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Abstract

Stormwater ponds are now common features of the urban landscape. They have been constructed to mitigate the adverse effects of development, to control flooding and to improve water quality. This evolution has now reached an epoch where hundreds of ponds are now dotted throughout Auckland and increasingly in other parts of New Zealand.

Ponds are designed to reduce flooding and accumulate tones of sediment, which often contains harmful contaminants that would otherwise negatively impact waterways and marine environments. In many ways they succeed in their design objectives; however it is becoming increasingly clear that there are unforeseen impacts of ponds.

This paper investigated the challenges that are faced with ongoing pond maintenance and summarises possible solutions for a more sustainable future.

1 Introduction

The reasons, rational and motivation to do things can often be in stark contrast with the subsequent results and the true intention of a given act. As Robert Burns the famous Scottish poet is quoted "The best-laid plans of mice and men/Go oft awry."

This paper begins by framing the context of this paper around an analogy. The first known release of rabbits in New Zealand was in Queen Charlotte Sound by Captain James Cook in 1777. The released rabbits where considered a potential food source to be available on subsequent visits to the area. At first, the spread of rabbits was limited by the scarcity of suitable habitat such as farmland, but by 1890 they had spread throughout much of New Zealand. This fast breeding species had few predators. Stoats were introduced to New Zealand in the 19th Century in an early and failed attempt at bio-control of the out–of-control rabbit populations.

This is a classic example of cause and effect, action and reaction beginning a chain of events otherwise not intended. Tragically, New Zealand's flightless ground nesting birds, its lizards and its insects proved easier to catch than rabbits for the stoats. This resulted in the extinction of many bird species or reducing their populations and distribution to unsustainable levels. A seemingly well laid plan gone awry?

So what have stormwater ponds got to do with rabbits, stoats and the subsequent environmental degradation? Well the analogy seems clear, even though our intentions have been true to use ponds (being the Stoat) in the mitigation of environmental effects associated with landuse intensification (being the Rabbit) such as flood flows and erosion. There are many things we have yet to understand about how ponds function to improve water quality and protect habitat, and the implications of ongoing maintenance. However one thing is certain, as the use of ponds is becoming ever more common practice, with an estimated 350 public stormwater ponds in the Auckland Region alone and more across the country each month, the time has come to consider that they may indeed be the environmentally damaging Stoat and in themselves causing additional damage in union with the ubiquitous Rabbit.

This paper intends to share observations, focus attention and provide commentary about stormwater ponds and their implications on the environment.

2 Background to Stormwater Ponds

Stormwater ponds can be either dry ponds only temporarily detaining flood flows or wet ponds having a permanent standing pool of water.

Stormwater ponds are used for three main primary purposes:

1. Minimising flooding downstream,
2. Improving water quality,
3. Reducing downstream channel erosion.

For water quantity performance stormwater ponds detain and then discharge over time in order to mimic calculated predevelopment runoff discharge rates. They are designed to detain the difference between the pre and post-development flow rate hydrographs and to release this volume over time. Water quality is generally achieved through the storage of contaminant laden water so most of the particles held in suspension have time to settle before leaving the pond.

Stormwater ponds in the Auckland Region are designed under guidelines provided by the Auckland Regional Council (ARC), Technical Publication 10 Design Guidelines Manual for Stormwater Treatment Devices. The principle aim of these guidelines is to outline and demonstrate the ARC's preferred design approach for structural stormwater management devices. These guidelines are being increasingly used in other parts of New Zealand to guide in the design of stormwater ponds.

The primary contaminant removal mechanism of all ponds is the settling or sedimentation of the particles of clay, heavy metals and pesticides. In simple terms they are sediment traps, designed to collect as much material as possible and remove the highest percentage of the incoming material as possible. In the Auckland Region the design target for sediment removal is 75% of suspended solids. This target is also used by other countries including Australia and the USA.

Hundreds of ponds are now dotted throughout Auckland, and increasingly in other parts of New Zealand. They have been well blended into the urban landscape becoming centre pieces for public amenity. In many other instances they are a tag-on afterthought, squeezed into the deepest most remote corner of developments, to facilitate maximum profit yields and meet consenting requirements. Their forms and quality is wide and varied.

