TECHNICAL REPORT - 1001

LAGUNA SCIENCE

WREN PROPERTIES

City Quay Water Feature Rehabilitation Plan

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1 INTRODUCTION

Laguna Science Ltd was commissioned by Wren Properties to prepare a report for the City Quay Management Company on the rehabilitation of the water feature within the City Quay residential development in Liverpool.

The scope of this report is to further develop the detail of the recommendations made within the report prepared by Atmos Consulting Ltd in entitled 'City Quay Water Feature Baseline Assessment and Rehabilitation Strategy – September 2015, the subsequent discussions at the follow-on residents meeting together with the results of additional chemical testing of water supplies undertaken in March 2016. These previous reports should be read to provide background on the current issue and status of the water feature.

At the public meeting, a range of opinions were expressed which highlighted the need to develop a clearly defined rehabilitation approach for the water feature. The report will therefore present two key rehabilitation routes:

1) Complete redevelopment of the water feature; and
2) A range of rehabilitation measures to be applied to the water feature in its current form.

In addition, this report will present both the timing schedule for sequencing of works together with budget costings, where possible, to allow the Management Company and Residents to plan and allocate available resources accordingly.

1.1 Background

The water feature within the City Quay Development was formerly the site of one of the four graving docks of the Herculaneum Dock system which formed part of the South Liverpool docklands area. This dock area fell in to disuse in 1972 and the main dock areas backfilled. In 2004 the site was purchased by David McLean Homes to construct the City Quay Development. One of the former graving docks was retained and modified to create a key focal landscape waterbody feature within this large residential development.

The baseline survey, and subsequent testing of water supply, undertaken by Atmos Consulting demonstrated that the water feature displays a range of water quality, ecological and aesthetic issues that are impacting on its performance as an attractive landscape feature within the development. The key issues are:

- The existing borehole water supply is of poor quality as a principal water supply to the water feature, primarily due to its high elevated nutrient status;
- The water feature displays typical water quality issues associated with the process of nutrient enrichment resulting from elevated phosphorus concentrations. These include fluctuations in and depression of dissolved oxygen concentrations, elevated ammoniacal nitrogen and biochemical oxygen demand (BOD);
- There is a relatively small volume of sediment on the water feature bed but that which is present is black and odorous and indicative of anoxic conditions (lacking oxygen). This is likely to be associated with the microbial breakdown of organic matter resulting from the degradation expired algae that have settled to the bed;
- The three fountains in the waterbody currently serve little function in improving water quality and may present a potential health risk by creating aerosol and spray drift of potentially toxic blue-green algae (when present);
- In the absence of higher aquatic plants and given the water feature's highly nutrient enriched status, it displays persistent phytoplankton blooms (green turbid water) conditions. This includes the presence of potentially harmful blue-green species;

- The butyl / EDPM type liner does not allow higher aquatic plant establishment to be made without the use of a planting system. The lining material combined with poor conditions within sediments also creates a relatively sterile aquatic invertebrate habitat conditions and the diversity of species is low;
- The water feature is used by geese which will be impacting on establishment of previous aquatic plant introductions, contributing to nutrient enrichment of the waterbody together with the unsightly fouling of surrounding footpaths and grassed areas; and
- An absence of fish within the water feature may be contributing to reports from residents of nuisance non-biting midge swarms developing.

2 REHABILITATION OPTIONS

Three rehabilitation options are presented for the City Quay Water Feature which are:

- Re-development of the Water Feature;
- Rehabilitation of the Water Feature; and
- Agreed Rehabilitation Approach.

2.1 Re-development of the Water Feature

The existing water feature is of a poor design and this is reflected in the range of management issues its presents that are impacting on its performance as an attractive feature within the development. To re-develop the water feature into an optimal design will be a major undertaking in terms of cost, disruption to residents and also carries significant unknown budget risks. The key elements of the re-development will be to address the issues of water depth and lake lining.

2.1.1 Water Feature Bathymetry

The original graving dock from which the water feature has been formed would originally have had a water depth of around 8 – 10m. During it transformation into a water feature, the dock has been back-filled to create a shallow waterbody. The existing bathymetry (water depths) of the water feature are shown in Figure 1. Currently the waterbody has a shallow shelf of approximately 0.5m depth and 1 to 1.5m in width running around the entire marginal perimeter. The shelf slopes down to a relatively uniform depth of 1.4 – 1.6m across the entire basin with slightly deeper water towards its northern end.

Shallow nutrient enriched waterbodies, in the absence of higher aquatic plants typically display the development of persistent phytoplankton blooms (green water) which reduce their visual quality and directly impact upon water quality conditions. Water quality maybe more easily managed if increased water depths are present.

Figure 2 provides a representation of an optimised bathymetry for the waterbody with increased water depths from a shallow marginal shelf for planting and safety aspects sloping down to a central deep area. Given the relatively narrow width of the water feature there is a limit of the depth that can be achieved using standard lake lining techniques which require the underlying soils to be contoured to a slope gradient of 1 in 3 or less to ensure stability. This would allow a maximum depth of 4m to be achieved in the centre channel of the water feature.

The estimated volume of material that would need to be removed and disposed of the achieve the optimal bathymetry is estimated at 7550 m^3 (inclusive of a 20% bulking factor for disturbance of the 'soils'). This equates to around 11325 tonnes of material.

A key issue and costing uncertainty for excavation works to the water feature to provide an improved bathymetry, is the unknown nature of the material used to backfill the original dock basin. The upper proportion of the fill may be a sand blinding or felt layer over which the exiting butyl / EDPM liner was laid. Alternatively, the liner may have been laid on to a felt protective fleece. At best this underlying material would be inert building material waste and soils generated during construction of the development. However, it may be possible that contaminated materials which would significantly increase disposal costs could be present, particularly given the former use of the site. The main redevelopment project risk lies in that the type and nature of this fill material cannot be determined until the existing liner of the water feature is removed.

2.1.2 Lining of Water Feature

The existing water feature is currently lined with a butyl / EDPM type liner to retain water. The life expectancy of this type of material is typically guaranteed in the range of 30 – 40 years depending

on the quality of material used. The existing liner may therefore be approximately 38 – 50% through its expected lifespan. At the end of its lifespan, repair or replacement of the liner will be required.

