A Mauri Model Analysis of Proposed Upgrades to the Waitomo Wastewater Treatment Plant

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2017

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Abstract

This research used the Mauri Model, an value-based, indigenous decision-making framework, to evaluate the proposed upgrade options for the Waitomo Wastewater Treatment Plant (WWTP) in New Zealand. A revision of the plant was critical because the current WWTP violates tangata whenua cultural values, exceeds Council consent limits for several pollutants, and may not be able to support the expected increase in users. Based upon this mauri model assessment, the needs and values of tangata whenua may best be achieved by adding a constructed wetland to the current treatment plant. Specific goals and constraints decided upon by TOWT and RUHT may render seasonal irrigation with storage, land treatment with irrigation year round, a nitrifying filter or a floating wetland as effective alternatives to constructed wetlands as well. The Mauri Model was effective in incorporating environmental, cultural, social and economic values into the decision-making process, which is conventionally dominated by economic considerations.

Introduction

For centuries people have struggled to effectively deal with the waste we create, as its disposal can be harmful to our environment and community, and the responsibility of its treatment can be a highly political issue. In the New Zealand context, not only of concern are the ecological impacts, but conventional methods of waste treatment often conflict with the cultural values of tangata whenua (Māori, the indigenous people of New Zealand). This is the case with the Waitomo Wastewater Treatment Plant (WWTP), located in New Zealand's Waikato region, northeast of the world famous tourist attraction, Waitomo Caves. The WWTP discharges treated wastewater into the Waitomo stream, an act that tangata whenua find culturally abhorrent (Morgan 2006, Kapea 1994). The act of discharging anything contaminated with human waste into freshwater degrades the mauri of the waterway, violating tangata whenua values of kaitiakitanga, or guardianship, of their sacred waters (TOWT et al. 2015). These concerns are bolstered by the fact that the WWTP discharge exceeds the limits for certain chemicals outlined in the Waikato Regional Policy statement, particularly during peak tourist season. Surveys of aquatic macroinvertebrates and water quality analysis also indicate that there is moderate pollution downstream of the WWTP (Beca Ltd. 2016).

The Waitomo Wastewater Treatment Plant was developed on tangata whenua lands in 1969, and the current consent, held by Tourism Holdings Ltd (THL), expired April 2015. When THL applied for the renewal of the existing resource consent to discharge treated wastewater into the Waitomo Stream for a further 25 year term, the Tanetinorau Opataia Whanau Trust (TOWT) and Ruapuha Uekaha Hapū Trust (RUHT) released the 2015 Tangata Whenua Effects Assessment Report (TWEA) to assess how the WWTP has impacted how tangata whenua use and value of the Waitomo stream area. In this document, TOWT and RUHT both strongly objected to the continued discharge of wastewater into the Waitomo Stream and recommended looking into alternative options, particularly those that discharge the waste onto land (TOWT et al. 2015). Their main concerns were the cultural abhorrence of the waste water disposal into the Waitomo stream, and the wastewater infrastructure's capacity to meet the future need of the Waitomo community (TOWT et al. 2015).

As part of THL's application to renew the consent, they enlisted Beca Ltd. to review the options available for improving the discharge quality from the treatment plant (Beca Ltd. 2017). However, Beca Ltd.'s review primarily considers only how the option will impact the effluent quality, with little concern for how the proposed options will impact tangata whenua and the environment as a whole. To inform TOWT and RUHT in their decision making about what improvements to make with the WWTP, the proposed options were assessed using the Mauri Model. The Mauri Model is a decision-making framework that calculates the sustainability of different options by assessing how those options will impact mauri, the 'essence' or 'life force' and a metric of sustainability, for environmental, cultural, social and economic factors (Morgan 2006). The goal was to, by providing an assessment of these options using the Mauri model, help TOWT and RUHT identify what WWTP options will best allow tangata whenua to meet their social, cultural, economic and environmental aspirations, and in doing so, reduce the pollution problem caused by the WWTP. This research goes beyond the traditional framework of strictly economic cost and benefit analysis to assist tangata whenua in making decisions that address their needs and examines the effects of wastewater treatment in a holistic manner. This project has important implications for assisting tangata whenua as they continue to address the cultural grievances posed by modern wastewater treatment plants in New Zealand.

Background

Wastewater management is a challenging environmental, cultural and political issue in New Zealand. Conventional wastewater treatment methods often negatively impact our environment and conflict with the cultural values of tangata whenua.

Water, Waste, and Tangata Whenua

Water is taonga, or 'treasure', to tangata whenua. Water and bodies of water have their own mauri (life force; the binding force between the physical and the spiritual), and it is important to Māori to protect the mauri and life sustaining qualities of water so their descendants may use it (Te Taumutu Runanga and Jolly 2003, Morgan 2006). Water bodies are also integral to Māori self identity and mana (authority; the ability to exert control over a resource; status; prestige of hapū) (Morgan 2006). Māori have a special role as kaitiaki (guardian) of local waterways, a role inherited through whakapapa (genealogy) (Ihaka 2000).

