A Case Study Investigation into the Effectiveness of Waterbody Management:

Lorong Halus Wetland

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ABSTRACT

With the emergence of rapid urbanisation in recent decades, cities worldwide have developed numerous ways to better manage their waterbodies, which have become increasingly integral features of the communities they are situated in. Lorong Halus Wetland was originally a dumping ground from 1970 to 1999. With the damming of the nearby Serangoon river to form a reservoir in 2006, contaminated water leaching from the wasteland became a serious concern, triggering its makeover into a wetland to protect the reservoir's water quality. This project aims to gain a deeper insight into waterbody management by examining the case study of Lorong Halus Wetland. In addition to evaluating the effectiveness of the bioremediation processes through readings of nitrate, phosphate, heavy metal concentration and dissolved oxygen, this project will consider the utilisation of Lorong Halus Wetland as a community space for interaction under the Active, Beautiful and Clean Waters programme as well as its value in education to boost public awareness of water conservation. Such an investigation could not only highlight possible areas of improvement for the management of Lorong Halus Wetland at a local scale, but also provide broader insights into the role which waterbodies play in their respective communities today. (199 words)

KEYWORDS

Water quality refers to the degree to which water is clean. It can be measured through various indicators and aspects and is not confined to nitrate, phosphate, lead and cadmium concentrations which are the focus in this research. Bioremediation involves the usage of biological processes to treat water and improve its quality.

Community utilisation refers to the extent and nature of activities which a group of residents belonging to a particular neighbourhood undertake in a particular space.

Water or waterbody management refer to the process of controlling the various aspects of water resources (including supply, efficiency and demand) or the usage of waterbodies in order to maximise benefits.

Water education refers to process of imparting knowledge regarding water and its origins, how it is and can be managed as a resource as well as the importance of its conservation.

I. PURPOSE OF RESEARCH

1.1 Background

Lorong Halus Wetland, located along the eastern bank of Serangoon Reservoir, originally served as a 234-ha dumping ground from 1970 to 1999 before the designation of Pulau Semakau as Singapore's main landfill. [1] In 2006, the Public Utilities Board (PUB) dammed the Punggol and Serangoon rivers to form Singapore's 16th and 17th reservoirs. Water leaching from the waste dump became a serious concern, triggering the makeover of Lorong Halus from a man-made wasteland into a water landscape. The PUB constructed a cut-off wall to prevent the baseflow of contaminated water into the reservoir. However, in the event of heavy rain, the water level of the dump could exceed that of the cut-off wall, resulting in the overflowing of contaminated water into the reservoir. As such, the PUB also remade Lorong Halus into a wetland to protect the reservoir's water quality.

Today, Lorong Halus Wetland collects and treats water passing through the former landfill, preventing it from flowing into the reservoir. This prevents the leaching of contaminated water from the old landfill to Serangoon Reservoir.

There are three main steps to the treatment process. [1, 2]

1. Tanks and Lagoons

Water is first piped into an equalisation tank, where suspended particles are removed. It is then piped into the aeration lagoons, where oxygen is introduced to help remove organic matter and break down nitrogen compounds in the waste water for easier absorption by plants. Finally, in the sedimentation tank, all remaining suspended particles in the waste water are removed.

2. Reed beds

Waste water piped in from the tanks goes under the gravel in the reed beds. Here, bioremediation processes, or specifically phytoremediation processes, occur. The reeds remove nitrogen and phosphorous out of the waste water.

The three main reeds used are cattails (*Typha angustifolia*), vetivers (*Chrysopogon zizanioides*), and papyrus sedge (*Cyperus papyrus*). These plants were selected for their ability to uptake nutrients, resist pests as well as tolerate low phosphorus concentrations.

3. Polishing ponds

Finally, aquatic plants such as water lilies purify the water further by absorbing the nitrogen and phosphorous that remain in the waste water.

Water that has passed through the polishing ponds is then reintroduced into the sewage system of Singapore.

The man-made wetland landscape also supports a unique reed bed ecosystem with distinctive species like dollarbirds and nightjars. According to a study conducted by Singapore Environmental Consultancy and Solutions (SECS), five birds of significant conservation status are present. The Nature Society Singapore has also been conducting nature walks there since 1999. [3]

Lorong Halus Wetland was also conceived under the Active Beautiful and Clean (ABC) Waters Programme in 2011. The ABC Waters Programme is an initiative by the PUB to better harness the full potential of Singapore waterbodies. By integrating drains, canals and reservoirs with the surrounding environment in a holistic way, it aims to create beautiful and clean streams, rivers, and lakes with community spaces for all to enjoy.

Present actions taken under the ABC Waters Programme to increase the vibrancy of Lorong Halus Wetland include a pedestrian footbridge across Serangoon reservoir connecting it to Punggol Waterway, gravel trails for visitors into the wetland, in addition to informative signboards about the importance of the bioremediation processes, Singapore's reservoir and catchment network, as well as the aquatic animals and birds which the wetland hosts.

1.2 Scope and Objectives

This project hopes to better understand how waterbodies located within communities can be managed from an integrated approach and interdisciplinary point of view using the case study of Lorong Halus Wetland in Singapore.

Firstly, this project aims to investigate the effectiveness of pre-existing water treatment methods in place at Lorong Halus Wetland. Readings of ions (in particular nitrate and phosphate) concentration could be taken at the reed beds, polishing ponds and reservoir to evaluate how well the reed beds and polishing ponds are able to reduce nitrates and phosphates in line with their purpose as well as consider the extent to which leaching into the reservoir occurs. Although they have been previously measured to be negligible, heavy metal concentrations (which were a major concern initially due to the waterbody's previous landfill status) could also be taken. The above data would provide recommendations with regard to the improvement as well as the viability of the application of the waterbody's treatment processes on a wider scale.

Based on prior knowledge of previous studies conducted by the PUB, it is hypothesised that water quality improves (nitrate and phosphate concentration decrease) after it passes

through the respective stages of bioremediation, while cadmium and lead concentrations should be rather low.

Secondly, our project aims to find out the extent of the utilisation of Lorong Halus Wetland as a waterscape, which could pave way for suggestions for the better utilisation of waterbodies within neighbourhoods as community spaces.

In line with the ABC Waters Programme, Lorong Halus Wetland provides a green and blue space for community and environmental interaction, promoting social cohesiveness and a vibrant Punggol waterfront town.

As such, traffic counts could be undertaken involving the recording of the frequency of visitors as well as the identification of the activities which visitors carry out in this particular location. Bipolar perception surveys could also be conducted to evaluate visitors' opinions about the maintenance of the location in order to assess the vibrancy and utilisation of Lorong Halus Wetland as a waterscape and whether it truly serves its purpose in fostering community interaction.

From a more normative perspective, concepts from the sociology of space could be applied to analyse the interactions between the public and Lorong Halus Wetland. Qualitative studies could be conducted evaluating Lorong Halus Wetland's relevance to the communities that interact with it as well as the role it plays in Punggol's identity.

Given the relative inaccessibility of as well as lack of varied activities that can be conducted at Lorong Halus Wetland, it is regrettable that a low level of utilisation can be expected, contrary to the aims of ABC Waters Programme.

Finally, our project aims to evaluate the degree of success of Lorong Halus Wetland in increasing public awareness of water conservation, innovative water-treatment processes and the value of waterscapes.

Lorong Halus Wetland currently uses wireless learning trails and educational signboards to achieve water education. There are currently two learning trails: one by Waterways Watch Society, the other by the ABC Water Programme involving Greendale Secondary School, North Vista Secondary School, Punggol Secondary School and Seng Kang Secondary School. In addition, schools and organisations can also participate in water education through adoption and field trips.

