western Lagoon the halocline typically forms at about 1.5m depth. A halocline is less common in the Central Lagoon because of the shallow (0.9m) water under the footbridge, but they do occur at about 1.5m deep (e.g. April 2022), and can persist in the deepest basin (below about 3m deep) even when the halocline in the western lagoon has dissipated (e.g. Nov 2022 to April 2023).

During periods of stratification dissolved oxygen is depleted in the bottom water. Depth profiles found near anoxic bottom water (DO < 1 mg/L) on 89% (16/18) of occasions in Awatapu Central, and 75% (15/20) of occasions in Awatapu West. In Awatapu West the pattern of bottom water anoxia can be complicated by tidal inflows of oxygenated brackish water from the river.

The anoxic conditions that eventually form changes the geochemistry of the sediments and results in the release of nutrients (DRP and NH4-N) from the sediment. Elevated nutrient concentrations in the low oxygen bottom water is evident in the sampling from Awatapu (**Figure 3.13, Table 3.5**). Elevated nutrients from the bottom water become more available for phytoplankton growth when the top and bottom waters eventually mix. The effects of this in the western lagoon may be mitigated because the mixing that results in the loss of the halocline in the western lagoon is often associated with higher river flows and more flushing.

On 16 March 2021, the bottom water of Awatapu Lagoon West had competed anoxia (DO = 0 mg/L). Measurement of gas in the bottom water found $H_2S$ at 984 ppm, CH4 at 0.7% and CO2 at 1.7%. This is consistent with literature showing decomposition of organic matter in eutrophic lakes being a source of greenhouse gasses.

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



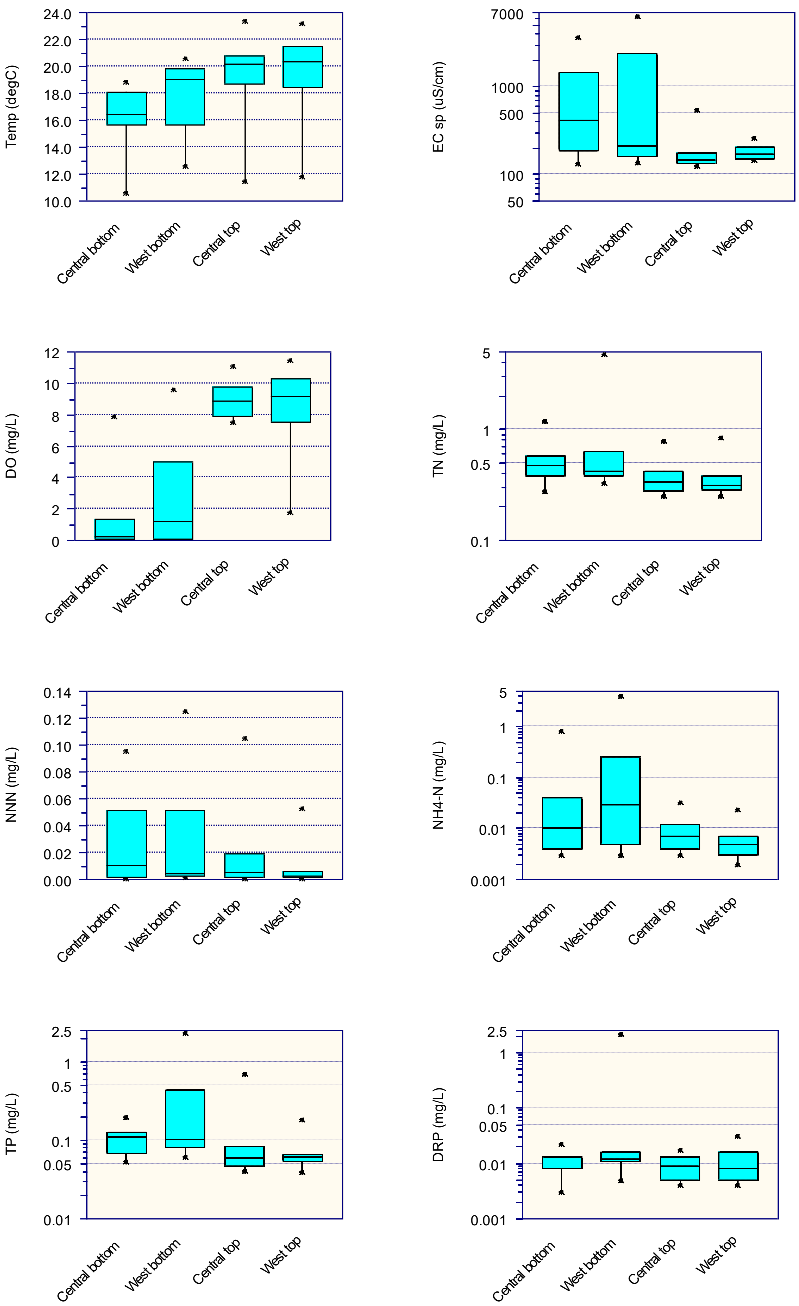



**Figure 3.13:** Top and bottom water quality from mid-lake sites of Awatapu Lagoon West and Awatapu Lagoon Central (February 2021 to April 2023, n= 10).

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



**Table 3.5**: Summary statistics for top and bottom water samples from Awatapu Lagoon West and Awatapu Central.

| Site | Variable | n | Min | Max | Mean | Median | 75 %ile | 25 %ile |
|---|---|---|---|---|---|---|---|---|
| Central bottom | Temp (degC) | 9 | 10.6 | 18.9 | 16.2 | 16.4 | 18.1 | 15.6 |
| Central bottom | pH | 8 | 5.9 | 7.1 | 6.5 | 6.4 | 6.9 | 6.1 |
| Central bottom | EC sp (uS/cm) | 9 | 132 | 3620 | 1071 | 421 | 1465 | 188 |
| Central bottom | DO (mg/L) | 9 | 0.0 | 7.9 | 1.4 | 0.2 | 1.3 | 0.1 |
| Central bottom | DO sat (%) | 9 | 0.9 | 71.0 | 19.0 | 2.6 | 43.3 | 1.6 |
| Central bottom | TN (mg/L) | 9 | 0.28 | 1.20 | 0.53 | 0.47 | 0.58 | 0.38 |
| Central bottom | NH4-N (mg/L) | 9 | 0.003 | 0.835 | 0.11 | 0.01 | 0.04 | 0.004 |
| Central bottom | NNN (mg/L) | 9 | 0.001 | 0.096 | 0.028 | 0.01 | 0.051 | 0.002 |
| Central bottom | TP (mg/L) | 9 | 0.053 | 0.201 | 0.109 | 0.112 | 0.125 | 0.069 |
| Central bottom | DRP (mg/L) | 9 | 0.003 | 0.022 | 0.01 | 0.008 | 0.013 | 0.008 |
| Central bottom | Turbidity (NTU) | 5 | 5.7 | 70.0 | 21.0 | 9.0 | 26.5 | 7.7 |
| Central bottom | TN:TP | 9 | 3.6 | 7.2 | 4.9 | 4.7 | 5.5 | 4.2 |
| West bottom | Temp (degC) | 9 | 12.6 | 20.6 | 17.8 | 19.0 | 19.8 | 15.7 |
| West bottom | pH | 8 | 6.2 | 7.1 | 6.6 | 6.5 | 6.9 | 6.3 |
| West bottom | EC sp (uS/cm) | 9 | 139 | 6482 | 1692 | 214 | 2404 | 162 |
| West bottom | DO (mg/L) | 9 | 0.0 | 9.6 | 2.9 | 1.2 | 5.0 | 0.1 |
| West bottom | DO sat (%) | 9 | 0.0 | 91.0 | 30.5 | 12.3 | 55.0 | 1.3 |
| West bottom | TN (mg/L) | 9 | 0.33 | 4.71 | 0.96 | 0.42 | 0.64 | 0.39 |
| West bottom | NH4-N (mg/L) | 9 | 0.003 | 4.06 | 0.559 | 0.029 | 0.252 | 0.005 |
| West bottom | NNN (mg/L) | 9 | 0.002 | 0.125 | 0.03 | 0.004 | 0.051 | 0.003 |
| West bottom | TP (mg/L) | 9 | 0.061 | 2.34 | 0.465 | 0.102 | 0.433 | 0.081 |
| West bottom | DRP (mg/L) | 9 | 0.005 | 2.19 | 0.254 | 0.012 | 0.016 | 0.011 |
| West bottom | Turbidity (NTU) | 5 | 4.6 | 15.0 | 8.6 | 7.3 | 10.4 | 6.5 |
| West bottom | TN:TP | 9 | 1.0 | 5.5 | 3.6 | 4.2 | 4.9 | 1.9 |
| Central top | Temp (degC) | 10 | 11.5 | 23.4 | 19.2 | 20.2 | 20.8 | 18.7 |
| Central top | pH | 9 | 6.1 | 7.4 | 6.8 | 7.1 | 7.1 | 6.3 |
| Central top | EC sp (uS/cm) | 10 | 126 | 551 | 190 | 149 | 176 | 135 |
| Central top | DO (mg/L) | 10 | 7.5 | 11.1 | 9.0 | 8.9 | 9.8 | 7.9 |
| Central top | DO sat (%) | 10 | 80.0 | 120.0 | 96.4 | 90.4 | 111.6 | 86.0 |
| Central top | TN (mg/L) | 9 | 0.25 | 0.79 | 0.39 | 0.34 | 0.42 | 0.28 |
| Central top | NH4-N (mg/L) | 9 | 0.003 | 0.033 | 0.01 | 0.007 | 0.012 | 0.004 |
| Central top | NNN (mg/L) | 9 | 0.001 | 0.105 | 0.02 | 0.005 | 0.019 | 0.002 |
| Central top | TP (mg/L) | 9 | 0.041 | 0.71 | 0.133 | 0.06 | 0.083 | 0.047 |
| Central top | DRP (mg/L) | 9 | 0.004 | 0.018 | 0.01 | 0.009 | 0.013 | 0.005 |
| Central top | Turbidity (NTU) | 5 | 2.6 | 7.7 | 5.2 | 5.3 | 6.4 | 3.8 |
| Central top | E coli (cfu/100ml) | 9 | 8.0 | 1200.0 | 186.0 | 57.0 | 110.0 | 29.3 |
| Central top | TLI3 | 9 | 4.6 | 6.3 | 5.3 | 5.1 | 5.5 | 4.8 |
| Central top | TN:TP | 9 | 0.6 | 8.0 | 5.6 | 6.1 | 6.4 | 5.5 |
| West top | Temp (degC) | 10 | 11.8 | 23.2 | 19.3 | 20.4 | 21.5 | 18.4 |
| West top | pH | 8 | 6.6 | 7.5 | 7.1 | 7.2 | 7.3 | 6.9 |
| West top | EC sp (uS/cm) | 10 | 147 | 260 | 183 | 169 | 204 | 153 |
| West top | DO (mg/L) | 10 | 1.8 | 11.5 | 8.5 | 9.2 | 10.3 | 7.5 |
| West top | DO sat (%) | 10 | 17.6 | 126.2 | 91.3 | 91.4 | 114.3 | 84.7 |
| West top | TN (mg/L) | 9 | 0.25 | 0.85 | 0.37 | 0.31 | 0.38 | 0.29 |
| West top | NH4-N (mg/L) | 9 | 0.002 | 0.024 | 0.007 | 0.005 | 0.007 | 0.003 |
| West top | NNN (mg/L) | 9 | 0.001 | 0.053 | 0.009 | 0.003 | 0.006 | 0.002 |
| West top | TP (mg/L) | 9 | 0.04 | 0.184 | 0.072 | 0.062 | 0.066 | 0.054 |
| West top | DRP (mg/L) | 9 | 0.004 | 0.031 | 0.012 | 0.008 | 0.016 | 0.005 |
| West top | Turbidity (NTU) | 5 | 3.1 | 10.0 | 5.8 | 5.4 | 7.5 | 3.6 |
| West top | E coli (cfu/100ml) | 9 | 9.0 | 160.0 | 44.9 | 27.0 | 54.0 | 18.0 |
| West top | TLI3 | 9 | 4.8 | 6.0 | 5.1 | 5.0 | 5.2 | 4.9 |
| West top | TN:TP | 9 | 4.2 | 7.3 | 5.4 | 4.8 | 6.5 | 4.6 |

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



### 3.6.5 Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental for the health of almost all aquatic ecosystems. Reduced concentrations of DO (e.g. <4 mg/L) can impair the growth and reproduction of aquatic organisms, and shift the community composition to more tolerant organisms. As DO further reduces (e.g. 1 to 2 mg/L), death of aquatic organisms becomes increasingly common unless organisms can avoid low DO zones (Davies-Colley et al. 2013). The complete loss of DO (anoxia) from bottom waters of lakes causes changes in geochemistry that facilitates the release of nitrogen (as NH4-N) and phosphorus (as DRP) from the sediment; this can stimulate further eutrophication, which itself contributes to conditions that caused the anoxia.

Algae blooms can cause large daily fluctuations in dissolved oxygen (DO) and pH due to the photosynthesis and respiration of the phytoplankton. Oxygen concentrations will typically increase with photosynthesis during the day, and decrease with respiration at night. Other factors that have an important influence on lake DO, in addition to photosynthesis and respiration, are: wind re-aeration (that moves the DO towards 100% saturation), sediment oxygen demand, and biochemical oxygen demand from the water.

#### 3.6.5.1 Temporal Variation in DO

Dissolved oxygen loggers were installed in Awatapu Lagoon Central in February/March 2017 and in Awatapu Lagoon West from April to June 2022. Moderately large diurnal fluctuations of DO occur in the surface water of the lake in response to photosynthesis and respiration from phytoplankton and plants. When the lake is stratified the bottom water has low DO concentrations and the surface water is aerated, but when the stratification breaks down, the mixing of the bottom water reduces the DO in the surface water (**Figure 3.14** and **Figure 3.15**).

During early April 2022 there was strong salinity stratification in Awatapu West with the halocline at about 1.5m depth. Bottom waters were anoxic while the surface water had over 100% saturation. Bottom waters became progressively less brackish during April (likely due to higher flows in the Whakatāne River (to 44 $m^3/s$) reducing saline inflows). By 10 May 2022 the depth of the halocline had reduced to 2.0m to 2.5m. On 21 May 2022, flood in the Wainui Te Whara initiated full mixing of the western lagoon, and the lagoon was fully mixed follow further floods in early June. Following full mixing, the surface water DO range between about 40% and 70% saturation (**Figure 3.14**).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



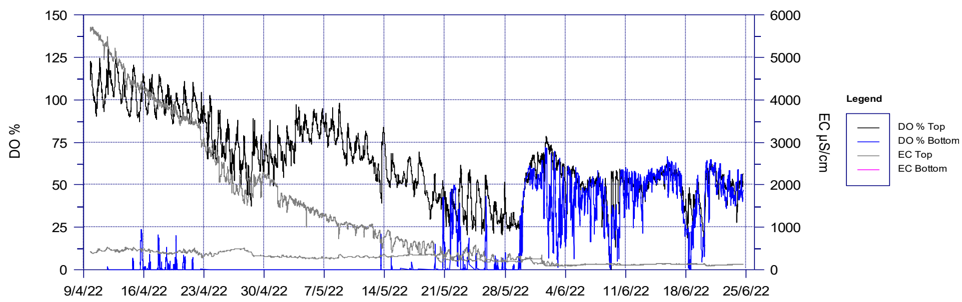



**Figure 3.14**: Dissolved oxygen and electrical conductivity in the top and bottom waters of Awatapu Lagoon West, autumn 2022. Bottom waters became progressively less brackish during April. Oxygen returned to the bottom water around 21 May following a flood in the Wainui Te Whara Stream.

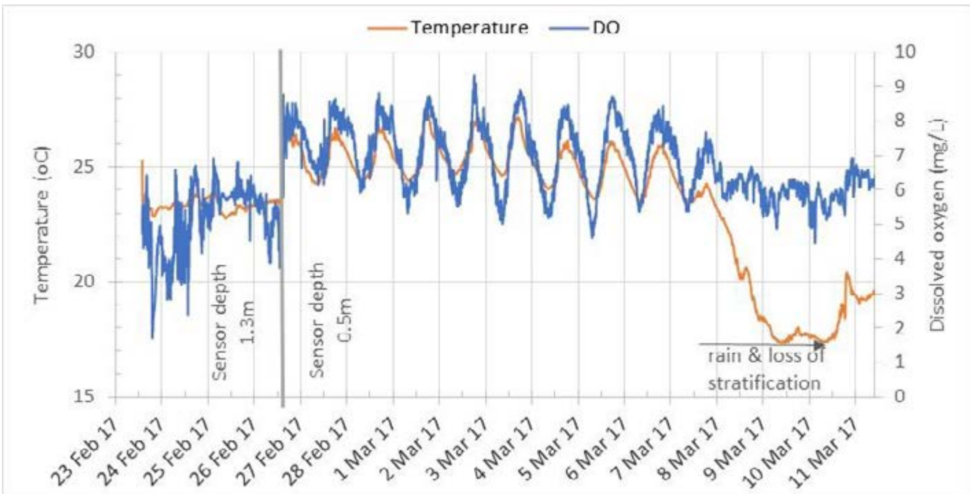



**Figure 3.15**: Dissolved oxygen in Awatapu Lagoon Central. The logger was initially located at 1.3m depth and moved to 0.5m depth after four days. On 24/2/2017 the DO was < 0.5 mg/L below 1.5m depth.

#### 3.6.5.2 Spatial Variation in DO

Awatapu Lagoon can have considerable spatial variations in DO, pH and EC. Synoptic surveys undertaken in the late afternoon on 11 April 2022 found the western end of Awatapu Lagoon generally

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



had DO mostly above full saturation and elevated pH. In stark contrast, the southern lagoon and south of the Wainui Te Whara delta have very low DO and slightly acidic pH. These patterns are consistent with the distribution of aquatic macrophyte cover. Floating mats of hornwort and associated epiphytes had accumulated in the western end of the western lagoon and readings of DO and pH varied depending of whether the sensor was in water just above a mat (high DO and pH) or beneath a mat (low DO and pH). The southern lagoon has persistently high macrophyte cover which accumulates and decomposes. The mats are surface reaching and reading we made just below the floating mats (**Figure 3.16, Figure 3.17**).

EC was lowest near the Wainui Te Whara delta and increased towards the western end of the Western Lagoon. This reflects the inflow of brackish water from the Whakatāne River. Interestingly, EC is also slightly elevated in the Southern Lagoon, which may reflect more dissolved ions from decomposition processes (**Figure 3.18**).

The DO results from the synoptic survey are consistent with previous measurements. In 2021 the spot readings of percent DO saturation in the Southern Lagoon ranged from 3.5% to 57% saturation. In February 2021 floating rafts of hornwort (about 400mm thick) covered large areas of the Central Lagoon, the DO concentration immediately underneath these rafts less than 5% saturation (0.45 mg/L), and got lower with depth. This is much less than the oxygen requirements of even very tolerant fish, and dead goldfish were observed in the lagoon on this occasion.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 3.16:** Spatial variation of dissolved oxygen saturation (%) in Awatapu Lagoon during late afternoon on 11 April 2022. High DO saturation in the western lagoon is associated with the photosynthesis of hornwort mats in this part of the lagoon. Very low DO saturation in the southern lagoon and near the Wainui Te Whara delta is consistent with decomposition of macrophyte organic matter in this area.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



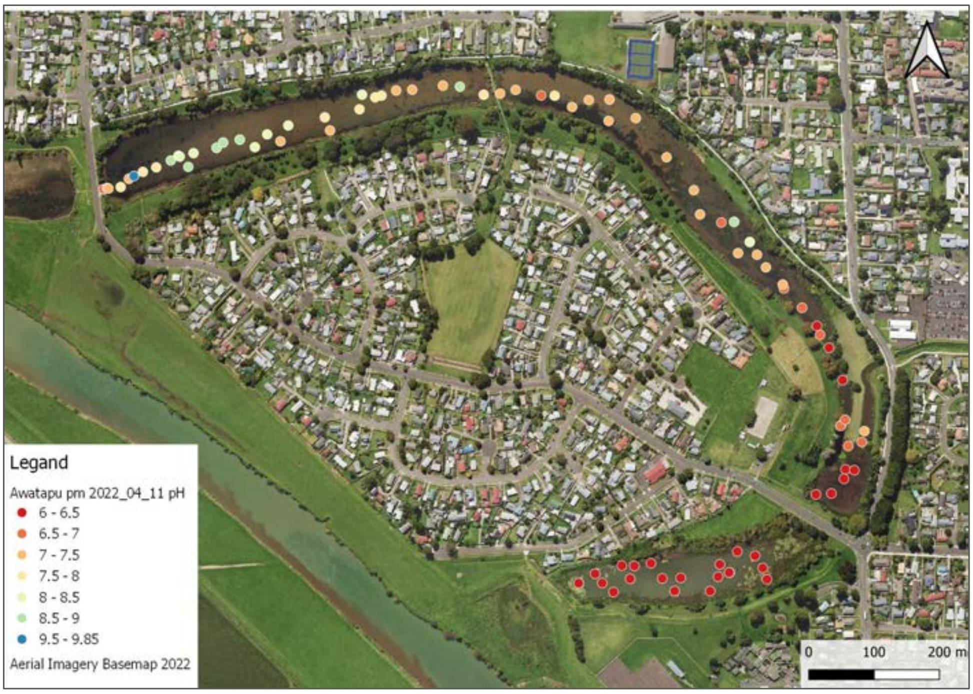



**Figure 3.17:** Spatial variation of pH in Awatapu Lagoon during late afternoon on 11 April 2022. pH is high in the western lagoon associated with the photosynthesis of hornwort accumulating in this part of the lagoon. Low pH in the southern lagoon and near the Wainui Te Whara delta is consistent with decomposition of macrophyte organic matter.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 3.18**: Spatial variation of electrical conductivity (uS/cm) in Awatapu Lagoon during late afternoon on 11 April 2022. EC is higher in the western lagoon due to the influence of brackish water from the Whakatāne River.

**3.6.5.3 Summary of DO regime**

Awatapu Lagoon West and Awatapu Lagoon Central can have persist salinity stratification due to brackish water that enters from the Whakatāne River during high tides and when the river has low flows (i.e. less than about three quarters of median flow).

When Awatapu Lagoon West and Lagoon Central are stratified the surface water is usually replete in oxygen, while the bottom water has very low oxygen. During periods with high macrophyte cover the southern lagoon can have very low dissolved oxygen concentrations. When the stratification breaks down, the bottom water becomes aerated but the mixing of the bottom water reduces the DO in the surface water.

There can be strong spatial variability in surface water DO associate with the distribution of floating mats of hornwort. Thick mats block the air from aerating the surface water and partial decomposition within the mats creates an oxygen demand. In 2021, DO was measured at less than 5% saturation directly below and expanse of thick macrophyte mats floating over deep water. Furthermore, the sinking of hornwort mats to the lake bed and their subsequent and decomposition will be a major contribution to accumulated organic matter that drives the rapid decline in DO in bottom water following stratification.

## 3.7 Water quality issues affecting Awatapu Lagoon

Key ecological and water quality issues identified in Awatapu Lagoon include:

- Poor water quality: Low clarity, high nutrients (particularly phosphorus), cyanobacteria blooms, and low dissolved oxygen in the southern lagoon.
- Water quality not suitable for recreational bathing due to cyanobacteria blooms. However microbial water quality (*E.coli* bacteria) is usually within contact recreation guidelines.
- During periods of stratification, bottom waters of Awatapu Lagoon rapid loss DO due to oxygen demand from organic matter on the lake bed. Anoxic conditions can mobilise nutrients from the lake bed sediment. During extreme stratification, methane and sulphur dioxide is released as during organic matter decomposition and can accumulate in the bottom waters.
- Floating mats of hornwort can occur throughout the lagoon and cause low DO conditions beneath them.
- Awatapu Lagoon South consistently has low DO due to extensive cover of hornwort and high organic matter load when the hornwort dies back during winter.
- The extensive cover of aquatic pest plants (hornwort and parrots feather) make establishment of native aquatic macrophytes more difficult.
- There is opportunity to improve water quality by harvesting the hornwort and parrot's feather. Harvesting would not only mitigate their effect on the DO regime, but also remove organic matter and nutrients from the lake system.
- Herbicide could be used to maintain low cover of hornwort between harvests, but there is a risk of causing worse water quality conditions if herbicide is the only method of control.
- There is an opportunity to improve water quality and habitat by creating in lake wetlands.
- Rubbish is a persistent problem in Awatapu.

# 4 Management Actions to improve Awatapu Lagoon

## 4.1 Introduction

There is a strong community desire to improve the water quality and ecological values of the Awatapu Lagoon. Approaches to improving lake water quality have been described in several recent reviews for New Zealand lakes (e.g., Abell *et al*. 2020, Hamilton 2019, Abell 2018, Hill 2018, Gibbs and Hickey 2012). Abell et al. (2020) grouped restoration techniques as: a) controlling external loads, b) controlling internal loads, c) biomanipulation and d) hydraulic manipulation. A summary of restoration techniques described in Abell *et al*. (2020) is in **Appendix 2**.

Aquatic macrophytes can be perceived as a nuisance by some lake users. While excessive growth of pest macrophytes cause water quality problems in Awatapu, they also have a vital role in maintaining lake water quality and ecology. There are multiple control options for macrophytes that have been discussed in detail in de Winton et. al (2013) and are described on the NIWA website: https://niwa.co.nz/freshwater/our-services/aquaticplants/outreach/weedman .

Awatapu Lagoon will require an integrated approach that reduces external and internal nutrient loads, and enhances biological processes mediated through aquatic macrophyte and wetland vegetation. Potential intervention measures to address specific water quality and ecological issues in Awatapu Lagoon are described in **Table 4.1**. A sub-set of these management interventions were selected based on their potential benefits and input from WDC. This section describes these management options, including their benefits, risks and value for money.

The key management interventions assessed for Awatapu Lagoon are:

- Reducing catchment sediment and nutrient loads (e.g. by use of detainment bunds in the upper Wainui Te Whara catchment).
- Harvesting macrophytes to manage plant cover and remove nutrients (possibly in conjunction with herbicide to maintain low biomass between harvesting).
- Construct treatment wetlands near the Wainui Te Whara delta and southern lagoon to treat nutrients and improve biodiversity values. [8]
- Floating wetlands to remove nutrients and improve biodiversity.
- Sediment phosphorus (P) locking to reduce internal load of P.
- Increase flushing flows through Awatapu by directing a proportion of flow from the Whakatāne River to Awatapu Lagoon South.

[8] The 2021 Long Term Plan approved funding to creation of wetland areas in Awatapu lagoon including diverting baseflow of the Wainui Te Whara into Awatapu south. The concept design for this project has been modified to extend water quality benefits for the whole of Awatapu Lagoon at a lower cost.

## 7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)



**Table 4.1**: Potential interventions to address ecological and water quality issues in Awatapu Lagoon

| Ecological issues | Causes | Potential management options |
|---|---|---|
| Supertrophic high concentration of nutrients, algae, poor clarity. Cyanobacteria blooms. | External nutrient load | o Create treatment wetlands in vicinity of Wainui Te Whara delta.<br>o Floating wetlands for N removal and habitat.<br>o Sediment detention bunds in upper catchment<br>o Educate to reduce nutrient use in catchment |
| | Internal nutrient load via sediment resuspension or anoxia | o Harvest aquatic macrophytes / azolla and remove from the lagoon.<br>o Phosphorus-locking of sediments with focus on deep areas the develop halocline (west and central lagoon). |
| | Bottom water anoxia | o Harvest macrophytes to reduce load of organic matter. |
| Poor oxygen conditions | Floating macrophyte mats | o Harvest aquatic macrophytes. Option of using spray to managing biomass between harvesting. |
| | Halocline stratification in Western lagoon | o Naturally occurring but may have limited impact if brocken only during high flow events. |
| | Negligible flow in South lagoon | o Divert WTW Stream to flow via South Lagoon in conjunction with creating treatment wetlands.<br><br>o Pipe or syphon water from Whakatāne River to Awatapu south using tidal head. |
| Excessive aquatic pest plant cover affecting WQ, biodiversity, recreation and aesthetics. (contribute C and N) | Pest plants of hornwort and parrots feather as floating rafts and rooted in shallow areas | o Harvest aquatic macrophytes<br>o Herbicide spray of aquatic macrophytes to maintain low biomass between harvests (risks worsening low DO and high nutrients). |
| Pest plants on riparian zone | *Glyceria maxima* near the foot bridge | o Targeted herbicide spray of reed *Glyceria* sp.<br>o Remove weeds on floating wetlands |
| Siltation | Stream inflow. WTW delta, Sullivan Lake footbridge | o Continue sediment removal from WTW delta<br>o Extend WTW delta to create a wetland area.<br>o Silt traps at source. Sullivans - floculation at footbridge stream. |
| Litter | Rubbish directly and via stormwater | o Street sweeping<br>o Litter traps<br>o Regular "pick-ups" |
| Riparian management restricting development of marginal wetlands | | o Plant native riparian vegetation to optimise habitat values.<br>o Create shallow sloping banks into water and plant with wetlands. |
| Poor access to the water | Lack of structures in water | o Construct jetties and boat launching areas in western lagoon |
| Enhance biodiversity | | o Create wetlands and floating wetlands for birds, fish and invertebrates.<br>o Harvest pest aquatic macrophytes to assist natives.<br>o Establish native macrophytes (e.g. *Ruppia* sp. in Western Lagoon).<br>Animal pest control (Halo) |

## 4.2 Reduce external nutrient loads from catchment

### 4.2.1 General Description

A major driver of lake eutrophication is excess nutrient loading from the catchment, and reducing external nutrient loads is an important strategy for lake restoration. The control of both nitrogen and phosphorus is important in New Zealand lakes where nitrogen limitation of phytoplankton biomass accumulation is common (Abell et al. 2010).

Successful control of external nutrient loads requires knowledge of where, when and how nutrient losses are occurring from the catchment. For many lakes, diffuse pollution from agriculture contributes the majority of nutrients (Gluckman 2017). But in urban catchments, point sources (e.g. sewage or sewage overflows) can be a major source of external nutrient loads and controlling these can provide substantial nutrient load reductions. A summary of key measures to reduce external nutrient loads is provided in **Appendix 2**.