Water is strongly embedded in creation traditions of Māori, which entails the separation of Papatuanuku (Papa; the earth mother) and Ranginui (Rangi; the sky father). In grief over their separation, rainfall is seen as tears of Rangi and wellsprings as the weeping of Papa, and thus both water sources are considered sacred. Because of this, rainfall and spring water are only suitable for human use after it has travelled over Papa and become noa (non-sacred). Accordingly, when water is used to carry human waste, its mauri is destroyed, even if it is technically treated. When wastewater is discharged into waterways, the mauri of that waterway is also degraded (Morgan 2006, Kapea 1994). Hence, tangata whenua find it culturally offensive for wastewater to be discharged into any body of water. For instance, in the case of the Mangere Treatment Plant that was dumping treated wastewater into the harbour, local tangata whenua perceived that the harbour had the "status of a toilet bowl" (Kapea 1994). Waimate is water that has lost its mauri and its power to rejuvenate itself and other living things (Ihaka 2000).

Waimate can also cause harm to people and kaimoana (seafood, shellfish). For the mauri of wastewater to be restored, wastewater must be returned to the earth, or Papatuanuku (Morgan 2006, Kapea 1994).

Another relevant consideration is tangata whenua's belief in maintaining the integrity of kai (food), by keeping all human sewage separate from food preparation, harvesting and processing, even if the sewage is treated and appears clean (Te Taumutu Runanga & Jolly 2003). The discharge of sewage into waters is culturally inappropriate because water is the source of mahinga kai (indigenous freshwater species traditionally used as food, tools, or other resources) (Te Taumutu Runanga & Jolly 2003). For Māori, water is valued not only intrinsically, but for the sustenance it provides (Ihaka 2000).

Concerning wastewater management, the following tangata whenua perspectives are essential: 1) Māori find discharge to bodies of water culturally abhorrent and prefer land-based discharge 2) if wastewater is to be discharged to water, it should first pass through earth before re-entering water and 3) a strong disapproval for the use of human waste in products, including fertilisers, intended for agricultural and food production (Ferguson 2003, Ihaka 2000).

The cultural abhorrence of dumping wastewater into other waterways or bodies of water, or of associating biosolids with food processes, make many conventional waste management schemes culturally offensive from a tangata whenua perspective, including the Waitomo WWTP. These difficulties are partially due to the conflicting paradigms of municipal engineering and tangata whenua views, which, as Morgan points out, can often be marginalised as 'spiritual sensitivities' (2005). Even though Mātauranga Māori (Māori knowledge) has been proved valid, and indeed uses many of the same methods as modern science, it is not commonly accepted as legitimate as 'hard' or 'modern' science (Crawford 2009).

Constructed Wetlands

An alternative treatment system of recent interest in New Zealand are constructed wetlands (CWs). There are two types, surface flow and sub-surface flow, with the first having wastewater slowly flow through wetland vegetation, allowing natural biological processes to reduce an remove contaminations from the wastewater. Sub-surface flow wetlands involve effluent treatment flowing through some porous granular medium (Ferguson 2003). Some, but not all, iwi accept constructed wetlands as satisfying the need for human wastewater to flow through the earth before entering natural waterways. Wetland systems have been implemented with a wide range of success in New Zealand, and seem to be best used as a further tertiary treatment stage (Ferguson 2003). Constructed wetlands have been implemented and proposed for several cities, including Tauranga Te Maunga and Rotorua, in part because they address tangata whenua views (Bradley et al. 2003).

Study Site: Waitomo WWTP

The Waitomo WWTP was developed in 1969, and is located downstream of the Waitomo Glowworm caves, famous NZ tourist destination and sacred place to Maori (TOWT 2015). It services thirteen users, including the Caves and some of the surrounding businesses. Tourism Holdings (THL) the company running the tourism aspect of the caves, also owns and manages the wastewater treatment plant. However, the WWTP is located on tangata whenua lands (TOWT 2015). The tangata whenua parties currently involved with the management of the Waitomo Caves and WWTP include the Tanetinorau Opataia Whanau Trust (TOWT), Ngāti Ruapuha Hapū, Ngāti Uekaha Hapū and Ruapuha Uekaha Hapū Trust (RUHT).

Fig. 1a) Map of Waitomo WWTP in relation to Waitomo stream and Caves, New Zealand, 1b) Map of Waitomo WWTP

The current plant includes two oxidation ponds connected in series. Wastewater is aerated continuously in the ponds, before being filtered through a rock gallery into Waitomo Stream. Pond 1 has baffle curtains and Pond 2 has a brush aerator. The WWTP discharges up to 97m3/day of treated wastewater via a rock gallery into the Waitomo Stream, and typical flows to the plant are 50-70 m3/day (including storm flows) with an occasional peak closer to the consented maximum discharge of 97 m^3/day (Beca 2017).

Options/Upgrades Proposed for Waitomo WWTP

Table A in the appendix provides a brief overview of the WWTP technologies and methods proposed for Waitomo, along with information on their costs and contaminants addressed. For more information, also see Table 6-1: Summary of Options and Assessment Matrix in Beca 2017.

Methods

The Mauri Model was used to evaluate the proposed WWTP alternatives and upgrades. The Mauri Model is a decision-making framework that uses the Māori concept of 'mauri' – the 'essence' or 'life force' – as a metric of sustainability (Morgan 2006). The model measures impacts to social, cultural, environmental and economic well-being using a number system ranging from positive 2 (fully restored mauri) to a -2 (denigrated mauri), with 0 being no effect (Figure 2, Morgan 2006). The users of the model come up with a list of indicators for the four categories, and then rank whether the options enhance, diminish, or have neutral effect on the mauri of each indicator (Morgan 2006). This method has been effectively used to find solutions for the restoration of an industrial waste dump site at Te Kete Poutama (Hikuroa et al. 2011) and stormwater management (Morgan 2006).