Replacement of the water feature liner will be a major undertaking as it will require all the perimeter post and chain barrier to be removed from the water feature and the surrounding footpath excavated in order to provide an anchor trench for the lining material. For re-lining of the water feature it would be recommended that a Geosynthetic Clay Liner (GCL) is used. GCL comprises a layer of bentonite sandwich between layers of geotextile and has several advantages over butyl / EDPM type or traditional puddled clay liners which include:

- GCL are easy to install unlikely puddled clay;
- This type of liner will self-seal if punctured due to the bentonite core;
- The lifespan of GCL is expected to be over 100 years.
- The installation of GCL requires an overburden layer of soil which provides a good planting substrate for direct introduction of aquatic plants.

2.1.3 Other Redevelopment Works

Other redevelopment works for the water feature following excavation and relining are set out in section 2.2 and would follow a similar course to rehabilitation of the existing waterbody. The key differences are that the use of a GCL liner would effectively remove the need for specialist planting systems for the introduction of aquatic plants (see section 2.2.5) and there would be a need for a much reduced aeration / mixing system to maintain water quality (see section 2.2.3).

2.1.4 Sequence of Redevelopment Works

The following sequence of works would need to be undertaken to redevelop the lake.

1. **Dewatering**

   The water feature would need to be drained. This would be achieved by bringing in temporary pumps and discharging the water through the existing lake overflow which is assumed to connect to local surface water sewer network. Prior to any pumping operation agreement would need to be made with United Utilities on acceptable flow rates of pumping. During pumping it should be ensured that the discharge of sediment to the drainage system is kept to a minimum and any residual fish stock that may be present, removed. It should be noted that draining of the water feature may result in some temporary local odour issues due to the anoxic nature of the veneer of sediment present across the bed.

2. **Removal of liner**

   The existing liner should be removed. The liner would be cut below the existing coping stones, the rocks from the marginal shelf removed, and the fountains and any electric cables removed. Any sediment deposits should be moved to one end of the water feature and then the lining material removed and disposed of to an appropriate licensed waste site.

3. **Ground investigation**

   With the liner removed a ground investigation will need to be undertaken to determine the composition and contamination status of fill material in the former graving dock. The investigation will need to ensure that the material proposed to be excavated is adequately characterised during the investigation to ensure appropriate disposal routes are established. It should be noted if the fill material is found to be contaminated then this will have major and significant implications on disposal costs.

4. **Excavation**

   Excavation of the water feature basin would be undertaken to achieve the optimal bathymetry. This will be a major civil engineering operation given the volume of material requiring removal and disposal. Removal of a section of the perimeter post and chain would be required to provide plant access and a temporary aggregate ramp structure may be required to assist

with plant access into the water feature basin. Careful consideration and planning would need to be given to how this operational is undertaken within an occupied residential development due to disturbance and health and safety issues. Areas would need to be allocated for material stockpiling, pollution prevention measures implemented to prevent sediment-laden run-off entering local drainage systems and haul routes for lorries removing material established. If suitable uncontaminated, low nutrient material is present this may be stockpiled for reuse as an overburden layer on the GCL. Given the use of a GCL there would be a need to over excavate the depth of water feature by 300 – 500mm to ensure the correct finished water depth due to the need to use overburden material of this depth on top of the liner.

5. **Liner Installation**

   Prior to liner installation, the post and chain barrier around the entire lake perimeter would need to be removed. The existing coping stones and block paving would be lifted and stored to allow excavation of the anchor trench for the new lining material. The GCL would be installed into the water feature and a minimum depth of 300m of overburden put on top of the liner. The overburden material would ideally be a subsoil with a low nutrient status (for phosphorus) and high sand and moderate stone content to provide a good substrate for the introduction of aquatic plants and minimise nutrient loading to the redeveloped water feature. The block paving, coping stones and post and chain barrier would then be reinstated.

6. **Re-Filling of Water Feature**

   Ideally refilling of the water feature would be allowed to occur naturally by rainfall although this would take an extended period to achieve and would delay the implementation of other works such as aquatic planting. Therefore supplementary filling is likely to be required from the existing borehole supply that would introduce nutrient enriched water into the water feature. However, the existing abstraction licence on the borehole supply is limited in terms of the daily and total annual volume that can be abstracted and it is likely that a variation to the licence would need to be applied for through the Environment Agency to permit the filling operation. Following refilling of the lake it is recommended that an application of 'Phoslock' (see section x.x), following testing of water quality, is undertaken to 'lock-up' the phosphorus loaded into the redeveloped water feature from the borehole supply.

   It should be noted than following re-filling there is likely to be a period of increased turbidity due to suspended solids in the water feature. Given the use of suitable overburden material (i.e material that does not have a high fine clay content) then this turbidity will usually settle relatively quickly.

2.1.5 Timing of Works

Re-development works would ideally be undertaken during the Spring and Summer so works are completed by early autumn. Drier weather conditions during this period will facilitate the construction works and their management. The water feature would then be allowed to naturally partially fill with rainwater during the autumn and winter and this would also allow settlement of suspended solids. During the early Spring, under an abstraction licence variation, the water would be topped-up to top water level. A 'Phoslock' application made and then aquatic plants introduced in the April / May period together with any water quality maintenance equipment.

2.1.6 Budget Costs

The costings for redevelopment of the water feature present in Table 1 below should only be viewed as indicative, particularly given the uncertainty of the nature of the fill material below the existing liner. If the option is pursued, then it is recommended that full detailed costing would need to be prepared by different contractors through a formal tendering process.

Table 1: Indicative Costs for Water Feature Redevelopment

Work Element		Cost Estimate
Dewatering	Pump hire / fish removal	£1,500
Removal of Liner	Liner removal and disposal	£4,000
Ground Investigation and Testing	Contamination investigation	£7,500
Excavation*	Excavation, management and haulage disposal of material	£160,000
Disposal of Material**	Disposal of material assuming removal to local landfill facility	Inert Non-Hazardous Waste - £487,000 (inc Landfill Tax) Hazardous Waste - £2.1 million (inc Landfill Tax)
Lake Lining	Lining of lake with GCL and perimeter works (anchor trench reinstate footpath)	Lake Liner - £64,000 Perimeter works - £40,000
Lake Refilling	Abstraction licence variation and water charge	£2,000
'Phoslock' Application	Applying Phoslock to remove nutrients from partial borehole refilling.	£5,800
Lake Planting	Planted directly into overburden	£8,000

*Costs will depend on distance of disposal site.

** Costs will be dependent on nature of material, distance of site and gate costs.

The costs above do not include the deployment of water quality maintenance equipment i.e diffuser aeration system.

It can be seen from the above costs that re-development of the water feature will incur high capital costs. There is significant project cost risk associated with the disposal of excavated material as the nature and contamination status of the fill material below the liner is unknown. This alone is likely to make the redevelopment of the water feature an unviable option given the limited financial resources available.