Through surveys conducted on visitors, our project could also find out whether Lorong Halus Wetland as a waterbody is able to increase visitors' water awareness of the points raised above and its effectiveness in water advocacy.

While educational features are already in place in Lorong Halus Wetland, they have largely been poorly maintained since their inception during the waterbody's conception. As such, it is likely that the attractiveness, and concomitantly, the effectiveness of water education efforts at the waterbody are largely diminished.

1.3 Literature Review

Previous research has indicated effectiveness of the bioremediation processes in reducing the levels of nitrates, phosphates, and heavy metals. [2] Removal efficiencies of various parameters from April 2011 to August 2012 were recorded on a monthly basis by PUB, starting one month after the wetland was launched in March 2011.

Parameter	Reed Beds /%	Polishing Ponds /%	Combined Pre-treatment, Reed Beds, and Polishing Ponds
BOD_5	47.0	0.0	77.4
COD	42.2	0.8	56.2
TSS	57.0	-155.1	50.8
NH_4-N	82.5	47.1	97.9
TP	29.3	-19.5	43.7
TN	83.9	39.8	96.1

Table 1: Removal efficiency of Reed Beds, Polishing Ponds, and Pre-treatment System combined with Reed Beds and Polishing Ponds

Overall, the treatment effluent was able to sewer discharge water quality limits, and the treatment system was able to successfully reduce the levels of total phosphorus (TP), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH_4-N), and Total Nitrogen (TN). Interestingly, it was observed that the volume of leachate was lower than expected, resulting in an "uneven flow distribution" in the reed beds and negatively affecting the growth of the reeds. Given that this data was taken early after the wetland commenced operations nearly 7 years ago, this project aimed to provide a more recent update of the effectiveness of the bioremediation system.

Given a lack of data or research on the extent of utilisation of Lorong Halus Wetland, this project aims to explore this area with regard to the community utilisation of the waterbody.

II. METHOD OF RESEARCH

2.1 Water testing: Quantitative

2.1.1 2018 Sampling

Water samples from the reed beds, polishing ponds and the reservoir were collected on Tuesday, 20 February 2018 and Wednesday, 21 February 2018 in the afternoon. Unfortunately, security regulations by the PUB made it impossible for water from the equalisation tanks, aeration lagoons and sedimentation tanks to be obtained. All results drawn were calculated from the arithmetic mean of the average readings from both days so as to increase reliability.

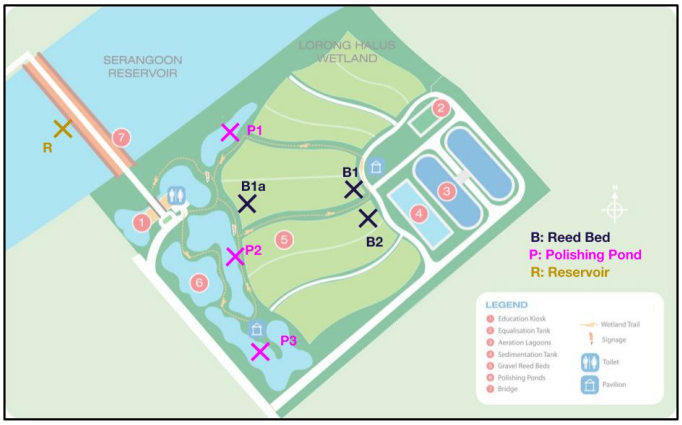


Figure 1: Water Sample Collection Points

The above points in Figure 1 were selected so as to ensure representation of all the various bodies of water located within Lorong Halus Wetland. The points chosen were also located at or as close to the central points of the water bodies as possible to reduce the possible interference of particles from the banks on water quality.

A bucketful of water from each point was then obtained for analysis, from around the midpoint of the depth profile.

Unfortunately, water at the reed beds was located largely underground as the dominant flow consisted of sub-surface throughflow through root zones at a depth of about 150 mm [2], resulting in difficulties in the collection of water above the surface. As there was a tendency for water to pool closer to the point where water is introduced from the aeration lagoons, the samples were collected from there instead, rather than from a central location within each the reed bed. An exception to this was on 21 February 2018, when water was collected from both ends of one reed bed (B1a), as surface collections of water were observed at that point. In addition, the depth of water at the polishing ponds was less than 1m, which could have possibly affected the reliability of the samples collected.

On-site testing

A glass-bulb thermometer was then used to measure the temperature of each water sample collected, before it could be affected by and vary due to environmental conditions.

For dissolved oxygen readings, a small vial was submerged into the water sample, before adding two Dissolved Oxygen TesTabs (3967A) into the vial. The vial was then inverted over and over to allow the tablets to dissolve. After the colour was developed, it was then compared against the Dissolved Oxygen colour chart.

An Eutech Instruments Oaklon pHTestr Basic was calibrated at pH 7 buffer before inserting it into the water sample. 3 readings at 5 second intervals were taken from the meter. The depth at which the meter was placed was kept constant. The arithmetic mean of each set of 3 readings was then calculated.

The above procedure was then repeated for a HI 3292 ATC Conductivity Probe.

Laboratory testing

50 ml airtight containers within a chilled and insulated styrofoam box were then used to transport a portion of each sample to the school laboratory. These samples were refrigerated in the laboratory. Prior to testing, the water samples were then passed through a filter funnel lined with Double Ring Qualitative Filter Paper with a flow rate of 102 to reduce the influence of sediments on results.

Nitrate tests were conducted using a sera test kit. 6 drops of the 4 reagents involved were added respectively to a 10 ml portion of each sample in a glass vial, with vigorous shaking after the addition of each reagent. After 5 min, the colour of the solution in the vial was then compared to a colour chart.

Phosphate tests were conducted similarly with an Aquarium Pharmaceutical test kit with the 2 necessary reagents.

Levels of cadmium and lead were also measured using a flame atomic absorption spectroscopy machine.

2.1.2 2017 Pilot testing

Readings of pH, dissolved oxygen as well as phosphate and nitrate concentration were recorded at the various collection points durings a fieldwork conducted on 12 March 2017. These readings were used to compare and contrast with the

main readings in January 2018 in order to gain a better understanding and overview of the possible temporal and seasonal trends in the effectiveness of the water treatment processes for analysis.

2.2 Traffic count: Quantitative

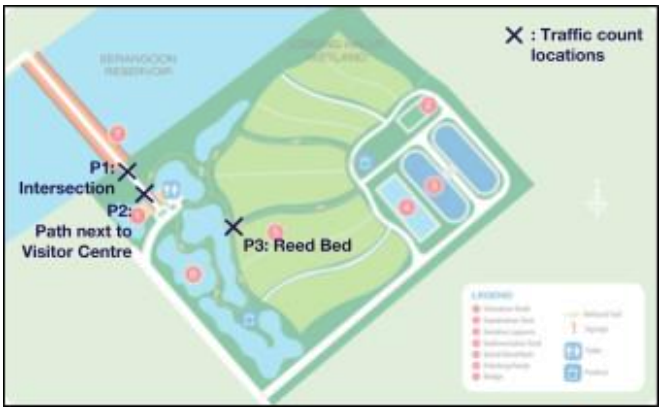


Figure 2: Locations of Traffic Count

Traffic counts of visitors were carried out from 8am to 6pm on Tuesday, 16 January 2018 and Sunday, 28 January 2018. The two dates were chosen so as to provide a means of comparison between a weekday and a weekend, allowing for better representation of human traffic and activities at Lorong Halus Wetland. Three points in figure 2 – namely (1) the intersection between Main bridge and the cycling path, (2) the path next to the visitor centre as well as (3) the interior of the wetland– were identified as they could adequately reflect the purpose of each visitor.