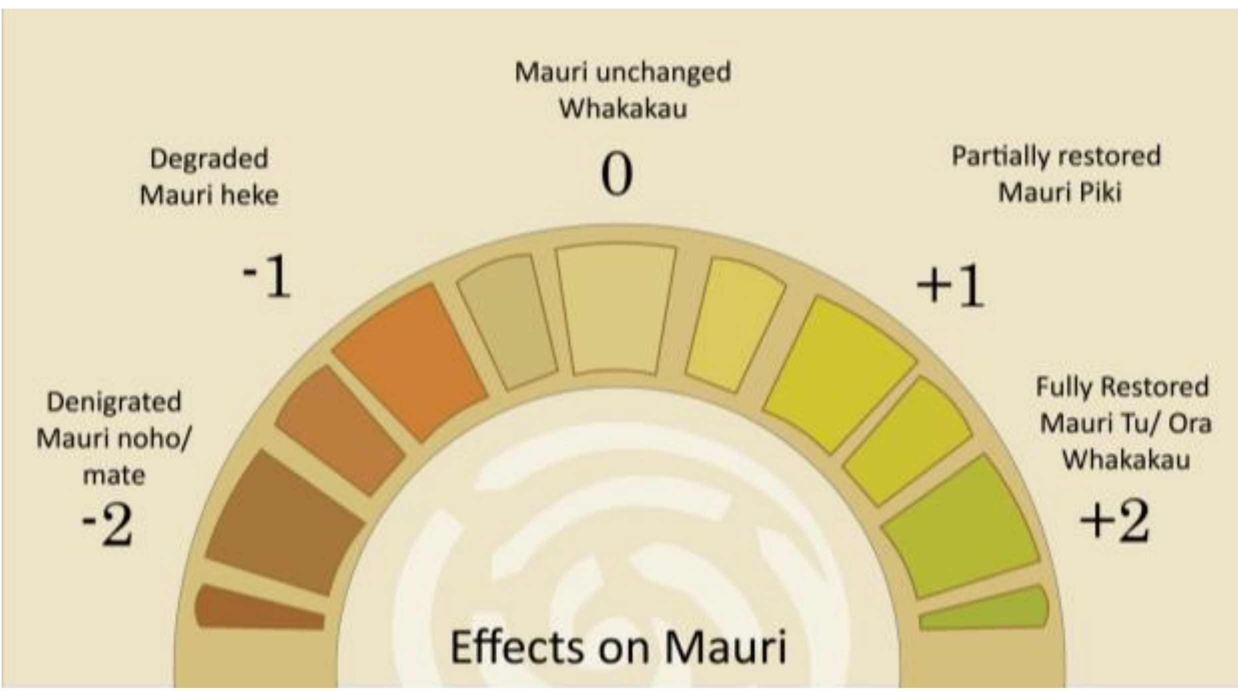

Figure 2. Mauri model scoring schematic, adapted from Morgan 2006

Indicators

After conducting a literature review of tangata whenua perspectives on wastewater treatment and on the proposed treatment upgrades, I came up with a list of indicators that could be used to assess how the upgrades would impact the mauri of Waitomo and its community. These indicators were discussed with fellow FA students and our class instructor to refine the list and ensure there was not overlap amongst the indicators.

Environmental indicators

- Anthropogenic contaminants (affecting water quality)
    - Total Suspended Solids (TSS)
    - Biochemical Oxygen Demand (BOD) - BOD is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material in a given water sample for a given temperature and time period (Sawyer et al. 2003). In other words, BOD is how much oxygen will be used by aerobic bacteria to convert organic material to new bacteria (Ferguson et al. 2003). The BOD of untreated wastewater is around 200-300g/m3 and less than 5g/m3 for a healthy ecosystem (Ferguson et al. 2003).
    - Ammoniacal Nitrogen (AM) and Total Nitrogen (TN)- Note that is the pollutant of most concern with the Waitomo WWTP.
    - Total phosphorous (TP) and Dissolved reactive phosphorus (DRP) - Often dissolved in effluent
- Indicator organisms and Native Biodiversity of Waitomo
    - E. coli (individual bacterial cells, some with TSS, others free in solution)
    - Fish (such as torrentfish and longfin eel, both 'At Risk-Declining', also freshwater shrimp and koura (crayfish))
    - Freshwater macroinvertebrates (Ephemera, Plecoptera, Trichoptera (EPT); both taxonomic richness and number of taxa from EPT, serves of indicators of water quality)

- Native Flora and Algal Diversity in Waitomo Stream and surrounding area. Plants are also of cultural importance, for instance harakeke (flax) can be collected for weaving.
- Native Biodiversity in/near WWTP - this refers to diversity of species present in the treatment plant itself (for instance, in a constructed wetlands, this includes the plant species planted for the wetland).
- Native biodiversity in connected areas, such as the wider Waipā and Waikato river catchment. The Waitomo Stream flows into the Waipā River at Otorohanga, and the tangata whenua kaitiaki responsibility is to ensure the Waitomo stream is clean and healthy and does not compromise the quality and integrity of the Waipā River (TOWT 2015).