2.2 Rehabilitation of the Water Feature

The existing water feature shows a range of management issues due to its initial poor design. However, by adopting a structured rehabilitation approach and investment combined with a pro-active long term management and maintenance commitment, substantial improvements in the water quality, ecology and visual appearance may be achieved.

The core objective of the rehabilitation strategy needs to focus primarily on water quality and addressing the problems associated with nutrient enrichment and low ecological quality. It should be noted that the improvement of the water feature would be expected to occur as a gradual

process over a two to three year period as various measures are implemented and realised through a phased improvement programme.

The following sections detail the approach for the rehabilitation including the sequencing and scheduling of works along with indicative costs.

2.2.1 Water Supply Management

The borehole water supply and emergent spring on the embankment above the Casemates on the eastern perimeter of the development were tested for chemical composition by Atmos Consulting in March 2016. As discussed in the letter report issued by Atmos, neither of the water sources are suitable as a supply to the water feature due to their highly nutrient enriched statuses resulting from elevated total phosphorus and phosphate concentrations.

Regular use of the borehole as a top-up supply to replace evaporative losses will continue to cause a high rate of nutrient loading to the water feature impacting on its water quality and ecological performance and exacerbating the development of dense phytoplankton blooms (green water). It has been recommended that given the nutrient status problem with the borehole water supply that its use is kept to a minimum and it is maintained as an emergency supply for top-up only during prolonged dry weather or drought conditions. This would be the case for both a redevelopment or rehabilitation option for the water feature. As such the water level in the lake would be expected to typically drop during the summer months (June, July and August).

There are two main negative effects from reduced water level which are:

- Increased exposure of marginal butyl / EDPM lake liner to UV radiation that will reduce its expected lifespan; and
- A reduction in visual quality from the water feature having a lower water level and the marginal liner below the coping stones being exposed.

Both of these may be offset by wide scale planting of marginal vegetation around the water feature's margins. A minimum level for the waterbody would need to be set just above the level of the marginal shelf to ensure that the introduced aquatic plants are maintained in wet conditions to prevent dieback. This may be achieved through simple changes made to the float switch system that operates the borehole pump. Therefore the primary use of the borehole supply would be to maintain the minimum level to support aquatic marginal plant introductions.

The water levels would be restored to normal top water height by rainfall during the autumn / winter period. It was found that where the water level was allowed to drop during the summer of 2015 that this level was relatively quickly restored during the 2015- 16 autumn / winter period.

2.2.2 Internal Nutrient Reduction

As the borehole supply is unsuitable for flushing or dilution of the current high phosphorus concentrations in the water feature, then it is recommended that an application of 'Phoslock' is made to reset the waterbody to a lower nutrient status condition. Within the UK Phoslock is the only approved treatment for reducing phosphorus concentrations in lakes and is a lanthanum clay based compound that when added to the lake forms a permanent chemical bond with the phosphorus in the water and surface of the sediment. The 'Phoslock' is mixed with the lake water and added as a slurry across the surface from a boat which sinks through the water and binds with the phosphorus before settling on the bed where it also forms a cap on any sediment deposits.

Based on previous testing data it is estimated that a total of 2.1 tonnes of 'Phoslock' would be required. This application would be completed within a day. To maximise the effectiveness of the Phoslock it should be applied in the winter months when phosphorus concentrations will be highest in the water due releases associated with seasonal die back of aquatic plants and animals.

2.2.3 Water Quality Maintenance Systems

Water quality within waterbodies can be improved by mixing to prevent stagnation (low dissolved oxygen) and prevent odour development. Mixing of a lake can also ameliorate the development of harmful blue green algae blooms which show a preference for still water conditions. This is particularly the case for the most harmful species which from highly toxic marginal scums that can present a health risk to site users and pets.

The development of low oxygen conditions is a common feature of nutrient enriched lakes. Such waterbodies show high levels of biological activity and production (i.e algae) and the decomposition of expired animals and plants by bacteria creates a high oxygen demand. Typically this oxygen depletion effect occurs in the lower water column and across the bed and sediments within the lake and has a range of subsequent water quality and ecological impacts. These can include remobilisation of nutrients from sediments which further exacerbating algae blooms (a process known as internal nutrient cycling), restrict aquatic invertebrate diversity to those species tolerant of low oxygen conditions i.e chironomids, oligochaete worms, leeches and tubificid worms.

The previous baseline survey of the City Quay water feature demonstrated that there was a high oxygen demand within the water column (indicated by elevated Biochemical Demand concentrations) and also a decline in oxygen towards the bed resulting from demand created by the sediment deposits. Therefore the deployment of aeration / mixing equipment within the water feature is recommend to help maintain and improve water quality conditions.

There are a range of techniques for mixing water in lakes that can include pumped circulation systems, propeller mixers, fountains, surface splasher aerators and diffused based aeration systems. Looking at each of these technologies:

- Pumped circulation systems are expensive to operate as it requires large pumps to move sufficient volumes of water to be effective.
- Propellor mixers are visually intrusive due to the large flotation units required to support them and create relatively high velocity currents with the lake which may not be desirable.
- Surface splasher units tend to be relatively ineffective as they tend to circulate surface water that already has high dissolved oxygen conditions rather than addressing improvement of the low quality water developing at the lake bed.
- Fountains are relatively ineffective unless they draw water from the bed, although this can lead to potential issues with clogging. They are also have high energy costs in relation to achieving aeration and effective mixing effect. Fountains are visually pleasing but can also create issues with spray drift that may be potentially harmful if blue-green algae are present in the lake.
- Diffused air systems tend to be most efficient and effective as they operate by creating multiple airlifts across the lake which entrain the poor quality from the bed and forces it to the surface where it is oxygenated by the atmosphere. As all the equipment is located on the lake bed there is no visual intrusion from these systems and the all that is seen at the surface is circles of bubbles across the lake. (see Photograph 1 below as an example)

Photograph 1: Operational diffuser aeration system installed in a park lake.

For the City Quay Water Feature, we would recommend that a diffuser based aeration system is pursued as the most cost-effective long-term method for improving and maintaining dissolved oxygen concentrations. For diffuser aeration to be effective they need to be correctly designed to ensure there are sufficient number of diffuser (airlift points) to mix the entire waterbody. The number of diffusers is a function of water depth with each diffuser having a primary mixing area with a radial distance of 5 to 7 times the water depth. Therefore shallow system require a greater density of diffusers than deeper waterbodies. This can be seen in Figures 3 and 4 which show the diffuser aeration layout required for effective aeration and mixing for the optimised water depth in the redeveloped water feature option and for the existing lake water depths. Six diffusers would be required for the optimised water depths compared to 18 diffusers for the current water depths.