2.1 Land Development and Ponds

Urban development plays a major part in the modification of catchment hydrology. Hard surfaces such as roads and roofs tend to absorb less and discharge more during rainfall events increasing the volume and rate of stormwater flow compared to predevelopment runoff conditions.

Stormwater management is a principal factor in the planning and design of urban development. Resource consent requirements drive the use of stormwater ponds as a stormwater management tool to minimise and mitigate the adverse affects of development on receiving environments. Unfortunately, the details are often not addressed until the final stages of the planning and design process. Additionally management options such as the use of ponds have been considered in favour of less prescriptive and difficult to apply onsite mitigation options. Onsite solutions typically require the support and implementation of regulatory authorities.

Stormwater ponds are an end of pipeline solution. They provide developers with the opportunity to plan their developments to have the maximum allowable impervious coverage as permitted by district planning rules (as long as they can achieve guideline standards for discharge). This in part has resulted in a general over reliance on this management technique. Although there are examples of low impact design approaches that consider water sensitive urban design principles (Roon, Marjorie van. 2007), such as the Long Bay Infrastructure Plan, the majority of new subdivisions are serviced by stormwater quality and quantity ponds.

3 Impacts Unforeseen

3.1 Hydrology

Ponds are often designed to meet maximum peak discharge rates of predevelopment conditions. However as a consequence of changes in catchment hydrology associated with development the volume of water that has to be conveyed during such events is greater. Effectively catchment yields have increased with the predominance of impervious surfaces. What this means is that the period of time when high flow events occur will also increase. This has the potential to stress in-stream fauna and have adverse environmental affects. There is at the present time no way to reduce these impacts. They are a direct result of the increase in impervious cover in catchments.

3.2 Ecology

The physical habitat created by the construction of stormwater ponds is in many ways the most complex dynamic associated with ponds. Typically the designers of ponds are not ecologists and subsequently the management of ponds for ecological values is poorly understood and applied.

Although ponds provide a refuge for a number of aquatic and terrestrial species they also inherently change the structure of the ecological setting they are placed in; this results in habitat loss. This is particularly relevant with online ponds as they are constructed on the bed of perennial waterways.

Accumulation of persistent pesticides and herbicides and heavy metals can bioaccumulate and impact organisms within the ponds and potentially organisms within the receiving waters (Serrano, 2005). Changes in carbon and nutrient loadings also cause shifts in stream trophic status.

3.2.1 Aquatic Weeds

New Zealand was not well represented with aquatic plant species prior to European colonisation. Those species that did occupy stream and lake beds are not known for being physically robust and are slow to re-populate once disturbed or out competed. The combination of clearing vegetation that shaded streams and the introduction of vigorous and subsequently invasive species, such as Oxygen Weed *Egeria densa* and Parrots Feather *Myriophyllum aquaticum*, has resulted in most of our North Island streams and rivers in developed urban catchments being dominated by introduced plants.

Stormwater Ponds offer an optimal habitat type for many invasive aquatic species. The communities that live next to ponds have played an unwitting yet major role in the spread through the release of unwanted aquarium fish into ponds. Additionally, many of these species distribute themselves by way of vegetative reproduction. Consequently physical maintenance and breakup of the infestations can result in further spread to previously un-infested downstream reaches.

These introduced plants can proliferate in a very short time. Many ponds in the Auckland Region can have much of their surface area covered within a 12 month period after weed clearance. Unfortunately the density of infestations peaks during the warm days of summer only to crash when conditions become less favourable later in the season. The breakdown of the plant material is an oxygen demanding process that can reduce the dissolved oxygen levels in downstream receiving environments stressing the in-stream fauna.

The mass of plant material can also displace large amounts of water and thus can limit the storage available for storm flows. Large rafts of weeds can block service outlets resulting in potential flooding.

3.2.2 Fish Passage Barrier

It is the nature of ponds to detain water. In so doing there is a necessary change in free water surface elevation from upstream to downstream of the detaining structure. This can result in the damming structure forming a fish passage barrier. Many of the native freshwater fish that live in New Zealand streams are diadromous, in that they travel between salt and fresh water during their life cycle. These structures can block these migratory patterns. Although many native fish are proficient climbers, ponds often have outlet control structures that are barriers to the passage of climbing and non-climbing species (Boubée et al. 1999).