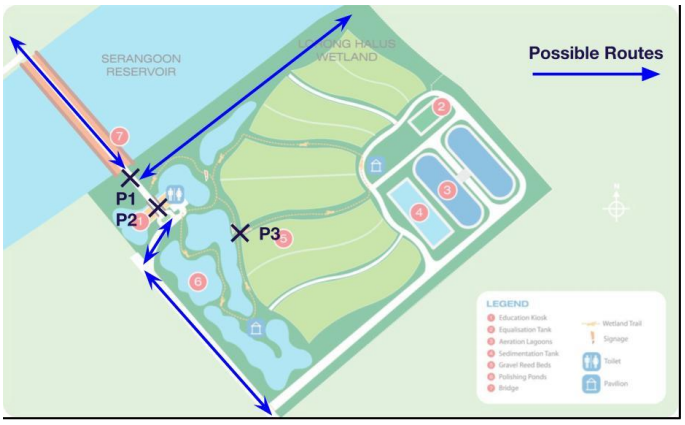


Figure 3: Possible routes at perimeter of Lorong Halus Wetland

Based on the figure above as well as observations made, it was generalised that visitors merely passing through point 1 or 2 before turning back or heading on the paths marked in Figure 3 were likely to be largely uninterested in viewing and understanding the features of Lorong Halus Wetland. In contrast, visitors passing through point 3 in addition to either points 1 or 2 were more likely to spend more time in Lorong Halus Wetland.

Visitors were classified into five main categories: strollers, joggers, cyclists, bird-watchers as well as users of personal mobility devices. The number of visitors belonging to each category passing each point was counted for 10 min at 30 min intervals. Regular intervals were chosen to allow even coverage throughout the day, in order to better represent visitor trends over the course of a day. However, such a sampling method also resulted in possible over- and under-representation of particular groups of visitors. Visitors who stayed at Lorong Halus Wetland longer than 30 min, as well as those who visited multiple times a day might be represented multiple times in our data. Additionally, we encountered visitors that arrived in large groups for specific events, which could have arbitrarily inflated the count recorded for their specific arrival periods.

2.3 Survey: Quantitative

Surveys were given out to visitors at Lorong Halus Wetland in order to identify the purpose of their visit as well as their general perceptions of the attractiveness of the waterbody. Further questions were also included within the survey in order to evaluate their understanding of the wetland's functions as well as the importance of water sampling in Singapore's context.

Given the overall low number of visitors and consequently, foot traffic, convenience sampling was employed while giving out surveys in order to maximize the number of respondents surveyed. The unwillingness of bicycle and PMD users to answer surveys was considered as well, and as such only riders who dismounted were approached.

2.4 Observation: Qualitative

During the dates on which traffic counts and surveys were conducted, observations regarding the general state of the wetland as well as visitor activity were made.

The maintenance level of the paths as well as signboards on the learning trails were noted, while information regarding the cleanliness, safety, aesthetics, vibrancy, uniqueness and identity of the location was recorded. In addition, the activities and distribution of visitors across the span of the day were monitored.

2.5 Interview: Qualitative

On 16 January 2018, a PUB officer Ms Gui Mei facilitating the learning journey of a group of Dunman Secondary School students visiting the wetland kindly agreed to the conducting of an informal interview. Despite no transcript being

recorded, key points regarding the purpose of the wetland as well as visitor activities at Lorong Halus Wetland were noted.

III. RESULTS OF RESEARCH

3.1 Water testing

3.1.1 Pilot testing 12 March 2017

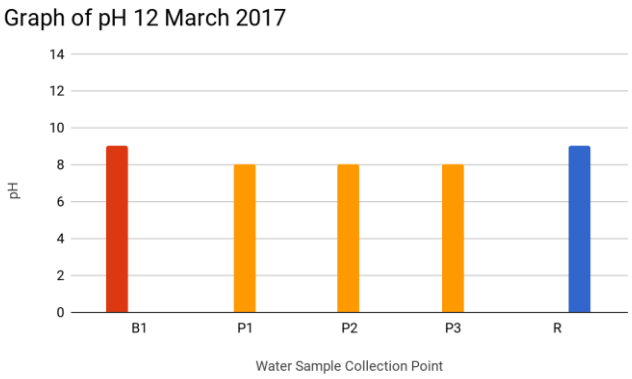


Figure 4: Graph of pH 12 March 2017

Overall, a dissolved oxygen concentration of 4 ppm was observed at all water sampling locations. From figure 4, a slight difference in pH from 9 to 8 existed between water from the reed beds, reservoir and the polishing ponds.

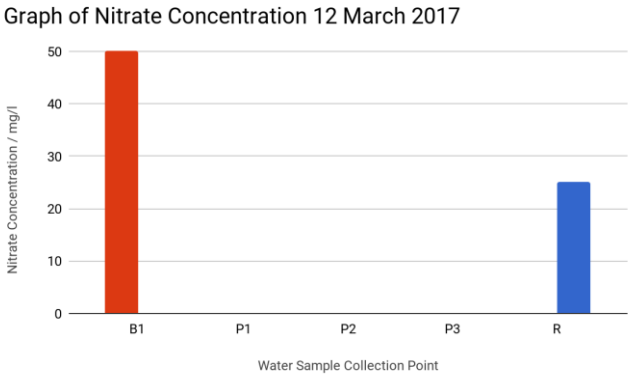


Figure 5: Graph of Nitrate Concentration 12 March 2017

Nitrate levels at the polishing ponds, shown in figure 5, were significantly lower than that of the reed beds, as evidenced by the reduction in concentration from 50 mg/l to 0 mg/l. A 25 mg/l nitrate concentration at the reservoir indicates that there is no significant leaching of nitrates into it.

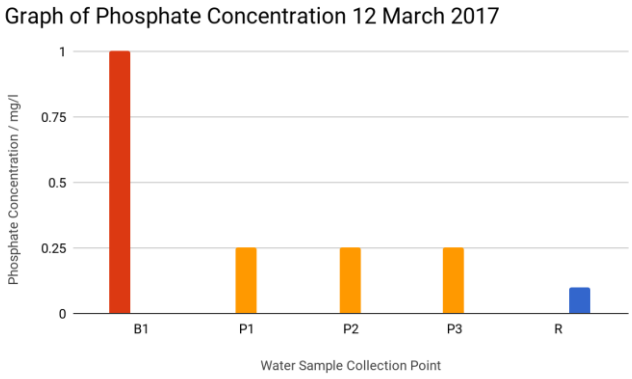


Figure 6: Graph of Phosphate Concentration 12 March 2017

Figure 6 indicates that phosphate concentrations had a 75% reduction from 1.00 mg/l at the reed beds to 0.25 mg/l at the polishing ponds. In contrast, the phosphate concentration of the reservoir was lower at 0.10 mg /l.

3.1.2 Water testing 20, 21 January 2018

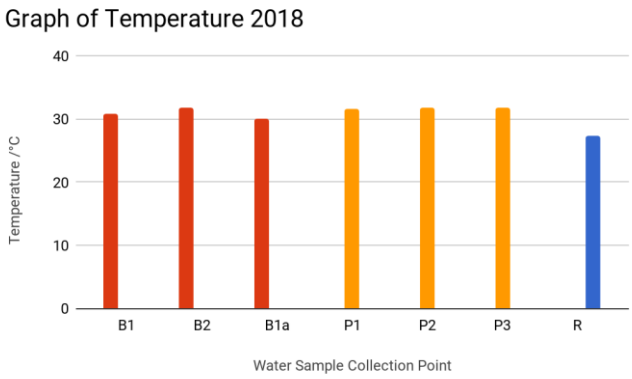


Figure 7: Graph of Temperature 2018

A dissolved oxygen concentration of 4 ppm was observed at all water sampling locations. The temperatures of the water samples collected were largely similar, with an average of 31 °C. The temperature of the reservoir water sample was slightly lower in comparison at 27.5 °C.