The layouts shown are based on the ISS / Flowthrough Aeration System which allows multiple diffusers to be operate from a single airline and a patented airflow control valve ensures the correct volume of air is delivered to each diffuser regardless of its position in the array. As such the system is self-balancing in operation and simply needs to be switched on and off. This may be contrasted traditional diffuser based system that require an individual airline to each diffuser and the airflow to be manually adjusted from a manifold to achieve the correct air flow balance across the system. This system is recommended as it is highly robust and reliable, economical to operate, has low maintenance requirements and a proven track record of effectiveness across a wide range of waterbody types.

Air to the system would be supplied from two compressors housed in an acoustic cabinet with an electrical control panel incorporating a timer control. Air would be delivered to the diffusers through an armoured self-sinking airline. For the proposed layout shown in Figure 4, air would be delivered through two 1" airlines each fitted with 9(no) rubber membrane diffusers operating at 4m3 / air / hr. Rubber membranes diffusers are used on these system as their flexing during operation reduces the potential for clogging by biological growth.

The expected operating electrical requirements for this system would be 3.7 KW. This may be compared to the system for the optimised lake which would have an energy requirement of around 1.5 KW. These systems are preventative in action and so normal operation is on a 24 / 7 basis between April and September for 30 minutes / day for the rest of the year to maintain the compressors in good condition. The maintenance requirements for this system involves routine maintenance of the compressors and an annual clean of the diffusers which is normally undertaken in the early Spring.

2.2.4 Aquatic Plant Introductions

A key part of the water feature rehabilitation will be the introduction of aquatic plants. These will serve a range of purposes that include assisting in maintaining water quality and reducing algae bloom development through utilisation of nutrients, improving in-lake habitat diversity, enhancing visual appearance and creating natural barriers to geese movements between the lake and surrounding grazing areas.

The establishment of aquatic plants in urban waterbodies is challenging and this is normally due to grazing pressure on the plants from waterfowl and a lack of suitable planting substrate for the plants introductions. In nutrient enriched water features, introduced plants can show excessive growth which can lead to high on-going maintenance needs. Therefore plant species need to be carefully selected such that they are robust to the attentions of waterfowl, once established, attractive and functional and easily maintained.

City Quay Water Feature is lined with a butyl / EDPM liner which provides no suitable substrate for plant introductions. This is a common issue on many urban lakes and often the approach adopted is to pin planted coir rolls into the margins. The problem with coir rolls is that they relatively quickly degrade leaving the plants with no substrate. The water feature is also visited by geese and so any plant introductions need to be temporarily protected during the establishment phase and subsequently resistant to the attentions of the birds.

The proposed layout of the planting scheme is presented in Figure 5. This shows creation of a planting fringe around the margins of the lake combined with introductions of patch of marginal lilies and some submerged plant introductions. It is recommended that the planting is undertaken in two phases with the first phase of planting concentrating on the development of a marginal fringe at the northern and southern ends of the water feature and at the midpoints on the east and western bank. The purpose of this planting will be to create a barrier between the lake and the grass areas used for grazing and roosting by geese and thereby reduce the attractiveness of the water feature to these birds. The phase 1 areas would be planted with Yellow Flag Iris (*Iris pseudocorus*) and Sweet Rush (*Acorus calamus).* These are both evergreen species and should therefore provide a year round natural barrier.

Phase 2 of the planting scheme establishes plants around the rest of the marginal fringe and also introduces the large white robust lily *Nymphaea gladstoniana* on to the marginal slope. In addition, it is proposed that a series of planters are introduced containing the submerged aquatic plant Hornwort (*Ceratophyllum demersum*). This is usually a low maintenance submerged aquatic plant species that is adapted to nutrient enriched conditions and grows well in low light conditions caused by the presence of algae blooms. The establishment of submerged aquatic plants in the water feature should further reduce the potential for algae bloom development. The submerged plants should be introduced on a trial basis at first to determine their growth response before full deployment.

All the proposed plant species are resistant or unpalatable to geese but will require protection during establishment. If the phase 1 barrier planting, together with other measures is successful in preventing geese from using the water feature then other plant species may be considered in Phase 2 planting to increase the floral diversity.

Given the lack of planting substrate in the City Quay Water Feature, Laguna Science has been in discussion with a geotextile fabricator to develop a bespoke planting system solution for the water feature. A prototype is shown in Photograph 2.

Photograph 2: Prototype Marginal Planting System for City Quay

The proposed planted would be manufacture to fit the marginal shelf of the water feature. The planter incorporates two horizontal tubes for insertion of scaffold bars for lifting the unit into position. A key element of the planter is with the integral corner pockets into which plastic upright supports can be inserted to which a protective mesh can be attached to ensure the plants are provided with full protection while they become established. Once the plants have grown sufficiently then the uprights and mesh would be removed. Each marginal planting unit would be filled with a subsoil that has a high sand and stone content to provide a stable substrate to support the plants and a low nutrient status to prevent additional nutrient loading to the water feature. Each planter unit would be 1 metre in length and this modular approach will allow for a phased introduction of planting into the water feature as resources become available.

Lily and submerged aquatic plant introductions would be made from a manufactured geotextile 1 metre square 'growbag' filled with the same type of substrate.

Ideally plant introductions should be made in April – June such that they have a full growth season to become established before seasonal dieback. As with any planted area the, aquatic plants will need to be subject to periodic maintenance and harvesting of top growth in the autumn can be used to effectively remove nutrient from the system. The cut material can be used for composting.

2.2.5 Algal Bloom Control

To create transparent water conditions usually requires approximately 40-50% of a waterbody's area to be covered by higher aquatic plants. However, often in nutrient enriched systems this is difficult to achieve, can interfere with other amenity use and can also create a large maintenance burden due to excessive growth. Aquatic plant introductions therefore tend to be undertaken on a more conservative basis to improve the visual appearance of the water feature and often concentrate on creation of vegetated fringe of emergent marginal species. With a restricted planting approach there may still be potential for algae blooms to develop. It is likely that algae blooms will continue to be a feature of the water feature during the rehabilitation stage, whilst

planted areas are establishing and may also arise in the future depending on the degree of nutrient control and aquatic plant deployment.