Detainment bunds are a cost-effective option for reducing sediment and P that may have potential in the upper catchment of the Wainui Te Whara Stream. Detainment Bunds are low earth berms placed across ephemeral storm water flow paths on farms to temporarily detain storm water run-off. The detained water allows the settling of sediment and associated phosphorus and microbial contaminants within the paddock and reduces export to waterways. They also increase water infiltration and this enhances their effectiveness at contaminant removal. The infrequent and short-term inundation does not compromise pasture production. Standard criteria have been developed for detainment bund design referred to as “Detainment BundPS120”, which incorporates a key design element of having a minimum water storage of 120 m3 per hectare of contributing catchment (Paterson et al. 2020).

### 4.2.2 General Application and Constraints

There is typically a lag between reducing external nutrient loads from the catchment and improvements in lake water quality because it takes time to reduce the stores of nitrogen and phosphorus within the lake sediments. Jeppesen et al. (2005) reviewed changes in 35 lakes subject to external nutrient load reductions and found that in-lake TN concentrations typically took <5 years to decline, but in-lake TP typically took 10-15 years. This reflected slower removal of internal phosphorus loads compared to removal of nitrogen by denitrification.

Detainment bunds are very effective preventing the export of sediment and phosphorus and retaining it on the paddock. Studies have found that they retain 47% - 68% of the TP in stormwater run-off, 57-72% of the TN and 51% - 59% of suspended sediments. Average removal rates were 0.72 kg TP per ha of catchment per year and about 2.0 kg TN/ha/yr. In the Rotorua catchments, the detainment bunds allows about 50% of the runoff to infiltrate back into soils, and this is likely to be similar in the sandy soils around Lake Wiritoa. The detainment bunds also reduce peak storm flows that can accelerate stream bank erosion (Levin et al 2020). Their practical application depends largely on the topography and farming practices.

### 4.2.3 Cost-effectiveness

McDowell and Nash (2012) found that land management strategies (e.g. fertiliser management) were the most cost-effective way of mitigating phosphorus exports. Edge-of-field strategies, which remove P from runoff (i.e., wetlands) or prevent runoff were less cost-effective, but had other benefits including removing other contaminants like nitrogen. Similarly in urban areas, addressing external nutrient loads at source is often the most cost-effective management strategy.

Detainment bunds are relatively cheap to construct which makes them a very cost-effective way to reduce the export of phosphorus. Levin (2020) estimated their cost-effectiveness as $120 - $140 /kg of phosphorus retained (based on an average cost of $20,000 per detainment bund and annualised). The costs depend on the permitted activity rules in a region. Resources may also need to be assigned to identifying suitable locations within a catchment to locate detainment bunds and to liaise with landowners.

### 4.2.4 Application to Awatapu Lagoon

#### 4.2.4.1 Suitability

Potential options to reduce external nutrient loads entering Awatapu Lagoon from its catchment include:

- Use of sediment detainment bunds in the upper catchment of the Wainui Te Whara
- Encourage no or low fertiliser use in the lake's catchment area. Where it must be used, encourage slow-release fertilisers and application when rain is unlikely.
- Use P-sorbents within waterways.

Lake catchments are particularly sensitive to nutrient inflows. There may be good potential for using Detainment Bunds in the upper catchment of the Wainui Te Whara Stream, but this would need further investigation.

The practical implementation of P-sorbents within waterways is restricted by the nature of the catchment being either urban or very steep. However, there may be opportunity to use P-sorbents within the lower Wainui Te Whara Stream. McDowell et al. (2007) described the use of melter slag contain in a mesh bag (called "P socks") and placed on the bed of the Mangakino Stream (Lake Rerewhakaaitu) to sorb phosphorus. These reduced, on average, the concentration of DRP and TP by 35% and 21% respectively, and reduced loads by 44% and 10% respectively. They were more effective at low-flow.

One option may be to trial the use of melter slag P-socks in the Wainui Te Whara, but some additional sampling of inflows is recommended assess their likely effectiveness. Regular monitoring would be needed to assess their effectiveness over time and when they would need to be maintained and replaced.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



#### 4.2.5 Summary

Reducing external nutrient loads very important for lake restoration and reducing eutrophication. Reducing nutrient loads from within the catchment is often also very cost-effective. For Awatapu Lagoon there may be potential to:

- Use detainment bunds in the upper catchment of the Wainui Te Whara Stream.
- Educate land owners about reducing sediment and nutrient discharges to the stormwater network.
- Use P-socks at culvert outlets to bind phosphorus.

### 4.3 Re-divert part of the Whakatāne River to increase flushing flow

#### 4.3.1 General Description

Manipulating lake inflows to promote flushing can support lake restoration by increasing the rate of phytoplankton algae removal or by diluting poor water quality with higher quality water. Generally, flushing of algae is only effective when it can reduce the hydraulic residence time to less than the time it takes for phytoplankton to double their biomass (c. <20 days) (Jørgensen 2002, Hamilton 2019).

Biological uptake often reduced dissolved nutrients to low levels in lakes. Thus, introducing only a small amount of water, without sufficiently reducing the residence time, can create a risk of introducing additional nutrients in a bioavailable form that promotes additional phytoplankton growth.

The goal of increasing flushing was a major driver for implementing the re-diversion of the Kaituna River to the Maketū Estuary. In this situation, higher flushing by river water has helped reduce the biomass of macroalgae accumulated on the mudflats.

#### 4.3.2 General Application and Constraints

The potential to increase hydraulic flushing is very lake specific and requires a suitable donor water body nearby which can dilute poor quality water with higher quality water, and/or sufficiently increase flushing rates. Consideration also needs to be given to the quality of the water being used for flushing to avoid making water quality issues worse.

#### 4.3.3 Cost-effectiveness

The cost-effectiveness of using flushing to improve lake water quality is very site specific. In the case of Awatapu Lagoon, increasing the volume of flow augmentation from the Whakatāne River during summer is likely to have moderate cost-effectiveness.

#### 4.3.4 Application to Awatapu Lagoon

Two options for increasing flushing Awatapu Lagoon are:

1. Directing flow from the Wainui Te Whara Stream to enter Awatapu South before flowing through the rest of the lagoon, and/or

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



2. Taking water from the Whakatāne River to the Awatapu lagoon south. This could be via a pump, or a gravity culvert or by using syphon with manifold to avoid airlocks.

Implementing just the diversion of the Wainui Te Whara to Awatapu South would reduce the reduce the median residence time in Awatapu South to 7 days (42,400 $m^3$/ 6048 $m^3$/day), but would increase the median residence time in Awatapu Central/West to 35 days (209,200 $m^3$ / 6048 $m^3$/day).

Implementing both these options with a 60 L/s flow from the Whakatāne River to Awatapu south and 70 L/s from the Wainui Te Whara would reduce the median residence time in Awatapu South to 3.8 days (42,400 $m^3$/ 11,232 $m^3$/day), and reduce the median residence time in Awatapu Central/West to 18 days (209,200 $m^3$ / 11,232 $m^3$/day).

The diversion of flow from the Wainui Te Whara to the Awatapu South lagoon was considered in a concept plan for Awatapu Lagoon South. If this option is undertaken, it would be important to size the pipe sufficiently large so as to ensure fish passage can be maintain for most flows.

#### 4.3.4.1 Proposed implementation

Getting flow into Awatapu Lagoon would require either pumping of harnessing tidal fluctuations. One option is a large culvert with a fish friendly flap gate at the upstream end and a normal flap gate at the downstream end. A tidal model has shown that this could achieve a monthly average inflow of about 60 L/s. However, constructing the culvert through the stop bank would be very expensive and require approval of BOPRC.

Alternatively, an enhanced syphon system could be used with a manifold to remove airlocks. A tidal model has found a syphon for a 381mm (internal diameter) pipe could achieve a monthly average inflow of about 70 L/s. This would be considerable cheaper to install constructing a culvert through the stop bank. Details in **Appendix 3**.

Flow augmentation should also be applied in conjunction with installing treatment wetlands that will help remove incoming nutrients.

#### 4.3.4.2 Cost

Infrastructure is already in place. To increase the flow augmentation to Awatapu may require installing and running a larger pump.

To add: Pumping is high, Culvert is very high, syphon is moderate.

### 4.3.5 Summary

An enhanced syphon system with a manifold to remove airlocks has potential to provide a reasonable flow of water to Awatapu Lagoon South for a reasonable cost. This option should be considered for further investigation.

## 4.4 Treatment Wetlands

### 4.4.1 General Description

Wetlands are the 'kidneys of the landscape'. They are a natural interface between land and water that cleans the water. Contaminants are attenuated and removed through processes of denitrification, plant uptake, deposition, adsorption and mineralization. Emergent wetland plants filter the water, enhance denitrification and help remove and immobilise heavy metals from the water (e.g. Kadlec and Wallace 2009, Guigue J et al. 2013).

Constructed treatment wetlands are commonly used to remove sediment, nitrogen (**N**) and phosphorus (**P**) from surface water. Constructed wetlands replicate and optimise the treatment mechanism found in natural wetlands including: denitrification, uptake and storage by plants, precipitation, settling and burial within sediment, and sorption of phosphorus to material.

Numerous guidelines are available to inform the design of treatment wetlands (e.g. Tanner 2020, Farrant et al. 2019). Some key aspects of treatment wetland design are:

- Wetlands should be sized to keep water velocity sufficiently low to avoid scour and to provide sufficient residence time to achieve the required removal rates. contaminant reduction efficacy increases as constructed wetland area increases, but with gradually diminishing returns. Often wetlands are sized to be between 1% and 5% of their contributing catchment (i.e. 100-500 $m^2$ of wetland per ha) [9].
- Flow must be dispersed across the wetland so that there is minimal short circuiting. This can be achieved by attention to dispersion of inflows, having a length to width ratio of between 5:1 and 10:1,[10] dense planting across the wetland, and banded planting perpendicular to flows.
- Incorporate a sediment forebay/sedimentation pond to settle sediment and assist with regular maintenance. Sedimentation ponds are often sized as 10% of the wetland size or alternative between 40 $m^2$/ha and 80 $m^2$/ha of catchment depending on the rainfall intensity.
- Maintain water depths at 0.2-0.4 m to maintain healthy emergent wetland plants and optimise nutrient removal. Deeper water (>1.2m) zones help disperse the flow across the width of the wetland.
- Use soils with low potential for release of P. This might be achieved by mixing with sub-soil or P-retaining material (e.g. allophane, tephra) (Ballantine and Turner 2010).
- Maximise ancillary benefits for biodiversity by using a diverse range of locally sourced wetland plants.

[9] Small wetlands still remove contaminants but have lower percentage removal rates and need more attention to design for bypass flows to avoid being overwhelmed by stormflows.
[10] Not less than 3:1

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



In-lake wetlands and riparian wetlands work in the same away as treatment wetlands by intercepting and treating groundwater or runoff percolating through the soil. They also provide habitat for zooplankton that predate on phytoplankton and provide a natural control on their biomass.

### 4.4.2 General Application and Constraints

Treatment wetlands are extensively used to treat stormwater, wastewater and stream inflows to lakes. They are often used to remove sediment, nutrients (N and P), and metal contaminants. The effectiveness of wetlands for nutrient removal depends on a range of factors including: design, hydraulic loading, incoming nutrient concentrations and seasonal temperatures.

Misch et al. (2000) estimated sustainable annual removal rates for non-point source nitrogen and phosphorus of respectively 100 – 400 kg N/ha and 5 – 50 kg P/ha. Hamill et al (2010) used empirical relationships developed by Kadlec and Wallis (2009) to calculate average annual removal rates for constructed wetlands to treat water in the Rotorua catchment of 368 kg N/ha and 11 kg P/ha of wetland. The lower removal rate for P is due to both lower concentrations of P in the incoming water and less efficient removal of dissolved P.

Tanner et al. (2020) calculated the performance of constructed treatment wetlands for pastoral runoff. An appropriately constructed wetland sized at 2% of the catchment area would remove 65%, 36% and 35% of TSS, TN and TP respectively. But this assumes that most P is in particulate form associated with sediment. Wetlands are not very effective at removing P in dissolved form.

Phosphorus removal rates in constructed wetlands can vary widely depending on the design and past land use. If the underlying soil is high in phosphorus, then the wetlands can desorb phosphorus and be a net source of phosphorus. The risk of this occurring can be mitigated, and the ability of wetlands to retain phosphorus enhanced, by augmenting the sediment with phosphorus binding material.

### 4.4.3 Cost-effectiveness

Wetlands provide multiple benefits to support ecological functions, nutrient removal and biodiversity. Constructed wetlands can be a cost-effective way of removing sediment and nitrogen (estimated as $79 / kg N /yr), but are less cost-effective at removal of phosphorus (estimated at $2550 kg P/yr) (Hamill et al. 2010)[11]. Cost-effectiveness for phosphorus removal is considerably improved if the source of P is predominately associated with particles P sorbing material is used and the sediment forebay is well maintained.

### 4.4.4 Application to Awatapu Lagoon

#### 4.4.4.1 Suitability

There is considerable potential to build in-lake wetlands in Awatapu Lagoon that would provide multiple benefits of reducing sediment accumulation, improved water quality, improved biodiversity and habitat for invertebrates, fish and birds. The most cost-effective location is near the delta of the Wainui Te Whara.

[11] Based on long-term sustainable removal rates (excluding sorption to wetland sediments) and using whole-of-life costs (including land acquisition, maintenance and rejuvenation).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



AR & Associates (2020) developed a wetland concept for the southern lagoon, including directing the Wainui Te Whara to flow via the southern lagoon by drilling a separate culvert under Bridge Street and forming peninsulas to direct the flow in the delta area and in the southern lagoon. We have refined this concept to achieve more lake wetlands for less cost, by having less infill of the southern lagoon and more wetlands near the Wainui Te Whara delta where the lagoon is shallower (**Figure 4.1**).

Key features of the proposed design are:

- Diverting water from the Wainui Te Whara to the Southern Lagoon using a peninsula and additional culverts under Bridge Street. The size will need reviewing to ensure fish passage.
- Forming a peninsular in the southern lagoon to direct water from the Wainui Te Whara along the southern edge and set up a circulation current.
- Creating 1.34ha of wetland area to provide biodiversity and water treatment. This consists of about 0.95ha in the lagoon south and 0.39ha in the Wainui Te Whara entrance of the central lagoon. It would result in wetlands covering about 35% of the southern lagoon area.
- Using sand deposited in the delta from the Wainui Te Whara to form the peninsula and wetland areas.

The water depth in shallow zones of the wetland should be about 300-400mm, but most emergent wetland plants need to be established in shallower water below the height of the shoots (e.g. about 100mm deep). This can be achieved by either temporarily lowering water levels, or by planting along shallower edges and allowing plants to spread naturally over time. Once established, plants can survive periods of exposure and extend into deeper water. Deep zones (e.g. >1.2m) prevent the vegetative spread of emergent macrophytes.

Riparian wetlands would be low cost and easy to establish using a long reach digger from the lake edge to redistribute sediment.

There are a number of native emergent plants suitable for Awatapu Lagoon including: *Eleocaris sphacelate, Machaerina articulata*[12]*, Carex secta,* and *Schoenoplectus tabernaemontani*. *Typha orientalis* (raupo) could be considered but would need care to ensure it is contained by surrounding deep zones (**Figure 4.2**)

#### 4.4.4.2 Cost

The cost of establishing areas of wetland filters near the delta of Wainui Te Whara Stream is estimated to cost in the order of $xxx, plus consenting costs.

The budget will need to allow for control of pest plants during establishment.

### 4.4.5 Summary

Treatment wetlands are common and cost-effective way to filter water to remove sediment, nutrients and metals. Wetlands also support ecological functions in lakes and enhance biodiversity. There is good

[12] Formally *Baumea articulata.*

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



potential to incorporate both treatment wetlands and riparian wetlands into Awatapu Lagoon to treat inflows and improve biodiversity values.

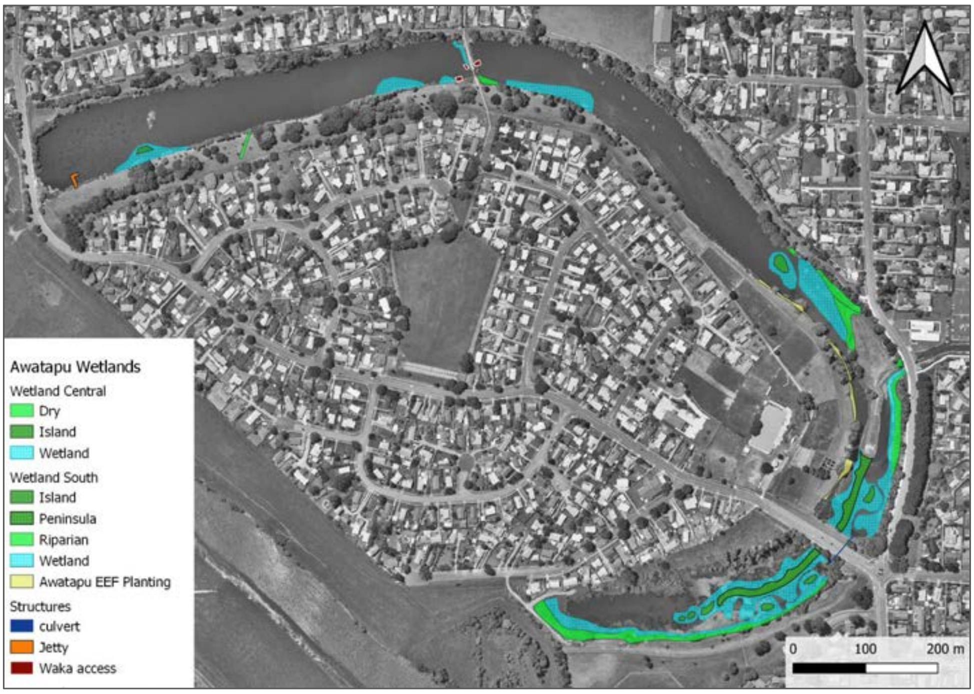



**Figure 4.1**: Potential layout for a treatment wetland and riparian wetlands in Awatapu Lagoon to improve water quality and provide biodiversity values.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Figure 4.2:** An example of *Baumea sp.* growing along a lake wetland margin (from Tanner et al. 2021).

## 4.5 Floating Wetlands

### 4.5.1 General Description

Floating wetlands consist of buoyant mats or platforms that are mass planted with emergent wetland plants, and are anchored on the surface of treatment ponds or nutrient rich lakes. The plant roots grow through the mats and down into the water column forming large, dense mats. Large root systems develop to allow the plants to obtain their nutrient requirements from the water column. Localised anaerobic zones are created beneath/within the floating mats where the process of denitrification is favoured. Biofilms develop over the extensive root surface area and serve to increase organic matter breakdown, nutrient adsorption and trapping of fine particulates (Sukias 2010).

The shade provided by the plant mats reduces algal growth and results in increased settling of suspended solids onto the bottom of the lake.

### 4.5.2 General Application and Constraints

Floating wetland are widely used around New Zealand for water treatment and ecological enhancement. To be most effective, floating wetlands need to be installed in a location where there is a flow of water passing through them. They are not very effective at removing nutrients if placed in a lake without any current or flow.

Floating wetlands are best used in deeper water (e.g. >1 m) where the plant root systems will not reach the sediment.

The harvesting of plant material is important for long-term sustainable nutrient removal by floating wetlands, and this is particularly important for phosphorus removal (Pavlineri et al. 2017). Some ongoing maintenance is required to control weeds.

The buoyant mats of some floating wetlands can degrade over time and release plastic into the water; however, this can be avoided by using rafts made of HDPE.

### 4.5.3 Cost-effectiveness

Floating wetlands have similar removal mechanisms to conventional wetlands but are about twice as effective at removing nitrogen and phosphorus as conventional constructed wetlands. Where located where water flows, nitrogen removal rates for floating wetlands are about 584 – 876 kg/ha/yr while phosphorus removal rates are about 7.3 – 18 kg/ha/yr (Tanner et al. 2011).

However floating wetlands are relatively expensive to install, so are best used in situations with high nutrient concentrations to take advantage of their good removal rates, or in situations which utilise their co-benefits in providing for shading the water and providing habitat for birds and fish. Hamill et al (2010) estimated the average cost-effectiveness[13] of floating wetlands as $473 / kg N and $24,000/kg P, however these costs may now be lower with availability of new, cheaper, floating wetland products. Because of their relatively high cost, floating wetlands are better suited to situations that optimise their treatment ability (i.e., areas with flow and high nutrient concentrations), have space constraints, or where other benefits (e.g., shading, habitat, biomanipulation) are valued.

### 4.5.4 Application to Awatapu Lagoon

#### 4.5.4.1 Suitability

Additional floating wetlands could be installed in Awatapu Lagoon near the inflows where surface flow treatment wetlands are proposed. They could achieve a similar amount of nutrient removal as surface flow wetlands in about half the area, but they would cost considerably more, and are thus not recommended for mass deployment.

A small number of floating wetlands would be beneficial to enhance settling in sediment forebays, where flows are greatest. Also, their use on the main body of a lake for enhancing habitat remains valuable. Floating wetlands can be used as floating nurseries, with mature plants harvested and planted along the lake's riparian margin.

#### 4.5.4.2 Cost

A rough order cost to install a set four floating wetlands in Awatapu Lagoon, with an effective surface area of about xx $m^2$, is $xxx.

### 4.5.5 Summary

Floating wetlands are a widely used and effective way to remove sediment, nutrients and other contaminants from water. In addition, they provide co-benefits of shading the water and providing habitat for invertebrates, fish and birds. However, they are more expensive than surface flow wetlands,

[13] Annualised cost spread over 50 years.

and less cost-effective for most natural waterbodies. Installing floating wetlands in Awatapu Lagoon would be beneficial, but would be less cost-effective than creating a larger area of conventional wetlands.

## 4.6 Phosphorus Locking

### 4.6.1 General Description

Phosphorus locking and flocculation is commonly used for lake restoration around the world. The internal load of phosphorus from lake sediments is reduced and made unavailable for algae use by applying chemicals to bind and inactivate the phosphorus in the water column and as it is mineralised and released from the sediment.

A number of materials can be used to adsorb dissolved phosphorus from lake water or inflows and thus reduce the bioavailability of phosphorus within the lake. These can be applied directly to the lake surface or continually drip dosed into a stream inlet. The materials often also cause the flocculation of suspended sediments from the water column. Many products can be used to bind dissolved phosphorus but the most commonly used and/or effective for lakes are aluminium sulphate (‘alum’), Aqual-P (an aluminium zeolite combination product), and Phoslock (bentonite clay modified with lanthanum) (Douglas 2016, Wagner 2017, Abell et al. 2021).

Flocculation can be enhanced by adding a separate flocculant; commonly used flocculants include polyaluminium chloride (PAC) and polyacrylamide (PAM). PAM is promising as a flocculant in turbid freshwater systems because they are very efficient and can have low eco-toxicity when formulated in the anionic form (Gibbs and Hickey 2017). Products such alum, Phoslock and Aqual-P perform a dual function of adsorbing dissolved phosphorus and physically capping the sediment.

The alum causes aggregation of particulate matter and causes it to sink to the lake bed and this has potential to removed cyanobacteria /algae within the water column. On the sediment surface, alum forms a thin layer a few millimetres thick, and this layer of alum can sequester DRP as it released from the sediment.

Phosphorus locking methods are widely used in lake restoration including their successful use in Lake Okaro and Lake Rotorua (McBride et al. 2018, Hamilton 2019, Abell et al. 2021). However, the effectiveness of phosphorus locking for lake restoration is lake specific depending on water chemistry, hydraulics, timing and the presence of macrophyte beds. For example, it has been highly effective in inflows to Lake Rotorua but has had very limited effect in inflows to Lake Rotoehu – likely due to interference by ions in geothermal waters and flocculation with hornwort beds (Eger 2018).

### 4.6.2 General Application and Constraints

It is important to consider site-specific constraints when identifying appropriate products and application strategies. pH is an important consideration; pH >8.5 results in the release of phosphorus bound to aluminium or iron, making products like alum and Aqual-P ineffective. For alum applications in low-alkalinity lakes, it is necessary to use with a buffer (e.g. sodium carbonate or bicarbonate) to maintain pH >6.5 and avoid the formation of toxic $Al^{3+}$ ions (Hickey and Gibbs 2009).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



Consideration should be given to the potential ecotoxicological effects of materials being used to avoid acute or chronic effects on lake ecology, but assessment of these risks is well documented (Tempero 2015, 2018, McBride et al. 2018). Consideration also needs to be given to cultural concerns regarding the application of material to lakes.

Geoengineering using phosphorus locking needs to be tailored for a specific lake. It is advisable to evaluate efficacy based on jar tests, laboratory experiments and small-scale field trials. Consideration needs to be given to the costs, ecotoxicity and risk of smothering benthic biota (Hickey and Gibbs 2009).

**Table 4.2** provides a summary of geoengineering materials and their applications. The materials likely to be most applicable to Awatapu Lagoon are alum, Phoslock and Aqual-P. PAC is a flocculant and can be used in combination with alum of Phoslock which absorb the phosphorus. For the immediate management of cyanobacteria blooms, algaecide (e.g. hydrogen peroxide) can used in before phosphorus locking to reduce the risk them later floating from sediments to re-emerge as blooms. Alum and Aqual-P have reduced P binding at high pH.

The longevity of phosphorus locking will depend on incoming nutrient loads, rates of burial and resuspension. Sediment locking is typically less effective in shallow lakes because of higher rates for burial and wind resuspension. One study found alum treatment was typically effective for 15 years in deep lakes compared to five years in shallow lakes (Huser et al. 2016 in Abell 2018). In Lake Ōkaro, alum treatment has been undertaken twice a year for most years since 2013 to control algae.

### 4.6.3 Cost-effectiveness

The use of phosphorus locking material to control eutrophication can be effective, reliable and cost-effective. One study of four urban lakes found in-lake alum treatment was *c*. 50 times more cost-effective than catchment-based measures to reduce storm water nutrient loads (Huser et al 2016). However, they are not suitable for all lakes.

### 4.6.4 Application to Awatapu Lagoon

#### 4.6.4.1 Suitability

Awatapu Lagoon is nitrogen limited but reducing phosphorus concentrations is important for controlling cyanobacteria. The source of phosphorus in Awatapu via localised areas of anoxic waters. DRP may also be released with wind-induced mixing mobilising porewater from bottom sediments.

Phosphorus locking (probably with alum) may be a useful remediation to apply in specific areas of Awatapu where bottom waters are commonly anoxic e.g. Awatapu West and in the deep section of Awatapu Central.

The longevity of applying alum or another product is unknown, but may be short-lived if bottom sediment is resuspended or if there is settling of P-rich sediments or plant material. Any application of P-locking should occur after creating of treatment wetlands to reduce nutrient and sediment inflows.

To better assess the potential for successful P-locking in Awatapu Lagoon will require collecting water and sediment samples from around the lake and incubating sediment cores to determine DRP release rates. This information is also required to calculate application rates. Application rates can be calculated using the areal load of TP in the top 4 cm of sediment plus the areal load of DRP in the overlying water. The amount of buffer required is normally about twice the amount of alum but needs to be checked using lake water.

#### 4.6.5 Summary

The use of phosphorus locking material to control eutrophication can be effective, reliable and cost-effective when appropriately tailored for a lake. Phosphorus locking may be a useful restoration tool to control cyanobacteria blooms in Awatapu Lagoon. Additional investigations or trials are required to better determine its likely success. P-locking will be more successful if implemented in conjunction with actions to reduce the deposition of sediment and plant material (e.g. macrophyte harvesting and forming treatment wetlands).

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



**Table 4.2:** Lake geoengineering materials used for phosphorus inactivation and flocculation (reproduced from Table 3 in Hamilton 2019).

| Flocculant | Active com-pound | Carrier | Requirements | Cost (approx.) | Side effects/toxicity | Application difficulty |
|---|---|---|---|---|---|---|
| Alum, PAC | $Al^{3+}$ | None. | Mostly used with a buffer; careful checks required to avoid acidification | Low | Free (uncomplexed) Al ion toxicity to biota (primarily a gill toxicant), highly pH dependent (Gensemer and Playle 1999) | Low-medium |
| Phoslock® | $La^{3+}$ | Bentonite | - | Medium-high | Low-alkalinity waters could lead to greater susceptibility of biota to side effects from $La^{3+}$ | Medium |
| Chitosan (Zou et al. 2006) | | Has been used in association with flocculants for sinking (ballast) purposes | Check for contaminants released by flocculant (if used) | High | Benign: toxicity to higher organisms highly unlikely but appears to act as an algaecide to cyanobacteria | High |
| Oxygen nanobubble modified natural particles (Zhang et al. 2018) | - | A local mined soil is often used, to which oxygen nanobubbles are impregnated | Has not been scaled up; still experimental (laboratory-scale) | Likely to be high | Benign unless the modified soil releases contaminants | Medium |
| Aqual-P | $Al^{3+}$ | Zeolite | - | Medium | Evidence to date indicates Aqual-P is relatively benign | Medium |

## 4.7 Macrophyte harvesting to manage aquatic plants and reduce nutrients

### 4.7.1 General Description

Aquatic macrophytes ('lake weeds') are an important part of lake ecosystems, and moderate water quality by stabilising sediment and cycling nutrients from the sediments and water column. However, excessive growth of (usually) exotic invasive macrophytes can cause a nuisance or contribute to water quality problems. Harvesting and removal of macrophyte biomass can control excessive cover and remove carbon and nutrients from the lake system. This prevents the nutrients being cycled back into the lake water column during periods of pant senescence or die-off.

Macrophyte harvesting in lakes is usually done by a custom-made boat-operated harvester that cuts the plants below the water surface and collects the mown sections (**Figure 4.1**). Larger harvesters can cut plants up to about 2m below the water surface. Harvested material is transported to the lake shore where it is dewatered and removed for disposal (e.g. to compost). To maximise nutrient removal from a lake, the harvested material should be removed from the catchment or treated in a way so as to prevent nutrient leaching back to the lake.

The harvester mows off the top of surface reaching weed beds, it does not pull up the roots, and the macrophytes grow back over time. This regrow is itself be beneficial for water quality as macrophytes reduce the amount of dissolved nutrient available for algae growth.

Macrophyte harvesting can be undertaken using a long reach digger with a modified cutting head, but this method is limited to the reach of the digger, so is more suited to drains.

**Figure 4.1**: A lake macrophyte harvester in operation on Lake Rotoehu (source: www.lakeweed.co.nz).

### 4.7.2 General Application and Constraints

Macrophyte harvesting is commonly used to control macrophytes in both small ponds and large lakes. Macrophyte harvesting is commonly used in New Zealand to reduce nutrient loads (e.g., hornwort harvested from Lake Rotoehu by Bay of Plenty Regional Council (**BOPRC**) (Horne 2020)), reduce nuisance macrophyte cover in drains, hydro lakes (e.g. Genesis) and stormwater ponds (Auckland Council).