Fish such as inanga, Galaxias maculatus, are particularly affected being essentially unable to climb any in-stream obstacle. The result is that upstream of ponds the diversity of fish species is altered and in many instances severely depleted.

3.2.3 Pest Fish

Pest fish are becoming an increasingly bigger problem in New Zealand. The physical, chemical, and biological characteristics that ponds provide as an environment have proven ideal habitat for many of the introduced fish species. Some of which have since become pest species.

Gambusia affinis, or as they are more commonly known mosquito fish, are a small fish introduced to New Zealand in the 1930's from the Gulf of Mexico to control mosquito larvae (Ref 2). However, common understanding today is that they are not that effective at doing this. Unfortunately being a very fast breeder giving birth to live young and being tolerant of a wide range of temperature and salinity conditions they have infested many stormwater ponds. They are considered to compete with native fish for food and have been reported to nip at the fins of native fish, with whitebait species being particularly vulnerable. One of the main vectors of distribution is by people, in particular children. To an innocent child the “guppy’s” in the local pond make great house pets. Until of course they start to smell, die or become an inconvenience and then they are liberated to the nearest pond; not necessarily the pond they originally came from.

Koi carp thrive in the conditions present in ponds. They are an ornamental strain of the common carp (Cyprinus carpio) native to Asia and Europe (Ref 1). They were introduced to New Zealand accidentally in the 1960’s as part of a consignment of goldfish. Since then they have consolidated, with wild populations in the upper North Island. In recent years, being popular with Asian migrants, they have been liberated to many ponds in the Auckland Region and it is not uncommon to see people fishing with a line and rod on the edge of a stormwater pond for carp.

Once pest species get into the ponds they can very easily get out with little help from people. During storms, many of these exotic species are washed downstream and are able to then inhabit previously un-infested reaches of waterway. In the streams of North Shore City, in Auckland, this trend has been observed in numerous waterways where stormwater ponds have been constructed. Upper stream reaches without ponds are typically free of the pest fish Mosquito Fish, *Gambusia affinis,* but are found down stream of the majority of online stormwater ponds in North Shore City.

3.3 Water Quality

3.3.1 Thermal Impacts

The thermal impacts of ponds although not widely considered can act to reduce water quality. When water discharges into a pond from inlets it is generally cooler than the surface layer of the pond. To maximise the treatment efficiency of a pond the sediment entering must be retained for the longest time possible until ideally the sediment is deposited on the pond bottom and removal of the sediment from the water column is achieved. This incoming water being denser tends to sink to the bottom of the pond. (Wetzel 2001, Fischer et al 1979) The upper part of the pond surface at the greatest distance from the original inlet point is then discharged through the pond service outlet.

The permanent pool of ponds acts as a heat sink during the summer months, and discharges warmer waters during both storm and baseflow conditions (Schueler and Helfrich, 1988). These on-line ponds are well known to cause significant increases in water temperature, often for hundreds of meters downstream (Maxted et al 2004).

Incoming solar radiation is absorbed at higher rates as sediment particles tend to soak up the light energy and release heat into the water (Wetzel 2001, Fischer et al 1979). This is like a heat island affect further increasing the thermal loading on downstream environments (Galli, 1991).

3.3.2 Dissolved Oxygen

Stormwater pond surface waters are documented to have poor water quality indicators (Drescher, S et al 2007). The increased organic matter content from large masses of algae and weeds can result in decreased dissolved oxygen concentrations stressing downstream fauna. This tends to occur in the late summer as growing conditions alter resulting in a die off of plant growth. Organic matter breaking down in water is an oxygen demanding process as shown in Photograph 1.

This consumption of oxygen needed for biodegradation can be a major problem. Oxygen is not very soluble in water. The equilibrium concentration of oxygen in water is approximately 10 mg/L. That means that the degradation of a few mg/L of a biodegradable compound in a river could result in the depletion of dissolved oxygen.

Ponds can act to reduce dissolved oxygen concentrations caused by the accumulation and decomposition of organic sediments (Maxted et al 2004). Many of the more sensitive aquatic macroinvertebrates such as stoneflies and caddisflies can be affected by these changes.

Increases in temperature as a consequence of thermal impacts also act to reduce dissolved oxygen levels. As water temperatures increase the concentration of dissolved oxygen decreases as shown in Figure 1.