During the rehabilitation programme it is recommended that barley straw is deployed in the water feature to aid in algal bloom control. For City Quay water feature the high dose rate would equate to 150kg of hay (7 to 8 x 20 kg bales) and 60kg (3x 20kg bales) for the lower dose rate. The straw needs to be well distributed around the waterbody for greatest effect as the reactive algicidal chemicals appear to have a short effective range. The straw should be deployed in loose mesh bags or by using one of the commercial containment systems that are now available. Water movement by mixing and aeration may improve the efficacy of the straw by increasing the rate of water contact with the straw. The straw usually takes 6 – 8 weeks to become active and is effective for 4 to 6 months.

Ultrasonic devices are available for control of algae but there is little proven controlled experimental evidence of the efficacy of these systems on larger waterbodies.

2.2.6 Waterfowl Management

The development of natural planted barriers across access routes between the water feature and geese grazing / roosting areas should reduce the attractiveness of the water feature these birds. Further measures should be implemented on these grass areas to enhance these effect which may include:

1) Replanting of part of the grass areas with the inclusions of low growing shrubs;
2) Leaving the grass at a long length or possibly replacing with wild flower meadow;
3) Inclusion of mesh on the lower half of the post and chain barrier.

2.2.7 Non-Biting Midge Management

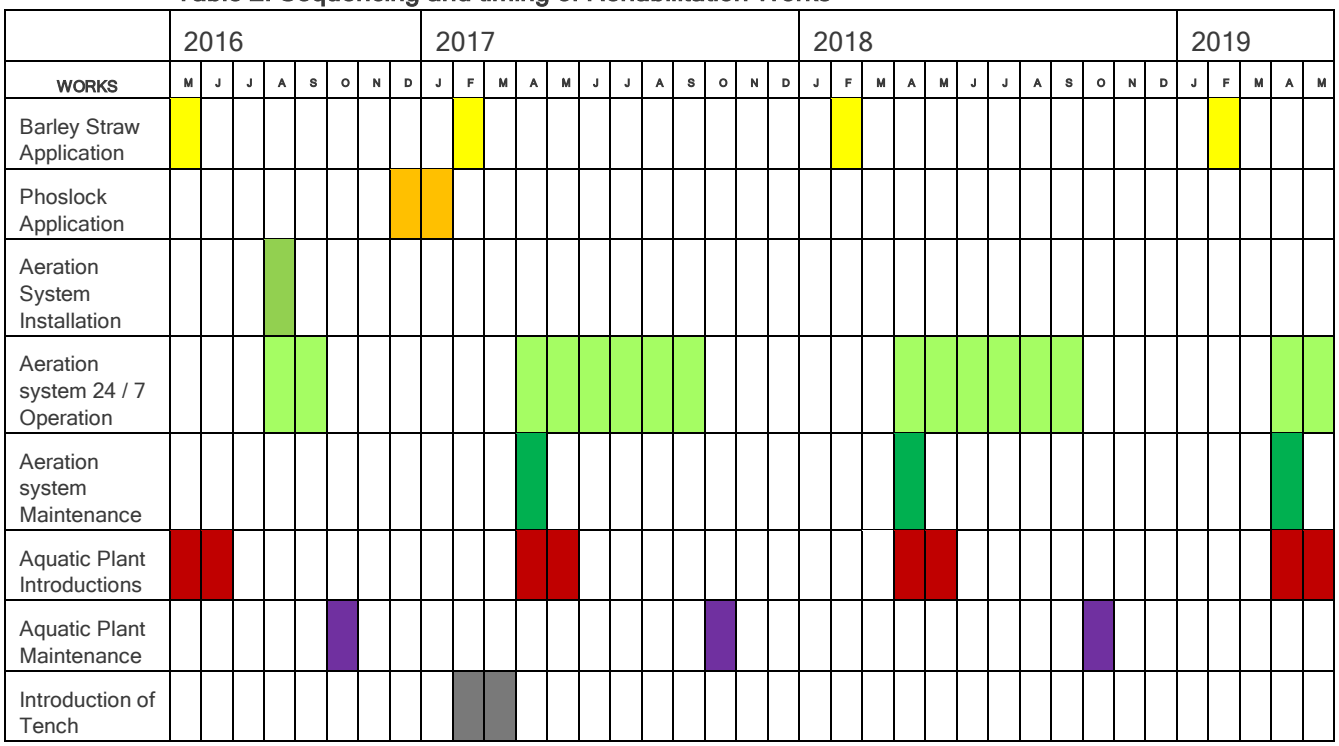
In the absence of fish, problems can develop with dense swarms of non-biting midge swarms appearing around lake margins. These can cause a nuisance to visitors and given the proximity of residential properties to the local residents. The issue was highlighted within the public meeting. The swarms of midges results from the lack of predation pressure on the larvae by fish. Therefore this issue can be addressed by stocking fish at a low density. It is important that the correct species of fish are introduced as fish populations can have a significant and direct impact on the visual quality and functioning of a waterbody. For example, some fish species such as roach (*Rutilus rutilus*) selectively predate on large zooplankton which are important in assisting in the control of phytoplankton algae density. Therefore, a high density stocking of small roach can exacerbate the development of phytoplankton blooms (green water).

For landscape type lakes, it is recommended that they are stocked with fish species that are associated with waterbodies which are characterised by clear water conditions and a dominance of higher aquatic plants. For the City Quay Water Feature, we would recommend a low density stocking of tench (*Tinca tinca*) at a stocking density of 100kg / ha. This would require 60Kg of fish to be introduced. The individual fish would be in the 0.25kg to 0.375kg size range to reduce potential for losses from cormorant predation.

2.2.8 Sequence of Rehabilitation Works

A proposed sequence of rehabilitation works is presented in Table 2. This sequence assumes that works would start immediately and would be undertaken as a 3 year programme. The speed of implementation will be dependent on resource availability.

Table 2: Sequencing and timing of Rehabilitation Works



It would be recommended that the aeration system is implemented early in the rehabilitation process to start improving water quality, reducing internal nutrient cycling, enhancing the action of barley straw and reducing the potential for blue green algae developing potentially harmful scums. Plant introductions may be undertaken on a phased basis with the priority being the Phase 1 plant barriers to reduce use of the water feature by geese..

With adoption of the proposed water supply management approach, it is only anticipated that one 'Phoslock' application will be required in the winter of 2016 / 2017. However, it is recommended that on-going water quality sampling is pursued to monitor water quality conditions and nutrient staus. As a minimum sampling should be conducted in August of each year when the worst case water quality conditions may be expected.