Its suitability as a method depends on goals for lake management, site constraints and the biomass of plants present. It is effective at managing dense macrophyte beds, however because macrophyte beds help maintain a clear water state in lakes, harvesting operations should be done in a way to ensure weed beds to not collapse without any replacement native communities to replace them.

Harvesting is not a suitable method to eradicate weeds or control new incursions, as plant fragments caused by harvesting can act as propagules.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



Harvesting operations need to follow good biosecurity practices to avoid the spread of pest plants and animals. This requires cleaning all equipment before transporting between waterbodies by following the Check, Clean and Dry procedures from Ministry for Primary Industries (**MPI**)[14].

Permission is required from Ministry of Primary Industries (**MPI**) if transporting, outside a catchment, pest plants classified as 'unwanted organisms' under the Biosecurity Act (1993). This would apply to hornwort (*Certatophyllum demersum*) and parrots feather (*Myriophyllum aquaticum*) both found in Awatapu Lagoon.

### 4.7.3 Cost-effectiveness

Macrophyte harvesting has multiple benefits of controlling excessive macrophyte biomass to maintain recreational and water quality values, maintaining some macrophyte cover to support biodiversity and water quality benefits, and removing a load of carbon, nitrogen (N) and phosphorus (P) from the lake system. An alternative practice of herbicide spraying is cheaper to achieve the single purpose of controlling macrophyte cover, but does not achieve any of the co-benefits for water quality.

Lake weed harvesting of hornwort from Lake Rotoehu (Bay of Plenty) removes about 1.2 kg N and 0.16 kg P per tonne of wet weed (Gibbs 2015). The harvesting from Lake Rotoehu is estimated to cost about $53,000 per year and remove about 320 kg P/yr and 2,400 kg N /yr (Hamilton and Dada 2016), i.e. a cost-effectiveness of $166 /kg P and $22 / kg N. However, the cost of small-scale operations is considerably more.

Weed harvesting from Awatapu Lagoon South, Whakatāne in 2019 cost c. $35,000 for c. 200 tonnes of weed which would have removed about 240 kg of N and 32kg of P with a cost-effectiveness of $146 /kg N and 1095 / kg P. This cost included consenting, establishment, harvesting, dewatering and disposal. It may be higher if the weed harvester has to be transported further.

### 4.7.4 Application to Awatapu Lagoon

#### 4.7.4.1 Suitability

Harvesting of hornwort has been proven tot work in Awatapu Lagoon and is very effective at reducing macrophyte cover. Harvested material needs to be dewatered for one to two days and the site chosen for this needs to be accessible to a truck and digger.

Using herbicide to control aquatic plants is cheaper than mechanical harvesting but does not provide any water quality benefit because it does not remove any organic matter or nutrients. However, herbicide might be used in alternative years to keep biomass low.

#### 4.7.4.2 Cost

The cost of macrophyte harvesting can vary widely depending on the scale of the operation. The cost of macrophyte harvesting in Awatapu Lagoon South and part of Awatapu Central is expected to be in the

[14] https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/check-clean-dry/#CCDmethod

range of $80,000 per harvest, but will depend on the amount to be harvested. The cost is likely to reduce as operations become more efficient, e.g. for composting.

### 4.7.5 Summary

Macrophyte harvesting is a widely used method for controlling excessive macrophyte biomass, improving water quality, and contributing to long-term removal of nutrients from the lake system. Harvest Awatapu South and Awatapu Central. Harvesting is more expensive than herbicide spray, but provides water quality benefits not achieved by herbicide spraying. Macrophyte harvesting could be used in conjunction with herbicide spraying in alternative years to control regrowth.

## 4.8 Summary: Actions to improve water quality and ecology

Intervention options to improve water quality in Awatapu Lagoon are summarised in **Table 4.2**. The high priority actions were chosen that would address multiple issues, in a cost-effective way, and with low risk of adverse effects.

There is no single quick fix to improving water quality in lakes, there is no “magic bullet”, but there are effective actions that can shift Awatapu Lagoon towards being a healthier ecosystem. The path towards sustainable improvement in lake water quality requires reducing both external and internal nutrient loads, and improving the functioning and diversity of aquatic habitat. Highest priority should be given to actions that would address multiple issues in a cost-effective way, and with low risk of adverse effects.

The management actions with most potential to improve water quality and ecology in Awatapu Lagoon include:

- Harvesting and control of aquatic pest macrophytes is a priority to improve the DO regime, reduce organic matter load to lake sediments and reduce nutrients.
- Constructing treatment wetlands provide multiple benefits in removing nutrients, providing habitat for aquatic life and increasing biodiversity values.
- Phosphorus locking of sediments in deeper basins has considerable potential to reduce the internal load of phosphorus from anoxic bottom waters. However, this needs to be undertaken in conjunction with actions to reduce the organic matter load from hornwort.

The management interventions to improve water quality that should be considered but are either less cost-effective or require additional investigations are:

- Increasing the number of floating wetlands to remove nutrients and improve biodiversity.
- Harnessing tidal fluctuations to drive a flow of water from the Whakatāne River to Awatapu South via a culvert with flap gates or via a syphon system. This would improve flushing but would likely be insufficient to stop cyanobacteria blooms in the absence of other actions, and would do little to reduce excessive macrophyte growth and associated problems. Further investigation is required in consultation with BOPRC.

- There is potential to reducing catchment sediment and nutrient loads to Awatapu Lagoon. One option for further investigation is to use detainment bunds within the upper Wainui Te Whara catchment.

**Table 4.2**: Summary of intervention options to address ecological and water quality issues in Awatapu Lagoon

| Priority | Management Option | Description | Effectiveness in | Limitations |
|---|---|---|---|---|
| High | Harvest hornwort /parrots feather | Harvest hornwort during summer to improve oxygen regime. Remove nutrients. Recreation/aesthetics. Use of herbicide could be considered in alternative years to maintain low cover but could exacerbate water quality issues if used as the sole method of control. | WQ - High<br>Weeds - High (but short term).<br>Habitat - Moderate | Requires ongoing effort. Access to equipment limited at peak times. |
| High | Create Treatment Wetlands | Construct treatment wetlands near the Wainui Te Whara delta and southern lagoon. Option to include a diversion of the Wainui Te Whara Stream into Awatapu South. | WQ - High<br>Habitat - High | Requires a large area. Moderate to high capital cost. Good design important to ensure nutrient removal and minimise maintenance |
| High / Moderate | Phosphorus locking / flocculation | P-inactivation to reduce internal P load. | WQ - High (but may require repeated application) | Reduced efficacy in shallow lakes with sediment resuspension. Important to first reduced organic deposition form macrophytes. pH conditions are critical. Can be culturally sensitive. |
| Moderate | Measures to reduce catchment sediment and nutrient loads | Reduce external nutrient loads including:<br>- Sediment Detention Bunds in the upper catchment of Wainui Te Whara Stream.<br>- P-socks at culvert outlets to bind P. | WQ - High (address root causes) | Investigations required to better assess feasibility. A social challenge to achieve changes in land use or land management. |
| Moderate | Floating wetlands | Install additional floating wetlands to remove nutrients and provide habitat. | WQ - High<br>Habitat - High | Costly compared to wetlands. Best suited to near inflows with high nutrient concentrations. |
| Moderate | Increase flushing flows through Awatapu Lagoon from the Whakatāne River | Increase flushing flows through Awatapu by directing a proportion of flow from the Whakatāne River to Awatapu Lagoon South using either a gravity culverts with flap gates, or a syphon with manifold to avoid airlocks. . | WQ- Moderate<br>Cultural benefit. | Requires further discussion with BOPRC and iwi. |

# 5 Conclusions and Recommendations

## 5.1 Conclusion

The water quality in Awatapu Lagoon is poor with low water clarity, high nutrient concentrations and high phytoplankton growth indicative of eutrophic to supertrophic conditions. The lake has internal loading of nutrients from the sediment via bottom water sediment anoxia during periods of stratification and in Awatapu South because of the high cover of the aquatic weeds hornwort and parrots feather.

This report has identified priority management interventions that are cost-effective and have a track record of working in small lakes. There is no single quick fix to improving water quality in lakes. Improvement of water quality in Awatapu Lagoon over the long term will require multiple actions over a sustained period to reduce nutrient loads (internal and external) and enhance natural processes that attenuate nutrients. Reducing the biomass of hornwort is a high priority for many water quality issues in Awatapu. However, maintaining some aquatic plants is also important for maintaining reasonable water quality in small natural lakes. Creating natural wetlands can help achieve this goal.

## 5.2 Future monitoring and investigations

Water quality monitoring of Awatapu Lagoon has been limited in recent years. While we have been able to draw useful information about the current state and issues affecting Awatapu Lagoon, additional monitoring would provide greater understanding and certainty. Monitoring is also an important part of management remediation options by measuring success in achieving specific outcomes and identifying where different management interventions may need to be implemented. This type of outcome monitoring focuses on specific aspects of the lake ecology or water quality. E.g. release of phosphorus from anoxic zones, extent of pest plant cover.

In the context of limited budgets, a balance needs to be found between monitoring and implementing actions. In our view, initiating actions to improve the lakes water quality should not be delayed by monitoring; monitoring should be used to support and inform action rather than delay action through lack of resources.

General monitoring that would assist in managing Awatapu Lagoon and understanding the success of any mitigation should include:

- Monitoring water quality of main stormwater inflows to Awatapu Lagoon during rainfall to characterise the quality and contribution of stormwater entering the lake (including an estimate of flow from the culvert).
- Undertake a bathymetry survey of Awatapu Lagoon to more accurately calculate residence time and to better estimate the cost of creating treatment wetlands in the lagoon.

**7.4.1 Appendix 1 Awatapu Lagoon Water Quality Ecology and Options for Improvement(Cont.)**



- Investigating the potential for using P-locking products. Including sampling of surface sediment (for TP and Al) and overlying water (for DRP and hardness), incubation of sediments to assess P release.
- Repeat synoptic surveys of DO and pH following macrophyte harvest / control operations.
- Water quality monitoring of the lake surface water with a minimum frequency of two monthly and analysing at least the variable of: Temperature, specific EC, DO, %DO, water clarity, pH, TN, TP, Chl-*a*, and *E.coli* bacteria. Field observations of macrophyte cover. More frequent monitoring may be required to assess the effectiveness of some management actions.
- Dissolved oxygen logger during spring/early summer to assess DO depletion in bottom waters following the start of stratification.

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# Appendix 1: Temperature, DO depth Profile for Awatapu Lagoon

Depth profiles of temperature, dissolved oxygen and electrical conductivity in Awatapu Central and Awatapu West.

# Appendix 2: Restoration techniques to address eutrophication in shallow lakes.

**Restoration techniques to address eutrophication in shallow lakes. Reproduced from Table 1 in Abell et al. (2020).**

| Group | Restoration method | Purpose | Application | Examples | Advantages | Disadvantages | References |
|---|---|---|---|---|---|---|---|
| **Reduce external nutrient loads** | Diffuse and point source control | Minimize nutrient loading | Essential component of a sustainable lake restoration strategy to control eutrophication | • Lake Müggelsee, Germany<br>• Lake Peipsi, Estonia/Russia<br>• Loch Leven, Scotland<br>• City Park Lake, Louisiana, USA | • Addresses the root cause | • Sufficient reductions typically require major economic costs, for example, to fund land-use change or improved wastewater treatment | Ruley and Rusch (2002); Jeppesen et al. (2005) |
| **Reduce internal nutrient loads (physical)** | Dredging | Reduce internal loading by removing nutrient-enriched sediments | Best suited to small lakes and/or iconic lakes due to the high costs | • City Park Lake, Louisiana, USA<br>• Lake Kraenepoel, Belgium | • Directly removes nutrients<br>• Increases depth | • Expensive<br>• Disposal of dredgeate can be difficult | Peterson (1979, 1981); Van Wichelen et al. (2007) |
| | Sediment capping (passive) | Reduce internal load by creating a physical barrier between benthic sediments and the water column | Generally suited to smaller lakes with high internal loads | • Taihu Lake, CN (one embayment) | • Maybe opportunities to use inexpensive local soil/sand | • Adverse effects to benthic biota such as mussels | Xu et al. (2012) |
| **Reduce internal nutrient loads (chemical)** | Phosphorus inactivation/ flocculation | Reduce concentrations of dissolved nutrients (primarily P) by adsorption. May be combined with flocculant use to remove organic material | Generally suited to smaller lakes with high internal loads | • Minneapolis Chain of Lakes, USA<br>• Lake Rotorua, New Zealand | • Potentially rapid improvements<br>• Cost-effective (internal) load reductions<br>• Well-established | • Reduced efficacy in shallow lakes due to sediment resuspension<br>• Adding chemicals to waterbodies can be culturally/ socially sensitive<br>• Metal toxicity needs to be considered<br>• Not a sustainable solution alone | Welch et al. (1988); Huser et al. (2016); Smith et al. (2016); Wang and Jiang (2016); Vargas and Qi (2019) |
| **Bio-manipulation** | Fish removal (zooplanktivorous) | Increase cladoceran zooplankton biomass → reduce phytoplankton biomass | Applicable to lakes with abundant zooplanktivores, for example, juvenile *Perca fluviatilis* | • Lake Vaeng, Denmark | • Established method in western European lakes with abundant zooplanktivores | • High, ongoing effort required to maintain low biomass<br>• Results are inconsistent<br>• Only suitable for lakes with abundant zooplanktivorous fish | Meijer et al. (1999); Søndergaard et al. (2008) |
| | Fish removal (benthivorous) | Reduce bioturbation and nutrient excretion | Applicable to lakes with high biomass of benthivorous fish such as *Cyprinus carpio* | • Wolderwijd, The Netherlands<br>• Lake Susan, Minnesota, USA<br>• Lake Ohinewai, New Zealand | • Can support biodiversity objectives if fish are invasive | • High, ongoing effort required to maintain low biomass<br>• Results are inconsistent | Meijer et al. (1999); Søndergaard et al. (2008); Bajer and Sorensen (2015); Tempero et al. (2019) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Promote bivalves | Increase filtration rates and phytoplankton grazing | Untrialled as a deliberate method, although potentially suitable for lakes that are very shallow (relatively low volume) and oligo-mesotrophic (more suitable physicochemical habitat conditions) | ◦ Lake Faarup, Denmark (following an undesired invasion by zebra mussels) | ◦ Could promote biodiversity if native species are used | ◦ Requires suitable host fish for larval development ◦Habitat conditions may be unsuitable in lakes that are the greatest priorities for restoration | Jeppesen et al. (2012); Burns et al. (2014) |
| Macrophyte harvesting | Remove nutrients present in plant tissues | Very shallow (low volume) lakes with high abundance of invasive macrophytes | ◦ Lake Wingra, Wisconsin, USA<br>◦ Lake Rotoehu, New Zealand | ◦ Removing invasive plants can promote native plant biodiversity<br>◦ Plants could provide a resource (e.g., feedstock), pending research and development | ◦ High, ongoing effort required to maintain low biomass<br>◦ Nutrient removal expected to be minor compared with external loads | Carpenter and Adams (1978); Quilliam et al. (2015) |
| Floating wetlands | Uptake dissolved nutrients. Potentially also increase denitrification and settling. | Small lakes, embayments, and drains where high coverage is feasible | ◦ Lake Rodó, Uruguay | ◦ May provide additional habitat values<br>◦ Can provide a visual focus for lake restoration efforts | ◦ Field trials that demonstrate successful application to manage eutrophication are lacking<br>◦ Not applicable to restore medium-large lakes<br>◦ Plant harvesting necessary for optimum performance | Rodríguez-Gallego et al. (2004); Pavlineri et al. (2017); Bi et al. (2019) |
| Algicides | Directly reduce phytoplankton biomass | May be suitable as an emergency measure | ◦ Cazenovia Lake, New York, USA | ◦ Effective at causing rapid short-term declines in phytoplankton biomass with sufficiently high doses | ◦ Toxic effects on other biota<br>◦ Sediment contamination<br>◦ Culturally/socially controversial<br>◦ Not generally recommended as a lake restoration method | Effler et al. (1980); Fan et al. (2013) |

(*continued*)

**Table 1.** Continued.

| Group | Restoration method | Purpose | Application | Examples | Advantages | Disadvantages | References |
|---|---|---|---|---|---|---|---|
| | Macrophyte reestablishment | Promote reestablishment of macrophytes by planting founder colonies and/or protecting plants with exclosures and wave buffers | Suitable for lakes that have experienced improved clarity but macrophyte reestablishment is hindered by lack of viable seeds/propagules or grazing | ◦ Delta Marsh, Manitoba, Canada | ◦ Can yield improved macrophyte growth in some areas | ◦ Only suitable for lakes that have already been partially restored and have suitable light conditions and substrate | Evelsizer and Turner (2006); Hilt et al. (2018) |
| **Hydrologic alterations** | Inflow diversion | Reduce external loads | Applicable to lakes for which external loads are dominated by a single surface inflow, and there is a suitable receiving waterbody nearby | ◦ Lake Rotoiti, New Zealand | ◦ Step-change reductions in external loads | ◦ Potential ecological impacts to receiving waterbody<br>◦ High capital costs<br>◦ Feasibility depends on local hydrology and not possible for most lakes | Hamilton and Dada (2016) |
| | Increase dilution and/or flushing | Dilute poor-quality lake water with higher quality water | Applicable to lakes for which there is a suitable donor waterbody nearby | ◦ Moses and Green lakes (USA)<br>◦ Lake Veluwe (The Netherlands)<br>◦ West Lake, CN | ◦ Major improvement in water quality possible | ◦ Potential ecological impacts to donor waterbody<br>◦ High capital costs<br>◦ Feasibility depends on local hydrology and not possible for most lakes | Welch (1981); Ibelings et al. (2007); Jin et al. (2015) |
| | Water-level management | ◦ Increasing depth can reduce sediment resuspension<br>◦ May restore riparian vegetation, depending on the hydrologic regime | Very shallow lakes or lakes where the riparian vegetation communities are impaired due to the existing hydrologic regime | ◦ Volkerak–Zoommeer lake system, The Netherlands | ◦ Can improve habitat for plants and wildfowl | ◦ Can only improve water quality indirectly<br>◦ Land tenure and surrounding topography can be a constraint to increasing lake level<br>◦ Not a primary method to reduce trophic status | Gulati and van Donk (2002) |

**Summary of efficacy and cost of phosphorus mitigation strategies for farms (reproduced from Table 2 of McDowell and Nash 2013).**

| Strategy | Main targeted P form(s) | Effectiveness (% total P decrease) | Cost, range ($ per kg P conserved)† | Cost, Waikakahi ($ per kg P conserved)† |
|---|---|---|---|---|
| Management | | | | |
| Optimum soil test P | dissolved and particulate | 5–20 | highly cost-effective‡ | (15) |
| Low solubility P fertilizer | dissolved and particulate | 0–20 | 0–20 | 0 |
| Stream fencing | dissolved and particulate | 10–30 | 2–45 | 14 |
| Restricted grazing of cropland | particulate | 30–50 | 30–200 | na |
| Greater effluent pond storage/application area | dissolved and particulate | 10–30 | 2–30 | 13 |
| Flood irrigation management§ | dissolved and particulate | 40–60 | 2–200 | 4 |
| Low rate effluent application to land | dissolved and particulate | 10–30 | 5–35 | 27 |
| Amendment | | | | |
| Tile drain amendments | dissolved and particulate | 50 | 20–75 | na |
| Red mud (bauxite residue) | dissolved | 20–98 | 75–150 | na |
| Alum to pasture | dissolved | 5–30 | 110 to >400 | na |
| Alum to grazed cropland | dissolved | 30 | 120–220 | na |
| Edge of field | | | | |
| Grass buffer strips | dissolved | 0–20 | 20 to >200 | 30 |
| Sorbents in and near streams | dissolved and particulate | 20 | 275 | na |
| Sediment traps | particulate | 10–20 | >400 | >400 |
| Dams and water recycling | dissolved and particulate | 50–95 | (200) to 400¶ | 200 |
| Constructed wetlands | particulate | –426 to 77 | 100 to >400# | 300 |
| Natural seepage wetlands | particulate | <10 | 100 to >400# | na |

† Numbers in parentheses represent net benefit, not cost. Data taken as midpoint for average farm in Monaghan et al. (2009a).

‡ Depends on existing soil test P concentration.

§ Includes adjusting clock timings to decrease outwash <10% of inflow, installation of bunds to prevent outwash, and releveling of old borders.

¶ Upper bound only applicable to retention dams combined with water recycling.

# Potential for wetlands to act as a source of P renders upper estimates for cost infinite.

# 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement

Appendix 2

RIVER LAKE

# Sullivan Lake Water Quality, Ecology and Options for Improvement

Prepared for:

**Whakatāne District Council**

# Sullivan Lake Water Quality, Ecology and Options for Improvement

**Prepared for:**

Whakatāne District Council

**Prepared by:**

K. D. Hamill (River Lake Ltd)

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**Title:** Sullivan Lake Water Quality, Ecology and Options for Improvement **Project No.:** wk-1167

| Version | Date | Status | Prepared by | Reviewed by | Approved by |
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| 1 | Nov. 2023 | Draft | K. Hamill | | |
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| 3 | 22 Nov 2023 | Final Draft | K. Hamill | S. Millar | |
| | | | | | |
| | | | | | |



**Cover Photo**: Evening at Sullivan Lake, Whakatāne, May 2022.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**




# Acknowledgements

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# Executive Summary

Whakatāne District Council (WDC) has responsibility for managing Sullivan Lake. In order to inform the management of Sullivan Lake, WDC commissioned science investigations to: a) provide robust information on water quality and ecology values, and b) identify key management options for improving water quality and ecological values in Sullivan Lake.

**Sullivan Lake condition and values**

Sullivan Lake is a small, shallow, urban lake located in Whakatāne township. It has an area of 2.7 ha, mean water depth of less than 1m and maximum depth of 2.2m. The lake substrate is predominately soft silts that have an average depth of 0.4m. The lake's catchment area is about 105ha of which about two thirds is in urban landuse and the rest is steep escarpment.

*Hydrology*

The average hydraulic residence time for Sullivan Lake is 11.4 days; however, because there is limited baseflow, there is little flushing outside of rain events. WDC pumps water from the Whakatane River into Sullivan Lake to improve flushing, and there is potential to increase the flushing during summer dry periods.

*Birds*

Sullivan Lake provides habitat for a wide range of waterfowl. While birds are an important value of the lake, high densities of birds can reduce water quality. Outbreaks of avian botulism occasionally occur in the lake. There are a complex set of factors associated with avian botulism outbreaks, but one practical action that can help reduce the severity of an outbreak is to collect and dispose of bird carcasses affected by avian botulism.

*Fish*

Fish present in Sullivan Lake and its catchment include: shortfin eel, common smelt, common bully, inanga, and the introduced fish goldfish and *Gambusia*. However, connection to the Whakatāne River for migratory fish (shortfin eel and inanga) is restricted by the outlet weir and flood gate.

*Plants*

Water lily commonly covers a large area of Sullivan Lake in the west end near King Street. Apart from the waterlily, aquatic macrophytes have been absent from Sullivan Lake for many years. However, curled pondweed (*Potamageton crispus*) has recently re-established in Sullivan Lake. This is an annual aquatic plant that grows from seeds during late spring, proliferates across the lake during early summer and collapses during mid-summer.

Aquatic plants are a key to maintaining good water quality in natural lakes, by regulating water quality, stabilising sediments, and providing habitat for invertebrates and fish. Studies have found that greater than 30% plant cover is required to maintain a clear-water state. The recent occurrence of *P. crispus* in Sullivan Lake provides an opportunity to improve the water quality by harvesting. If harvesting is not

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



undertaken prior to collapse of macrophyte beds, then adverse effects on DO could be minimised by increasing the volume of flow augmentation during this time.

*Water quality*

The water quality of Sullivan Lake is poor; with low water clarity and high concentrations of nitrogen, phosphorus and phytoplankton. Cyanobacteria blooms are very common in Sullivan Lake during summer and autumn, and exceed recreational use guideline (Action mode) about 62% of the time. the dominant cyanobacteria is *Anabaena* sp. The Trophic Level Index (TLI) (6.0) is borderline between supertrophic and hypertrophic.

Phytoplankton growth in Sullivan Lake is more strongly limited by nitrogen than by phosphorus. Occasions with high TN are associated with cyanobacteria blooms – which can fix nitrogen from the atmosphere.

Management interventions that reduce nitrogen loads have good potential to be successful in Sullivan Lake (e.g. wetlands), but management options to remove or bind phosphorus may also be needed to control cyanobacteria blooms in the long term.

*Dissolved oxygen and pH regime*

The DO regime in Sullivan Lake has high temporal and spatial variability. The lake often has very large diurnal fluctuation in DO due to algae blooms, but the DO regime also appears influenced by heavy rain flushing algae biomass, BOD loads associated with stormwater, the growth of macrophytes curled pondweed moderating phytoplankton biomass, the collapse of curled pondweed exerting an oxygen demand, and aeration from strong winds. At the western end of Sullivan Lake, where waterlily was prevalent, pH and DO concentrations were lower and daily fluctuations smaller than in the main body of the lake. This is likely due to both oxygen demand of organic sediments, and shading by waterlily supressing algae growth.

**Interventions to improve water quality**

Nine potential management options were identified to address ecological issues associated with Sullivan Lake. The management interventions recommended as highest priority to improve water quality and ecology in Sullivan Lake were:

- Increase the volume of flow augmentation during summer.
- Treatment wetlands to remove nutrients and improve biodiversity.
- Partially dredging the southern end to remove organic sediments and manage water lily extent.
- Bottom-liners to contain the spread of water lily following partial removal.
- Harvesting macrophyte to manage plant cover and remove nutrients – early summer if sufficiently abundant.

The management interventions to improve water quality that could be considered but are less cost-effective or require more investigation are:

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



- Various measures to reduce catchment sediment and nutrient loads.
- Floating wetlands to remove nutrients and improve biodiversity.
- Sediment phosphorus locking to reduce internal load of P (e.g. applying alum).

The management interventions not recommended for Sullivan Lake at this stage are due to practical difficulties or their likely limited benefits are:

- Spraying macrophytes with herbicide to manage plant cover.
- Grass carp to control aquatic plants.
- Silver carp to control phytoplankton.

There is no single quick fix to improving water quality in lakes, there is no “magic bullet”, but there are effective actions that can shift Sullivan Lake towards a healthier ecosystem. The high priority actions would address multiple issues in a cost-effective way, and with low risk of adverse effects. In particular:

- Increasing the volume of flow augmentation during summer (January to March) is a cost-effective way to increase flushing of phytoplankton and help reduce algae biomass. This would be best undertaken in conjunction with treatment wetlands. Flow augmentation during winter, is not recommended due to elevated nitrate in the Whakatāne River.
- The treatment wetlands will help trap sediment and external nutrients while providing biodiversity benefits.
- Partially dredging the southern end of the lagoon will remove organic sediments which contribute to low dissolved oxygen and internal nutrient loads, while also managing the extent of the water lily cover.
- Placing bottom liners on the lake bed after excavation will slow the expansion of the water lily while retaining core areas of water lily for their ecological and water quality benefits.
- Allowing the growth of curled pondweed during spring and harvesting in early summer is an opportunity to both improve water quality and permanently remove nutrient from the lake system.

# Contents

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**

# 1 Introduction

## 1.1 Background

Whakatāne District Council (**WDC**) has responsibility for managing Sullivan Lake. In order to inform the management of Sullivan Lake, WDC commissioned science investigations to: a) provide robust information on water quality and ecology values, and b) identify key management options for improving water quality and ecological values in Sullivan Lake.

This work is being undertaken by River Lake Ltd in partnership with NIWA and WSP Ltd. In this report we:

a. Describe the geographical context of Sullivan Lake (including hydrology, morphology).

b. Describe the current state for water quality and ecology.

c. Identify the key issues for Sullivan Lake with respect to water quality and ecology.

d. Describe and prioritise potential management actions to address the key issues.

Pre-feasibility assessments have been prepared for key management options. These assessed the benefits, risks, cost-effectiveness and application to Sullivan Lake, so as to inform prioritisation of action.

## 1.2 Location and Context

Sullivan Lake is a small (2.7ha), shallow (maximum depth 2.2m), urban lake located in Whakatāne township. It consists of two basins joined by a short channel and has two small vegetated islands (**Figure 1.1)**. The lake has a catchment area of about 105ha of which about two thirds is in urban landuse and one third is the tree covered escarpment east of Valley Road.

The water levels are controlled by a weir at King Street, from which the water flows under King Street into a drain with a gravity discharge to the Whakatāne River (water is pumped during high river flows).

### 1.2.1 Historical context

Sullivan Lake was originally a naturally oxbow of the Whakatāne River that developed into an oxbow lake wetland system. It was developed from an oxbow wetland into a more formal lake, and set aside as a reserve, when the area was subdivided into residential sections in the 1960s (**Figure 1.2** and **Figure 1.3**).

### 1.2.2 Management

The Sullivan Lake Reserve Management Plan (2015) provides objectives and policies for the management of Sullivan Lake Reserve. It identifies five goals in managing the reserve:

1. To manage and enhance conservation values.
2. To manage and improve water quality.
3. To actively manage vegetation and open space areas.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



4. To provide for a range of passive recreation activities.
5. To plan and manage the effects of utility infrastructure on the reserve.

WDC has undertaken a number of activities to help achieve the goals of enhancing conservation values and water quality. These include:

- Pumping up to about 40 $m^3$/hour of water from the Whakatāne River into the lake to provide flushing and help improve the water quality.
- Planting fringes of native riparian wetland plants have been established along sections of the lagoons southern side.
- Forming a sediment trap, consisting of a low bund, near the footbridge at the western end of the lake and downstream of the main stormwater inputs. This report includes a discussion of how this feature can be enhanced and improved.
- Removal of fine sediment from eastern end of Sullivan Lake in 2019 using a suction dredge.

Sullivan Lake and reserve are an integral part of the stormwater management network by providing live storage to attenuate peak flows during heavy rain events.