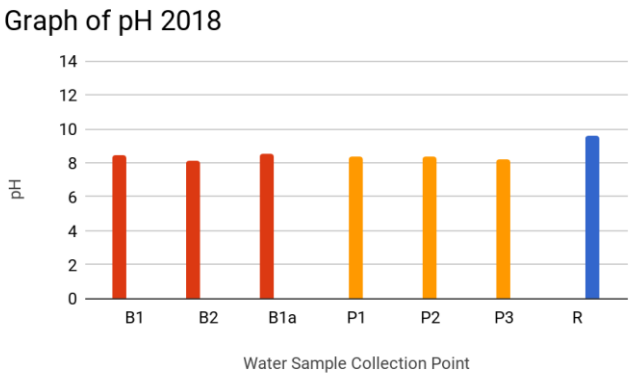


Figure 8: Graph of pH 2018

pH levels indicated in figure 8 were also largely consistent across all the water samples collected. The average pH was 8.5, while the pH at the reservoir was slightly higher at 9.6. The average pH of 8.5 is supportive of freshwater aquatic life. The reservoir pH of 9.6 is above pH 9.0, the general satisfactory limit for most freshwater aquatic life; however, this is a general figure and exceptions do exist. [4]

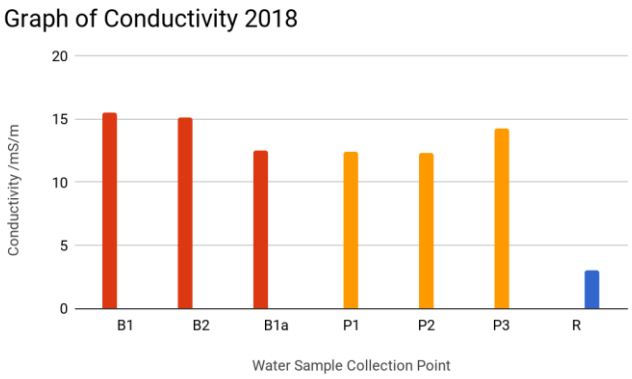


Figure 9: Graph of Conductivity 2018

Overall, a general decrease in conductivity of the water samples from the reed beds to polishing ponds and reservoir. The average conductivity of polishing ponds water samples was 12.99 mS/m, with a 15% reduction from 15.31 mS/m at the reed beds.

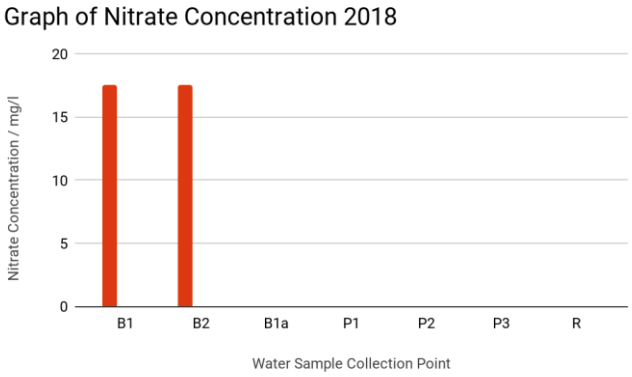


Figure 10: Graph of Nitrate Concentration 2018

A complete reduction in nitrate levels was observed from 17.5 mg/l at the reed beds. Little or insignificant nitrate concentration was also recorded for the reservoir water sample.

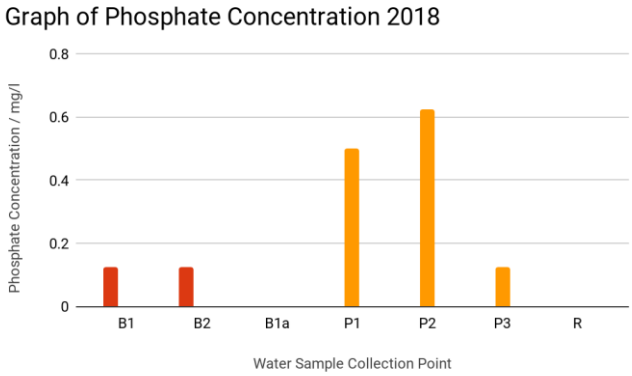


Figure 11: Graph of Phosphate Concentration 2018

However, readings for phosphate concentration deviated largely from expectations. The average phosphate concentration at the polishing ponds of 0.417 mg/l was higher than the 0.125 mg/l observed at the reed beds, while no phosphate was recorded in the reservoir water sample. It is worth noting that an Aquarium Pharmaceutical test kit was used for the 2018 phosphate tests in contrast to the sera test kits used for all the other tests, including the pilot phosphate concentration tests in 2017.

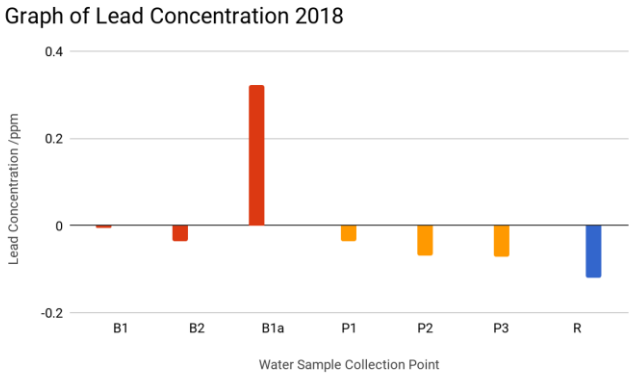


Figure 12: Graph of Lead Concentration 2018

Lead concentration decreased overall from 0.093 ppm at the reed beds to -0.059 ppm at the polishing ponds and -0.12 ppm reservoir, demonstrating how the higher lead concentrations exist at Lorong Halus Wetland as a previous landfill and that measures in place at Lorong Halus Wetland are indeed effective in preventing a leakage of lead into the reservoir.

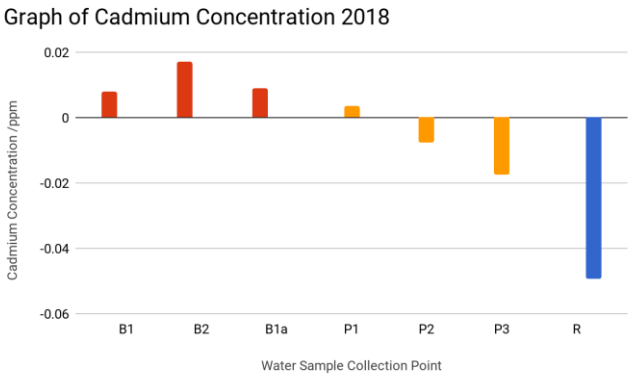


Figure 13: Graph of Cadmium Concentration 2018

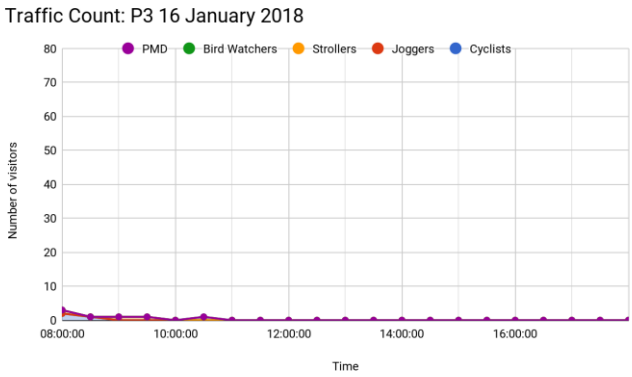
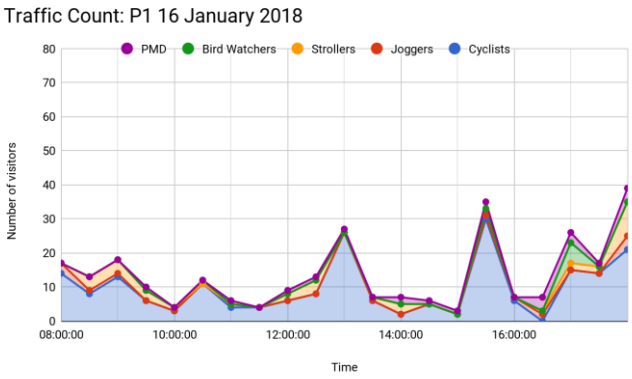