2.2.9 Budget Costs

The costings for rehabilitation of the water feature are presented in Table 3. These costs should only be viewed as indicative and fully costed detailed proposals should be sought for each element of the work. The estimated costings supplied for the aeration system are based on the ISS / Flowthrough system and for plant introductions using the techniques previously described.

In addition to the costs stated in Table 3, there will be additional ongoing operational and maintenance costs that will include electrical supply costs for the aeration system, maintenance costs for the aeration system and costs for maintenance of aquatic plants.

Table 3: Indicative Costs for Water Feature Rehabilitation

Work Element		Cost Estimate
Barley Straw Application	Pump hire / fish removal	£1,500 (annual cost)
'Phoslock' Application	Applying Phoslock to remove nutrients from partial borehole refilling.	£5,800
Aeration Equipment Supply and Installation	Install ISS / Flowthrough type aeration system	£36,000
Plant Introductions – Phase 1	Protected Planting in bespoke planting system – 198m of marginal planting	£25740 (excluding installation labour costs)
Plant Introductions – Phase 2	Protected Planting in bespoke planting system – 217m of marginal planting and lily and submerged plant introductions.	£30205 (excluding installation labour costs)
Fish Introduction	Supply of 60kg of Tench	£1400

2.3 Agreed Rehabilitation Approach

Following issue of the draft version of this report, that set out the full redevelopment and rehabilitation options of the water feature, Laguna Science attended a City Quay Management Company Board meeting on the 10th May 2016 to discuss the report findings and agree the way forward. The purpose of the meeting was to select the options proposed from the rehabilitation strategy that may provide the most cost effective method for affecting improvements in the performance of the water feature.

The following rehabilitation works were identified for implementation during 2016 and 2017:

- Works to reduce access to the water feature by geese;
- Management of the water supply as an emergency top-up supply only;
- Trial introductions of submerged aquatic plants and lilies;
- Installation of a permanent diffuser based aeration system; and
- Treatment of the water feature by 'Phoslock' during the winter of 2016 / 2017.

2.3.1 Reducing Access by Geese

Works are currently underway to reduce the attractiveness of the water feature to geese by restricting their access between the water feature and surrounding grassed areas used for roosting and grazing. These works will involve creating a shrub barrier at the edge of the grazing area at the northern end of the water feature. The success of this approach will need to be monitored and further planting may be required at other areas around the water feature were short grassed areas are present.

If issues continue to occur with geese using the lake, then the plantings may be supplemented by the use of a double line of stainless steel cables fitted to the lower part of the perimeter posts at strategic points around the water feature. This approach would be the lowest cost and least visually intrusive method for enhancing the development of barriera to the birds.

2.3.2 Management of Water Supply

The water supply to the water feature will be managed as set out in section 2.2.1. Therefore a reduction in water level will take place over the summer months and the water supply will only be used in the event of prolonged dry conditions arising that leads to significant evaporative losses. The water feature will be allowed to naturally refill over the autumn / winter period.

The float valve control on the borehole pump will need to be reconfigured with a longer float line such that it only operates once the water level has dropped to a significant degree i.e approaching the bed level of the marginal shelf.

2.3.3 Trial Aquatic Plant Introductions

Trial aquatic plant introductions will be undertaken at the northern and southern ends of the water feature using the submerged aquatic plant *Ceratophyllum demersum* (Hornwort) and the large white flowering, robust ornamental lily *Nymphaea gladstoniana.* The success of plant establishment will be dependent on the effectiveness of measures to reduce the use of the water feature by geese and this should be monitored. Deployment of the plants will take place at the earliest opportunity so that they have the 2016 growth season to become established.

It should be noted that submerged aquatic plant introductions are often not undertaken on nutrient enriched systems as the excessive growth that can take place can interfere with other recreational amenity uses such as angling and boating. On landscape type waterbodies, such as the City Quay Water Feature, they can however provide a useful approach for utilisation of available nutrients (soluble phosphorus) and reduce the potential for algal bloom development. The plants are being introduced on an initial trial basis to determine their growth response. If excessive growth does develop then it should be noted that the only method for their control is by periodic manual removal as there are now no aquatic herbicides currently permitted for use in the UK. Removal of excessive growth is a useful technique in that it effectively removes nutrients from the system and the waste plants can be composted and used as a soil conditioner on landscaped areas within the development.

Plant introductions will be made on the shallow marginal slope areas using geotextile planters.

Following review of the trial aquatic plant development, further plant introductions may then be scheduled to take place during the Spring period of 2017.

2.3.4 Diffuser-based Aeration System

A diffuser-based aeration system will be installed into the water feature to assist in improving and maintaining water quality conditions within the water feature. The system will be based on the design outlined in section 2.2.3 and Figure 4. The system will comprise of two airlines running down the length of the water feature, each supporting 9(no) rubber membrane diffusers. A full detailed proposal for the system will be developed that will set out the full installation and operational costs together with on-going maintenance requirements.

It should be noted that there is an equipment procurement lead time of around 6 to 8 weeks for these bespoke systems. Therefore, it is likely that installation may not be undertaken until the beginning of August 2016.

2.3.5 'Phoslock' Application

An application of 'Phoslock' will be undertaken in the winter of 2016 / 2017. The purpose of this application is to permanently reduce the high concentrations of the phosphorus currently present within the waterbody. Application will be undertaken in the winter as this is when phosphorus concentrations would be at their highest due to release from biota following seasonal dieback. The application of 'Phoslock' will take approximately one day to complete.

2.3.6 Costings

Detailed proposals and costings for consideration will be developed for each of the following work elements and submitted to the City Quay Management company within the next two weeks:

1) Trial aquatic plant introductions;
2) Diffuser-based aeration; and
3) 'Phoslock' Application

The costed proposals for this work will include full technical specification together with any associated on-going operational and maintenance requirements and costs.

3 SUMMARY

A re-development and rehabilitation option approach for the City Quay Water Feature have been described together with proposed schedule of works and indicative costings.

Redevelopment of the water feature will be a major civil engineering project that would potentially cause a great deal of disruption to the residents and also incur high costs. There is significant uncertainty on cost due to the unknown nature of the fill material and its contamination status below the existing water feature lining and this presents a major financial risk to a redevelopment project. At some stage during the next 15 to 20 years the lifespan of the existing liner may be expected to reach an end and repairs or replacement is likely to be required. Even without excavation to deepen the lake, replacement of the liner will be a costly and disruptive process due to the need to lift the coping marginal coping stones and block paving to allow liner anchoring.