A wastewater pumpstation is located near the foot bridge at the eastern end of the lake. Wastewater over-flows during severe rain-events have occurred in the past, but the risk of this is now low since the pipes and pumping capacity at Douglas Street was upgraded in 2012.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



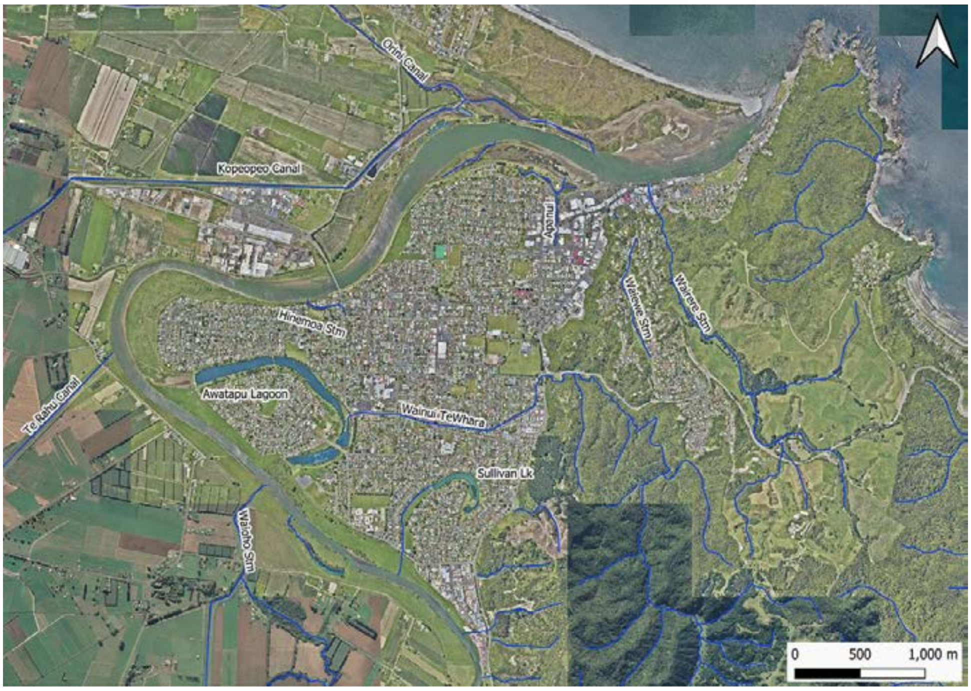



**Figure 1.1:** Location of Sullivan Lake and stream networks in Whakatāne township.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)




**Figure 1.2**: Aerial photos of Sullivan Lake in 1962 (before subdivision while still a wetland system) and 1974 (after subdivision when it was formed into a lake) (Source: Retrolens).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 1.3**: Aerial photos of Sullivan Lake in 1982 (top) and 2022 (bottom) (Source: Retrolens).

# 2 Methods of investigation

The descriptions of Sullivan Lake water quality and ecology used in this report is a synthesis of information from existing reports, analysis of historic datasets and specific investigations and monitoring collected as part of this project.

This project undertook multiple investigations in Sullivan Lake to inform our understanding of the waterbody and key mitigation options, these included:

- Bathymetry survey of the lake using a combination of sonar and manual measurements amongst areas of water lily) which were combined into a Digital Elevation Model (**DEM**).
- Dissolved oxygen, pH and temperature spatial surveys to characterise spatial variability.
- Dissolved oxygen and temperature loggers to characterise diurnal variability.
- Water quality samples of Sullivan Lake surface water during the summer of 2022/23.
- Fish presence using eDNA in Sullivan Lake and inflow stream.

## 2.1 Bathymetry

A bathymetry survey of the lake was undertaken for Sullivan Lake in June 2022. This used a combination of sonar and manual measurements (n=49) using a 'weighted line' where sonar readings were not practical due the density of water lily. The sonar readings were collected by WDC staff using depth sounder installed on a remote-controlled boat.

A comparison of depth measurements from the lead-weight method and the sonar method found that the lead weight method read was about 0.15m deeper than the sonar method. Manual measurements were reduced by 0.15m to provide consistency with sonar data. The discrepancy may be due to the sonar being mounted below water level, or the sonar bounding off a soft sediment layer that was penetrated by the 'weighted line'.

The sonar data was processed by removing duplicate data (8638 data points remained after cleaning), manually shifting the data to fit within a New Zealand co-ordinate system. The water edge was defined using the Bay of Plenty Regional Council (BOPRC) digital elevation model and assigned a depth of 0.2m to reflect the vertical edging around most of Sullivan Lake. The three sets of depth points (depth sounder, bathymetry and water edge) was used as inputs into a IDW interpolator to create a Digital Elevation Model (**DEM**), that was merged with the BOPRC DEM (**Figure 2.1**). The resulting raster had a water depth per 1 $m^2$.

Sediment depth was measured at the location of each manual depth reading by measuring the depth that a blunt probe could be pushed into the sediment using a constant pressure.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



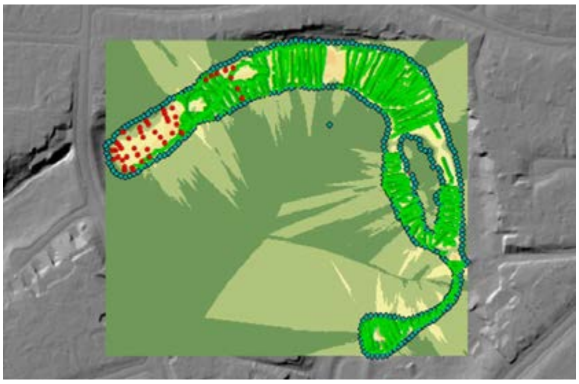


**Figure 2.1**: The three sets of depth points used to create a Digital Elevation Model for Lake Sullivan. Depth-sounder (green), lead-line (red), and water margin (blue).

## 2.2 Spatial variability of dissolved oxygen and pH

Synoptic surveys were undertaken in Sullivan Lake to characterise the spatial variability of dissolved oxygen (**DO**), pH and temperature. The surveys were on 5 April 2022 in the early morning (*c.* 6am to 7am) and on 9 April 2022 in mid-afternoon (*c.* 3pm to 4pm). The early morning and afternoon surveys correspond to when diurnal fluctuations of DO and pH are respectively near their minimum and maximum values.

The measurements were collected from a kayak at a sample depth of *c.* 0.2m, using a YSI Pro Plus multi-meter with a polarographic DO sensor. The sample location was recorded using a GPS tracker and linked with each measurement using the date-time stamp. Prior to the survey the time was synchronised between devices, and the multi-meter was calibrated for both DO (at 100% saturation) and pH (three-point calibration).

## 2.3 Temporal variability of dissolved oxygen

The temporal variability of DO and temperature in Sullivan Lake was characterised by using a Hobo U26 optical dissolved oxygen logger located mid-lake, about 80m west of the Olympic Drive footpath access. The logger was attached to a buoy with the sensor about 0.35m below the water surface. The water depth at this location was 0.95m deep.

The logger was installed on two separate occasions; for 11 weeks in late autumn (from 9 April 2022 and 24 June 2022), and again for eight weeks in early summer (from 14 December 2022 to 8 February 2023).

The DO logger was calibrated before and after deployment using 100% water saturated air. As a further check, separate measurements of dissolved oxygen were made when installing, removing and checking the logger using a calibrated YSI Pro Plus multi-meter with a polarographic DO sensor.

Atmospheric pressure was recorded near the site using a Hobo U20 logger (measuring pressure and temperature). These measurements were used to adjust DO measurements for atmospheric pressure.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Measurements of temperature, DO, pH and electrical conductivity were made at the top (0.1m) and bottom (0.8m) of the water column when the loggers were installed and removed. The top and bottom measurements were similar and there was no thermal stratification – as would be expected in such a shallow lake.

## 2.4 Water quality sampling

BOPRC undertook regular water quality sampling of Sullivan Lake (at outlet) between September 2001 and June 2008 (including periods of weekly to fortnightly sampling during 2001 to 2003, and in 2007).

BOPRC also collected cyanobacteria samples from Sullivan Lake during summer between February 2013 and February 2020. The frequency of sampling ranged from weekly to monthly. Samples were analysed for species identification, biovolume and potentially toxic biovolume.

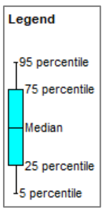
More recent water quality samples were collected as part of this Project and in a co-founded collaboration between River Lake and BOPRC. Water samples were collected from the edge of Sullivan Lake at Olympic Drive footpath access. This occurred on seven occasions between May 2022 and April 2023.

The samples were collected using a sample arm to reach about 2.5m from the water's edge and 0.1m below the surface water. Field measurements (temperature, dissolved oxygen (**DO**), specific electrical conductivity (**EC**), pH) were made from the same location using a YSI Pro Plus multi-meter, and clarity tube. The samples were sent to Bay of Plenty Regional Council laboratory for analysis of: total nitrogen (**TN**), nitrate-nitrite-nitrogen (**NNN**), total ammoniacal nitrogen (**NH4-N**), total phosphorus (**TP**), dissolved reactive phosphorus (**DRP**), turbidity (**TURB**), chlorophyll-a (**Chl-*a***), and *E.coli* bacteria (***E.coli***).

Additional field measurements have been collected on an *ad hoc* basis, including water clarity measurements by the Sullivan Lake Care Group and River Lake Ltd collected between March 2019 and February 2020.

Water clarity was usually measured using a clarity tube. This data was converted to black disc water clarity using the formula provided in Kilroy and Biggs (2002)[1].

Water quality data expressed using box plots show the median, interquartile range, 5 percentile, 95 percentile, minimum, and maximum, as illustrated below.




[1] Clarity tube reading (yCT) < 50cm = black disc (yBD); yCT >50cm adjusted as: yBD = 7.28 x 10^(yCT/62.5).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



## 2.5 eDNA

Waterways contain environmental DNA (eDNA) of organisms present. Analysis of eDNA shed from organism in the water give a qualitative assessment of what fish, aquatic insects, birds and plants may be present (David et al. 2021). Although used as a qualitative tool, the results do indicate the strength of the eDNA signal.

Fish presence in Sullivan Lake and inflow streams was confirmed by collecting eDNA samples from Sullivan Lake on 14 June 2022 and from the main stream entering Sullivan Lake at the foot bridge on 17 November 2022. Samples from the lake were collected from three locations on the northern side. The flow that is normally pumped by WDC from the Whakatane River had been stopped for six days prior to collecting the sample so as to avoid potential inflow of fish eDNA from this source.

Preservative was added to the samples and they were sent to Wilderlab for processing.

## 2.6 Assessing potential nutrient limitation

In order to accurately assess the extent to which nutrients may limit algal growth in a lake requires detailed investigations and bioassays. However, some indication of potential nutrient limitation can be gained by looking at the absolute concentration of nutrients in the lake and the stoichiometric ratio of N to P and assuming the absence of other factors limiting phytoplankton or macro-algal growth. Nutrient concentrations are balanced when they equate to the Redfield ratio (i.e., 7.2 by mass). In these situations, either or both N or P may limit growth. A TN:TP value less than 7 indicates potential nitrogen limitation, and a TN:TP value greater than 14 indicates potential phosphorus limitation.

Similarly, the ratio of DIN:TP can also be used to indicate potential nutrient limitation. Assuming the absence of other growth limiting factors a DIN:TP of < 1 (by mass) indicates potential N limitation and a DIN:TP > 1 indicates potential P limitation (Schallenberg et al. 2010).

## 2.7 Lake water quality guidelines

### 2.7.1 Trophic Level Index (TLI)

Lake water quality is often expressed in terms of trophic state, which refers to the production of algae, epiphytes and macrophytes in a lake. The trophic state of each lake was assessed using the Trophic Level Index (**TLI**) (Burns et al. 2000).

The TLI integrates four key measures of lake trophic state - total nitrogen, total phosphorus, chlorophyll *a* and Secchi depth. The overall TLI score for a lake is the average of individual TLI scores for each variable. The overall score is categorised into seven trophic states indicative of accelerated eutrophication as evidence more nutrients, more algal productivity and reduced water clarity (**Table 2.1**). Regular monitoring over multiple years is usually required to reliably characterise a lake's water quality or TLI.

There were few measurements of Secchi disc from the lake, so the TLI was expressed as **TLI3**, which excludes the Secchi disc measurements.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



**Table 2.1:** Definition of Trophic Levels based on water quality measures (Burns et al. 2000).

| Trophic State | TLI Score | Chl *a* (mg/m$^3$) | Secchi depth (m) | TP (mg/m$^3$) | TN (mg/m$^3$) |
|---|---|---|---|---|---|
| Ultra-microtrophic | <1 | < 0.33 | > 25 | < 1.8 | < 34 |
| Microtrophic | 1 - 2 | 0.33 – 0.82 | 15 - 25 | 1.8 – 4.1 | 34 - 73 |
| Oligotrophic | 2 - 3 | 0.82 - 2.0 | 15 - 7.0 | 4.1 – 9.0 | 73 - 157 |
| Mesotrophic | 3 - 4 | 2.0 - 5.0 | 7.0 - 2.8 | 9.0 - 20 | 157 - 337 |
| Eutrophic | 4 - 5 | 5.0 - 12 | 2.8 - 1.1 | 20 – 43 | 337 - 725 |
| Supertrophic | 5 - 6 | 12-31 | 1.1 - 0.4 | 43-96 | 725 - 1558 |
| Hypertrophic | >6 | >31 | <0.4 | >96 | >1558 |

### 2.7.2 Cyanobacteria guideline

The NZ guidelines for cyanobacteria in recreational waters (MfE and MoH 2009) that sets an alert level framework for assessing the health risk from planktonic cyanobacteria. The "Action (Red) mode" is triggered when either 1) cyanobacteria biovolume is ≥10 mm$^3$/L, or 2) cyanobacteria biovolume is ≥1.8 mm$^3$/L, of potentially toxic cyanobacteria, or 3) cyanobacteria scums are consistently present. The "Alert (amber mode)" is when cyanobacteria biovolume is 0.5 to <10 mm$^3$/L, or 2) cyanobacteria biovolume is 0.5 to <1.8 mm$^3$/L, of potentially toxic cyanobacteria. The "Surveillance (green) mode" is when the total cyanobacteria biovolume is <0.5 mm$^3$/L.

### 2.7.3 National Policy Statement for Freshwater Management (NPS-FM)

The National Policy Statement for Freshwater Management (**NPS-FM 2020**) (MfE 2020) sets out objectives and policies that direct local government to manage water in an integrated and sustainable way. The NPS-FM includes a National Objectives Framework (NOF) which sets compulsory national values for freshwater including: 'human health for recreation' and 'ecosystem health'. Appendix 2 of the NPS-FM sets water quality attributes that contribute to these values, and ranks attributes into bands to help communities make decision on water quality. This includes setting minimum acceptable states called 'national bottom lines'.

Appendix 2A of the NPS-FM (2020) describes attributes that require limits on resource use, while Appendix 2B of the NPS-FM (2020) describes attributes that require action plans to be developed (**Table 2.2**).

In this report, we discuss water quality state in the context of the NPS-FM bands where possible. For most attributes, insufficient samples have been collected in recent years to accurately define the band for the purpose of the NPS-FM (e.g. *E.coli* bacteria require 60 samples over 5-years), and in these cases the bands only provide a guideline of water quality state. Arguably, Sullivan Lake does not fall within the scope of the NPS-FM because it is an artificial waterbody, nevertheless the attributes bands provide a context for assessing water quality state.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



**Table 2.2**: NPS-FM attributes and values defining different quality bands pertaining to lakes. *E.coli* bacteria and cyanobacteria relate to suitability for contact recreation while the other bands relate to ecosystem health. Bolded values are the national "bottom-lines".

**Table 2A - Attributes requiring limits on resource consents**

| Attribute | Statistic | Units | Band A | Band B | Band C | Band D | Band E |
|---|---|---|---|---|---|---|---|
| NH4-N | Median | mg/L | ≤0.03 | **≤0.24** | ≤1.3 | >1.3 | |
| NH4-N | Maximum | mg/L | ≤0.05 | **≤0.4** | ≤2.2 | >2.2 | |
| *E.coli* bacteria | % samples >260 cfu/100ml | % | ≤20% | ≤30% | ≤34% | ≤50% | >50% |
| *E.coli* bacteria | % samples >540 cfu/100 ml | % | ≤5% | ≤10% | ≤20% | ≤30% | >30% |
| *E.coli* bacteria | Median | *E.coli* / 100mL | ≤130 | ≤130 | ≤130 | ≤260 | >260 |
| *E.coli* bacteria | 95%ile | *E.coli* / 100mL | ≤540 | ≤1000 | ≤1200 | ≤1200 | >1200 |
| Phytoplankton | Median | mg *chl-a* /$m^3$ | ≤2 | ≤5 | **≤12** | >12 | |
| Phytoplankton | Maximum | mg *chl-a* /$m^3$ | ≤10 | ≤25 | **≤60** | >60 | |
| TN (polymictic) | Median | mg/$m^3$ | ≤300 | ≤500 | **≤800** | >800 | |
| TP | Median | mg/$m^3$ | ≤10 | ≤20 | **≤50** | >50 | |
| Cyanobacteria biovolume | 80%ile of potentially toxic cyanobacteria | $mm^3$/L | ≤0.5 | ≤1.0 | **≤1.8** | >1.8 | |

**Table 2B - Attributes requiring action plans**

| Attribute | Statistic | Units | Band A | Band B | Band C | Band D |
|---|---|---|---|---|---|---|
| Submerged Plants Native Condition Index) | | % | >75 | >50 | **≥20** | <20 |
| Submerged Plants Invasive Condition Index) | | % | ≤1 | ≤25 | **≤90** | >90 |
| Lake-bottom DO | annual minimum | mg/L | ≥7.5 | ≥2 | **≥0.5** | <0.5 |
| Mid-hypolimnetic depth | annual minimum | mg/L | ≥7.5 | ≥5 | **≥4** | <4 |
| *E.coli* bacteria Primary Contact sites | 95%ile (summer) | *E.coli* / 100mL | ≤130 | ≤260 | **≤540** | >540 |

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



# 3 State of Sullivan Lake

## 3.1 Morphology

Sullivan Lake is small and shallow. The main lagoon has an average depth of about 0.92 m ± 8% [2]. The base is relatively uniform with the deepest point of 2.2m in the southern pond which has been deepened near the culvert from Te Tahi Street. The area of Sullivan Lake is about 2.7 ha and it has a volume of about 22,700 $m^3$. The water depth under the water lily at the western end of the lake ranged from 0.30m to 1.13m, with an average water depth of 0.89m.

### 3.1.1 Sediment depth

The soft sediment depth at the western end of the lake ranged from 0m to 0.61m, with an average soft sediment depth of 0.40m.

In 2017 spot measurements of sediment depth found soft sediment depth in the western end of the lake ranged from 0.1 to 0.8m, with an average depth of 0.6m, however the small number of samples collected in 2017 prevents making a reliable comparison with more recent measurements (Hamill 2017).


**Figure 3.1**: Bathymetry of Sullivan Lake. The darker areas indicate deeper water, with the maximum depth was 2.2m in the southern section and an average depth of 0.84m.

[2] Plus 8% if preferring measurements by 'weighted line' and minus 8% if preferring measurements by the sonar (see method).

## 3.2 Hydrology

### 3.2.1 Inflows

Sullivan lake has a catchment area of 105ha, of which about two thirds is in urban landuse and one third is the tree covered escarpment east of Valley Road (**Figure 3.2**). Ten 10 stormwater culverts enter Sullivan Lake. The largest flows enter near the foot bridge at the eastern end of the lake and drain the escapement east of Valley Road. The escarpment catchments respond quickly to rain and can carry large volumes of sediment. There is little room to control the sediment from this catchment (WSP 2021) (**Figure 3.3**).

In addition, WDC pumps up to about 40 $m^3$/hour (11.1 L/s) into Sullivan Lake from the Whakatāne River to improve flushing (Neil Yeats, WDC pers. comm., May 2022). The water is pumped into a culvert near the Whakatāne water treatment plant and enters Sullivan Lake via a 900mm culvert at the south-eastern end. Pumping occurs nearly continuously throughout the year except during flood events, but often flows rates are closer to 3 L/s.

The water levels are controlled by a weir at King Street, from which the water flows under King Street into a drain with a gravity discharge to the Whakatāne River (water is pumped during high river flows).

There are no measurements from inflow culverts suitable for estimating flow. However, the average catchment inflow to Sullivan Lake is estimated to be 0.0224 $m^3$/s. This was derived by multiplying the specific mean flow[3] for the catchment (0.02134 $m^3/km^2/yr$) by the catchment area (1.05 $km^2$). Measured inflows from the main culverts (near foot bridge and south lagoon) during baseflow in mid-November 2023 ranged[4] from 6.3 L/s to 7.8 L/s with about 2.4 L/s attributed to flow augmentation via the Te Tahi Street culvert.

### 3.2.2 Hydraulic residence time

Hydraulic residence time is an important factor in determining the water quality of lakes. In large oligotrophic lakes which act as a sink for nutrients, increasing residence time can be detrimental to water quality, however in shallow eutrophic lakes with high internal nutrient loads, a shorter residence time can improve water quality by better flushing nutrients and phytoplankton biomass (Jørgensen 2002). To be effective residence time should be reduced to less than about 20 days (Hamilton & Dada, 2016; Abell et al 2020).

The average residence time for Sullivan Lake is about[5] to be 11.7 days. Augmenting the inflow with an additional 40 $m^3$/hour (11.1 L/s) reduces the average residence time to 7.8 days, but the relative effect will be larger during dry conditions.

A mean residence time of 11 days is short for a natural lake and reflects the shallow depth of Sullivan Lake. However, because Sullivan Lake catchment is highly urbanised, there is limited baseflow and the flushing of the lake is highly skewed towards rain-events. To completely replace the volume of water in

[3] Data modelled by NIWA for New Zealand's Environmental Reporting Series: The Ministry for the Environment and Statistics New Zealand. Flow expressed for each unit of the River Environment Classification (REC).
[4] Both measured on a fine day but the higher flow measured when then had been 20mm of rain on the previous day.
[5] Calculated as: lake volume (22,700 $m^3$) / (86,400 s/day * catchment inflow (0.0224 $m^3$/s))

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Sullivan Lake in one day would theoretically require runoff from rainfall in the catchment of greater than 21.6mm per day.

One management option to improve water quality in Sullivan Lake may be to increase the volume of flow pumped to Sullivan Lake during summer dry periods when water quality is at its worst and other inflows are low. This may be partially balance by reducing flow augmentation during wet periods.

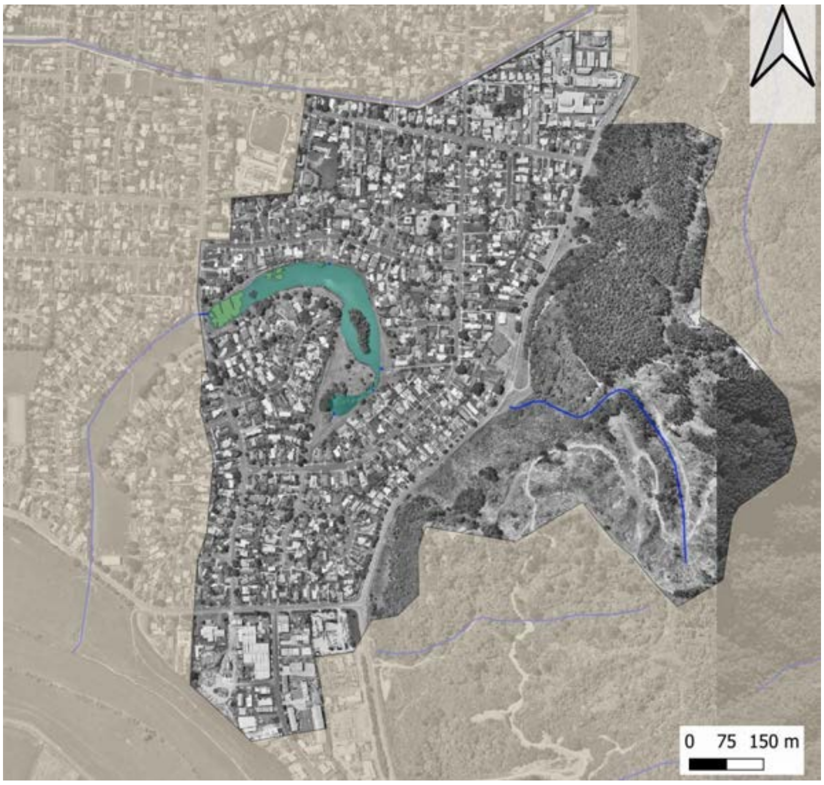



**Figure 3.2**: Sullivan Lake surface water catchment area (105 ha).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



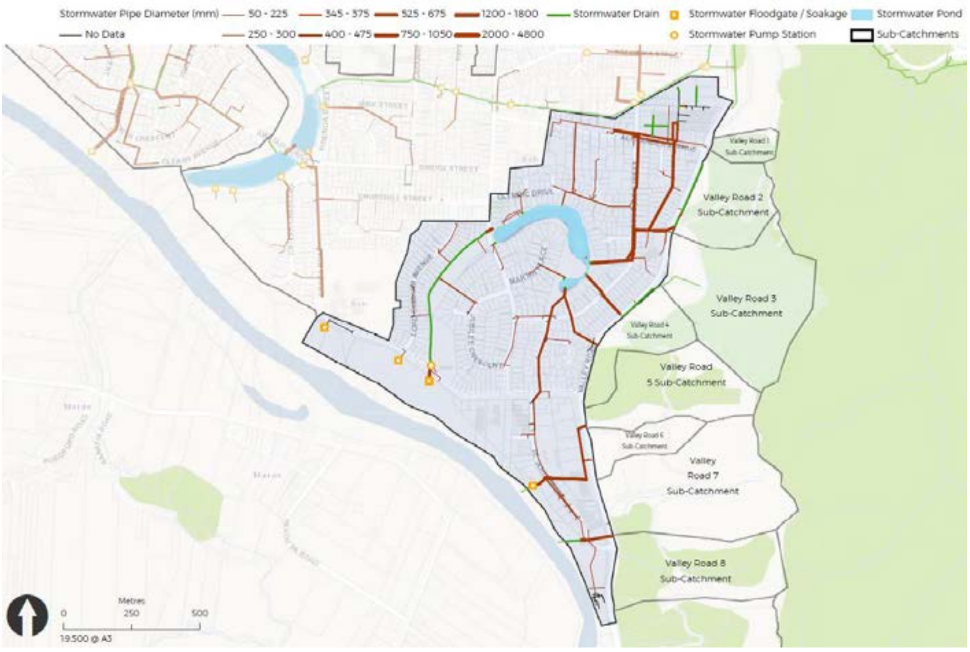



**Figure 3.3**: Whakatane South Stormwater Catchment entering and leaving Sullivan Lake (WSP 2021).

## 3.3 Birds

Sullivan Lake provides habitat for a wide range of waterfowl. Bird species commonly using the lake include: pūkeko (*Porphyrio melanotus*); Australian coot (*Fulica atra australis*), little black shag (*Phalacrocorax sulcirostris*), little shag (*Microcarbo melanoleucos*), black shag (*Phalacrocorax carbo*), silver gull (*Chroicocephalus novaehollandiae*), welcome swallow (*Hirundo neoxena*), mallard ducks (*Anas platyrhynchos*), paradise shelduck (*Tadorna variegata*), muscovy ducks (*Cairina moschata*), and mute swan (*Cygnus olor*). Other birds observed on the lake include: Australian shoveler (*Spatula rhynchotis*), spoonbill (*Platalea regia*), and occasionally white heron/ kōtuku (*Egretta alba*).

### 3.3.1 Avian botulism

Populations of duck can be high and occasionally outbreaks of avian botulism has occurred in wildfowl during extended dry summers. This causes progressive weakness and ascending paralysis and can be a common cause of death in migratory birds. Avian botulism is caused by toxins produced by some strains of the bacteria *Clostridium botulinum*. This is a naturally occurring bacteria found in anaerobic aquatic sediments. Dormant spores are harmless, but the botulism toxin is produced as the cells grow and is released at the end of a growth phase. Common factors in botulism outbreaks are anoxic sediments (devoid of oxygen), warm temperatures (e.g. >20 °C), decomposing organic matter (particularly material high in protein), and water pH in the range of c. 7.5 to 9.0 (Rocke and Samuel 1999).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



One feature of avian botulism that perpetuates mass die-off of birds is the 'carcass-maggot cycle'. This is where healthy birds ingest and carry dormant botulinum spores; upon death the spores germinate and grow in the carcass; maggots feeding on the carcass accumulate the toxin, and subsequent consumption of the maggots by other birds causes poisoning and death that perpetuates the botulism outbreak. Collecting and disposing of carcasses can help break this cycle (Rocke and Bolling 2007).

### 3.3.2 Potential impact of birds on water quality

While birds are an important value of the lake, high densities of birds can reduce water quality. A number of studies have found that water fowl can be a significant source of faecal coliform bacteria to some lagoons and beaches. This is partially because birds tend to defecate directly in the water, and partially because they have relatively high load of nutrients and faecal bacteria relative to their body size (e.g. Flemming and Fraser 2001, Don and Donovan 2001).

## 3.4 Fish

Fish species confirmed as present in Sullivan Lake are: shortfin eel, common smelt, bully species (probably common bully), goldfish and *Gambusia* (a pest fish). The tributary stream entering from the east supports the fish: shortfin eel, common bully, inanga, and gold fish (**Table 3.1**).

Fish access to the lake from Sullivan Lake to the Whakatāne River is restricted by the flood gate at the outlet near the stop bank, and steep weir at the outlet. However, it appears that at least some individuals of the migratory fish (shortfin eel and inanga) have migrated to Sullivan Lake and it's catchment streams.

**Table 3.1**: Fish present in Sullivan Lake and the main inflow stream as indicated by eDNA sequences detected.

| Common Name | Scientific Name | Sullivan Lake 14/6/2022 | Stream entering at Footbridge 17/11/2022 |
|---|---|---|---|
| Shortfin eel | *Anguilla australis* | 526 | 4280 |
| Common smelt | *Retropinna retropinna* | 21 | |
| Bullies | *Gobiomorphus* sp. | 7575 | 13782 |
| Common bully /Cran bully | *Gobiomorphus cotidianus / basalis* | 728 | |
| Inanga | *Galaxias maculatus* | | 103 |
| Goldfish | *Carassius auratus* | 5692 | 2925 |
| Mosquitofish | *Gambusia affinis* | 1198 | |

## 3.5 Aquatic Plants

Sullivan Lake is predominantly surrounded by parkland with mown grass and occasional mature tree. A narrow band of native riparian vegetation has been planted along about 240m of the southern edge consisting of flaxes, sedges and rushes. A formal wooden edge delineates the lake from the surrounding land and only a few wetland plants have established in the water near the footbridge (e.g. *Carex secta, Bolboschoenus fluviatilis, Machaerina articulata*).