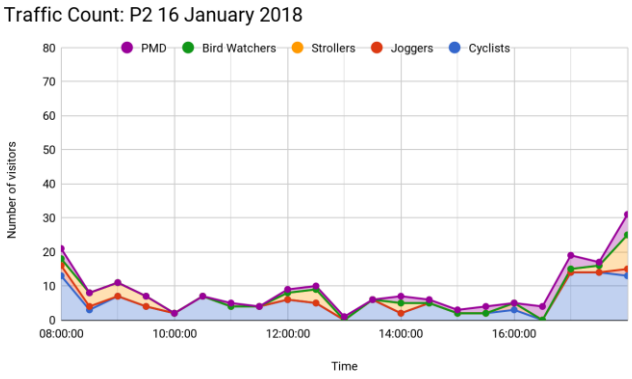
Figure 14: 16 January 2018 Traffic Count

Similarly, cadmium concentration decreased overall from an average of 0.0011 ppm at the reed beds to -0.0072 ppm at the polishing ponds and -0.0495 ppm at the reservoir, demonstrating how higher cadmium concentrations exist at Lorong Halus Wetland as a previous landfill and that measures in place at Lorong Halus Wetland are indeed effective in preventing a leakage of cadmium into the reservoir.

3.2 Traffic Count

3.2.1 Analysis of Traffic Count on 16 January 2018





Moving from P1 to P3, there is an evident decreasing trend in the number of visitors observed, from 287 at P1, 187 at P2 to 7 at P3. There were 100 more visitors counted at P1 than P2, indicating that 20.8% of visitors merely crossed the bridge to Lorong Halus before turning back or onto the paths shown in figure 3. As such, a significant proportion of visitors were merely passing by Lorong Halus Wetland on the way to other locations and displayed a lack of interest in the waterbody itself. Similarly, a meagre total of 7 visitors passed by point 3 throughout the entire day, demonstrating how most of the visitors did not venture into the reed beds of Lorong Halus Wetland, which form the majority of its land area. The trends reflected thus indicate a severe under-utilisation of much of Lorong Halus Wetland and could also pose ramifications on the level of appreciation by visitors of the waterbody's main purpose and the effectiveness of the water education features situated there.

When comparing the temporal trends over the span of 28 January 2018, it is worth noting that there was a huge spike in the number of cyclists at 1300 hrs and 1530 hrs at P1. The above anomaly was caused by a group of 26 Outward Bound School students and staff who were visiting and later returned to Lorong Halus Wetland for a physical education activity. The sudden increase in the number of visitors at the aforementioned times was likely to be an exception and is therefore not taken into consideration in this project's analysis. Beyond that, it is apparent that the the greatest number of visitors occur from 0800 hrs to 0830 hrs in the morning and from 1600 hrs to 1800 hrs in the evening for both P1 and P2. Due to the fact that the first traffic count was conducted on a weekday, it is likely that the majority of visitors were only able to arrive before or after their working hours, resulting in an increase in the number of visitors during those times. The insignificant number of visitors at P3 make it regrettably unsuitable and unrepresentative for analysis.

Between the five categories of visitors, it is evident from the above figure 12 that the cyclists and personal mobility device users constituted the majority with 77.8% of the total number

of visitors. Such a phenomenon could be attributed to the relative inaccessibility if Lorong Halus Wetland by car as well as its remoteness from the closet MRT (Mass Rapid Transit) station. As such, the most convenient method to reach Lorong Halus Wetland is through the nearby Punggol Waterway Park and across the main bridge, for which a bicycle or personal mobility device is most suited. The proportion of joggers and cyclists was significantly lower at 20.6% while only 2 birdwatchers visited Lorong Halus Wetland across the entire day.

3.2.2 Analysis of Traffic Count on 28 January 2018

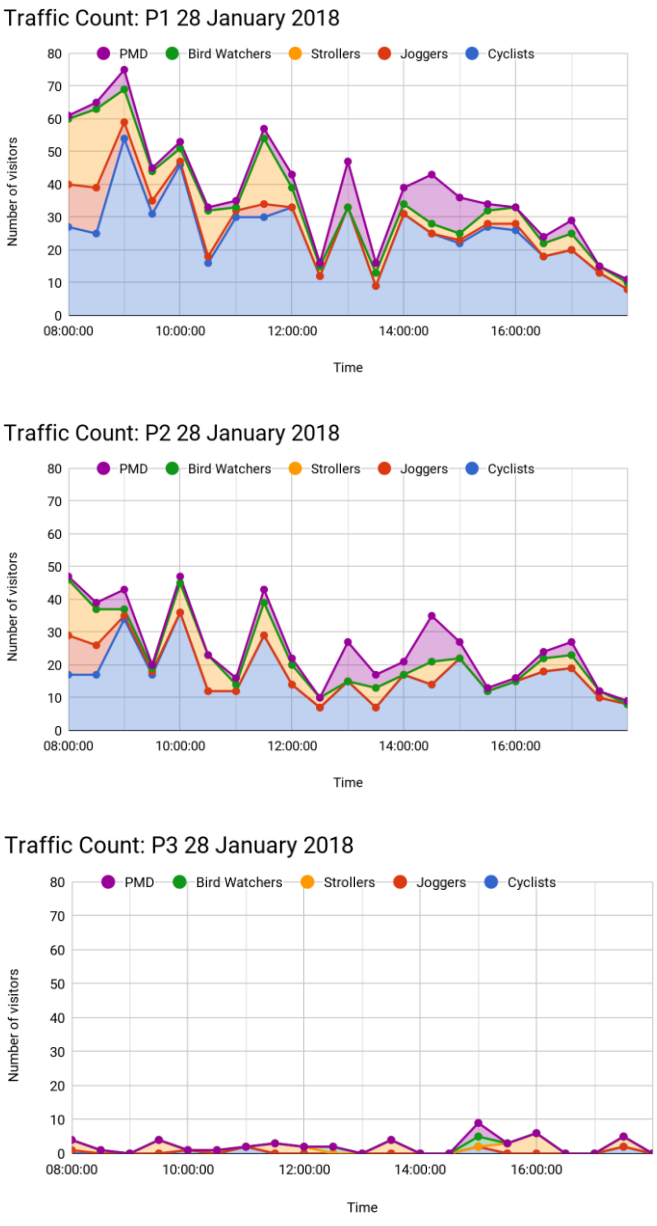


Figure 15: 28 January 2018 Traffic Count

Similarly to the traffic count on 16 January 2018, there is clear graduation in the number of visitors tabulated from P3 to P1, from 810 at P1, 537 at P2 to 47 at P3. As a result, similar issues with regard to low levels of community utilisation and effectiveness of water education at Lorong Halus Wetland can be considered applicable on both days of the traffic count.

However, it is also evident that the visitor traffic in and out of Lorong Halus Wetland was significantly higher on 28 January 2018 as opposed to 16 January 2018, with 1395 visitors as opposed to 481 visitors and up to 75 visitors being recorded at P1 0830 hrs. The 190% increase in number of visitors was likely a result of the difference between a weekday and a weekend. Given that residents were likely to have more time to themselves without the need to go to work, it was more convenient for them to visit Lorong Halus Wetland.