Cultural indicators

- Cultural abhorrence of human effluent being expelled into a waterway (I scored a positive number 1 or 2 if this was improved, and a 0 if upgrade did nothing to address cultural concern).
- Cultural abhorrence to the reuse of human effluent (ex for irrigating food crops)
- Ability to collect Mahinga kai, including tuna koura, downstream of the WWTP
- Ability for tangata whenua to exercise Kaitiakitanga
    - "That responsibility is characterised as an obligation to leave Te Taiao – the environment and its resources – in a condition better than that inherited by them, the obligation passing to the next generation." (TWEA 2015)

Social indicators

- Swimming - Children are advised to swim upstream from the discharge point of the WWTP.
- Land use/impacted - Considers the loss of ability to use the land where WWTP upgrades are located.

- Aesthetic environment - how pleasing to the eye is the WWTP upgrade

Preservation and protection of sites of significance and or wāhi tapu - this indicator was not used because of lack of sufficient information about wāhi tapu in the area. However, note that there are many wāhi tapu and archaeological sites in the Waitomo area, including Repo cave (Te Ana o Uekaha), home for tupuna Uekaha and Hinerangi, located near the WWTP (TOWT 2015).

Economic Indicators

- Initial cost of development/upgrade, including costs associated with additional land purchase if necessary
- Cost of maintenance and operating costs of new system
- Costs of future expansions to meet necessary capacity, or additional improvements needed within given time span to improve water quality. This was considered with the prediction that visitors to Waitomo Caves will continue to increase steadily over the coming decades.

**Potential earnings from selling recycled wastewater. This indicator was not used because of lack of information about potential prices that could be obtained from selling wastewater (and from uncertainties about the feasibility of this option).

Mauri Model Scoring and Calculation

These indicators were then scored for each WWTP upgrade, first by myself, then with two other Frontiers Abroad students (Emily Freilich and Laura Lilienkamp), whose backgrounds include environmental science, geology and engineering. The mauri scoring for constructed wetlands was conducted with a group of eight American study abroad students during a Research Methods class. Each option was scored for a 10 years and 50 years time period.

A mauri score was calculated for each option, for 10 years and 50 years, by taking the average of all the indicator scores for that option (Table 1). A secondary mauri score was calculated for each option by taking the average of the 10 and 50 year scores (Table 2).

Results

The mauri assessment scores for the proposed WWTP upgrades can be viewed in Table 1. The total mauri scores for 10 and 50 years, and an average between the two, are presented in Table 2, in order from highest scoring to lowest scoring. While some options scored higher in the 50year period than in the 10 year period, when the options were compared amongst each other for a specific time frame, the order was the same.

Table 1. Mauri Model Scoring for Upgrades to Waitomo Wastewater Treatment Plant

Indicators		Land Treatment								Tertiary Treatments								In-Pond Treatments							
		Rapid infiltration		Seasonal Irrigation w/ Storage		Seasonal Irrigation w/ Stream Discharge		Land treatment Irrigation Year Round		UV disinfection		Constructed Wetlands		Wood Chip Filter		Nitrifying Filter		Bio-domes		Additional Baffling		Outlet Shading		Floating Wetland/Floating Pond Media	
		10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs	10yrs	50yrs
Environmental	TSS	1	1	2	2	1	1	2	2	0	0	2	2	2	2	2	2	2	2	2	2	1	1	1	1
	BOD	1	1	2	2	1	1	2	2	0	0	2	2	2	2	2	2	2	2	2	2	1	1	1	1
	Nitrogen (AN, TN)	1	1	2	2	1	1	2	1	0	0	1	1	2	2	2	2	2	2	0	0	0	0	2	2
	Phosphorus	1	1	2	2	1	1	2	1	0	0	2	2	2	2	1	1	2	2	0	0	0	0	2	2
	E. coli	1	1	2	2	1	1	1	1	2	2	1	1	0	0	0	0	0	0	1	1	0	0	1	1
	Fish	2	2	2	2	1	1	2	2	0	0	2	2	2	2	1	1	2	2	1	1	0	0	2	2
	Freshwater macroinvertebrates	2	2	2	2	1	1	2	2	0	0	2	2	2	2	1	1	2	2	1	1	0	0	2	2
	Native flora & algal diversity	1	1	1	1	1	1	1	1	0	0	1	2	1	2	2	2	2	2	1	1	1	1	2	2
	Native biodiversity in WWTP	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	1	1
	Native biodiversity in connected waterways	0	1	0	1	0	0	1	1	0	0	0	1	0	1	0	1	0	1	0	1	0	0	0	1
Cultural	Cultural abhorrence of human effluent being expelled	1	1	1	1	0	0	2	2	0	0	2	2	1	1	1	1	0	0	0	0	0	0	0	0
	Cultural abhorrence to reuse of human effluent	0	0	-1	-1	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ability to collect Mahinga kai	1	2	1	2	1	1	2	2	1	1	1	2	1	1	1	1	1	1	1	1	0	0	1	1
	Ability to exercise Kaitiakitanga	1	1	1	1	0	0	2	2	0	0	2	2	1	1	1	1	1	1	0	0	0	0	1	1
Social	Swimming	2	2	2	2	1	1	2	2	2	2	1	1	1	1	1	1	0	0	1	1	0	0	1	1
	Land used/impacted	-1	-1	-1	-1	0	0	-1	-1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	Aesthetic environment	-2	-2	-1	-1	0	0	1	1	0	0	2	2	-1	-1	-1	-1	0	0	0	0	0	0	1	1
Economic	Initial cost of upgrades	-2	0	-2	0	-2	0	-2	0	-1	0	-2	0	-1	0	-1	0	-2	0	-1	0	-1	0	-1	0
	Maintenance/ operating costs	-1	-1	-2	-2	-1	-1	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1	-2	-2	-1	-1	-1	-1	-1	-1
	Costs of required future expansions	0	0	0	-1	0	-1	0	-1	0	-2	-1	0	-1	-2	-2	-2	0	-2	0	-2	-2	-2	0	-1
	Mauri Score Calculation	**.45**	**.65**	**.65**	**0.8**	**0.3**	**.35**	**.90**	**.85**	**.15**	**0.1**	**1.0**	**1.3**	**.65**	**.75**	**.50**	**0.6**	**0.6**	**.65**	**0.4**	**0.4**	**.05**	**0**	**0.8**	**.85**