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



Most of the year Sullivan Lake is devoid of macrophytes except for water lily (*Nymphaea* sp.) which covers a large section of the western part of the lake near King Street (**Figure 3.4**). However, during spring and early summer 2022 the curled pondweed *Potamageton crispus* covered about 90 percent of the open water area in association with epiphytic algae. Patches of floating sweet grass (*Glyceria fluitans*) can occur on the lake margins. Other species that are occasionally present include the floating fern *Azolla* spp., duckweed and pest plants of *Egeria densa*, *Elodea canadensis*, and hornwort (*Ceratophyllum demersum*). These macrophytes remain present in the drain downstream of the Sullivan Lake outlet.

Curled pondweed is an annual aquatic plant, that germinates from seeds during late spring, grows prolifically during early summer and typically collapses in mid-summer to late. During the growth phase, the curled pondweed often improves water quality by taking up nutrients and stabilising sediments. However, pondweed beds typically collapse around mid-summer and subsequent decomposition on the lake bed can reduce dissolved oxygen and cause and release of dissolved nutrients from the substrate that can be used by phytoplankton (Gibbs 2011). Potamogeton has a low tolerance to high temperatures and low alkalinity, but a high tolerance to sediment disturbance and to most aquatic herbicides such as Diquat and Endothall (Gibbs and Hickey 2012).

The cover of macrophytes has historically been controlled by use of herbicide sprays. This is a relatively cheap way to control macrophytes, but has can have a number of negative consequences, including decomposing macrophytes causing sediment anoxia, release of nutrients and promotion of algae blooms. Harvesting macrophytes, although more expensive, provide considerably more benefits for improving water quality and ecological values.

Although *P. crispus* is an introduced plant, it is relatively benign compared to hornwort (*Certatophyllum demersum*) and parrots feather (*Myriophyllum aquaticum*) that is dominant in Awatapu lagoon. It is much less dense than hornwort and consequently has less adverse effects on the dissolved oxygen regime during senescence.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



**Figure 3.4**: Water lilies at Sullivan Lake western end. Top photo: aerial facing west in August 2022; Bottom photo from May 2022.

### 3.5.1 Role of macrophytes in maintaining good water quality

Macrophyte beds are a key component of healthy lakes. They help improve water quality by stabilising the sediments, absorbing dissolved nutrients, mediating the nutrient release from sediments, and providing habitat for invertebrates that consume phytoplankton (Hilt et al. 2006; Kelly and Jellyman 2007; Schallenberg et al. 2010, Wetzel 1995). Overseas studies have shown that submerged aquatic plant cover needs to be consistently >30% to 60% to ensure a clear-water state (e.g. Jeppesen et al. 1994; Tatrai et al. 2009; Blindow et al. 2002).

It is well documented that shallow, eutrophic lakes can often undergo a regime shift (colloquially called “flipping”) from a clear water, macrophyte-dominated state to a de-vegetated, algae-dominated state with turbid water quality (Scheffer 2004, Tatrai et al. 2009). At least 37 shallow lakes in New Zealand that have undergone a “flip” between clear water and turbid states and/or vice versa.

The risk of a lake flipping to a turbid water quality state increases with increasing nutrient and sediment loads, and typically corresponds to increases in epiphytes, macroalgae, phytoplankton and cyanobacteria (**Figure 3.5**) (De Wit et al. 2001, Scheffer & van Nes 2007). Flipping to a turbid, algae dominated state is more likely when a lake has a high nutrient load, where exotic macrophytes have replaced native macrophytes, and where coarse fish species (e.g. catfish, goldfish, rudd, tench, or koi carp) are present (Schallenberg and Sorrell 2009).

Re-establishing submerged macrophytes is essential for the long-term success when restoring shallow lakes. However, simply establishing macrophyte beds does not always improve water quality even when they improve fish habitat. Ecosystems are complex and often other restoration activity is also needed. Establishing aquatic plants in shallow lakes does not guarantee clear water quality, but without them good water quality is unlikely without other expensive and ongoing interventions (Gulati et al., 2008; Jeppesen et al. 2005).

Native macrophytes are much more preferable than exotic macrophytes because they provide more biodiversity, have less aggressive growth and are less likely to attain high biomass that can adversely affect dissolved oxygen or cause a nuisance for recreation. However, even exotic macrophytes can provide water quality benefits if well managed. Where exotic macrophytes are present, a common

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



challenge for lake management is to retain the benefits of macrophytes in the lake while minimising the problems caused by excessive growth on water quality and recreation.

Sullivan Lake, with the exception of the water lilies at the western end, appears to have had a long period in a turbid, cyanobacteria dominated state. The establishment of curled pondweed in late 2022 may indicate a shift to improved conditions, although epiphytes, macroalgae and cyanobacteria remain abundant. Nevertheless, the establishment of curled pondweed improves water quality during its spring growth as evidenced by relative better clarity and lower nutrients while it was growing in late October 2022[6]. In addition, curled pondweed also provides an opportunity for improved management of water lake water quality and long-term nutrient removal through macrophyte harvesting prior to senescence.

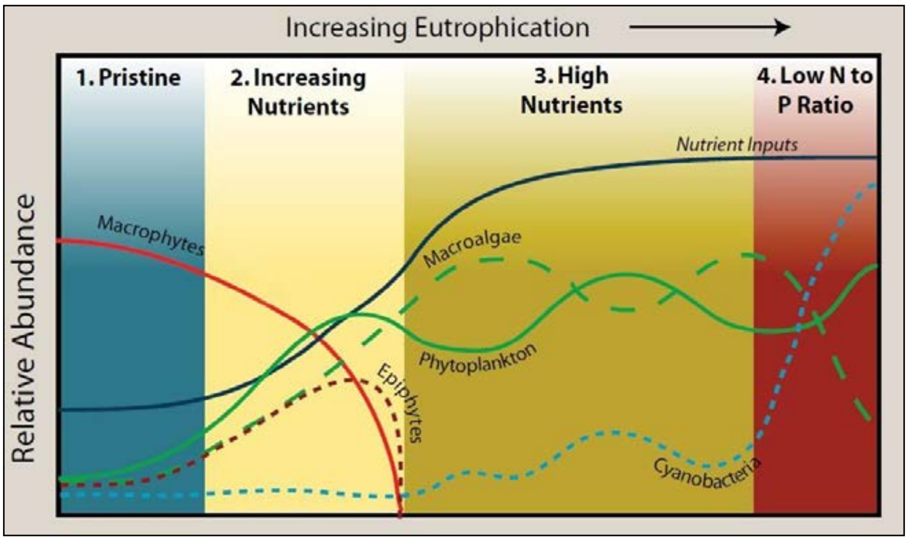



**Figure 3.5**: Generalised lake response to increasing eutrophication. Sullivan Lake appears to be in Stage 3 to 4 (adapted from De Wit et al. 2001).

## 3.6 Water Quality

### 3.6.1 Water quality samples

Sullivan Lake has poor water quality characterised by low water clarity (median 0.37m), high concentrations of nitrogen and phosphorus (median 0.48 and 0.143 mg/L respectively), and high concentrations of phytoplankton (median Chl-*a* 19.2 mg/L). Algae blooms are common, and are often dominated by potentially toxic cyanobacteria (**Table 3.2, Figure 3.7**). Algae blooms appear least common in November-December (**Appendix 2**).

[6] 30 October 2022, had TN, TP, Chl-a and black disk clarity of respectively 0.42 mg/L, 0.1 mg/L, 1.6 mg/m$^3$ and 1.3m.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Recent TLI results are about 5.90, which is borderline between supertrophic and hypertrophic (**Figure 3.6**). This reflects the low clarity and high concentrations of TN, TP, and Chl-*a*. National bottom-line values set for lake attributes in the NPS-FM appear to be exceeded for median TP, median Chl-*a*, maximum Chl-*a*, and cyanobacteria biovolume (see cyanobacteria section below).

Phytoplankton growth in Sullivan Lake appears to be more strongly limited by nitrogen than by phosphorus. The recent TN:TP ratio is about 3.5 (compared to a "balanced" ratio of 7) and the DIN:TP ratio is less than 0.1 (compared to a "balanced" ratio of 1). Absolute values of dissolved organic nitrogen (**DIN**) are often very low (median 0.01 mg/L), while DRP is moderately high (median 0.018 mg/L). High concentrations of TP and chlorophyll-*a* elevates the TLI (i.e. makes it worse) relative to the concentration of TN (expressed as TL-n) (**Figure 3.6**). Occasions with high TN (e.g. May 2022) are associated with cyanobacteria blooms – which can fix nitrogen from the atmosphere.

Water quality in Sullivan Lake considerably improved between 2001 and 2008. This was evident for most water quality variables, but the improvement was particularly strong for chlorophyll-*a* and TN. The TN:TP ratio reduced from about 9 during 2000-2002 to 5 during 2006-2008 (**Figure 3.6**, **Figure 3.7**). The level of improvement would be consistent with recovery from past pollution such as possible sewage overflows.

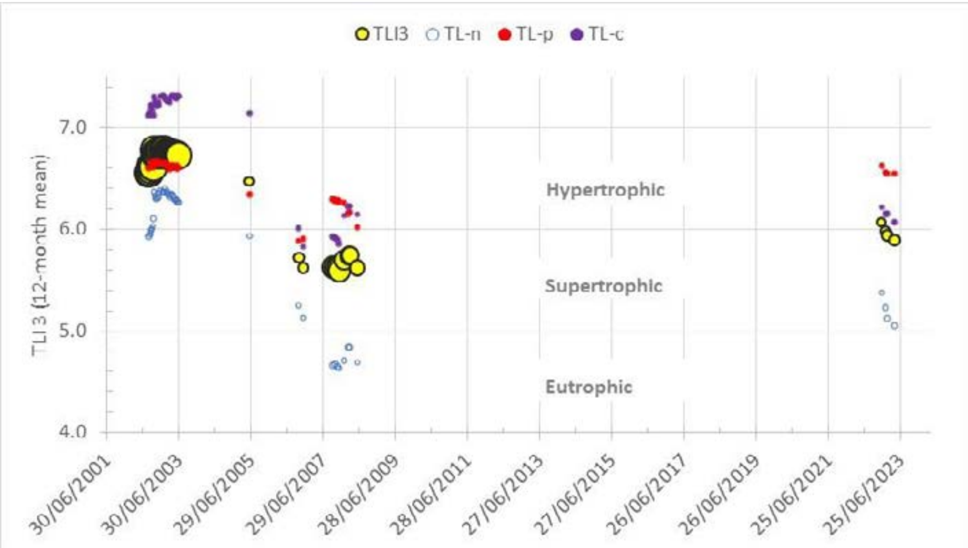



**Figure 3.6:** Annual Trophic Level Index (TLI3) of Sullivan Lake and its constituents for nitrogen (TL-n), phosphorus (TL-p) and chlorophyll-a (TL-c). For TLI3, the size of the circle indicates the number of samples used to calculate the rolling 12-month average (range 4-26).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



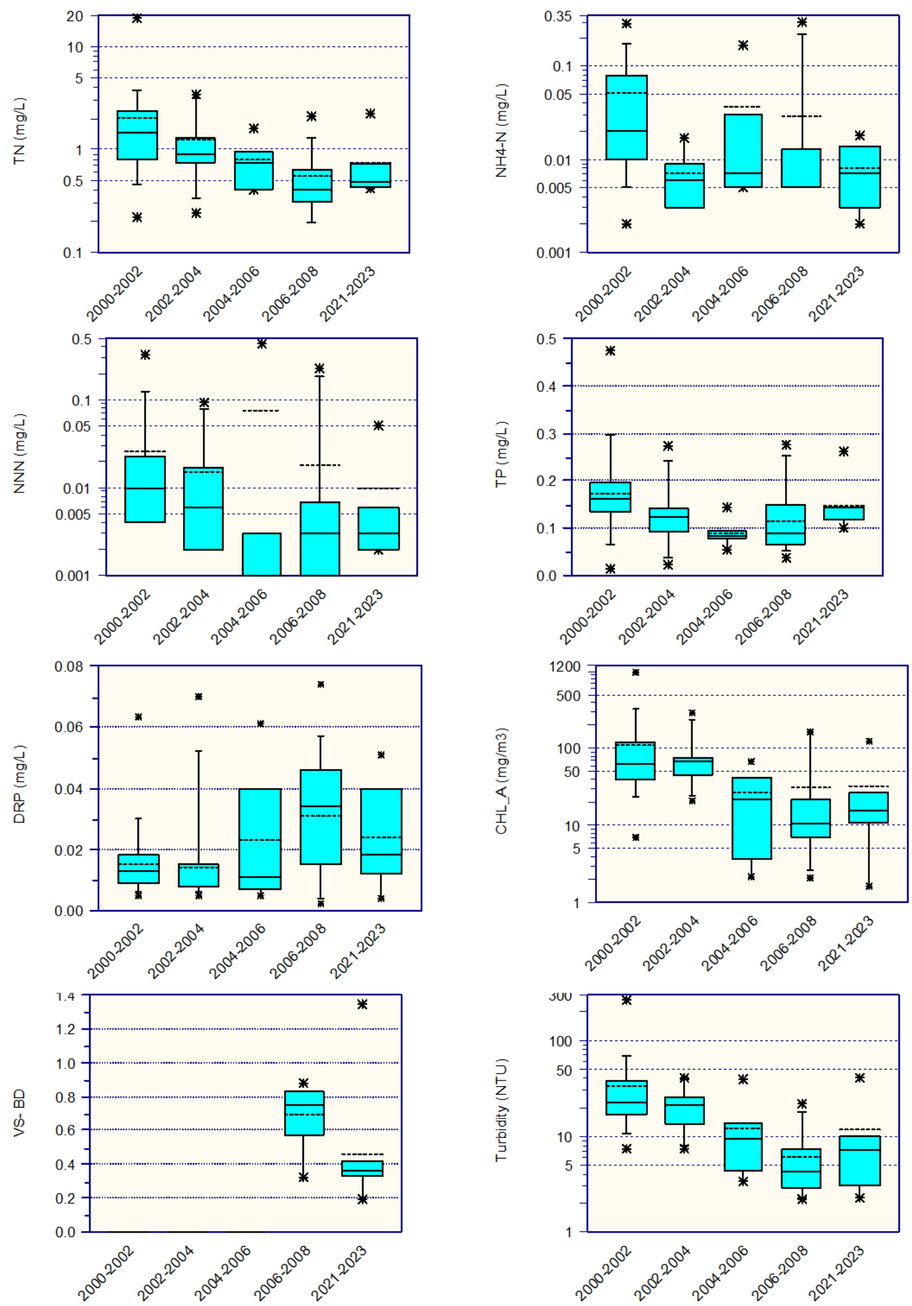



**Figure 3.7:** Water quality in Sullivan Lake expressed as box plots for two-year (July to June) periods.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



**Table 3.2**: Sullivan Lake water quality summary statistics for two-year (July to June) periods (data from 2004-2006 excluded for clarity of presentation).

| Years | Variable | n | Min | Max | Mean | Median | 95 %ile | 5 %ile |
|---|---|---|---|---|---|---|---|---|
| 2000-2002 | TN (mg/L) | 53 | 0.22 | 18.95 | 2.01 | 1.48 | 3.76 | 0.45 |
| 2000-2002 | NH4-N (mg/L) | 53 | 0.002 | 0.288 | 0.051 | 0.020 | 0.170 | 0.005 |
| 2000-2002 | NNN (mg/L) | 42 | 0.001 | 0.325 | 0.026 | 0.01 | 0.125 | 0.001 |
| 2000-2002 | TP (mg/L) | 54 | 0.013 | 0.475 | 0.171 | 0.161 | 0.295 | 0.065 |
| 2000-2002 | DRP (mg/L) | 53 | 0.005 | 0.063 | 0.015 | 0.013 | 0.030 | 0.006 |
| 2000-2002 | CHL_A (mg/m3) | 54 | 6.9 | 992 | 109.4 | 62.0 | 326.8 | 23.6 |
| 2000-2002 | Turbidity (NTU) | 44 | 7.3 | 265.0 | 33.1 | 22.5 | 68.8 | 10.7 |
| 2000-2002 | TN:TP | 53 | 1.2 | 95.2 | 12.0 | 9.3 | 25.5 | 4.0 |
| 2000-2002 | pH | 53 | 6.9 | 10.1 | 8.3 | 8.3 | 9.5 | 7.2 |
| 2000-2002 | DO (mg/L) | 50 | 5.6 | 14.4 | 10.1 | 10.4 | 13.3 | 6.8 |
| 2000-2002 | EC sp (uS/cm) | 43 | 96 | 763 | 150 | 138 | 172 | 104 |
| 2002-2004 | TN (mg/L) | 16 | 0.25 | 3.39 | 1.24 | 0.91 | 3.17 | 0.34 |
| 2002-2004 | NH4-N (mg/L) | 17 | 0.001 | 0.017 | 0.007 | 0.006 | 0.017 | 0.001 |
| 2002-2004 | NNN (mg/L) | 16 | 0.001 | 0.093 | 0.015 | 0.006 | 0.078 | 0.001 |
| 2002-2004 | TP (mg/L) | 16 | 0.023 | 0.272 | 0.124 | 0.124 | 0.241 | 0.038 |
| 2002-2004 | DRP (mg/L) | 17 | 0.005 | 0.070 | 0.014 | 0.008 | 0.052 | 0.006 |
| 2002-2004 | CHL_A (mg/m3) | 17 | 21 | 292 | 76.6 | 68.0 | 235.3 | 24.2 |
| 2002-2004 | Turbidity (NTU) | 16 | 7.3 | 40.0 | 20.8 | 21.0 | 38.8 | 7.8 |
| 2002-2004 | TN:TP | 16 | 2.8 | 33 | 10.9 | 9.3 | 28.7 | 3.5 |
| 2002-2004 | pH | 16 | 7.2 | 9.4 | 8.5 | 8.7 | 9.4 | 7.3 |
| 2002-2004 | DO (mg/L) | 17 | 8.7 | 13.6 | 10.7 | 10.5 | 13.4 | 8.8 |
| 2002-2004 | EC sp (uS/cm) | 16 | 93 | 138 | 109 | 107 | 136 | 93 |
| 2006-2008 | TN (mg/L) | 29 | 0.05 | 2.10 | 0.55 | 0.40 | 1.28 | 0.20 |
| 2006-2008 | NH4-N (mg/L) | 30 | 0.001 | 0.300 | 0.029 | 0.005 | 0.221 | 0.001 |
| 2006-2008 | NNN (mg/L) | 30 | 0.001 | 0.225 | 0.018 | 0.003 | 0.181 | 0.001 |
| 2006-2008 | TP (mg/L) | 30 | 0.038 | 0.276 | 0.115 | 0.09 | 0.252 | 0.051 |
| 2006-2008 | DRP (mg/L) | 30 | 0.002 | 0.074 | 0.031 | 0.034 | 0.057 | 0.004 |
| 2006-2008 | CHL_A (mg/m3) | 28 | 2.1 | 167 | 31.4 | 10.5 | 164.3 | 2.6 |
| 2006-2008 | VS- BD | 10 | 0.32 | 0.88 | 0.69 | 0.75 | | 0.32 |
| 2006-2008 | Turbidity (NTU) | 27 | 2.2 | 22.0 | 6.1 | 4.3 | 17.8 | 2.3 |
| 2006-2008 | TN:TP | 29 | 0.6 | 9.6 | 4.9 | 5.4 | 8.4 | 1.1 |
| 2006-2008 | pH | 29 | 6.8 | 9.5 | 8.1 | 8.3 | 9.4 | 6.9 |
| 2006-2008 | DO (mg/L) | 25 | 5.9 | 18.9 | 11.1 | 11.1 | 15.7 | 6.5 |
| 2006-2008 | EC sp (uS/cm) | 28 | 81 | 3500 | 256 | 106 | 818 | 87 |
| 2021-2023 | TN (mg/L) | 7 | 0.42 | 2.23 | 0.76 | 0.48 | | 0.42 |
| 2021-2023 | NH4-N (mg/L) | 7 | 0.002 | 0.018 | 0.008 | 0.007 | | 0.002 |
| 2021-2023 | NNN (mg/L) | 7 | 0.002 | 0.05 | 0.01 | 0.003 | | 0.002 |
| 2021-2023 | TP (mg/L) | 7 | 0.102 | 0.262 | 0.147 | 0.143 | | 0.102 |
| 2021-2023 | DRP (mg/L) | 7 | 0.004 | 0.051 | 0.024 | 0.018 | | 0.004 |
| 2021-2023 | CHL_A (mg/m3) | 6 | 1.6 | 126 | 32.7 | 15.7 | | 1.6 |
| 2021-2023 | VS- BD | 10 | 0.19 | 1.34 | 0.46 | 0.37 | | 0.19 |
| 2021-2023 | Turbidity (NTU) | 6 | 2.3 | 40.0 | 11.6 | 7.2 | | 2.3 |
| 2021-2023 | TN:TP | 7 | 3 | 18.9 | 5.7 | 3.5 | | 3.0 |
| 2021-2023 | E coli (cfu/100ml) | 7 | 30 | 1600 | 299 | 100 | | 30 |
| 2021-2023 | pH | 8 | 7.0 | 9.0 | 7.8 | 7.6 | | 7.0 |
| 2021-2023 | DO (mg/L) | 8 | 8.1 | 15.4 | 11.0 | 10.7 | | 8.1 |
| 2021-2023 | EC sp (uS/cm) | 8 | 132 | 280 | 175 | 157 | | 132 |

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



### 3.6.2 Cyanobacteria

Cyanobacteria are a natural part of the plankton community in lakes but can become a problem when they increase to high concentrations and form 'blooms'. Frequent cyanobacteria blooms are a feature of poor water quality in lakes and are caused by multiple factors including high nutrient concentrations, warm, calm conditions, and wind-driven accumulations of surface scums. High concentrations of cyanobacteria can also pose a potential health risk to recreational users, because they produce a range of different cyanotoxins.

Cyanobacteria blooms are very common in Sullivan Lake during summer and autumn, often exceeding recreational use guidelines (MfE and MOH 2009). Summer monitoring of cyanobacteria in Sullivan Lake from 2013 to 2020 (55 samples) found that the Surveillance Mode of biovolume ≥0.5 $mm^3$/L was exceeded 76% of occasions, while the Action Mode trigger of biovolume ≥10 $mm^3$/L was exceeded 49% of occasions, and the Action Mode trigger for biovolume of potentially toxic cyanobacteria ≥1.8 $mm^3$/L was exceeded 62% of occasions. On 18% of occasions the cyanobacteria biovolume was extremely high, at ten times the Action Mode.

The 80$^{th}$ percentile of potentially toxic cyanobacteria biovolume for the three-year period of 2018-2020 was 23 $mm^3$/L. This is worse than the NPS-FM national bottom-line (i.e. threshold of 1.8 $mm^3$/L for "D" Band).

*Anabaena* spp. is the dominant cyanobacteria present, and it is particularly prevalent during blooms where it can be visible as green flocs suspended in the water (**Figure 3.8**, **Figure 3.9**, **Table 3.3**).

**Figure 3.8**: Australian coot on Sullivan Lake during a cyanobacteria bloom, January 2022.

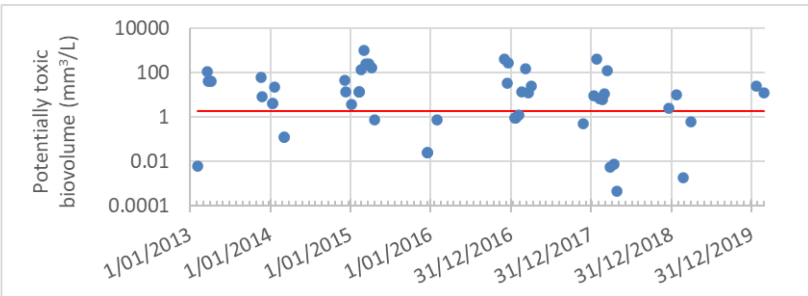



**Figure 3.9**: Biovolume volume of potentially toxic cyanobacteria in Sullivan Lake during summer ('Action' mode guideline is the red line).

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



**Table 3.3**: Occurrence of cyanobacteria species in Sullivan Lake during summer, 2013-2020 (source BOPRC). Shading groups common genesis.

| Species | % occurance | % occurance when biovolume ≥10 $mm^3$/L |
|---|---|---|
| *Anabaena circinalis* | 6% | 4% |
| *Anabaena lemmermannii* | 17% | 19% |
| *Anabaena spiroides* | 38% | 67% |
| *Aphanocapsa delicatissima* | 2% | |
| *Aphanocapsa elachista* | 1% | |
| *Aphanocapsa sp* | 4% | |
| *Chroococcus dispersus* | 2% | |
| *Chroococcus limneticus* | 4% | 4% |
| *Merismopedia sp* | 5% | |
| *Microcystis flos-aquae* | 2% | |
| *Microcystis sp* | 1% | |
| *Oscillatoria sp* | 1% | 4% |
| *Phormidium sp* | 1% | |
| *Planktothrix sp* | 9% | 4% |
| *Pseudanabaena limnetica* | 1% | |
| No Cyanobacteria | 5% | |

### 3.6.3 Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental for the health of almost all aquatic ecosystems. Reduced concentrations of DO (e.g. <4 mg/L) can impair the growth and reproduction of aquatic organisms, and shift the community composition to more tolerant organisms. As DO further reduces (e.g. 1 to 2 mg/L), death of aquatic organisms becomes increasingly common unless organisms can avoid low DO zones (Davies-Colley et al. 2013). The complete loss of DO (anoxia) from bottom waters of lakes causes changes in geochemistry that facilitates the release of nitrogen (as NH4-N) and phosphorus (as DRP) from the sediment; this can stimulate further eutrophication, which itself contributes to conditions that caused the anoxia.

Algae blooms can cause large daily fluctuations in dissolved oxygen (DO) and pH due to the photosynthesis and respiration of the phytoplankton. Oxygen concentrations will typically increase with photosynthesis during the day, and decrease with respiration at night. Other factors that have an important influence on lake DO, in addition to photosynthesis and respiration, are: wind re-aeration (that moves the DO towards 100% saturation), sediment oxygen demand, and biochemical oxygen demand from the water.

#### 3.6.3.1 Temporal Variation in DO

Dissolved oxygen loggers were installed in Sullivan Lake in autumn 2022 (April to June 2022) and during summer 2023 (December 2022 to February 2023). During autumn 2022 Sullivan Lake had large diurnal fluctuations in DO (commonly changing by 7mg/L) and for a six-week period during April-May the DO was consistently above 100% saturation. These features indicate a high level of primary production

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



which is consistent with observations of an algae bloom occurring at the time. Having super-saturation during the night-time is unusual for a lake and is discussed further below.

A moderate rain event (21mm daily) on 21 April 2022 reduced DO concentrations (to 8 mg/L) - possibly due to suspension of bottom sediment or introduction of a BOD load with the stormwater. A large rain event (40mm daily) on 18 May 2022 resulted in a similar reduction in DO (to 8 mg/L) as well as a reduction in diurnal fluctuations in the subsequent week – suggesting that flushing from the larger rain-event substantially reduced the phytoplankton biomass. Further large rain-events during early June 2022 reduced the DO to below 4 mg/L – indicating a source of BOD from either the catchment stormwater or sediment suspension. DO concentrations below 4 mg/L start to cause chronic effects on sensitive aquatic life. The lake recovered to a healthier, oxygenated DO regime after about two weeks (**Figure 3.10**).

During October 2023 the curled pondweed *P. crispus* germinated and grew to cover about 90% of the Sillivan Lake's open water[7]. During this time chlorophyll-*a* concentrations were low (1.6 mg/m$^3$). When DO loggers were installed on 14 December 2022, the macrophyte cover had slightly reduced and Chl-a increased to 11.6 mg/m$^3$; and by 18 January 2023 macrophyte cover was low and an algae bloom was developing (Chl-a of 26.8 mg/m$^3$). The DO regime was supressed by rain-events on 15 December and 21 December 2022, and recovered in the following week.

Between 27 Dec 2022 to 3 Jan 2023, there were large diurnal fluctuations in DO (c. 6 mg/L), in addition to a steady decline in the daily minimum DO from 9.15 mg/L to 1.46 mg/L (ie. 7.69 mg/L over 7-days). This equates to an oxygen demand of 1.1 mg/L per day, or 1.16 g/m$^2$/day. DO increased again on 4 January 2023 – probably due to aeration from a strong nor-easterly wind that occurred from 4$^{th}$ to 6$^{th}$ January (**Figure 3.11**). The oxygen demand observed in Sullivan Lake over the new year is likely due to the seasonal collapse of pondweed, causing sediment hypoxia.

During January to February 2023 there were multiple days when the daily minimum DO concentration were not only below guideline values (4 mg/L), but sufficiently low (< 2 mg/L) to cause fish to exhibit avoidance behaviour or potentially acute toxicity. These periods of very low DO occurred in early January (probably due to the pondweed collapse), in mid-late January due to very large diurnal fluctuations associated with an algae bloom, and during 6-7 February, that was associated with a week of heavy rain (and night-time anoxia).