When comparing the temporal trends over the span of 28 January 2018, it is evident that there is a more even spread of visitors throughout the day, as opposed to the clear surge of visitors in the morning and in the evening for 16 January 2018. The time period with the greatest number of 105 visitors is still 0830 hrs, when a large proportion of visitors are carrying out recreational activities and exercising. Nevertheless, there is a gradual reduction in the number of visitors toward the end of the day. It is also worth noting that a shower which later developed into a full storm began at 1437 hrs, stopping intermittently before continuing to around 1800 hrs. Such an event could have potentially affected traffic count results by (1) temporarily increasing the number of visitors passing through P1 and P2 at 1430 hrs in order to seek shelter at the visitor centre as well as (2) reducing the number of visitors to Lorong Halus Wetland thereafter due to the wet weather. As such, it remains to be seen if the overall reduction in the number of visitors from 78 at 1430 hrs to to 20 at 1800 hrs is indeed representative of a typical weekend.

Between the five categories of visitors, cyclists and personal mobility device users formed the majority with 75.1% of the total number of visitors similarly to the traffic count on 16 January 2018. 24.6% of visitors were strollers and joggers, while only 5 birdwatchers visited the Wetland across the entire day. The slight increase in the percentage of strollers and joggers could be attributed to the greater amount of time for residents on weekends, allowing them stroll or jog despite the possible increased duration due to the waterbody's inaccessibility.

3.3 Survey

3.3.1 Respondent demographics and information

18 surveys of visitors to Lorong Halus Wetland were obtained over the two traffic count dates. A rather even spread of respondents of varying ages was obtained.

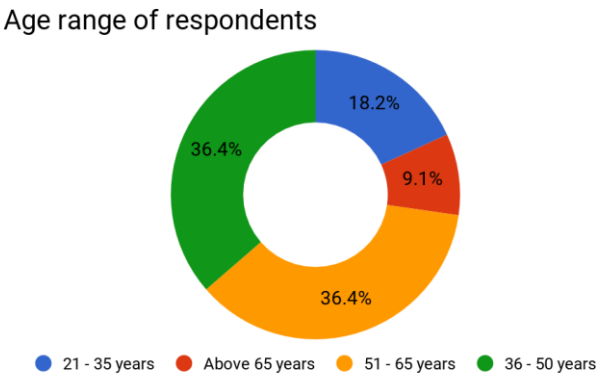


Figure 16: Respondent Demographics

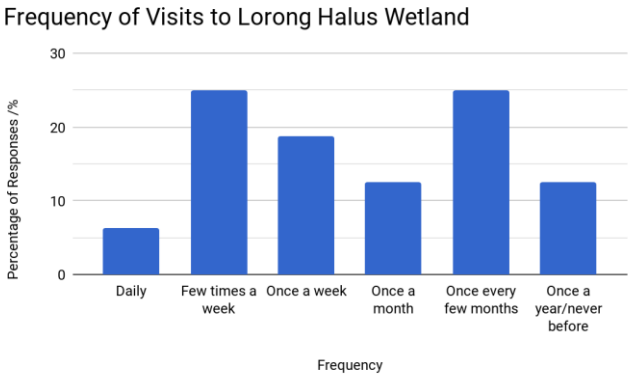


Figure 17: Frequency of Visits to Lorong Halus Wetland

There exists a great distribution in the frequency of visits by the respondents to Lorong Halus Wetland. The median frequency of visits was however between one visit a week and one visit a month.

3.3.2 Community utilisation of waterscape

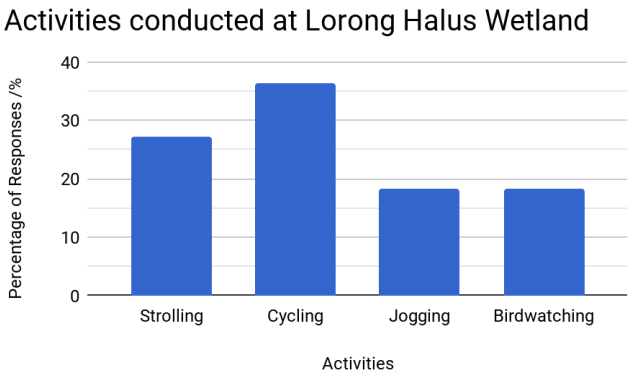


Figure 18: Activities conducted at Lorong Halus Wetland

From the survey, cycling only accounts for 37% of the activities which respondents undertake, significantly lower than the figure of 75% obtained from the traffic count conducted. Similarly, the proportion of activities which jogging and strolling take have increased to around 45% together, while birdwatching constitutes around 18% of all activity. The increase in joggers, strollers and birdwatchers contrary to the traffic count data could be a result of the fact that a greater number of joggers, strollers and birdwatchers compared to cyclists agreed to be surveyed out of convenience. As such, the proportion of activities conducted at Lorong Halus Wetland according to the survey could be skewed as a result.

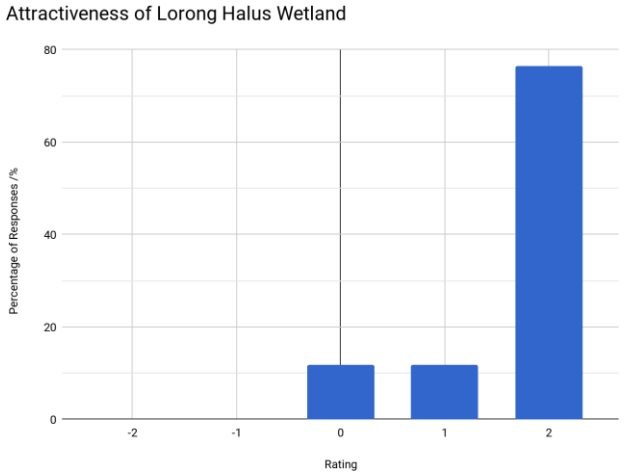
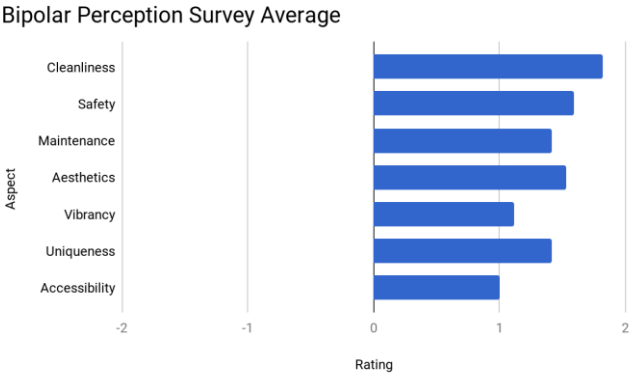


Figure 19: Overall Attractiveness of Lorong Halus Wetland

Over 75% of respondents rated Lorong Halus Wetland as +2 (Excellent) on a scale of -2 to +2, indicating highly favourable views on the level of attractiveness of the waterbody. The arithmetic mean of the ratings given was +1.65.



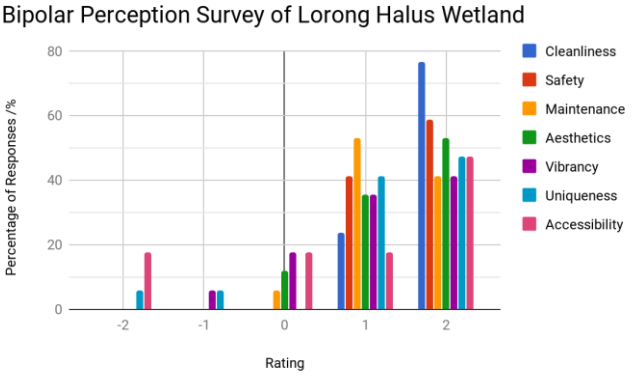


Figure 20: Bipolar perception survey

When analysing the ratings given with respect to the various aspects of Lorong Halus Wetland, the average scores all remain in the range of +1 to +1.85.