Figure 3. Results of Waitomo Wastewater Treatment Plant Mauri Model Analysis

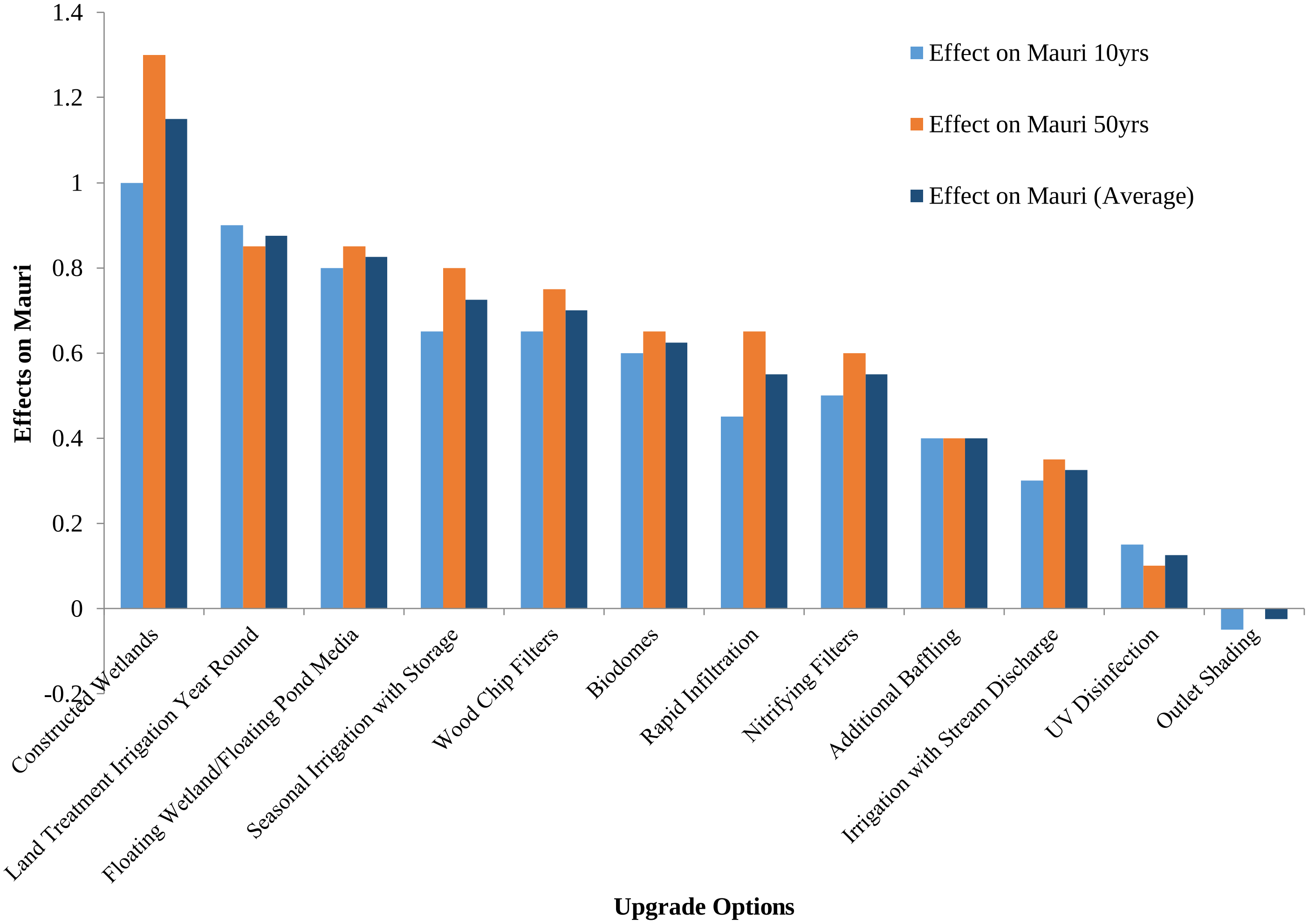

Table 2. Summary Table of Mauri Scores for WWTP Proposed Upgrades

WWTP Upgrade Options	**Effect on Mauri**			**Recommended by BECA?**
	10yrs	**50yrs**	**(Average)**	
Constructed Wetlands	1.00	1.30	1.15	Maybe
Land Treatment Irrigation Year Round	0.90	0.85	0.88	No
Floating Wetland/Floating Pond Media	0.80	0.85	0.83	Yes
Seasonal Irrigation with Storage	0.65	0.80	0.73	No
Wood Chip Filters	0.65	0.75	0.70	Maybe
Biodomes	0.60	0.65	0.63	Yes