[7] Excluding the area covered by waterlily.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



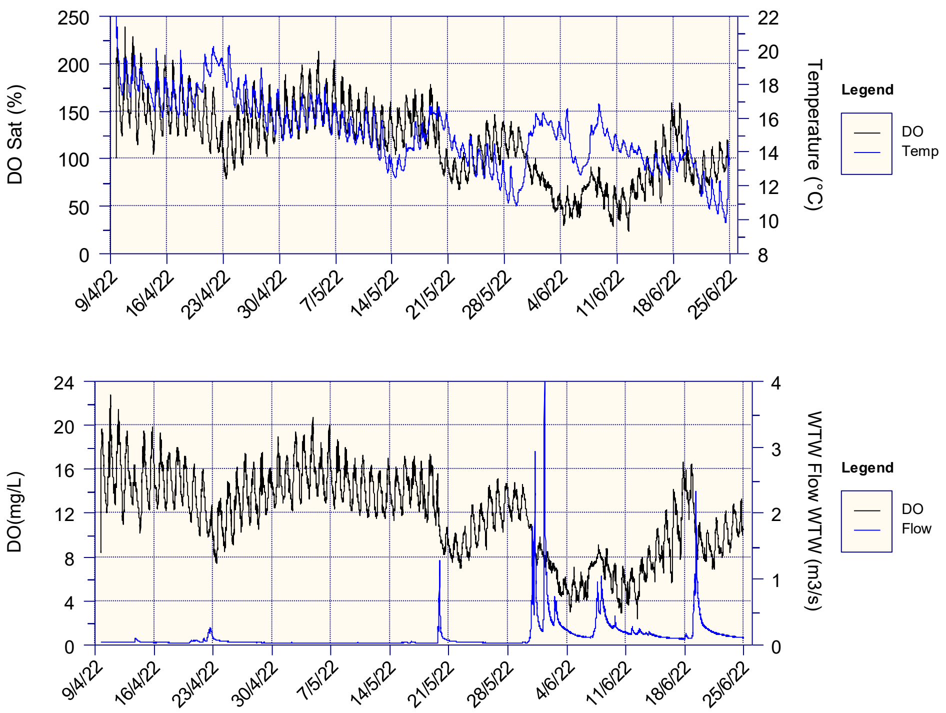



**Figure 3.10**: Dissolved oxygen in Sullivan Lake during autumn 2022. Expressed as %DO vs. temperature (top graph), and DO vs. flow (bottom graph). Flow in the Wainui Te Whara is used as a proxy for the pattern of inflows to Sullivan Lake.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



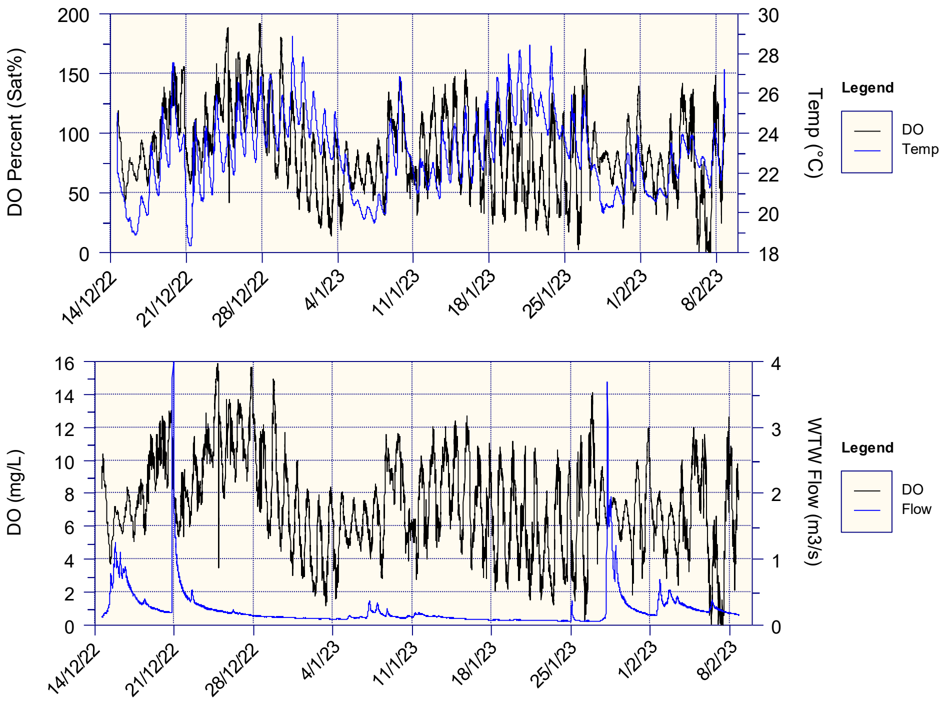



**Figure 3.11**: Dissolved oxygen in Sullivan Lake during the summer of 2022/23. Expressed as %DO vs. temperature (top graph), and DO vs. flow (bottom graph). Flow in the Wainui Te Whara is used as a proxy for the pattern of inflows to Sullivan Lake.

*Night-time supersaturation*

Diurnal fluctuations in DO is a common feature of lakes, but it is unusual for a lake to remain super-saturated in DO during the night as occurred throughout April to May 2022 - normally respiration would reduce night-time DO to less than 100% saturation. There are several possible explanations for night-time supersaturation. Accumulation of DO may occur in a waterbody if the import (via photosynthesis and diffusion) exceeds the export (via respiration and diffusion). Algae often produce more oxygen during the day than they consume at night, but this can reverse if photosynthesis is reduced (e.g. by low irradiance), or if respiration increases (e.g. by algae senescence). Super-saturated oxygen stored in the water is slowly lost to the atmosphere by diffusion, and the rate of this loss can increase with mixing, which reduces the DO in the water that can later be used at night.

Burke (1995) found that oxygen produced by benthic cyanobacteria caused supersaturation (up to 370%) in the bottom water of a stratified saline lake. This was because the transport of oxygen across the sediment-water interface was limited by diffusion, and the export of oxygen out of benthic cyanobacteria during the day proceeded faster than the daytime import, thus allowing supersaturation of the bottom waters.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



The relative strength of respiration and photosynthesis is influenced by multiple factors. Wieland and Kuhl (2006) found that at low irradiance, oxygen consumption (through respiration) increased more strongly with temperature than production (through photosynthesis), but the opposite occurred at high irradiances.

#### 3.6.3.2 Spatial Variation in DO

Sullivan Lake can have large spatial variations in DO and pH. Synoptic surveys undertaken in the early morning and late afternoon during May 2022 found super-saturation in the main body of the lagoon (consistent with DO logger results) and low DO at the western end where there was dense water lily. Areas of low DO in the western end were independent of whether the samples were collected under the water lily or in open water at the western end (**Figure 3.12** and **Figure 3.13**).

Sullivan Lake also exhibits large spatial variation in water pH. This has the same pattern as DO – high in the main body of the lagoon (associated with algae photosynthesis) and low at the western end (likely) due to respiration/decomposition of organic sediments (**Figure 3.14** and **Figure 3.15**). It is likely that the western section of the Sullivan Lake had organic sediments exerting a high sediment oxygen demand. It is also likely that shading by the waterlily supressed phytoplankton growth, resulting in less extreme diurnal fluctuation in DO and pH.

The pattern observed during the synoptic surveys in April 2022 was consistent with measurements collected through 2022, i.e. lower DO and pH in the western end (near King Street) compared to the main body of the lake (near Olympic Drive walkway) (**Table 3.4**).

**Table 3.4**: Spatial comparison of temperature, DO and pH in Sullivan Lake at Olympic Drive and the western end at King Street.

| Site | Date | Time | Temp. (oC) | %DO | DO (mg/L) | pH |
|---|---|---|---|---|---|---|
| Sullivan Lake Olympic Dv | 23/01/22 | 6:55 | 24.6 | 45 | 3.8 | 8.3 |
| Sullivan Lake West | 23/01/22 | 6:50 | 25.0 | 2.7 | 0.22 | 6.8 |
| Sullivan Lake Olympic Dv | 09/05/22 | 17:15 | 15.3 | 154 | 15.4 | 8.9 |
| Sullivan Lake West | 09/05/22 | 17:24 | 15.2 | 133 | 13.3 | 8.3 |
| Sullivan Lake Olympic Dv | 24/06/22 | 15:03 | 11.1 | 119 | 13.1 | 7.1 |
| Sullivan Lake West | 24/06/22 | 14:49 | 9.9 | 56 | 6.3 | 5.9 |
| Sullivan Lake Olympic Dv | 30/10/22 | 12:00 | 19.5 | 119 | 10.7 | 9.0 |
| Sullivan Lake West | 30/10/22 | 12:40 | 18.4 | 7.7 | 0.72 | 6.3 |

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 3.12:** Spatial variation of dissolved oxygen in Sullivan Lake during early morning on 5 April 2022. Note super-saturation in the main body of the lagoon and low DO at the western end.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



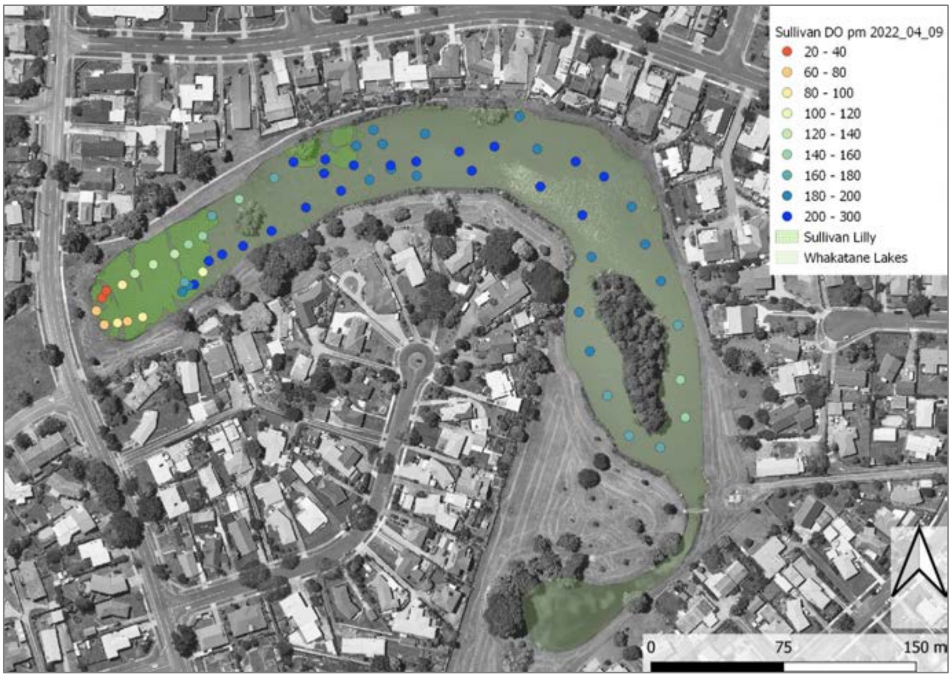



**Figure 3.13:** Spatial variation of dissolved oxygen in Sullivan Lake during late afternoon on 9 April 2022. Note super-saturation in the main body of the lagoon and persistent low DO at the western end.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



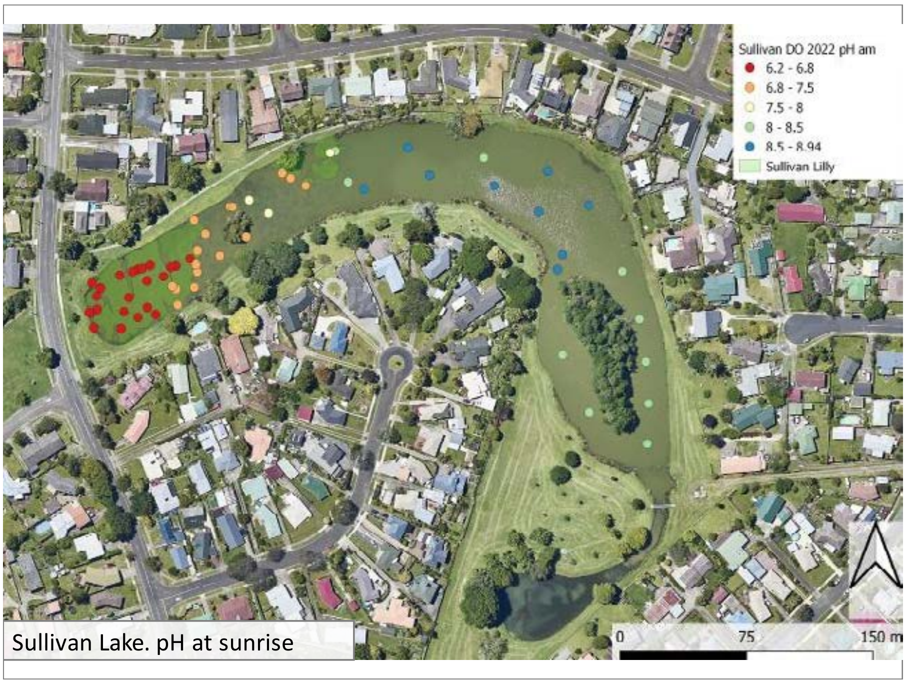



**Figure 3.14:** Spatial variation of pH in Sullivan Lake during early morning on 5 April 2022. pH is very high in the main body of the lagoon (consistent with photosynthesis) and low at the western end (consistent with respiration/decomposition).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**




**Figure 3.15**: Spatial variation of pH in Sullivan Lake during late afternoon on 9 April 2022. pH is very high in the main body of the lagoon (consistent with photosynthesis) and low at the western end (consistent with respiration/decomposition).

#### 3.6.3.3 Summary of DO regime

Overall, the DO regime in Sullivan Lake has high temporal and spatial variability. The lake often has very large diurnal fluctuation in DO due to algae blooms, but the DO regime also appears influenced by heavy rain flushing algae biomass, BOD loads associated with stormwater, the growth of macrophytes curled pondweed moderating phytoplankton biomass, the collapse of curled pondweed exerting an oxygen demand, and aeration from strong winds. At the western end of Sullivan Lake, where waterlily was prevalent, pH and DO concentrations were lower and daily fluctuations smaller than in the main body of the lake. This is likely due to both oxygen demand of organic sediments, and shading by waterlily supressing algae growth.

### 3.6.4 Metals from stormwater

Stormwater enters Sullivan Lake from the Whakatāne South Stormwater catchment; this includes stormwater from the industrial area around Te Tahi Street. Hamill (2017) found that the lake water itself is well within ANZG default guideline values (**DGV**) for all metals, however the lake sediment was moderately high in zinc (i.e. between the sediment DGV but within the guideline high values). This was likely due to stormwater inputs over many years, including stormwater associated with industrial activities near Te Tahi Street culvert. Other heavy metals (i.e., copper, lead) had sediment concentrations less than the sediment DGV.

## 3.7 Water quality issues affecting Sullivan Lake

Key ecological and water quality issues identified in Sullivan Lake include:

- Poor water quality: Low clarity, high nutrients (particularly phosphorus), cyanobacteria blooms, and low dissolved oxygen.
- Water quality not suitable for recreational bathing during frequent cyanobacteria blooms and *E.coli* bacteria.
- Extreme fluctuations in dissolved oxygen with daily minimum (night-time) DO commonly below guideline values.
- Lower dissolved oxygen at the western (King Street) end of the lake, probably due to a high sediment oxygen demand.
- Water lily cover expanding at the western (King Street) end to cause issues for aesthetics and boat usage.
- A lack of native aquatic macrophytes to regulate water quality and phytoplankton growth, and providing habitat for invertebrates and fish.
- The recent occurrence of *P. crispus* in Sullivan Lake improves water quality during spring growth, but can reduce DO following collapse and senescence of beds during mid-summer. There is opportunity to improve water quality by harvesting. If harvesting is not undertaken prior to collapse of macrophyte beds, then adverse effects on DO could be minimised by increasing the volume of flow augmentation during this time.
- Lack of emergent macrophytes or wetland margins to improve water quality and provide habitat for invertebrates and fish.
- Siltation from sediment shallowing the lake over the long-term.
- Occasional outbreaks of avian botulism during summer.
- Lack of fish passage for migratory fish (e.g. shortfin eel and inanga).
- Pest plants in drain downstream of Sullivan Lake.

# 4 Management Actions to improve Sullivan Lake

## 4.1 Introduction

The Sullivan Lake Reserve Management Plan (**SLRMP**) was updated in 2015 and includes goals to both manage and enhance the conservation values, and to manage and improve the water quality of the lagoon. Although the SLRMP does not identify specific targets, it is clear that further interventions are required to improve the water quality and ecology of the lake.

Approaches to improving lake water quality have been described in several recent reviews for New Zealand lakes (e.g., Abell *et al*. 2020, Hamilton 2019, Abell 2018, Hill 2018, Gibbs and Hickey 2012). Abell et al. (2020) grouped restoration techniques as: a) controlling external loads, b) controlling internal loads, c) biomanipulation and d) hydraulic manipulation. A summary of restoration techniques described in Abell *et al*. (2020) is in **Appendix 2**.

Aquatic macrophytes can be perceived as a nuisance by some lake users. While excessive growth can cause water quality problems, they also have a vital role in maintaining lake water quality and ecology. There are multiple control options for macrophytes that have been discussed in detail in de Winton et. al (2013) and are described on the NIWA website: https://niwa.co.nz/freshwater/our-services/aquaticplants/outreach/weedman .

Sullivan Lake will require an integrated approach that reduces external and internal nutrient loads, and enhances biological processes mediated through aquatic macrophyte and wetland vegetation. Potential intervention measures to address specific water quality and ecological issues in Sullivan Lake are described in **Table 4.1**. A sub-set of these management interventions were selected based on their potential benefits and input from WDC. This section describes these management option, including their benefits, risks and value for money.

The key management interventions assessed for Sullivan Lake are:

- Reducing catchment sediment and nutrient loads (including use of silt traps)
- Increase flow augmentation during summer.
- Treatment wetland to trap sediment, nutrients and improve biodiversity.
- Floating wetlands to remove nutrients and improve biodiversity.
- Sediment phosphorus (P) locking to reduce internal load of P (e.g. using alum).
- Dredging to remove organic sediments near waterlilies.
- Bottom-lining to contain the spread of water lily.
- Harvesting macrophytes to manage plant cover and remove nutrients.
- Grass carp to control / remove macrophytes.
- Silver carp to control phytoplankton.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



**Table 4.1**: Potential management options to address ecological and water quality issues in Sullivan Lake

| Issue | Cause | Potential management options |
|---|---|---|
| Supertrophic high concentration of nutrients, algae, poor clarity. Cyanobacteria blooms. | External nutrient load. | o Create treatment wetlands at western and southern end of lake.<br>o Floating wetlands for N removal and habitat (risk of root attachemnt in very shallow areas)<br>o Continue to reduce risk of sewage overflows. |
| | Internal nutrient load via sediment resuspension, anoxia, plant senescence and/or waterfowl. | o Dredging of fine sediment at western end of lagoon.<br>o Harvest curled pondweed in early summer to remove nutrients and avoid collapse.<br>o P-locking |
| Poor oxygen conditions | Phytoplankton and cyanobacteria blooms | o Manage nutrient loads (as above)<br>o Ensure areas of macrophytes in lake to help suppress excess algae (i.e. maintain some areas of waterlily).<br>o Increase volume of flow augmentation during summer to increase flushing. |
| | Sediment organic matter exerting a BOD load in eastern end | o Dredging at western end (King St) where more organic muds and lower DO.<br>o Consider harvesting some waterlily prior to winter senescence to reduce BOD load. |
| Excessive aquatic plant cover affecting recreation and aesthetics | Waterlily cover dominating western end. Provides many WQ benefits but excessive cover adversely affects asethetics, recreation and possibly DO. Very few other macrophytes, but recently curled pondweed growing during spring/summer. | o Manage waterlily extent by dredging soft sediment and lily at western (King St) end (e.g. within 10m from shore).<br>o Contain lily regrowth using mats to cover sediment.<br>o Harvest curled pondweed in early summer prior to collapse.<br>o Harvesting is preferable to spraying as it avoids the risk lof releasing nutrients and oxygen demand.<br>o Grass carp are not recommended for Sullivan Lake as they risks with worsening eutrophication. |
| Pest plants in drain downstream of Sullivans Lake | Egeria, Elodia | o Direct removal<br>o Targeted herbicide spray |
| Siltation | Long term siltation from inflowing stormwater. Also biomass accumulation at King Steet end | o Silt traps for main stormwater inflows and eastern end (foot bridge) with possible flocuulation.<br>o Dredging at western end (King St).<br>o Limited opportunity for sediment control devices in stormwater catchment. |
| Occasional outbreaks of avian botulism during summer | Associated with warm water, anoxic sediments and high density of waterfowl. | o Remove carcasses of dead birds from the lake and margins. |
| Litter | Rubbish directly and via stormwater | o Operational street sweeping<br>o Litter traps<br>o Regular "pick-ups" |
| Riparian management resticting development of marginal wetlands | | o Plant native riparian vegetation to optimise habitat values.<br>o Create riparian wetlands in water with sloping banks. |
| Enhance biodiversity | | o Create wetlands, consider floating wetlands for invert., bird and fish habitat.<br>o Animal pest control (Halo) |

## 4.2 Reduce external nutrient loads from catchment

### 4.2.1 General Description

A major driver of lake eutrophication is excess nutrient loading from the catchment, and reducing external nutrient loads is an important strategy for lake restoration. The control of both nitrogen and phosphorus is important in New Zealand lakes where nitrogen limitation of phytoplankton biomass accumulation is common (Abell et al. 2010).

Successful control of external nutrient loads requires knowledge of where, when and how nutrient losses are occurring from the catchment. For many lakes, diffuse pollution from agriculture contributes the majority of nutrients (Gluckman 2017). But in urban catchments, point sources (e.g. sewage or sewage overflows) can be a major source of external nutrient loads and controlling these can provide substantial nutrient load reductions. A summary of key measures to reduce external nutrient loads is provided in **Appendix 3**.

### 4.2.2 General Application and Constraints

There is typically a lag between reducing external nutrient loads from the catchment and improvements in lake water quality because it takes time to reduce the stores of nitrogen and phosphorus within the lake sediments. Jeppesen et al. (2005) reviewed changes in 35 lakes subject to external nutrient load reductions and found that in-lake TN concentrations typically took <5 years to decline, but in-lake TP typically took 10-15 years. This reflected slower removal of internal phosphorus loads compared to removal of nitrogen by denitrification.

### 4.2.3 Cost-effectiveness

McDowell and Nash (2012) found that land management strategies (e.g. fertiliser management) were the most cost-effective way of mitigating phosphorus exports. Edge-of-field strategies, which remove P from runoff (i.e., wetlands) or prevent runoff were less cost-effective, but had other benefits including removing other contaminants like nitrogen. Similarly in urban areas, addressing external nutrient loads at source is often the most cost-effective management strategy.

### 4.2.4 Application to Sullivan Lake

#### 4.2.4.1 Suitability

Potential options to reduce external nutrient loads entering Sullivan Lake from its catchment include:

- Further minimising the (already low) risk of sewage overflows by identifying the potential for stormwater ingress into the sewage system, tracing and addressing any stormwater cross-connections.
- Encourage no or low fertiliser use in the lake's catchment area. Where it must be used, encourage slow-release fertilisers and application when rain is unlikely.
- Use P-sorbents within waterways.
- Sediment traps within culverts.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Lake catchments are particularly sensitive to nutrient inflows. This should be reflected in the priority for reducing the risk of stormwater ingress in the catchments of Sullivan Lake and Awatapu Lagoon. These is also potential for Whakatane District Council to be involved in education of property owners of ways to reduce nutrient loads from urban landuse in the catchment of these lakes.

The practical implementation of P-sorbents within waterways is restricted by the nature of the catchment being either urban or very steep. However, there may be opportunity to use P-sorbents at the outlet of culverts as they enter Sullivan Lake. McDowell et al. (2007) described the use of melter slag contain in a mesh bag (called "P socks") and placed on the bed of the Mangakino Stream (Lake Rerewhakaaitu) to sorb phosphorus. These reduced, on average, the concentration of DRP and TP by 35% and 21% respectively, and reduced loads by 44% and 10% respectively. They were more effective at low-flow.

There is potential to trial melter slag P-socks at the culverts near the Sullivan Lake footbridge, but some additional sampling of inflows is recommended assess their likely effectiveness. Regular monitoring would be needed to assess their effectiveness over time and when they would need to be maintained and replaced.

The implementation of sediment traps in the catchment is restricted by the steep topography. A practical location for sediment traps is at the outlet of culverts as they enter Sullivan Lake. This is discussed further in the context of wetland forebays. There may also be potential for installing proprietary devices to trap sediment within some culvert inlets, for example along Valley Road. Practical locations would need to be identified; they would be most effective on coarse sediment rather than fine sediment[8]. Installing sediment capture devices within the urban stormwater network would require significant capital work and, like all sediment traps, would require regular monitoring and maintenance.

### 4.2.5 Summary

Reducing external nutrient loads very important for lake restoration and reducing eutrophication. Reducing nutrient loads from within the catchment is often also very cost-effective. For Sullivan Lake there may be potential to:

- Further reduce the (currently low) risk of sewage overflows during heavy rain by prioritising the catchment for reducing storm water ingress.
- Educate land owners about reducing sediment and nutrient discharges to the stormwater network.
- Use P-socks at culvert outlets to bind phosphorus.

[8] E.g. SPEL Stormceptor claims up to 83% removal of suspended solids, 100% removal of sediment >3mm (larger than coarse sand), and 99.9% removal of light liquids (e.g. hydrocarbons) (SPEL Stormceptor product brochure).

- Install sediment traps at culvert outlets (see discussion on wetlands). There may also be opportunities at culvert inlets but practicality and costs need further investigation.

## 4.3 Increase flushing by flow augmentation

### 4.3.1 General Description

Manipulating lake inflows to promote flushing can support lake restoration by increasing the rate of phytoplankton algae removal or by diluting poor water quality with higher quality water. Generally, flushing of algae is only effective when it can reduce the hydraulic residence time to less than the time it takes for phytoplankton to double their biomass (c. <20 days) (Jørgensen 2002, Hamilton 2019).

Biological uptake often reduced dissolved nutrients to low levels in lakes. Thus, introducing only a small amount of water, without sufficiently reducing the residence time, can create a risk of introducing additional nutrients in a bioavailable form that promotes additional phytoplankton growth.

The goal of increasing flushing was a major driver for implementing the re-diversion of the Kaituna River to the Maketū Estuary. In this situation, higher flushing by river water has helped reduce the biomass of macroalgae accumulated on the mudflats.

### 4.3.2 General Application and Constraints

The potential to increase hydraulic flushing is very lake specific and requires a suitable donor water body nearby which can dilute poor quality water with higher quality water, and/or sufficiently increase flushing rates. Consideration also needs to be given to the quality of the water being used for flushing to avoid making water quality issues worse.

Increasing flushing to Sullivan Lake, as proposed below, will not prevent the formation of cyanobacteria blooms, but it will help reduce the intensity of these blooms by removing algae biomass.

### 4.3.3 Cost-effectiveness

The cost-effectiveness of using flushing to improve lake water quality is very site specific. In the case of Sullivan Lake, increasing the volume of flow augmentation from the Whakatāne River during summer is likely to have moderate cost-effectiveness.

Adding flow to increase flushing will have most benefit during summer/autumn dry periods. It will be considerably less cost-effective during winter when rain-events are common. Augmenting the flow to Sullivan Lake is easy to scale up and adjust according to rain conditions.

### 4.3.4 Application to Sullivan Lake

Augmenting flow to Sullivan Lake during summer has good potential to improve water quality by increasing flushing via flow augmentation from the Whakatāne River. This should occur summer dry periods when water quality in Sullivan Lake is worse (e.g. cyanobacteria blooms) and water quality in the Whakatāne River is better (e.g. lower dissolved nitrogen).

TN and TP concentrations are typically lower in the Whakatāne River (median 0.19 mg/L and 0.05 mg/L respectively) than Sullivan Lake (median 0.48 mg/L and 0.14 mg/L respectively); but bioavailable DIN and DRP are higher in the Whakatāne River (median 0.12 mg/L and 0.03 mg/L respectively) than in Sullivan Lake (median 0.01 mg/L and 0.018 mg/L respectively)[9]. During summer (December-March), the concentration of dissolved N and P in the Whakatāne River are lower (median DIN and DRP of 0.04 mg/L and 0.023 mg/L respectively), although DRP remains relatively high due to natural geology influences. To minimise the risk of dissolved nutrients in Whakatāne River water stimulating further algae growth, flow augmentation should be limited to January to March (inclusive), with the option of extending this to December to April (inclusive) if proceeded by at several weeks of dry weather and below median river flows.

Flow augmentation should also be applied in conjunction with installing treatment wetlands that will help remove incoming nutrients.

#### 4.3.4.1 Proposed implementation

WDC currently pumps up to about 40 $m^3$/hour (11.1 L/s) into Sullivan Lake from the Whakatāne River to improve flushing. However, in practice it is often closer to 3 L/s. During summer there is little rain to support natural inflows and lake water quality is typically worse. At this time (January to March inclusive), flow augmentation into Sullivan Lake from the Whakatāne River should be maintained at c. 40 $m^3$/hour to 50 $m^3$/hr (11.1 to 14 L/s).

Ensuring the flow pumped into Sullivan Lake of 11 to 14 L/s during summer will ensure a hydraulic residence time of about 20 days even during periods of low flow - which is sufficient to flush phytoplankton.

#### 4.3.4.2 Cost

Infrastructure is already in place. To increase the flow augmentation to Sullivan Lake may require installing and running a larger pump. Rough order costs are[10]: capital expenditure under $5000 and annual operating costs of c. $2000. Infrastructure is mostly already in place. The capital cost is low and it is easy to trial.

### 4.3.5 Summary

Ensuring flow augmentation from the Whakatāne River can reduce the intensity of algae blooms in Sullivan Lake by increasing flushing for relatively low cost. This would have most benefit and lowest risks if undertaken during summer (January to March) and when implemented in conjunction with the creation of treatment wetlands. Flow augmentation provides little benefit during rain events. If treatment wetlands are constructed, than flow augmentation should be reduced during rain events to ensure wetland treatment of stormwater is optimised.

[9] Hamill et al. 2020
[10] Based on increasing the flow rate to 1000 $m^3$/day (11.6 L/s) and lifting to 8m head, will require a pump size of about 1.5kW or two pumps of about 1.1kW, plus piping. Operating cost base on kWh for a pump operating 24/7 for 4 month using the pump power calculator in https://www.engineeringtoolbox.com/pumps-power-d_505.html

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



## 4.4 Treatment Wetlands

### 4.4.1 General Description

Wetlands are the 'kidneys of the landscape'. They are a natural interface between land and water that cleans the water. Contaminants are attenuated and removed through processes of denitrification, plant uptake, deposition, adsorption and mineralization. Emergent wetland plants filter the water, enhance denitrification and help remove and immobilise heavy metals from the water (e.g. Kadlec and Wallace 2009, Guigue J et al. 2013).

Constructed treatment wetlands are commonly used to remove sediment, nitrogen (**N**) and phosphorus (**P**) from surface water. Constructed wetlands replicate and optimise the treatment mechanism found in natural wetlands including: denitrification, uptake and storage by plants, precipitation, settling and burial within sediment, and sorption of phosphorus to material.

Numerous guidelines are available to inform the design of treatment wetlands (e.g. Tanner 2020, Farrant et al. 2019). Some key aspects of treatment wetland design are:

- Wetlands should be sized to keep water velocity sufficiently low to avoid scour and to provide sufficient residence time to achieve the required removal rates. contaminant reduction efficacy increases as constructed wetland area increases, but with gradually diminishing returns. Often wetlands are sized to be between 1% and 5% of their contributing catchment (i.e. 100-500 $m^2$ of wetland per ha) [11].
- Flow must be dispersed across the wetland so that there is minimal short circuiting. This can be achieved by attention to dispersion of inflows, having a length to width ratio of between 5:1 and 10:1,[12] dense planting across the wetland, and banded planting perpendicular to flows.
- Incorporate a sediment forebay/sedimentation pond to settle sediment and assist with regular maintenance. Sedimentation ponds are often sized as 10% of the wetland size or alternative between 40 $m^2$/ha and 80 $m^2$/ha of catchment depending on the rainfall intensity.
- Maintain water depths at 0.2-0.4 m to maintain healthy emergent wetland plants and optimise nutrient removal. Deeper water (>1.2m) zones help disperse the flow across the width of the wetland.
- Use soils with low potential for release of P. This might be achieved by mixing with sub-soil or P-retaining material (e.g. allophane, tephra) (Ballantine and Turner 2010).
- Maximise ancillary benefits for biodiversity by using a diverse range of locally sourced wetland plants.