In balance, the best option currently available appears to be to adopt a rehabilitation strategy to improve the visual appearance and functioning of the existing lake. The full rehabilitation approach will incur some significant costs which result from the need to address the shortfalls in the original poor design of the water feature. The rehabilitation strategy allows the measures to be implemented with a phased approach and a range of measures have been agreed with the City Quay Management Company Board for implementation during 2016 and 2017. It should be noted that there will be a period before the effects of the rehabilitation actions are fully realised i.e the need for introduced aquatic plants to become established. However, it is considered that if if a range of rehabilitation measures are implemented and combined with a pro-active approach to management and maintenance of the water feature, then a good quality waterbody that is fitting of this development may be realised.

FIGURES

335500

335600

387300

387200

N

Adler Way

Ellerman Road

1.5m

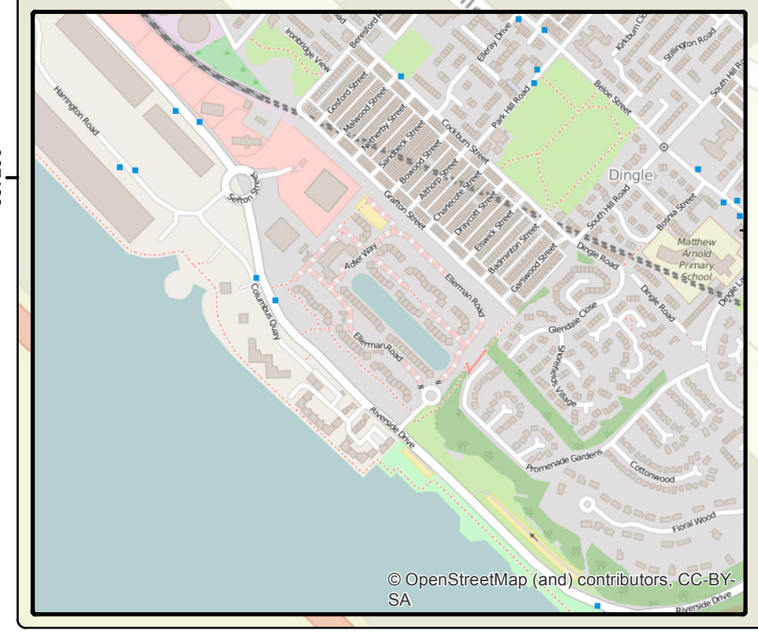
1.5m

0.5m

1m

Ellerman Road

Promenade G



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Key

Existing Water Depths (m)

- 0.5m
- 1m
- 1.5m

LAGUNA SCIENCE

Project:
City Quay

Title:
Figure 1:
Existing Water Depths

Status:	Revision:	Page Size:
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Website: www.gavia-environmental.co.uk

335500

335600

387300

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N

Adler Way

Ellerman Road

0.5m

1m

2m

3m

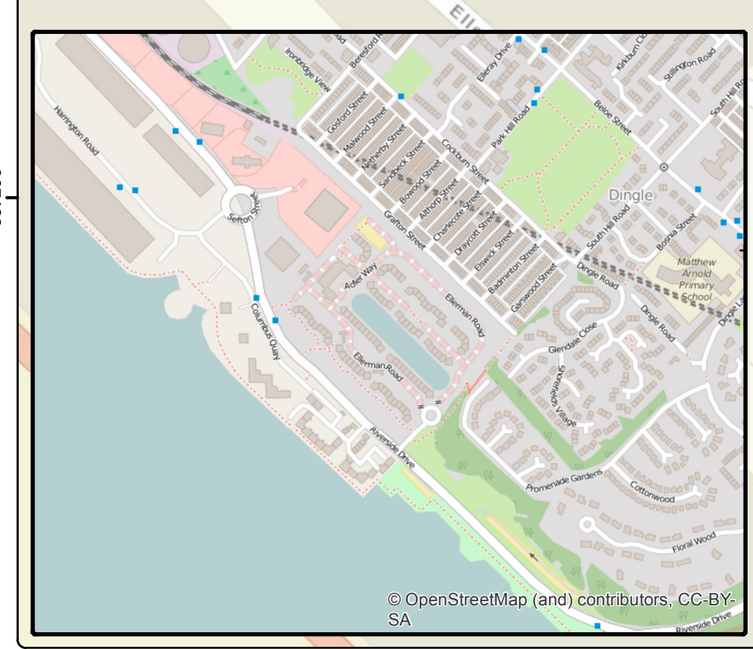
4m

Dingle

Matthew Arnold Primary School

Ellerman Road

Promenade G



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Key

Optimised Water Depths (m)

- 0.5m
- 1m
- 2m
- 3m
- 4m

LAGUNA SCIENCE

Project:
City Quay

Title:
Figure 2:
Optimised Water Depths

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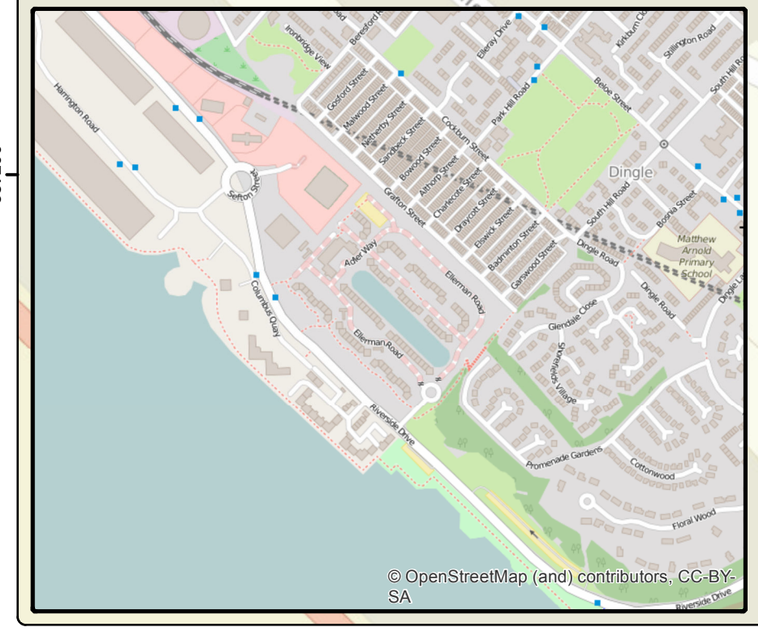
Adler Way

Ellerman Road

182.1m



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Key

Optimal Water Depths (m)