Rapid Infiltration	0.45	0.65	0.55	No
Nitrifying Filters	0.50	0.60	0.55	Yes
Additional Baffling	0.40	0.40	0.40	Yes
Seasonal Irrigation with Stream Discharge	0.30	0.35	0.33	Maybe
UV Disinfection	0.15	0.10	0.13	No
Outlet Shading	-0.05	0.00	-0.03	Maybe

Constructed wetlands are predicted to have the most positive effect on mauri, followed by land treatment (with irrigating nearby fields year round), a floating wetland, seasonal irrigation with storage and the wood chip filter. With the exception of outlet shading, all upgrades had a positive effect on the mauri of Waitomo and its community.

Discussion and Recommendations

Based on the upgrades that rated most highly in the mauri model, including constructed wetlands and land treatments, it is evident that the mauri model was successful in considering cultural concerns, in addition to environmental factors. Three out of the top four options rated by the mauri model address the cultural abhorrence associated with dispelling human waste water into freshwater. The mauri model is distinctive from conventional decision-making frameworks in that is does not prioritise economic considerations. It still considers them, but it doesn't allow the economic factors to dominate our thinking and prevent us from considering method that may be more beneficial for the environmental, social and cultural factors.

However, the top rated options with the exception of floating wetlands, are also reliant on the ability to obtain suitable land within the vicinity of the WWTP, and are likely to have higher capital costs. Beca estimates that approximately 0.12 – 0.84 h.a. would be required for a constructed wetland (based on flows of 60 m3/day), 15,000 m3 of storage would be required and 8-16 h.a. of land for seasonal irrigation with storage, and that greater than 10 h.a. would be required for year round irrigation. TOWT and RUHT need to determine whether it is feasible to obtain the amount of land required for these upgrades. Some options include approaching neighbouring farmers or DOC for a possible joint venture. There is an ancient kahikatea grove and DOC reserve located near the WWTP which could serve as a potential location for drip irrigation from the WWTP. For the constructed wetland, it is also imperative that further research is employed to determine the feasibility and effectiveness of a constructed wetland in the area.

If it is possible to obtain the necessary land, I recommend that TOWT and RUHT pursue a constructed wetlands or land treatment (preferably seasonal irrigation with storage, since it will be more likely to be able to obtain the necessary land for seasonal irrigation than year round irrigation). If deciding upon a constructed wetland, I would also recommend installing additional baffling or a nitrifying filter in the oxidation ponds. These are relatively inexpensive and easy to install, and could resolve the current issues with consent limits while the constructed wetland is being installed and is growing in.

If it is not possible to obtain the required land, a nitrifying filter, floating wetland, or wood chip filters should be considered. While the nitrifying filter did not score as high as a floating wetland, with the nitrifying filter, if the wastewater is sprayed onto rock bunding/rock filter, may satisfy the cultural need to pass wastewater through Papatuanuku before flowing into Waitomo stream. The nitrifying filter may be able to use the existing infrastructure of the WWTP, which would minimize costs and additional construction, and specifically targets NH4-N (the most problematic pollutant for Waitomo WWTP). Floating wetlands may also be a suitable option for Waitomo, and uses the same processes as constructed wetlands to improve water quality, but without the need for additional space. However, floating wetlands would not address the current cultural violations by the WWTP, and there is little research about its effectiveness in New Zealand.

To resolve the cultural issues and consent exceedances of the Waitomo WWTP, another option can be to instead work at managing the waste at the source. This can be partially achieved by installing composting toilets at the Waitomo caves, an idea that has been put forward by Dan Hikuroa. Composting toilets would altogether eliminate the issue of human effluent from Waitomo caves entering the WWTP and Waitomo stream, though there would still be human effluent coming from the other users of the WWTP.

While the cost and land use required for the recommended treatment upgrades is a substantial obstacle, the mauri model revealed that these options would be largely beneficial environmentally, culturally and socially. Implementing one of these more sustainable options could not only reduce the negative impact on the environment and address cultural concerns, but could also help to build Waitomo Cave's reputation as a sustainable tourist attraction. Because Waitomo Caves attracts so much local and international attention already, it could also further serve as a model of sustainable and culturally sensitive tourism, and could serve as a positive influence for other New Zealand tourist attractions.

Limitations

This research had a number of limitations. As someone without a Māori background, I was limited in my ability to assess how WWTP upgrades impacted mauri, especially with the cultural indicators. For instance, there is a question of what specifically satisfies as returning wastewater back to Papatuanuku in the case of the Nitrifying filter. Having a clearer standard, or at least one by TOWT and RUHT for the Waitomo case specifically, would assist in the development of a culturally appropriate WWTP. Impacts to mauri were also predicted without consultation from experts on each wastewater treatment option, and there is always uncertainties that accompany future projections. With each treatment type, there is also a ranging degree of uncertainty with how effective they will work in the given environmental conditions. However, the coarse scale of the Mauri model should minimize accuracy discrepancies.