[11] Small wetlands still remove contaminants but have lower percentage removal rates and need more attention to design for bypass flows to avoid being overwhelmed by stormflows.
[12] Not less than 3:1

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



In-lake wetlands and riparian wetlands work in the same away as treatment wetlands by intercepting and treating groundwater or runoff percolating through the soil. They also provide habitat for zooplankton that predate on phytoplankton and provide a natural control on their biomass.

### 4.4.2 General Application and Constraints

Treatment wetlands are extensively used to treat stormwater, wastewater and stream inflows to lakes. They are often used to remove sediment, nutrients (N and P), and metal contaminants. The effectiveness of wetlands for nutrient removal depends on a range of factors including: design, hydraulic loading, incoming nutrient concentrations and seasonal temperatures.

Misch et al. (2000) estimated sustainable annual removal rates for non-point source nitrogen and phosphorus of respectively 100 – 400 kg N/ha and 5 – 50 kg P/ha. Hamill et al (2010) used empirical relationships developed by Kadlec and Wallis (2009) to calculate average annual removal rates for constructed wetlands to treat water in the Rotorua catchment of 368 kg N/ha and 11 kg P/ha of wetland. The lower removal rate for P is due to both lower concentrations of P in the incoming water and less efficient removal of dissolved P.

Tanner et al. (2020) calculated the performance of constructed treatment wetlands for pastoral runoff. An appropriately constructed wetland sized at 2% of the catchment area would remove 65%, 36% and 35% of TSS, TN and TP respectively. But this assumes that most P is in particulate form associated with sediment. Wetlands are not very effective at removing P in dissolved form.

Phosphorus removal rates in constructed wetlands can vary widely depending on the design and past land use. If the underlying soil is high in phosphorus, then the wetlands can desorb phosphorus and be a net source of phosphorus. The risk of this occurring can be mitigated, and the ability of wetlands to retain phosphorus enhanced, by augmenting the sediment with phosphorus binding material.

### 4.4.3 Cost-effectiveness

Wetlands provide multiple benefits to support ecological functions, nutrient removal and biodiversity. Constructed wetlands can be a cost-effective way of removing sediment and nitrogen (estimated as $79 / kg N /yr), but are less cost-effective at removal of phosphorus (estimated at $2550 kg P/yr) (Hamill et al. 2010)[13]. Cost-effectiveness for phosphorus removal is considerably improved if the source of P is predominately associated with particles P sorbing material is used and the sediment forebay is well maintained.

### 4.4.4 Application to Sullivan Lake

#### 4.4.4.1 Suitability

There is potential to build an in-lake wetland at the southern end of Sullivan Lake near the footbridge to treat the main inflows of and enhance the current sediment trap. These locations allow the wetland to treat water from the main inflows to the lake. This would provide multiple benefits of reducing

[13] Based on long-term sustainable removal rates (excluding sorption to wetland sediments) and using whole-of-life costs (including land acquisition, maintenance and rejuvenation).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



sediment accumulation, improved water quality, improved biodiversity and habitat for invertebrates, fish and birds.

A possible layout for a treatment wetland to intercept the main inflows to Sullivan Lake is shown in **Figure 4.1**. This would consist of two treatment wetlands, one in the south capturing Te Tahi Street culvert with an area of c. 1200 $m^2$ (plus forebay) and one near the foot bridge with an area of 2400 $m^2$ (plus forebay). The presented wetland layout is smaller than ideal for a treatment wetland[14], nevertheless it would provide cost-effective treatment of inflows in terms of contaminant removal. The forebay at the footbridge for sediment settling currently exists, but would be deepened as part of the work.

The water depth in shallow zones of the wetland should be about 300-400mm, but most emergent wetland plants need to be established in shallower water below the height of the shoots (e.g. about 100mm deep). This can be achieved by either temporarily lowering water levels, or by planting along shallower edges and allowing plants to spread naturally over time. Once established, plants can survive periods of exposure and extend into deeper water. Deep zones (e.g. >1.2m) prevent the vegetative spread of emergent macrophytes.

Riparian wetlands would be low cost and easy to establish using a long reach digger from the lake edge to redistribute sediment.

There are a number of native emergent plants suitable in Sullivan Lake including: *Eleocaris sphacelate, Machaerina articulata*[15]*, Carex secta,* and *Schoenoplectus tabernaemontani*. *Typha orientalis* (raupo) could be considered but would need care to ensure it is contained by surrounding deep zones (F**igure 4.2**)

#### 4.4.4.2 Cost

The cost of establishing areas of wetland filters near stormwater outlets of Sullivan Lake is estimated to cost in the order of $50,000 to $90,000, plus consenting costs. The cost will vary depending on earthwork requirements to shallow some areas and deepen other areas, and the extent of initial planting. Some low P substrate may need to be imported to improve P binding.

The budget will need to allow for control of pest plants during establishment and ongoing removal of sediment from the forebays.

### 4.4.5 Summary

Treatment wetlands are common and cost-effective way to filter water to remove sediment, nutrients and metals. Wetlands also support ecological functions in lakes and enhance biodiversity. There is good potential to incorporate both treatment wetlands and riparian wetlands into Sullivan Lake to treat inflows and improve biodiversity values.

[14] The catchment contributing to these two wetlands would be about 50 ha, so the total wetland area would need to be about 0.5 ha to be 1% of the catchment.
[15] Formally *Baumea articulata.*


**Figure 4.1**: Potential layout for a treatment wetland and riparian wetlands in Sullivan Lake to improve water quality and provide biodiversity values.

**Figure 4.2:** An example of *Baumea sp.* growing along a lake wetland margin (from Tanner et al. 2021).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



## 4.5 Floating Wetlands

### 4.5.1 General Description

Floating wetlands consist of buoyant mats or platforms that are mass planted with emergent wetland plants, and are anchored on the surface of treatment ponds or nutrient rich lakes. The plant roots grow through the mats and down into the water column forming large, dense mats. Large root systems develop to allow the plants to obtain their nutrient requirements from the water column. Localised anaerobic zones are created beneath/within the floating mats where the process of denitrification is favoured. Biofilms develop over the extensive root surface area and serve to increase organic matter breakdown, nutrient adsorption and trapping of fine particulates (Sukias 2010).

The shade provided by the plant mats reduces algal growth and results in increased settling of suspended solids onto the bottom of the lake.

### 4.5.2 General Application and Constraints

Floating wetland are widely used around New Zealand for water treatment and ecological enhancement. To be most effective, floating wetlands need to be installed in a location where there is a flow of water passing through them. They are not very effective at removing nutrients if placed in a lake without any current or flow.

Floating wetlands are best used in deeper water (e.g. >1 m) where the plant root systems will not reach the sediment.

The harvesting of plant material is important for long-term sustainable nutrient removal by floating wetlands, and this is particularly important for phosphorus removal (Pavlineri et al. 2017). Some ongoing maintenance is required to control weeds.

The buoyant mats of some floating wetlands can degrade over time and release plastic into the water; however, this can be avoided by using rafts made of HDPE.

### 4.5.3 Cost-effectiveness

Floating wetlands have similar removal mechanisms to conventional wetlands but are about twice as effective at removing nitrogen and phosphorus as conventional constructed wetlands. Where located where water flows, nitrogen removal rates for floating wetlands are about 584 – 876 kg/ha/yr while phosphorus removal rates are about 7.3 – 18 kg/ha/yr (Tanner et al. 2011).

However floating wetlands are relatively expensive to install, so are best used in situations with high nutrient concentrations to take advantage of their good removal rates, or in situations which utilise their co-benefits in providing for shading the water and providing habitat for birds and fish. Hamill et al (2010) estimated the average cost-effectiveness[16] of floating wetlands as $473 / kg N and $24,000/kg P, however these costs may now be lower with availability of new, cheaper, floating wetland products. Because of their relatively high cost, floating wetlands are better suited to situations that optimise their

[16] Annualised cost spread over 50 years.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



treatment ability (i.e., areas with flow and high nutrient concentrations), have space constraints, or where other benefits (e.g., shading, habitat, biomanipulation) are valued.

### 4.5.4 Application to Sullivan Lake

#### 4.5.4.1 Suitability

Floating wetlands could be installed in Sullivan Lake near the inflows where surface flow treatment wetlands are proposed. They could achieve a similar amount of nutrient removal as surface flow wetlands in about half the area, but they would cost considerably more, and are thus not recommended for mass deployment.

A small number of floating wetlands would be beneficial to enhance settling in sediment forebays, where flows are greatest. Also, their use on the main body of a lake for enhancing habitat remains valuable. Floating wetlands can be used as floating nurseries, with mature plants harvested and planted along the lake's riparian margin.

#### 4.5.4.2 Cost

A rough order cost to install a set four floating wetlands in Sullivan Lake, with an effective surface area of about 16.4 $m^2$, is $5,000 to $10,000.

### 4.5.5 Summary

Floating wetlands are a widely used and effective way to remove sediment, nutrients and other contaminants from water. In addition, they provide co-benefits of shading the water and providing habitat for invertebrates, fish and birds. However, they are more expensive than surface flow wetlands, and less cost-effective for most natural waterbodies. Installing floating wetlands in Sullivan Lake would be beneficial, but would be less cost-effective than creating a larger area of conventional wetlands.

## 4.6 Dredging

### 4.6.1 Description

Dredging removes lake bed sediments which both deepens the lake and directly removes accumulated nutrients. It is a well-established method to control internal nutrient loads, and is particularly useful when surface sediments are rich in nutrients and anoxic conditions facilitate the release of these nutrients (Abell et al, 2021, Bormans et al, 2016).

Dredging can substantially reduce sediment nutrient releases in small lakes, and can result in considerable improvement in ecological health. Increasing the depth of the shallow lakes can also reduce the wind-driven resuspension of sediment and nutrients even when deepening is limited to localised areas (Penning et al, 2010 in Abell et al, 2021).

Sediment from dredging needs to be safely disposed. A dredging operation is more efficient if the material can be safely disposed of locally. Material could be used to develop area suitable for riparian wetlands but consideration should be given to immobilising nutrients.

## 7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)



#### 4.6.2 Application and Constraints

The effectiveness of dredging depends on the depth of the lake, composition of the sediment, and ability to target organic and nutrient rich sediments. Its benefits will be limited if organic, nutrient rich or contaminated sediments extend deeper than the depth being dredged. Sampling and testing sediments is valuable prior to undertaking dredging.

Dredging is best undertaken in conjunction with reduction in external nutrient loads to reduce the rate at which surface sediments again become enriched.

Dredging operations are intrusive; it disturbs the sediment and can cause short term reductions in water clarity. In some lakes with anoxic sediments, dredging can release sulphide which can be toxic to aquatic life. It also directly removes benthic fauna, which can be a major disadvantage for its application in some lakes where kākahi or koura are present (this is not the case for Sullivan Lake).

#### 4.6.3 Cost-effectiveness

Dredging is expensive and because of the expense, its use is generally restricted to small, iconic lakes. Hamilton et al. (2014) estimated dredging costs of $100,000 per ha for small lakes, but this will be an under-estimate for Sullivan Lake due to its very small size and urban setting.

#### 4.6.4 Application to Sullivan Lake

##### 4.6.4.1 Suitability for lake

The shallow depth of Sullivan Lake makes it suitable for dredging and suction dredging near the footbridge occurred in 2019. Dredging part of the western end of Sullivan Lake has the potential to achieve multiple goals of physically removing a part of the currently extensive water lily cover, removing organic sediments that are likely contributing to depressed dissolved oxygen concentrations, potentially reducing some internal nutrient load, and deepening sections of the lake.

One option is to remove organic sediment and water lily from the King Street end of Sullivan Lake, west of the island, in a *c.* 10m wide band around the lake edge. This would cover about 210m of lake shore. Removal of 0.5m of material over this area would equate to 1000 $m^3$. Water lily near the centre will be retained. Bottom-liner mats can be laid over the dredged area as a barrier to prevent regrowth of waterlily (discussed below).

The operation could occur with either a long reach digger or suction dredge. The material will need to be dewatered and disposed of and will involve heavy machinery.

Prior to dredging the substrate should be tested for nutrients and organic matter at different depths to inform the potential success of the operation and the depth to which dredging should occur.

##### 4.6.4.2 Cost

A rough order cost of the proposed dredging and disposal is $65,000 to $120,000, excluding the cost of resource consents, contingencies or any bottom-liners (discussed below).

#### 4.6.5 Summary

Dredging is relatively expensive, but dredging part of the western end of Sullivan Lake could provide multiple benefits of reducing water lily cover, improving the oxygen regime, and reducing internal nutrient loads.

### 4.7 Phosphorus Locking

#### 4.7.1 General Description

Phosphorus locking and flocculation is commonly used for lake restoration around the world. The internal load of phosphorus from lake sediments is reduced and made unavailable for algae use by applying chemicals to bind and inactivate the phosphorus in the water column and as it is mineralised and released from the sediment.

A number of materials can be used to adsorb dissolved phosphorus from lake water or inflows and thus reduce the bioavailability of phosphorus within the lake. These can be applied directly to the lake surface or continually drip dosed into a stream inlet. The materials often also cause the flocculation of suspended sediments from the water column. Many products can be used to bind dissolved phosphorus but the most commonly used and/or effective for lakes are aluminium sulphate ('alum'), Aqual-P (an aluminium zeolite combination product), and Phoslock (bentonite clay modified with lanthanum) (Douglas 2016, Wagner 2017, Abell et al. 2021).

Flocculation can be enhanced by adding a separate flocculant; commonly used flocculants include polyaluminium chloride (PAC) and polyacrylamide (PAM). PAM is promising as a flocculant in turbid freshwater systems because they are very efficient and can have low eco-toxicity when formulated in the anionic form (Gibbs and Hickey 2017). Products such alum, Phoslock and Aqual-P perform a dual function of adsorbing dissolved phosphorus and physically capping the sediment.

The alum causes aggregation of particulate matter and causes it to sink to the lake bed and this has potential to removed cyanobacteria /algae within the water column. On the sediment surface, alum forms a thin layer a few millimetres thick, and this layer of alum can sequester DRP as it released from the sediment.

Phosphorus locking methods are widely used in lake restoration including their successful use in Lake Okaro and Lake Rotorua (McBride et al. 2018, Hamilton 2019, Abell et al. 2021). However, the effectiveness of phosphorus locking for lake restoration is lake specific depending on water chemistry, hydraulics, timing and the presence of macrophyte beds. For example, it has been highly effective in inflows to Lake Rotorua but has had very limited effect in inflows to Lake Rotoehu – likely due to interference by ions in geothermal waters and flocculation with hornwort beds (Eger 2018).

#### 4.7.2 General Application and Constraints

It is important to consider site-specific constraints when identifying appropriate products and application strategies. pH is an important consideration; pH >8.5 results in the release of phosphorus bound to aluminium or iron, making products like alum and Aqual-P ineffective. For alum applications in low-alkalinity lakes, it is necessary to use with a buffer (e.g. sodium carbonate or bicarbonate) to maintain pH >6.5 and avoid the formation of toxic $Al^{3+}$ ions (Hickey and Gibbs 2009).

Consideration should be given to the potential ecotoxicological effects of materials being used to avoid acute or chronic effects on lake ecology, but assessment of these risks is well documented (Tempero 2015, 2018, McBride et al. 2018). Consideration also needs to be given to cultural concerns regarding the application of material to lakes.

Geoengineering using phosphorus locking needs to be tailored for a specific lake. It is advisable to evaluate efficacy based on jar tests, laboratory experiments and small-scale field trials. Consideration needs to be given to the costs, ecotoxicity and risk of smothering benthic biota (Hickey and Gibbs 2009).

**Table 4.2** provides a summary of geoengineering materials and their applications. The materials likely to be most applicable to Sullivan Lake or Awatapu Lagoon are alum, Phoslock and Aqual-P. PAC is a flocculant and can be used in combination with alum of Phoslock which absorb the phosphorus. For the immediate management of cyanobacteria blooms, algaecide (e.g. hydrogen peroxide) can used in before phosphorus locking to reduce the risk them later floating from sediments to re-emerge as blooms. Alum and Aqual-P have reduced P binding at high pH.

The longevity of phosphorus locking will depend on incoming nutrient loads, rates of burial and resuspension. Sediment locking is typically less effective in shallow lakes because of higher rates for burial and wind resuspension. One study found alum treatment was typically effective for 15 years in deep lakes compared to five years in shallow lakes (Huser et al. 2016 in Abell 2018). In Lake Ōkaro, alum treatment has been undertaken twice a year for most years since 2013 to control algae.

Scholes (2018) test two water treatment products in mesocosm trials in Sullivan Lake, these were PAP-5 Melter slag (a by-product of the iron making process) and Pond Treat PT-450 (anon-pathogenic microbial enzyme treatment). Both were effective at reducing algae biomass, reducing nutrients and improving water clarity, but he noted that the use of these products should be in conjunction with controlling external inputs.

### 4.7.3 Cost-effectiveness

The use of phosphorus locking material to control eutrophication can be effective, reliable and cost-effective. One study of four urban lakes found in-lake alum treatment was *c*. 50 times more cost-effective than catchment-based measures to reduce storm water nutrient loads (Huser et al 2016). However, they are not suitable for all lakes.

### 4.7.4 Application to Sullivan Lake

#### 4.7.4.1 Suitability

Sullivan Lake is nitrogen limited but reducing phosphorus concentrations is important for controlling cyanobacteria. The source of phosphorus in Sullivan Lake is not well understood, there may be a legacy of phosphorus rich sediment from historical sewage spills. Anoxic conditions that would cause P release appear relatively uncommon in the main water column, but there may localised anoxia at

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



waters in the western end of the lake or at the sediment surface. DRP may also be released with wind-induced mixing mobilising porewater with bottom sediments.

Phosphorus locking (probably with alum) may be a useful remediation for Sullivan Lake, but more information is required before determining its likely success, including the extent to which phosphorus is being released from the sediments.

The longevity of applying alum (or another product) is unknown, but may be short-lived if bottom sediment is resuspended or if there is settling of P-rich sediments. Any application of P-locking should occur after creating of treatment wetlands to reduce nutrient and sediment inflows.

To better assess the potential for successful P-locking in Sullivan Lake will require collecting water and sediment samples from around the lake and incubating sediment cores to determine DRP release rates. This information is also required to calculate application rates. Application rates can be calculated using the areal load of TP in the top 4 cm of sediment plus the areal load of DRP in the overlying water. The amount of buffer required is normally about twice the amount of alum but needs to be checked using lake water.

### 4.7.5 Summary

The use of phosphorus locking material to control eutrophication can be effective, reliable and cost-effective when appropriately tailored for a lake. Phosphorus locking may be a useful restoration tool to control cyanobacteria blooms in Sullivan Lake, but additional investigations are required to determine its likely success, and any implementing of P-locking should occur after creating treatment wetlands to reduce nutrient and sediment inflows.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



**Table 4.2:** Lake geoengineering materials used for phosphorus inactivation and flocculation (reproduced from Table 3 in Hamilton 2019).

| Flocculant | Active com-pound | Carrier | Requirements | Cost (approx.) | Side effects/toxicity | Application difficulty |
|---|---|---|---|---|---|---|
| Alum, PAC | $Al^{3+}$ | None. | Mostly used with a buffer; careful checks required to avoid acidification | Low | Free (uncomplexed) Al ion toxicity to biota (primarily a gill toxicant), highly pH dependent (Gensemer and Playle 1999) | Low-medium |
| Phoslock® | $La^{3+}$ | Bentonite | - | Medium-high | Low-alkalinity waters could lead to greater susceptibility of biota to side effects from $La^{3+}$ | Medium |
| Chitosan (Zou et al. 2006) | | Has been used in association with flocculants for sinking (ballast) purposes | Check for contaminants released by flocculant (if used) | High | Benign: toxicity to higher organisms highly unlikely but appears to act as an algaecide to cyanobacteria | High |
| Oxygen nanobubble modified natural particles (Zhang et al. 2018) | - | A local mined soil is often used, to which oxygen nanobubbles are impregnated | Has not been scaled up; still experimental (laboratory-scale) | Likely to be high | Benign unless the modified soil releases contaminants | Medium |
| Aqual-P | $Al^{3+}$ | Zeolite | - | Medium | Evidence to date indicates Aqual-P is relatively benign | Medium |

## 4.8 Macrophyte harvesting to manage aquatic plants and reduce nutrients

### 4.8.1 General Description

Aquatic macrophytes ('lake weeds') are an important part of lake ecosystems, and moderate water quality by stabilising sediment and cycling nutrients from the sediments and water column. However, excessive growth of (usually) exotic invasive macrophytes can cause a nuisance or contribute to water quality problems. Harvesting and removal of macrophyte biomass can control excessive cover and remove carbon and nutrients from the lake system. This prevents the nutrients being cycled back into the lake water column during periods of pant senescence or die-off.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Macrophyte harvesting in lakes is usually done by a custom-made boat-operated harvester that cuts the plants below the water surface and collects the mown sections (**Figure 4.1**). Larger harvesters can cut plants up to about 2m below the water surface. Harvested material is transported to the lake shore where it is dewatered and removed for disposal (e.g. to compost). To maximise nutrient removal from a lake, the harvested material should be removed from the catchment or treated in a way so as to prevent nutrient leaching back to the lake.

The harvester mows off the top of surface reaching weed beds, it does not pull up the roots, and the macrophytes grow back over time. This regrow is itself be beneficial for water quality as macrophytes reduce the amount of dissolved nutrient available for algae growth.

Macrophyte harvesting can be undertaken using a long reach digger with a modified cutting head, but this method is limited to the reach of the digger, so is more suited to drains.

**Figure 4.1**: A lake macrophyte harvester in operation on Lake Rotoehu (source: www.lakeweed.co.nz).

### 4.8.2 General Application and Constraints

Macrophyte harvesting is commonly used to control macrophytes in both small ponds and large lakes. Macrophyte harvesting is commonly used in New Zealand to reduce nutrient loads (e.g., hornwort harvested from Lake Rotoehu by Bay of Plenty Regional Council (**BOPRC**) (Horne 2020)), reduce nuisance macrophyte cover in drains, hydro lakes (e.g. Genesis) and stormwater ponds (Auckland Council).

Its suitability as a method depends on goals for lake management, site constraints and the biomass of plants present. It is effective at managing dense macrophyte beds, however because macrophyte beds help maintain a clear water state in lakes, harvesting operations should be done in a way to ensure weed beds to not collapse without any replacement native communities to replace them.

Harvesting is not a suitable method to eradicate weeds or control new incursions, as plant fragments caused by harvesting can act as propagules.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Harvesting operations need to follow good biosecurity practices to avoid the spread of pest plants and animals. This requires cleaning all equipment before transporting between waterbodies by following the Check, Clean and Dry procedures from Ministry for Primary Industries (**MPI**)[17].

Permission is required from Ministry of Primary Industries (**MPI**) if transporting, outside a catchment, pest plants classified as 'unwanted organisms' under the Biosecurity Act (1993). This would apply to hornwort (*Certatophyllum demersum*) and parrots feather (*Myriophyllum aquaticum*) both found in Awatapu Lagoon, but not to the waterlily or curled pondweed (*Potamogeton crispus*) that occurs in Sullivan Lake.

### 4.8.3 Cost-effectiveness

Macrophyte harvesting has multiple benefits of controlling excessive macrophyte biomass to maintain recreational and water quality values, maintaining some macrophyte cover to support biodiversity and water quality benefits, and removing a load of carbon, nitrogen (N) and phosphorus (P) from the lake system. An alternative practice of herbicide spraying is cheaper to achieve the single purpose of controlling macrophyte cover, but does not achieve any of the co-benefits for water quality.

Lake weed harvesting of hornwort from Lake Rotoehu (Bay of Plenty) removes about 1.2 kg N and 0.16 kg P per tonne of wet weed (Gibbs 2015). The harvesting from Lake Rotoehu is estimated to cost about $53,000 per year and remove about 320 kg P/yr and 2,400 kg N /yr (Hamilton and Dada 2016), i.e. a cost-effectiveness of $166 /kg P and $22 / kg N. However, the cost of small-scale operations is considerably more. Weed harvesting from Awatapu Lagoon South, Whakatāne in 2019 cost c. $35,000 for c. 200 tonnes of weed which would have removed about 240 kg of N and 32kg of P with a cost-effectiveness of $146 /kg N and 1095 / kg P. This cost included consenting, establishment, harvesting, dewatering and disposal. It may be higher if the weed harvester has to be transported further.

### 4.8.4 Application to Sullivan Lake

#### 4.8.4.1 Suitability

Macrophyte harvesting could effectively manage the cover or waterlily and/or curled pondweed in Sullivan Lake, but would be most cost-effective on occasions when curled pondweed is growing across the lake. To achieve benefits of managing curled pondweed, the harvesting operation will need to occur after it has become surface reaching and before it collapses, i.e. between about late October and early January. The cost-effectiveness of macrophyte harvesting from Sullivan Lake will be considerably less in years where curled pondweed is not prolific.

Sullivan Lake would require a small harvester, i.e. a smaller boat-based harvester or amphibious machine[18]. Harvested material needs to be dewatered for one to two days and the site chosen for this needs to be accessible to a truck and digger.

Using herbicide to control aquatic plants is cheaper than mechanical harvesting but does not provide any water quality benefit because it does not remove any organic matter or nutrients. Some

[17] https://www.mpi.govt.nz/outdoor-activities/boating-and-watersports-tips-to-prevent-spread-of-pests/check-clean-dry/#CCDmethod
[18] Enviroland's uses an amphibious machine that uses a cutting bar to cut vegetation below the water and once cut, the now floating vegetation is collected and pile on the bank for removal (https://www.envirolands.co.nz/services/).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



communities have concerns about the potential health and environmental risks from frequent herbicide use.

#### 4.8.4.2 Cost

The cost of macrophyte harvesting can vary widely depending on the scale of the operation. The cost of macrophyte harvesting in Sullivan Lake is expected to be in the range of $20,000 to $35,000 per harvest, but will depend on the amount to be harvested. The cost is likely to reduce as operations become more efficient, e.g. for composting.

### 4.8.5 Summary

Macrophyte harvesting is a widely used method for controlling excessive macrophyte biomass, improving water quality, and contributing to long-term removal of nutrients from the lake system. A small harvester could be used in Sullivan Lake between late spring to early summer to reduce the cover of curled pondweed and waterlily. It is more expensive than herbicide spray, but provides water quality benefits not achieved by herbicide spraying.

## 4.9 Bottom-liner to contain plant growth

### 4.9.1 General Description

Lining the bottom of waterbodies can be used to eradicate aquatic weeds and reduce regrowth by excluding light and preventing root access to substrate. A range of different material can be used for bottom-liners; plastic or sheets polyethylene woven mats are most common, but liners can also be made from woven cloth, jute or flax. The liners are usually held in place using gravel, sand bags or stakes. They are best installed when plants height is low (e.g early spring) (De Winton et al. 2013).

Bottom-liners have been successfully used to reduce the extent of a *lagarosiphon* cover in Rosie Bay, Lake Waikaremoana, and to manage water lily in Lake Ōkāreka (de Winton et al. 2013).

Harakeke flax mats (called Uwhi) have been trailed in Lake Rotorua (Hamurana springs) to smother invasive aquatic weeds. These have been found to last longer than hessian mats and the Uwhi were also used as a refuge for kōura.[19]

### 4.9.2 General Application and Constraints

Bottom-liners work better on flat slopes rather than on steep slopes. The build-up of gas from organic sediment can cause bubbles under liners and cause them to dislodge, but this can be avoided by perforating the liners or using woven mats that are permeable to gas. Consideration needs to be given to possible decrease in oxygen at the sediment interface below the liners, and the impact of this on benthic biota and geochemistry (de Winton et al. 2019).

[19] Rotorua Te Arawa Lakes Strategy Group agenda, 23 September 2023. https://nuwao.org.nz/uwhi-harakeke-weed-mats/

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



Bottom-liners are not effective against floating plants (e.g. *Azolla* sp) and are less effective for non-rooted plants like hornwort.

The effectiveness of bottom liners at controlling regrowth can last for years, depending on the materials used and the lake conditions. The life-span of control will be reduced by build up of sediments over the mats, and maintenance may be required if sediment depth over mats increases to more than 4cm (de Winton et al. 2013).

Hessian/coconut fibre mats have been successful in controlling lagarosiphon, egeria and hornwort, but disintegrate within about 10 months. The use of natural materials that decompose are an advantage if trying to reestablish native plants.

### 4.9.3 Cost-effectiveness

Most cost occurs with installation but regular checks are advised to ensure bottom-lining remain in-place. Build-up of sediment over the mats may require removal. De Winton et al. (2013) estimated the cost of bottom-liners to be $30,000 per ha, excluding any sediment removal. The expense makes them more suited to small scale applications.

### 4.9.4 Application to Sullivan Lake

#### 4.9.4.1 Suitability

In Sullivan Lake, placing bottom-liners following dredging of water lily could be an effective way to control water lily regrowth. The shallow water depth and flat bottom of Sullivan Lake makes bottom-liner relatively easy to install. Permeable woven mats should be used to allow gas exchange and avoid the build up of gases. A minimum liner width of 3m should be used to avoid water lily rhizomes.

#### 4.9.4.2 Cost

The rough order cost of bottom-lining to contain water lily following dredging is about $5000 to $9,000. Assuming bottom-lining would occur in a 3m wide strip around 200m perimeter of water lily (600m$^2$). This excludes any consenting or maintenance costs.

### 4.9.5 Summary

Bottom-lining could be an effective method to control the spread of water lily in Sullivan Lake following its removal by dredging. There is potential to trial in a small area to assess its effectiveness.

## 4.10 Grass Carp to Control Aquatic Plants

### 4.10.1 General Description

Grass carp (*Ctenopharyngodon idella*) are introduced herbaceous fish that are bred in New Zealand for aquatic vegetation control. They are non-selective grazers and if stocked in sufficient numbers grass carp can completely eradicate submerged aquatic vegetation. Even when all submerged vegetation is gone, a few fish can often survive by consuming fallen leaves, riparian grasses and epiphytic algae (de Winton et al. 2013).