However, accessibility attained the lowest average score of +1, further emphasising the level of difficulty in reaching Lorong Halus Wetland. The relative inaccessibility of the waterbody was also reflected in suggestions provided by the respondents to provide public transport from a nearby Light Rapid Transit (LRT) station to the waterbody, which is at least a 15 minute walk away.

The area with the second lowest score was that of vibrancy, referring to the lack of variety of activities which could be carried out at the wetland. For instance, a few respondents commented that more community events could be conducted at Lorong Halus Wetland, while the features there could be made more interactive, informative in line with educational activities. A playground as well as more elderly-friendly facilities including a concrete, paved walk path could also have been added to cater to various groups in the community as well as increase participation.

On the other hand, some responses raised the need to preserve the natural heritage and value of Lorong Halus Wetland as one of the few reed ecosystems and popular birdwatching spots in Singapore, rather than engage in development. Such opinions could also have been spurred by the fact that extensive construction activities were carried out in the nearby Punggol Waterway Park across the bridge on the days which surveys were conducted on, resulting in a large amount of noise pollution. As such, a particular respondent indicated his concerns on the possible effect of construction on the natural ecosystem at Lorong Halus Wetland.

3.3.3 Water education

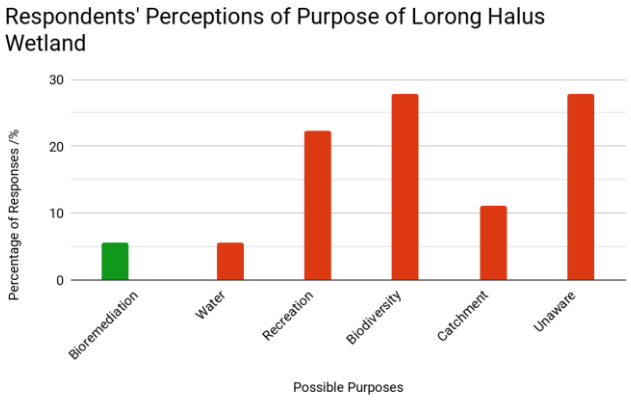


Figure 21: Respondents' perceptions of purpose of Lorong Halus Wetland

With reference to the above figure, awareness among visitors of Lorong Halus Wetland's role was very poor, with 5.56% of respondents indicating accurate knowledge of the site's purpose as a bioremediation site which carries out water treatment processes. Given that Lorong Halus Wetland is an example of how innovative biological processes may be employed in conjunction with a waterbody in order to safeguard the security of Singapore's water supply, the relatively low accuracy rate shines a worrying light on the effectiveness of Lorong Halus Wetland in increasing visitors' awareness on the value of readily-available potable water which the Serangoon and Punggol Reservoirs play an important role in providing.

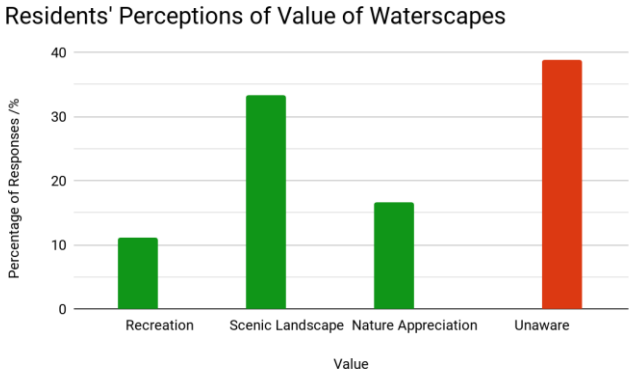


Figure 22: Residents' Perceptions of Value of Waterscapes

Despite the low awareness of the purpose of Lorong Halus Wetland which respondents displayed, it was however heartening to note that a majority (61%) of respondents were able to raise valid points (e.g. site for recreation, nature appreciation and to improve the scenery of the landscape) with regard to the value of waterscapes in their neighbourhood.

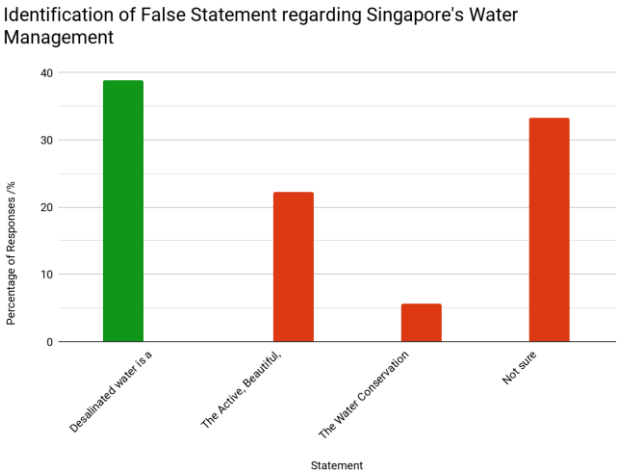


Figure 23: Identification of False Statement regarding Singapore's Water Management

However, when asked to discern a false statement out of four on various strategies employed by the PUB for Singapore's water management, only 38% of respondents were able to

correctly identify that desalinated water is not a source of drinking water from the continuous production of wastewater. Given that various exhibits and signboards located at the visitor's centre provided an overview of Singapore's water management as well as supply sources, it is thus evident that the effect of water education features at Lorong Halus Wetland in raising awareness of Singapore's water situation was limited.

3.4 Observation

3.4.1 State of Lorong Halus Wetland

Figure 24: Newly-Installed Signboard at Lorong Halus reed beds

In contrast to the pilot project conducted in 2017, many signs in a state of disrepair have since been replaced and appear to be in good condition. Figure 24 shows a newly installed signboard. Regular cleaning of the signboards by contractors was also observed. This upkeep indicates that efforts to raise awareness of the wetland's purpose, water-related issues, and biodiversity in the wetland through signboards are valued by PUB.

However, the overall landscape of Lorong Halus Wetland is rather monotonous and the reed beds and polishing ponds do not appear visually attractive. Portions of the gravel trails were inundated during the visits on 16 and 28 January due to rainfall, which prompted a survey respondent to mention this in their suggestions for improving site attractiveness. Some of the paths are not well maintained and appear to have cracks in them. In addition, the only amenities are that of a sheltered visitor centre with some signboards regarding water management by PUB with a nearby toilet as well as carpark with 6 parking lots. The visitor centre is viewed by most visitors as a place of shelter rather than an opportunity to learn more about water, with visitors observed using them as backrests and supports.

3.4.2 Visitor Activities

Figure 25: Student Learning Journey at Lorong Halus

During the traffic count on 16 January 2018, a group of 87 Secondary 1 Dunman Secondary students and staff were observed visiting Lorong Halus Wetland on a geographical learning journey, as seen in Figure 25. During their visit, they learnt more about the water management situation in Singapore as well as how to carry out water testing during fieldwork with the help of multiple PUB facilitators. Such outreach efforts are evidence of how PUB is indeed utilising Lorong Halus Wetland as a site to conduct water education and improve the water awareness of students.

Figure 26: Wedding photoshoot at reed beds

Interestingly, a wedding photoshoot was being carried out during the 28 January visit, as seen in figure 26. This implies that the wetland is considered aesthetically-pleasing while showing the potential of the site's reed beds and polishing ponds with their blooming water lilies for activities involving aesthetic appreciation.

However, the visitor activities observed on both days went in line with the findings of the traffic count. A majority of visitors used Lorong Halus Wetland as a place for recreation or exercise or merely as a checkpoint on their cycling and jogging routes. As a result, the appreciation of Lorong Halus Wetland's purpose as well as its effectiveness in water education could be limited.