If I were to revise my mauri model for the Waitomo WWTP, I would group options into combinations of treatments (ex: constructed wetland plus additional baffling) or separately assess 'full treatments' (like constructed wetland or year round irrigation) from 'minor upgrades' (like UV disinfection and outlet shading), since the treatment options operate on different degrees of treatment, and thus are obviously going to score differently on the mauri model scale. Additionally, I may continue to revise the list of indicators used because there may be overlap in the environmental indicators. For instance, freshwater macroinvertebrates are indicators of water quality, but I already included specific pollutants (phosphorus, nitrogen, etc) to measure water pollution.

Further Research

To assist TOWT and RUHT in deciding upon a WWTP upgrade, further research is necessary with specific goals and constraints in mind. The TOWT and RUHT may decide that specific indicators are more important than others, or decide upon a budget constraint. The TOWT and RUHT can weight whichever indicators or indicator categories that they deem most important to adjust the mauri model to fit their own values. Identifying parameters and weighting the indicators will assist the trustees in identifying the best option for the Waitomo WWTP. As noted before, further consultation with experts in the type of WWTP upgrade considered is necessary to determine the feasibility and appropriateness of the chosen WWTP option for Waitomo.

Conclusion

As New Zealand and tangata whenua are faced with the task of improving and developing their wastewater infrastructure, it is imperative that tangata whenua cultural values are addressed in the design and implementation of wastewater treatment plants. This research used the Mauri Model, a value-based decision making framework, to assist the TOWT and RUHT in deciding upon the best options for the Waitomo WWTP. Based upon this mauri model assessment, the cultural, social, environmental and economic aspirations of tangata whenua may can best be served by adding a constructed wetland to the current treatment plant. Specific goals and constraints decided upon by TOWT and RUHT may render seasonal irrigation with storage, land treatment with irrigation year round, a nitrifying filter or a floating wetland as effective additions to the WWTP as well. Upgrading the Waitomo WWTP will address the cultural abhorrence that has occurred from the expulsion of water tainted by human waste into a freshwater stream, beginning the process of restoring the mauri to Waitomo stream.

Acknowledgements

Special thanks to all the people who contributed to this project:

- Frontiers Abroad Program
- Dan Hikuroa
- Max Borella
- My fellow FA students, especially Laura Lilienkamp and Emily Freilich for their help with the Mauri Model
- Tanetinorau Opataia Whanau Trust, Ruapuha Uekaha Hapū Trust, Ngāti Ruapuha and Ngāti Uekaha Hapū

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Glossary

Hapu Clan group associated with a particular rohe

Iwi Tribal grouping of several hapū

Kaimoana Seafood, shellfish

Kaitiakitanga Ethic of guardianship

Kaitiaki Guardian; trustee

Mahinga kai Indigenous freshwater species traditionally used as food, tools, or other resources

Mana Authority, status or prestige of the hapū

Mātauranga Māori Māori knowledge

Mauri Binding force between physical and spiritual; the life force

Noa Profane

Papatuanuku Papa the earth mother

Ranginui Rangi The sky father

Tangata whenua The people of the Land; Māori

Taonga Treasure

Tapu Sacred

Urupā Cemeteries

Wāhi tapu Sacred sites

Waimate To be slack, spiritless; refers to water that has lost its mauri

Waitangi Tribunal Created by government to hear historic grievances

Whakapapa Genealogy

Appendix

Table A. Descriptions and notes for the treatment types and upgrades proposed for the Waitomo WWTP (Adapted from Beca 2017)

Treatment/ Upgrade Type		Description	Relative Cost	Contaminants Targeted	Notes
Land Treatment	Rapid infiltration	Effluent from the ponds would be discharged to rapid infiltration basins where the effluent infiltrates through sand layers before discharging to groundwater. If constructed near stream, discharge is expected to discharge via ground to the stream.	High initial cost, but low maintenance cost.	TSS, BOD, NH_4N, *E.coli*	Large amount of land required and high costs from construction of infiltration basins.
Land Treatment	Seasonal Irrigation with Storage	Effluent stored over the wetter months (autumn, winter and spring) and then irrigate the effluent over the summer months. No effluent would be discharged into the stream.	High costs of storage and land purchase.	TSS, BOD, NH_4N, TN, *E.coli*	Would require 15,000m^3 of storage and 8-16 ha of land.
Land Treatment	Seasonal Irrigation with River Discharge	Irrigate effluent over the summer months (during peak load) while continuing to discharge into stream during other months.	High costs (land purchase).	TSS, BOD, NH_4N, TN, *E.coli.*	Would require less land that year round land treatment (2-4ha). However, this would still involve large land purchase within vicinity of the WWTP.
Land Treatment	Land treatment Irrigation Year Round	Discharge would be irrigated onto surrounding farmland year round, but it will be difficult to find 3rd party farms interested in receiving effluent. May also be problematic if increases contaminant loss from farmland.	Very High cost (land purchase)	TSS, BOD, NH_4N, TN, *E.coli*	THL would have to purchase a significant portion of land (> 10 ha) to support year round irrigation.
Tertiary	UV disinfect-ion	UV unit installed downstream to provide disinfection, killing bacteria and virus in the effluent.	Medium initial cost and maintenance cost.	*E. coli*	Not recommended by Beca 2017 because of high relative costs and only targets bacteria.
Tertiary	Construct-ed Wetlands	Two potential types of artificial wetlands could be installed: surface flow wetlands (effluent flows over the	Low maintenance, but still	TSS, BOD, *E. coli*,	One con is the potential for E. coli to move from the