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



### 4.10.2 General Application and Constraints

Grass carp are only suitable in lakes requiring the near complete eradication of aquatic plants. They will eradicate both submerged plants and emergent wetland plants if the water is depth is sufficiently deep (e.g. 0.5m), although they don't graze some short growing turf plants or floating plants (e.g. *Azolla*) (Rowe and Schipper 1985 in de Winton 2013). This makes grass carp unsuitable for lakes where retaining aquatic plants or wetlands are required for water quality or habitat purposes.

The loss of aquatic plants caused by grass carp can, in some lakes, contribute to algae blooms. Grass carp introduced in 2010 to Lake Heather and Lake Swan, Northland, were very effective at removing pest macrophytes. In Swan Lake they removed most of the *Egeria* and about 40% of the hornwort in 12 months. The next summer Lake Swan developed algae blooms (Gibbs and Hickey 2012).

The loss of aquatic vegetation caused by grass carp may affect the habitat or spawning of other fish and of invertebrate (e.g. zooplankton). This can lead to more predation, changes in fish species composition and changes in the diversity and abundance of zooplankton composition (Rowe 1984, de Winton et al. 2013).

Grass carp are not suitable in waterbodies where they might escape and regulatory approval from DOC and MPI is required before transferring grass carp (Hofstra 2011).

The retrieval and eradication of grass carp following plant eradication can be challenging and potentially costly.

### 4.10.3 Cost-effectiveness

Grass carp can be a cost-effective way to remove aquatic vegetation, but eradication once vegetation is eradicated can be challenging. Having grass carp in a lake is incompatible with goals to improve water quality and biodiversity values. The loss of vegetation can sustain or worsen poor water quality and algae blooms.

### 4.10.4 Application to Sullivan Lake

#### 4.10.4.1 Suitability

Grass carp are not very suitable for Sullivan Lake because submerged vegetation is largely absent from the lake, with the exception of water lily and occasion spring growth of *P. crispus*. These macrophytes provide water quality benefits and are relatively easy to manage by other methods.

Stocking grass carp in Sullivan Lake would prevent the use of treatment wetlands to help improve water quality. They would also require additional barriers to stop fish escaping, and this would be inconsistent with aspirations to improve fish passage.

### 4.10.5 Summary

Grass carp can be an effective way to completely eradicate submerged aquatic vegetation and wetland plants. They are unsuitable for lakes where retaining aquatic plants or wetlands are required for water quality or habitat purposes. They are not well suited for Sullivan Lake because submerged vegetation is

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



largely absent with the exception of water lily and occasion spring growth of *P. crispus*. Stocking grass carp would prevent the use of other actions to improve water quality (e.g. wetlands).

## 4.11 Silver carp to control phytoplankton

### 4.11.1 General Description

Silver carp (*Hypophthalmichthys molitrix*) are an introduced planktivorous fish that are bred in New Zealand for control of phytoplankton. They do not breed in small lakes and must be stocked at high density to provide control (de Winton et al. 2013). They have a habit of jumping when disturbed, which can be a hazard in some waterways.

Silver carp are opportunistic filter feeders that will consume phytoplankton, cyanobacteria, zooplankton and detritus. Thus, they may have potential to control cyanobacteria in small eutrophic lakes (Rowe 2010, Ma et al. 2012). However, they selectively graze larger zooplankton (e.g. *Daphnia* sp.) and phytoplankton which can shift the species composition towards smaller species.

Sometimes introduction of silver carp causes more phytoplankton growth. Grazing of silver carp reduces the abundance of zooplankton, which in turn reduces zooplankton grazing of phytoplankton. Often the silver carp grazing of phytoplankton cannot compensate for the reduction in zooplankton grazing, resulting in an increase in phytoplankton biomass and lower clarity (Shen et al. 2021, Zhao et al in de Winton 2013).

### 4.11.2 General Application and Constraints

Silver carp have been used in the USA to reduce cyanobacteria blooms in reservoirs. However, their success in improving water quality in hyper-eutrophic ponds and lakes is variable. They have been stocked in several small NZ lakes (e.g. Lake Orakai, Lake Omapere), but there was insufficient monitoring to assess their success or effects. There is limited information available in New Zealand to assess benefits and risks of silver carp (Rowe 2010).

Silver carp produce substantial floating faecal matter, this can affect the aesthetics of the water which may affect their application (de Winton 2013).

Silver carp are not suitable in waterbodies where they might escape and regulatory approval from DOC and MPI is required before transferring grass carp (de Winton et al. 2013).

### 4.11.3 Cost-effectiveness

Costs of establishing silver carp are likely to be similar to grass carp, but removal could be more challenging and costly if they are found to be unsuccessful. They may be effective at controlling cyanobacteria blooms but their success is uncertain and there is a possibility that worse outcomes occur.  Any introduction of silver carp should occur with lake monitoring, which may increase its cost.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



### 4.11.4 Application to Sullivan Lake

#### 4.11.4.1 Suitability

The benefit of silver carp as a lake restoration tool is controversial. Silver carp might be effective at controlling cyanobacteria blooms in Sullivan Lake but their success is uncertain, and there is a risk of unintended consequences. If silver carp are unsuccessful, then removing them would be difficult and costly, making the use of silver carp a high-risk technique.

Silver carp would require additional barriers to stop fish escaping, which would further restrict any native fish passage.

### 4.11.5 Summary

Silver carp are not recommended of Sullivan Lake because of their uncertainty, risk and difficulty to later remove. Although they may be effective at controlling cyanobacteria blooms, their success is uncertain and they may influence the ecosystem in unexpected ways. The need to contain silver carp is incompatible with improving any fish passage to Sullivan Lake.

## 4.12 Summary: Actions to improve water quality and ecology

Intervention options to improve water quality in Sullivan Lake are summarised in **Table 4.2**. The high priority actions were chosen that would address multiple issues in a cost-effective way, and with low risk of adverse effects.

There is no single quick fix to improving water quality in lakes. There is no "magic bullet". A danger of seeking a quick fix to a particular water quality issue is that it aggravates other issues; this is because biological systems are interconnected. The path towards sustainable improvement in lake water quality requires reducing both external and internal nutrient loads, and improving the functioning and diversity of aquatic habitat.

### 4.12.1 Priority interventions

The management interventions recommended as highest priority to improve water quality and ecology in Sullivan Lake are:

- Increase flow augmentation during summer (January to March)
- Treatment wetlands to remove nutrients and improve biodiversity.
- Dredging to remove organic, nutrient rich sediments and partially remove water lily.
- Placing bottom-liners in to contain the spread of water lily following partial removal.
- Harvesting macrophyte to manage plant cover and remove nutrients – early summer when required.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



The management interventions to improve water quality that could be considered but are either less cost-effective or require additional investigation are:

- Floating wetlands to remove nutrients and improve biodiversity. A small number of floating wetlands would be beneficial near sediment forebays of the inflows.
- Sediment phosphorus locking to reduce internal load of P (e.g., applying alum).
- Various measures to reduce catchment sediment and nutrient loads.

The management interventions not recommended for Sullivan Lake at this stage are due to practical difficulties or their uncertain or limited benefits are:

- Grass carp to control aquatic plants (due to impact on other restoration actions and difficulty removing).
- Silver carp to control phytoplankton (due to uncertainty of outcome and difficulty removing).

In addition to water quality interventions:

- Fish passage to Sullivan Lake could be improved with instillation of a fish friendly flap gate at the Whakatāne River outlet and a retrofitting a ramp and /or spat rope over the outlet weir.
- The risk of avian botulism can be reduced by collecting and disposing of carcasses during an outbreak.

**Table 4.2**: Summary of intervention options to address ecological and water quality issues in Sullivan Lake

| Priority | Intervention Option | Description | Effectiveness in Sullivan Lake | Limitations |
|---|---|---|---|---|
| High | Increase flow augmentation | Increase flow augmentation to 1000 m3/day during summer dry periods better flush algae and nutrients. | WQ - Moderate. | Possible flow restrictions on water take during summer |
| High | Dredge sediments western end | Remove organic sediment and water lily from the western end of Sullivan Lake to control cover and to reduce internal load of nutrients. | WQ - Moderate to high.<br>Weeds - High | Suited to small lakes due to high cost. Risk of poor WQ during operation. Disposal can be costly. |
| High | Bottom-lining to contain the spread of water lily | Bottom-line to restrict regrowth of water lily following removal. | Weeds - High | Costly at large scale<br>Must first reduced weed biomass. Possible risk to benthic fauna |
| High | Treatment wetlands and riparian wetlands | Treatment wetlands and sediment traps to remove nutrients and create habitat. | WQ - High<br>Habitat - High | Requires a large area. Moderate to high capital cost. Good design critical to ensure P removal. |
| High | Harvest curled pondweed | Harvest pondweed in early summer to remove nutrients and reduce plant cover. | WQ - Moderate / High<br>Weeds - High (but short term).<br>Habitat - Moderate | Requires ongoing effort. Access to equipment limited at peak times. Limited value if low density or weed. Not suited for eradication. |
| Moderate | Floating wetlands | Floating wetlands to remove nutrients and provide habitat. | WQ - High<br>Habitat - High | Costly compared to wetlands. Best suited to near inflows with high nutrient concentrations. |
| Moderate | Phosphorus locking / flocculation | P-inactivation to reduce internal P load. | WQ - High (but may require repeated application) | Reduced efficacy in shallow lakes with sediment resuspension. pH conditions are critical. Can be culturally sensitive. |
| Moderate | Measures to reduce catchment sediment and nutrient loads | Reduce external nutrient loads including:<br>- Investigate stormwater ingress to further reduce risk of sewage overflows.<br>- Educate property lowers to reduce nutrient in stormwater.<br>- P-socks at culvert outlets to bind P. | WQ - High (address root causes) | Investigations required to find sources. A social challenge to achieve changes in landuse or land management. May be limited opportunity in Sullivan Lake. |
| Low; selective use | Herbicide | Herbicide spray to reduce plant cover when required. | Plants - High (and can be selective) | Is effective, cheap and easy. But risk of WQ issues and cultural sensitivity. |
| Not advised | Silver carp | Silver carp to reduce phytoplankton / cyanobacteria. | WQ - Moderate but uncertain and controversial. | Risk of worsening WQ. Changes ecosystem structure. Fish must be contained. Difficult to remove fish. |
| Not advised | Grass carp | Grass carp to eradicate aquatic plants. | Plants - High (total eradication)<br>Habitat - negative for Sullivan due to total loss of macrophytes | Total eradication of plants. Not compatible with wetlands. Risk of worsening WQ. Fish must be contained. Difficult to remove fish. |

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**





# 5 Conclusions and Recommendations

## 5.1 Conclusion

The water quality in Sullivan Lake is poor with low water clarity, high nutrient concentrations and high phytoplankton growth indicative of supertrophic to hypertrophic conditions. The lake is likely to have internal loading of nutrients from the sediment either by sediment suspension and via occasional bottom water/sediment anoxia. There are also internal nitrogen loading via cyanobacteria.

This report has identified priority management interventions that are cost-effective and have a track record of working in small lakes. There is no single quick fix to improving water quality in lakes. Improvement of water quality in Sullivan Lake over the long term will require efforts to reduce nutrient loads (internal and external) and enhance natural processes that attenuate nutrients. Establishing wetlands and aquatic plants are important for maintaining reasonable water quality in small natural lakes, but ongoing management of plant cover may be required in lakes dominated by exotic plants to avoid excessive biomass causing further water quality problems.

## 5.2 Future monitoring and investigations

Water quality monitoring of Sullivan Lake has been limited in recent years. While we have been able to draw useful information about the current state and issues affecting Sullivan Lake, additional monitoring would provide greater understanding and certainty. Monitoring is also an important part of management remediation options by measuring success in achieving specific outcomes and identifying where different management interventions may need to be implemented. This type of outcome monitoring focuses on specific aspects of the lake ecology or water quality. For example, more intensive monitoring may be required over spring and summer to better understand the dynamics of curled pondweed cover, phytoplankton biomass, nutrients and dissolved oxygen. Similarly, stormwater inflows might be monitored during rain-events to better understand the catchment inputs on the lake.

In the context of limited budgets, a balance needs to be found between monitoring and implementing actions. In our view, initiating actions to improve the lakes water quality should not be delayed by monitoring; monitoring should be used to support and inform action rather than delay action through lack of resources.

General monitoring that would assist in managing Sullivan Lake and understanding the success of any mitigation should include:

- Monitoring water quality of main stormwater inflows to Sullivan Lake during rainfall to characterise the quality and contribution of stormwater entering the lake (including an estimate of flow from the culvert).
- Monitor the development of pondweed cover during spring and early summer to inform potential management actions such as harvesting or increasing the volume of flow augmentation.

**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



- Monitoring water depth of any sediment trap to inform maintenance actions.
- Investigating the potential for using P-locking products. Including sampling of surface sediment (for TP and Al) and overlying water (for DRP and hardness), incubation of sediments to assess P release.
- Investigating the oxygen demand from sediment obtained from different locations in the lake would improve understanding of spatial variation in DO with Sullivan Lake, and better inform locations to focus any dredging.
- Following interventions to remove sediments at the western end of the lake, then repeat synoptic surveys of DO and pH.
- Recording incidences of avian botulism to inform potential management actions of removing and safely disposing of any carcases.
- Water quality monitoring of the lake surface water with a minimum frequency of two monthly and analysing at least the variable of: Temperature, specific EC, DO, %DO, water clarity, pH, TN, TP, Chl-*a*, and *E.coli* bacteria. Field observations of macrophyte cover. More frequent monitoring may be required to assess the effectiveness of some management actions.
- Dissolved oxygen logger during summer to assess DO fluctuations and success in reducing periods of low DO.
- Counts of waterfowl using the lake would allow estimates of the potential contribution of waterfowl to nutrient and bacteria loads.

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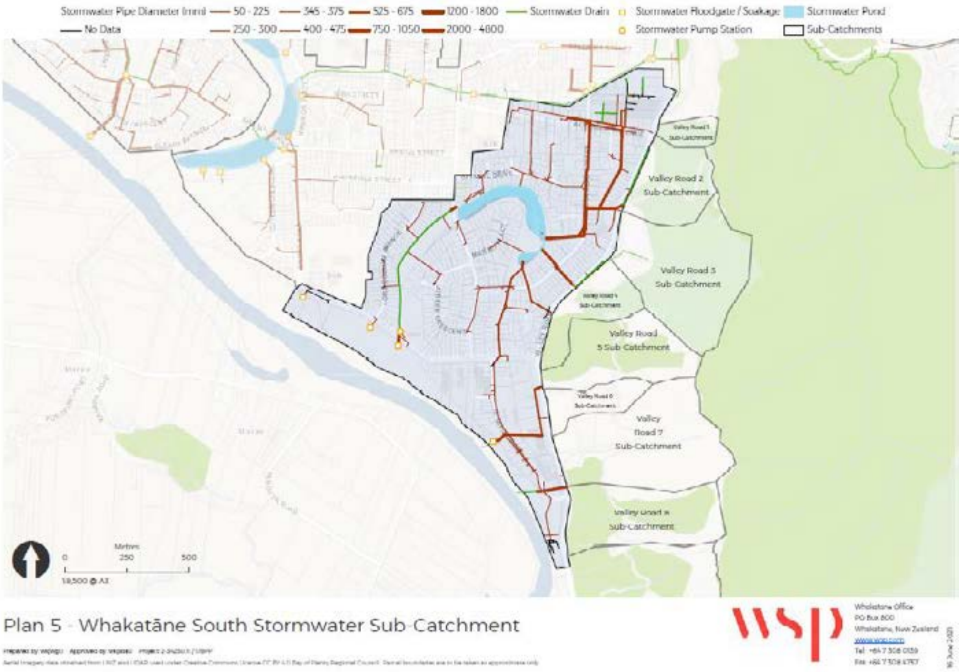
**7.4.2 Appendix 2 Sullivan Lake Water Quality Ecology and Options for Improvement(Cont.)**



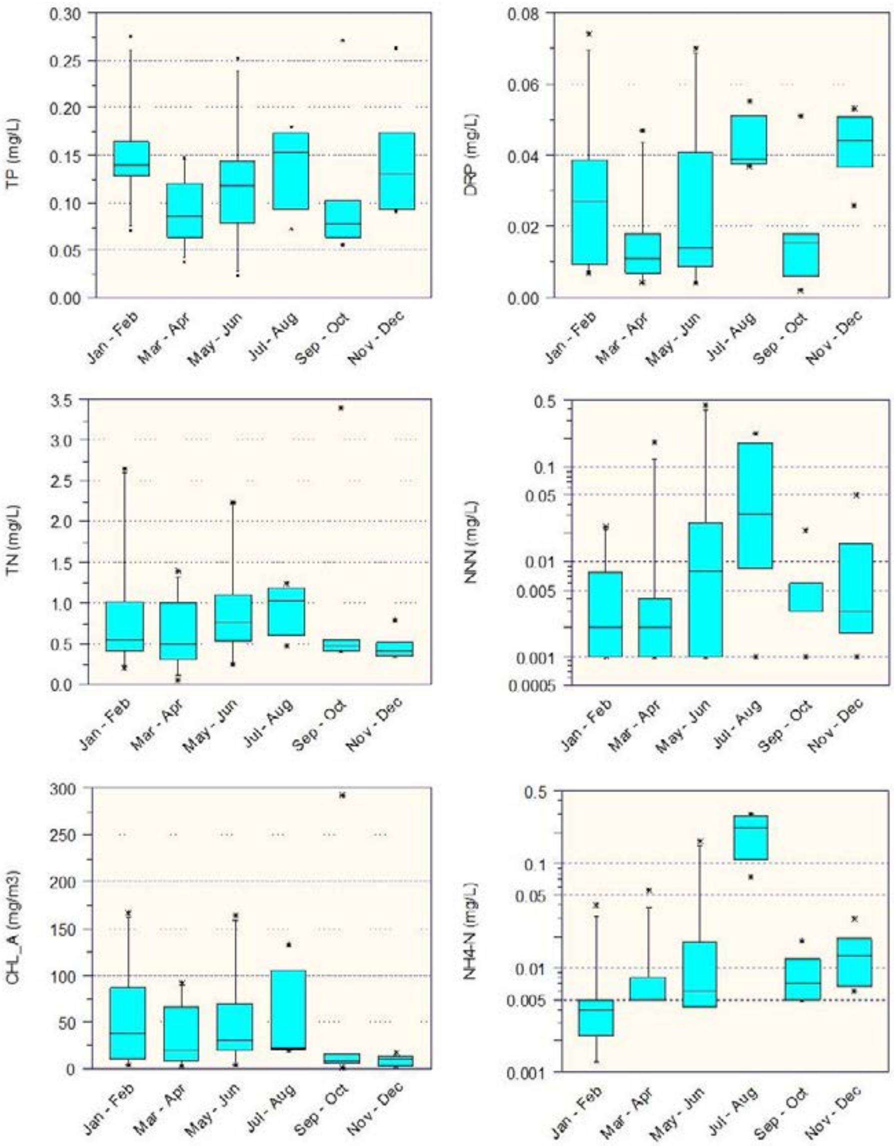
# Appendix 1: Sullivan Lake stormwater

Whakatāne South Stormwater catchment connected with Sullivan Lake (WSP 2021)



# Appendix 2: Seasonal water quality Sullivan Lake

Seasonal water quality in Sullivan Lake since 1 January 2023. Box plots without 95%ile bars have less than 12 data points.



# Appendix 3: Restoration techniques to address eutrophication in shallow lakes.

**Restoration techniques to address eutrophication in shallow lakes. Reproduced from Table 1 in Abell et al. (2020).**

| Group | Restoration method | Purpose | Application | Examples | Advantages | Disadvantages | References |
|---|---|---|---|---|---|---|---|
| **Reduce external nutrient loads** | Diffuse and point source control | Minimize nutrient loading | Essential component of a sustainable lake restoration strategy to control eutrophication | • Lake Müggelsee, Germany<br>• Lake Peipsi, Estonia/Russia<br>• Loch Leven, Scotland<br>• City Park Lake, Louisiana, USA | • Addresses the root cause | • Sufficient reductions typically require major economic costs, for example, to fund land-use change or improved wastewater treatment | Ruley and Rusch (2002); Jeppesen et al. (2005) |
| **Reduce internal nutrient loads (physical)** | Dredging | Reduce internal loading by removing nutrient-enriched sediments | Best suited to small lakes and/or iconic lakes due to the high costs | • City Park Lake, Louisiana, USA<br>• Lake Kraenepoel, Belgium | • Directly removes nutrients<br>• Increases depth | • Expensive<br>• Disposal of dredgeate can be difficult | Peterson (1979, 1981); Van Wichelen et al. (2007) |
| | Sediment capping (passive) | Reduce internal load by creating a physical barrier between benthic sediments and the water column | Generally suited to smaller lakes with high internal loads | • Taihu Lake, CN (one embayment) | • Maybe opportunities to use inexpensive local soil/sand | • Adverse effects to benthic biota such as mussels | Xu et al. (2012) |
| **Reduce internal nutrient loads (chemical)** | Phosphorus inactivation/ flocculation | Reduce concentrations of dissolved nutrients (primarily P) by adsorption. May be combined with flocculant use to remove organic material | Generally suited to smaller lakes with high internal loads | • Minneapolis Chain of Lakes, USA<br>• Lake Rotorua, New Zealand | • Potentially rapid improvements<br>• Cost-effective (internal) load reductions<br>• Well-established | • Reduced efficacy in shallow lakes due to sediment resuspension<br>• Adding chemicals to waterbodies can be culturally/ socially sensitive<br>• Metal toxicity needs to be considered<br>• Not a sustainable solution alone | Welch et al. (1988); Huser et al. (2016); Smith et al. (2016); Wang and Jiang (2016); Vargas and Qi (2019) |
| **Bio-manipulation** | Fish removal (zooplanktivorous) | Increase cladoceran zooplankton biomass → reduce phytoplankton biomass | Applicable to lakes with abundant zooplanktivores, for example, juvenile *Perca fluviatilis* | • Lake Vaeng, Denmark | • Established method in western European lakes with abundant zooplanktivores | • High, ongoing effort required to maintain low biomass<br>• Results are inconsistent<br>• Only suitable for lakes with abundant zooplanktivorous fish | Meijer et al. (1999); Søndergaard et al. (2008) |
| | Fish removal (benthivorous) | Reduce bioturbation and nutrient excretion | Applicable to lakes with high biomass of benthivorous fish such as *Cyprinus carpio* | • Wolderwijd, The Netherlands<br>• Lake Susan, Minnesota, USA<br>• Lake Ohinewai, New Zealand | • Can support biodiversity objectives if fish are invasive | • High, ongoing effort required to maintain low biomass<br>• Results are inconsistent | Meijer et al. (1999); Søndergaard et al. (2008); Bajer and Sorensen (2015); Tempero et al. (2019) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Promote bivalves | Increase filtration rates and phytoplankton grazing | Untrialled as a deliberate method, although potentially suitable for lakes that are very shallow (relatively low volume) and oligo-mesotrophic (more suitable physicochemical habitat conditions) | ◦ Lake Faarup, Denmark (following an undesired invasion by zebra mussels) | ◦ Could promote biodiversity if native species are used | ◦ Requires suitable host fish for larval development ◦Habitat conditions may be unsuitable in lakes that are the greatest priorities for restoration | Jeppesen et al. (2012); Burns et al. (2014) |
| Macrophyte harvesting | Remove nutrients present in plant tissues | Very shallow (low volume) lakes with high abundance of invasive macrophytes | ◦ Lake Wingra, Wisconsin, USA<br>◦ Lake Rotoehu, New Zealand | ◦ Removing invasive plants can promote native plant biodiversity<br>◦ Plants could provide a resource (e.g., feedstock), pending research and development | ◦ High, ongoing effort required to maintain low biomass<br>◦ Nutrient removal expected to be minor compared with external loads | Carpenter and Adams (1978); Quilliam et al. (2015) |
| Floating wetlands | Uptake dissolved nutrients. Potentially also increase denitrification and settling. | Small lakes, embayments, and drains where high coverage is feasible | ◦ Lake Rodó, Uruguay | ◦ May provide additional habitat values<br>◦ Can provide a visual focus for lake restoration efforts | ◦ Field trials that demonstrate successful application to manage eutrophication are lacking<br>◦ Not applicable to restore medium-large lakes<br>◦ Plant harvesting necessary for optimum performance | Rodríguez-Gallego et al. (2004); Pavlineri et al. (2017); Bi et al. (2019) |
| Algicides | Directly reduce phytoplankton biomass | May be suitable as an emergency measure | ◦ Cazenovia Lake, New York, USA | ◦ Effective at causing rapid short-term declines in phytoplankton biomass with sufficiently high doses | ◦ Toxic effects on other biota<br>◦ Sediment contamination<br>◦ Culturally/socially controversial<br>◦ Not generally recommended as a lake restoration method | Effler et al. (1980); Fan et al. (2013) |

(*continued*)

**Table 1.** Continued.

| Group | Restoration method | Purpose | Application | Examples | Advantages | Disadvantages | References |
|---|---|---|---|---|---|---|---|
| | Macrophyte reestablishment | Promote reestablishment of macrophytes by planting founder colonies and/or protecting plants with exclosures and wave buffers | Suitable for lakes that have experienced improved clarity but macrophyte reestablishment is hindered by lack of viable seeds/propagules or grazing | ◦ Delta Marsh, Manitoba, Canada | ◦ Can yield improved macrophyte growth in some areas | ◦ Only suitable for lakes that have already been partially restored and have suitable light conditions and substrate | Evelsizer and Turner (2006); Hilt et al. (2018) |
| **Hydrologic alterations** | Inflow diversion | Reduce external loads | Applicable to lakes for which external loads are dominated by a single surface inflow, and there is a suitable receiving waterbody nearby | ◦ Lake Rotoiti, New Zealand | ◦ Step-change reductions in external loads | ◦ Potential ecological impacts to receiving waterbody<br>◦ High capital costs<br>◦ Feasibility depends on local hydrology and not possible for most lakes | Hamilton and Dada (2016) |
| | Increase dilution and/or flushing | Dilute poor-quality lake water with higher quality water | Applicable to lakes for which there is a suitable donor waterbody nearby | ◦ Moses and Green lakes (USA)<br>◦ Lake Veluwe (The Netherlands)<br>◦ West Lake, CN | ◦ Major improvement in water quality possible | ◦ Potential ecological impacts to donor waterbody<br>◦ High capital costs<br>◦ Feasibility depends on local hydrology and not possible for most lakes | Welch (1981); Ibelings et al. (2007); Jin et al. (2015) |
| | Water-level management | ◦ Increasing depth can reduce sediment resuspension<br>◦ May restore riparian vegetation, depending on the hydrologic regime | Very shallow lakes or lakes where the riparian vegetation communities are impaired due to the existing hydrologic regime | ◦ Volkerak–Zoommeer lake system, The Netherlands | ◦ Can improve habitat for plants and wildfowl | ◦ Can only improve water quality indirectly<br>◦ Land tenure and surrounding topography can be a constraint to increasing lake level<br>◦ Not a primary method to reduce trophic status | Gulati and van Donk (2002) |

**Summary of efficacy and cost of phosphorus mitigation strategies for farms (reproduced from Table 2 of McDowell and Nash 2013).**

| Strategy | Main targeted P form(s) | Effectiveness (% total P decrease) | Cost, range ($ per kg P conserved)† | Cost, Waikakahi ($ per kg P conserved)† |
|---|---|---|---|---|
| Management | | | | |
| Optimum soil test P | dissolved and particulate | 5–20 | highly cost-effective‡ | (15) |
| Low solubility P fertilizer | dissolved and particulate | 0–20 | 0–20 | 0 |
| Stream fencing | dissolved and particulate | 10–30 | 2–45 | 14 |
| Restricted grazing of cropland | particulate | 30–50 | 30–200 | na |
| Greater effluent pond storage/application area | dissolved and particulate | 10–30 | 2–30 | 13 |
| Flood irrigation management§ | dissolved and particulate | 40–60 | 2–200 | 4 |
| Low rate effluent application to land | dissolved and particulate | 10–30 | 5–35 | 27 |
| Amendment | | | | |
| Tile drain amendments | dissolved and particulate | 50 | 20–75 | na |
| Red mud (bauxite residue) | dissolved | 20–98 | 75–150 | na |
| Alum to pasture | dissolved | 5–30 | 110 to >400 | na |
| Alum to grazed cropland | dissolved | 30 | 120–220 | na |
| Edge of field | | | | |
| Grass buffer strips | dissolved | 0–20 | 20 to >200 | 30 |
| Sorbents in and near streams | dissolved and particulate | 20 | 275 | na |
| Sediment traps | particulate | 10–20 | >400 | >400 |
| Dams and water recycling | dissolved and particulate | 50–95 | (200) to 400¶ | 200 |
| Constructed wetlands | particulate | −426 to 77 | 100 to >400# | 300 |
| Natural seepage wetlands | particulate | <10 | 100 to >400# | na |

† Numbers in parentheses represent net benefit, not cost. Data taken as midpoint for average farm in Monaghan et al. (2009a).

‡ Depends on existing soil test P concentration.

§ Includes adjusting clock timings to decrease outwash <10% of inflow, installation of bunds to prevent outwash, and releveling of old borders.

¶ Upper bound only applicable to retention dams combined with water recycling.

# Potential for wetlands to act as a source of P renders upper estimates for cost infinite.

# 8 Resolution to Exclude the Public - *Whakataunga kia awere te marea*

**THAT** the public be excluded from the following parts of the proceedings of this meeting, namely the EBOP LAP Appeal Process.

The general subject of each matter to be considered while the public is excluded, the reason for passing this resolution in relation to each matter, and the specific grounds under section 48(1) of the Local Government Official Information and Meetings Act 1987 for the passing of this resolution are as follows:

| **General subject of each matter to be considered** | **Reason for passing this resolution in relation to each matter** | **Ground(s) under section 48(1) for the passing of this resolution** |
|---|---|---|
| EBOP LAP - Appeal Process | Good reason to withhold exists under Section 7. | That the public conduct of the relevant part of the proceedings of the meeting would be likely to result in the disclosure of information for which good reason for withholding exists.<br>Section 48(1)(a) |

This resolution is made in reliance on sections 48(1)(a) of the Local Government Official Information and Meetings Act 1987 and the particular interest or interests protected by section 7 of that Act, which would be prejudiced by the holding of the relevant part of the proceedings of the meeting in public are as follows:

| **Item No** | **Interest** |
|---|---|
| 1 | Maintain legal professional privilege (Schedule 7(2)(g)) |

# 1 Reports - *Ngā Pūrongo*

## 1.1 Public Excluded - Eastern Bay of Plenty Local Alcohol Policy