3.5 Interview

The interviewee first reiterated the purpose of Lorong Halus Wetland as a site of water treatment to prevent unpurified leachate from the prior landfill site to overflow into the reservoir in the event of rain, in addition to construction of a wall underground to prevent the throughflow and baseflow of water. The main contaminants involved were heavy metals such as mercury, lead and cadmium as well as nitrogen and phosphorous which encourage algal bloom. Multiple monitoring stations were also placed in the reservoir to provide real time monitoring of its water quality.

However, the interviewee also raised a few concerns regarding Lorong Halus Wetland. Dissolved oxygen concentrations above 4 ppm were deemed as acceptable for the health of local ecosystems, but were however not met by the water in the reed beds and polishing ponds. In addition, the growth of the reed beds and water lilies appeared to be stunted. The activities of maintenance contractors removing excess hydrilla and cleaning the ponds were raised as a possible cause of damage to the water lilies. The interviewee also raised how dragonflies were an indicator of water quality; during the visit conducted on 16 January 2018, a few dragonflies and damselflies were spotted but no rigorous statistical analysis was conducted with regard to the size of their populations.

Moreover, the interviewee identified various issues with visitor activities. In particular, the interviewee was of the opinion that cyclists and users of personal mobility devices posed a serious safety hazard to pedestrians when they cycled across the main bridge connecting Punggol to Lorong Halus, in spite of clear signage on both sides of the bridge reminding cyclists to dismount. Such riders either hindered traffic flow by blocking a section of the path or endangered pedestrians by riding at dangerous speeds, possibly resulting in accidents. The interviewee recounted an anecdote of a grassroots group of more than 100 people crossing the bridge nearly being hit by a speeding cyclist. The interviewee identified laziness as the primary cause of cyclists' choosing not to dismount despite multiple reports to the police, and expressed hope that a solution could be found for the above problem.

IV. CONCLUSION

4.1 Bioremediation

Water indicators such as pH and turbidity at Lorong Halus Wetland were largely conducive for freshwater aquatic life, although a slightly higher dissolved oxygen concentration would have been more ideal.

The bioremediation processes at Lorong Halus Wetland were also measured to be highly successful at removing phosphate and nitrate ions, along with a decrease in conductivity. As such, it is likely that the plants at the waterbody are adequate in removing pollutants to prevent the possibility of an algal bloom which would severely affect the ecosystem. The only possible anomaly was that of an increase in phosphate concentrations from the reed beds to polishing ponds, contrary to expectations and the 2017 pilot study; however, the above contradiction may be have been caused by a variation in the testing equipment used, in which case it may be considered insignificant.

Coupled with the underoung cut-off wall between Lorong Halus Wetland and the reservoir, the features put into place seem to be adequate in prevent the leaching of toxic heavy metals (in particular lead and cadmium) into the reservoir and subsequently into Singapore's water supply.

4.2 Community utilisation

It is evident that significant traffic count is observed at Lorong Halus Wetland within a small land area. Given its remoteness, a majority of visitors are residents in the nearby Punggol.

As a waterbody, recreational activities occur predominantly at Lorong Halus Wetland, with a huge proportion of visitors being cyclists or personal mobility bike users. Most visitors visit the waterbody regularly, at least once a month. In this respect, Lorong Halus Wetland does fulfill its purpose as a space for community interaction.

Visitors mainly described Lorong Halus Wetland as a very attractive waterbody but also highlighted areas for improvement in its utilisation which were detailed in the provided hypothesis. In particular, a very limited range of activities can be conducted which is detrimental to its vibrancy under the ABC Waters Programme. More features and facilities could be added to cater to various groups within the community. Additionally, improving its accessibility would go a long way in increasing its attractiveness to Singaporeans who do not live in the vicinity. Hopefully, accessibility by foot can be improved after nearby construction projects are completed.

On the other hand, feedback from birdwatchers as well as nature advocates does indicate that Lorong Halus Wetland has biodiversity value and increased visitor traffic could as a result potentially irreversibly damage the ecosystem. As such, it is evident that further considerations and impact assessments would be needed before deciding on a course of action.

With regard to the instances of bicycle and PMD speeding on the main bridge, clearly demarcated lanes for bicycles and pedestrians could be introduced. In the event that the bridge is too narrow, barriers or bollards could be set in place preventing bicycles from being ridden onto the bridge so as to ensure visitors' safety.

Nevertheless, it is regrettable to note that Lorong Halus Wetland does not play a significant role in Punggol's identity and there exists an apparent lack of interaction between the environment and the community that surrounds it. Visitors to Lorong Halus Wetland mainly treated it as a space or stopover point for recreational activities without appreciating its significance. Lorong Halus Wetland is thus not unique to the identity of Punggol's residents.

4.3 Water education

There has been a recent revamp of the various educational signboards at Lorong Halus Wetland, making them more visually attractive. Evidence of schools' and organisations' participation in water education through adoption and field trip was observed.

Nevertheless, very few visitors paid much heed to the educational signboards located at the visitor centre and interspersed throughout the wetland. Responses provided were reflective of a low level of awareness regarding the purpose of Lorong Halus Wetland, the value of waterscapes, innovative water-treatment and water conservation. Given the disappointing results despite the abundance of signboards in the visitor centre, the key to increasing awareness lies perhaps in a more concerted effort in the revamp of the visitor centre and educational features at Lorong Halus Wetland.

In addition, educational learning journeys to impart awareness about the site to students seem to be effective, with students appearing to be engaged during the session which was observed. This strategy could perhaps be extended to more schools beyond the present range, or to community organisations' outings such as that of Residents' Committees, similar to that of grassroots groups which the interviewee previously facilitated. This active approach

requires manpower and is time-consuming, but would actively engage and educate visitors, as compared to the passive nature of the approach of installing informative signboards. Alternatively, outreach campaigns beyond the physical site of the wetland itself such as featuring Lorong Halus online could raise awareness more effectively, given the low traffic count at the wetland itself. These activities would introduce more people to Lorong Halus, which also contributes to vibrancy if more people subsequently decide to visit and utilize the wetland.

4.4 Limitations

Various limitations with regard to the representativeness of studies conducted at Lorong Halus Wetland exist.

Without a comparison to a different waterbody or park, it is difficult to gauge the extent of utilisation of Lorong Halus Wetland in relation to other similar locations. In addition, some of the respondents were impatient and did not complete the bipolar perception thoughtfully, for instance by giving a rating of +2 from -2 to +2 for all 7 considered aspects of the waterbody without much hesitation. Such behaviour could also potentially have resulted in our lower accuracy rate for questions related to water management.

Naturally, traffic counts conducted on 2 separate days with a survey sample size could be considered to be too few to be representative of the overall visitor population. A greater number of days coupled with a greater sample size of visitors would have made the results more representative and reliable.

V. ACKNOWLEDGEMENTS

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REFERENCES

[1] Cheong, S. (2012, June 23). The Smell of Success. *Straits Times*. Retrieved February 27, 2018, from http://wildsingaporenews.blogspot.sg/2012/06/smell-of-success-how-did-lorong-halus.html#.WpUca0xuI2w

[2] Sim, C., Quek, B., Shutes, R., & Goh, K. (2013). Management and Treatment of Landfill Leachate by a System of Constructed Wetlands and Ponds in Singapore. *Water Science and Technology, 68*(5), 1114-1122. doi:10.2166/wst.2013.352

[3] Tan, Y. (2007, October 21). Ruffled feathers. *The Straits Times*, p. 46

[4] Robertson-Bryan, Inc. . (2004, May). PH Requirements for Freshwater Aquatic Life. Retrieved February 28, 2018, from https://www.waterboards.ca.gov/centralvalley/water_issues/basin_plans/ph_turbidity/ph_turbidity_04phreq.pdf