		surface of a substrate and treatment occurs through solids filtering through plants, nutrient uptake by plants, biomass growing on the plants consuming nutrients) and sub-surface flow wetland (effluent flows through gravel or other media in which wetland is planted in).	required (weeding, desludging, planting). High start up costs (land purchase) and medium maintenance costs	NH_4-N (though less reliable because process very temperature dependent)	wetland into the birdlife/other organisms. The main issue with constructed wetlands is the necessity of sufficient land within the immediate vicinity of the WWTP.
	Wood Chip Filter	Filter is packed with wood chips/shavings on which a biofilm grows to consume contaminants. The lower part of the filter is filled with rocks or other filtration media to hold in the wood chips and help filter solids.	Requires monthly maintenance to the surface layer of filter and replacement of layer annually. Requires about 100-200 m2 of land.	NH_4-N, TSS, BOD	One company (Biofiltro Ltd.) used worms in the upper layer of the wood chips to provide additional aeration and consumption of nutrients. Would require a new tank structure and pumping of effluent to the filter. Studies have shown that wood chip filters can produce denitrification rates comparable to plastic media, but last much less longer than plastic media (Saliling et al. 2007)
	Nitrifying Filter	Pond effluent would be pumped to a simple rock media where growing biofilm would oxidise ammoniacal nitrogen. Another option, successfully implemented at Motueka WWTP (implemented by BECA), would involve spraying pond effluent on rock bunding along the perimeter of the pond.	Relatively cost effective. Medium/ low maintenance.	NH4-N Phosphorus Some *E. coli* removal	Effectiveness subject to changes in temperature (less effective at lower temperatures) (BECA 2017). Potential uncertainty about the amount of ammonia that will be removed, nitrifying bacteria may not grow quickly (BECA 2015). Could utilise the one of the two dry river beds located near WWTP or existing area retrofitted with

					rock media. Simple solution, targets the problem contaminant
In-Pond Treatments	Biodomes	Bio-domes are concentrically nested domes that sit on the floor of a treatment pond and are completely submerged. As water flows through dome and air is added to bioshells, biofilms reduce contaminants in wastewater	Medium ($100,000 - $500,000) initial operating and maintenance costs.	BOD TSS NH_4-N, TN	Pilot studies showed significant reduction in BOD, TSS, ammonia and total nitrogen, and would likely result in significant improvement for WWTP effluent quality (BECA 2017). Can work in colder weather. Has only been used in North America so far.
	Additional Baffling	BECA proposed installing additional baffling to reduce short-circuiting, which is the passage of untreated wastewater through the lagoon system in a short amount of time, making the treatment ineffective. Baffling essentially works by slowing down the flow of water, allowing sediment and other materials to have time to settle and filter (BECA 2017). Would improve the efficiency of the overall pond treatment.	Relatively low cost and simple to operate with little additional maintenance required.	BOD TSS *E. coli*	Successfully installed at Motueka and Geraldine WWTP (BECA 2017)
	Outlet Shading **(needs to be done in conjunction with other methods)**	Involves covering the area of the pond near the outlet to reduce the amount of sunlight and inhibit algal growth.	Relatively inexpensive and very little maintenance.	TSS BOD	While successful at Kerepehi WWTP, outlet shading has also been less successful at several other WWTP, or its effects have been difficult to separate from other work. BECA had low confidence outlet shading alone would be enough to improve effluent quality.

	Floating Wetland/Floating Pond Media	A floating wetland shades the surface of the oxidation ponds, reducing algae growth, which may assist in the reduction of TSS and associated BOD. Plant roots can also act as a support for biofilm to grow which may assist in nutrient removal, including nitrification. The effectiveness of such floating wetlands has varied around New Zealand, and often it has been difficult to determine whether improvements in effluent quality are attributed to the floating wetland. Additional maintenance would be required as it grows, as it would need to be maintained and harvested. (BECA 2017).	Relatively low life coast and relatively minimal maintenance inputs (Finnemore et al.). From a commercial company can be rather expensive depending on the size of the project. From BioHaven®, a 100 square foot AFI would cost around $3,000 (Garbs, [2013]). This cost to build an AFI is rather inexpensive as it can be constructed with PVC piping, metal pipes, and natural materials. Due to these variations, cost is an uncertainty as it is highly dependent on the budget and skill of those running the project.	NH_4-N (Ammonium), TSS, BOD	Floating Wetlands have more recently been viewed as an improved alternative to constructed wetlands because they do not require large amounts of space (can be retrofitted in existing oxidation ponds while still harnessing the benefits of wetland systems) (Finnemore et al.) The hanging root mat the forms below the floating mat also allows for a close interaction (and greater surface area) between the roots, attached biofilm and nutrients in the water column, encouraging a greater uptake of nutrients and contaminants that conventional sediment rooted wetlands (Finnemore et al.) While floating wetlands are a promising alternative, they are a relatively new technology and there is a lack of long-term performance data in actual systems, adding a level of uncertainty to the treatment (Hesse 2012). Helensville WWTP Kerepehi WWTP Marton WWTP Shannon WWTP