- 0.5m
- 1m
- 2m
- 3m
- 4m
- Airline
- Diffuser
- Primary Mixing Sphere
- Compressor Cabinet

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Project:
City Quay

Title:
Figure 3:Diffuser Aeration System Layout for Optimised Water Depth

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N

Adler Way

Ellerman Road

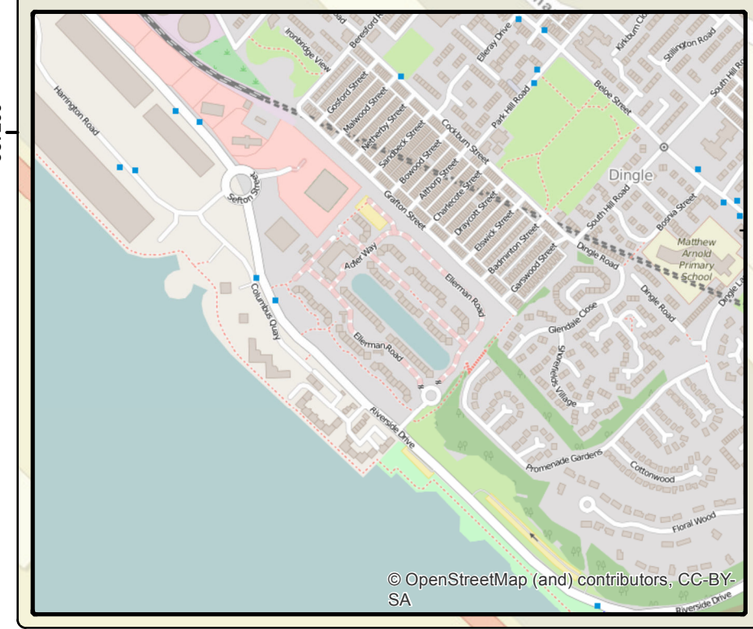
Grafton Street

177.5m

176.1m

Ellerman Road

Promenade Gardens



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Key

- Diffuser
- Airline
- Airline (through existing cable duct)
- Primary Mixing Spheres
- Compressor Cabinet

LAGUNA SCIENCE

Project:
City Quay

Title:
Figure 4: Diffuser Aeration System Layout for existing water depths

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Adler Way

Ellerman Road

51.8m

26.1m

27.6m

19.2m

30m

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22.5m

26.6m

23.3m

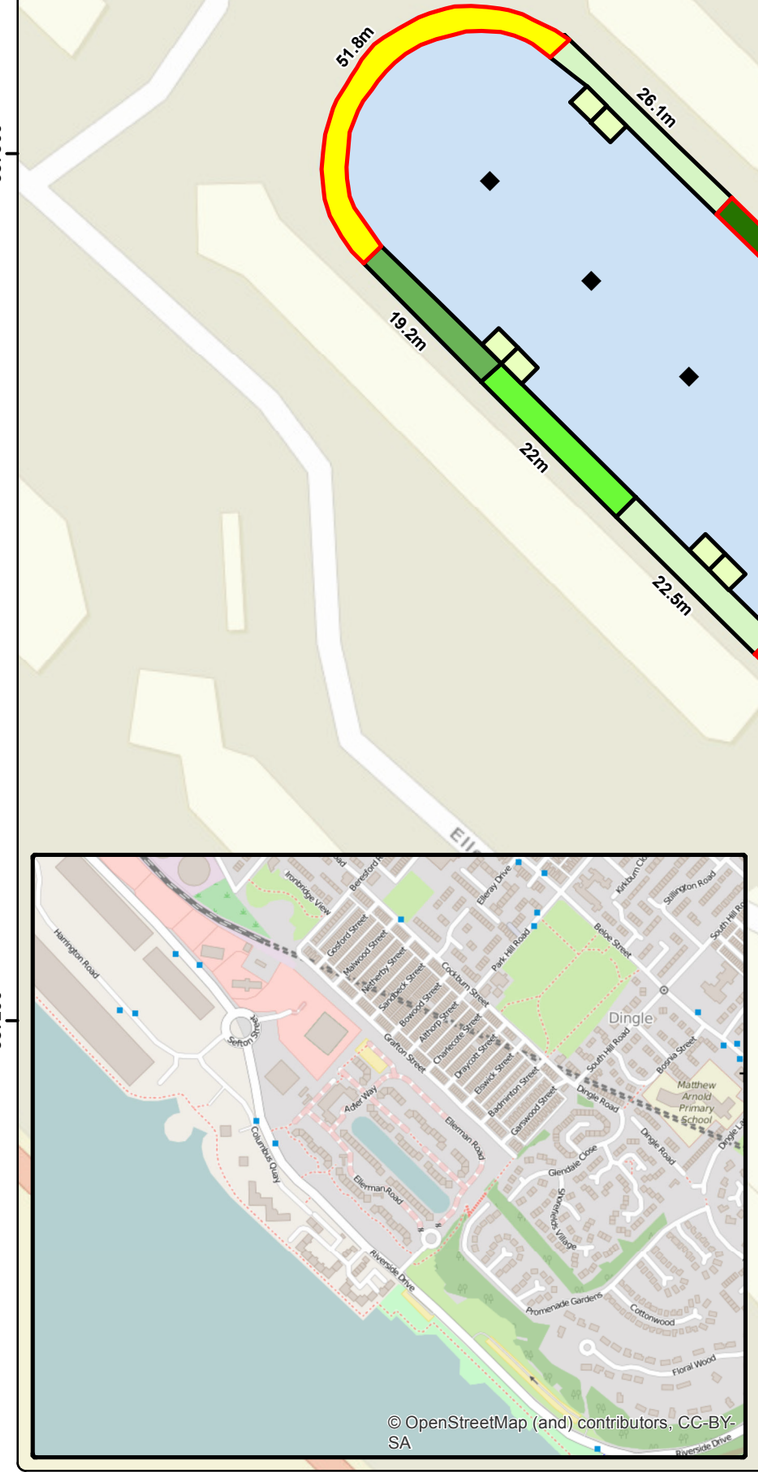
30.8m

20.9m

22m

33.4m

68.9m



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Key

Phase 1 Planting

- Acorus calamus
- Iris pseudacorus

Phase 2 Planting

- Butomus umbellatus
- Carex rostrata
- Mentha aquatica
- Myosotis scorpioides
- Nymphea 'Gladstoniana'
- Ceratophyllum demersum

LAGUNA SCIENCE

Project:
City Quay

Title:
Figure 5:
Proposed Aquatic Planting Scheme

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