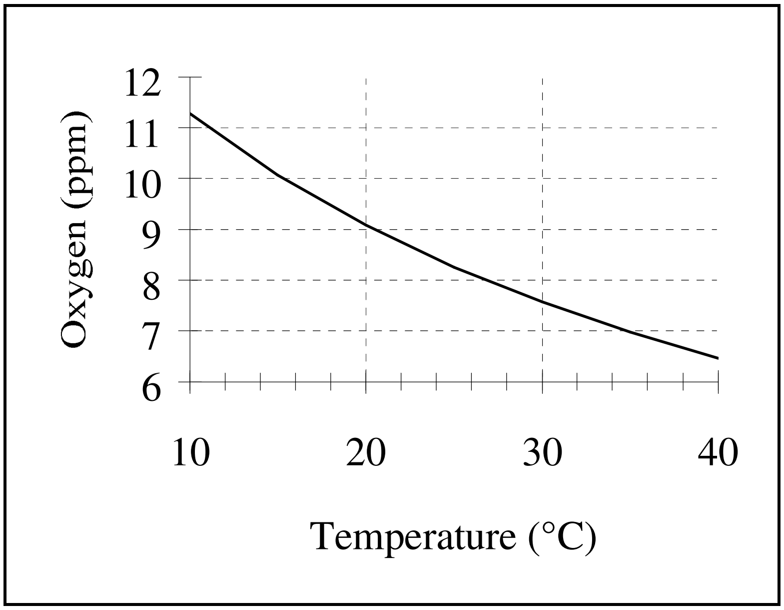

Figure 1: Dissolved Oxygen Sag Curve

Photograph 1: Aquatic weeds and algae clogging pond

4 Challenges of Pond Operation and Maintenance

4.1 Maintenance and Monitoring

Stormwater ponds require regular maintenance and inspection. This includes but not limited to checking and inspecting the following:

- Outfalls into Pond;
- Sediment Forebays (>50% full);
- Permanent Pool (Wet Pond >15% full);
- Embankment & Emergency Spillway conforming to design;
- Erosion Protection, Public and Amenity Features (fences, bridges)
- Riser and Service Spillway conforming to design;
- Sluice Gates, Pumps, Valves, Locks, Access Hatches;
- Aesthetics, Graffiti, Litter;
- Landscape Planting, Wetland Planting;
- Maintenance Access;

Pond maintenance plans are often required as a condition of consent. They may include description of monitoring procedures, frequency and methodology.

Monitoring the accumulation of sediment in ponds is an important part of maintenance planning. Because ponds accumulate material slowly over a long time they must be monitored regularly and efficiently. When the time comes that the collected material in the pond is compromising design function the material must be removed. This should involve the detailed measurement of the accumulated material so removal prices can be sought from contractors and so that this information can be used when assessing pond performance and catchment land-use impacts.

4.1.1 Sediment Removal

The accumulated sediments built up overtime eventually need to be removed as reduction in water quality performance will result. This is because permanent storage volume will directly correlate to a reduction in treatment efficiency and flood mitigation function (Refer Photograph 2).

Depending on the size of a catchment, land use and the relative size of the pond, sediment removal will typically be required every 2-10 years for pond forebays (designed to capture the larger size fraction of the sediment) and 10-50 years for the main pond area.

Disposal of sediments must comply with local and regional requirements. Testing should be carried out to determine the level of contamination in the material. This will dictate the suitable disposal location for the material and whether landfill disposal is required.

Access to stormwater ponds is extremely important because without good access for removal equipment the cost and time of removal operations may increase exponentially. In many instances through design errors, consenting process failures or lack of foresight ponds can be very difficult to access. Examples can include lack of heavy vehicle access, dense perimeter vegetation and houses constructed tightly around the pond. These factors act to restrict the options available for material removal.

Photograph2: Houses constructed close to a pond. Field officer measuring silt depth.

The removal of the sediment or sludge can be achieved through techniques such as vacuum pumping of wet sludge, or dewatering onsite and removal with small diggers. However, as access to the pond perimeter maybe restricted or the pond area precludes digging from the margins, removal from a barge with a long reach digger maybe necessary. As the material has low viscosity sludge dewatering using decanting devices, drying areas and centrifuges are often used to minimise the volume for removal. Mixing of sediment sludge with coalescing agents is a common practice to reduce viscosity and bind contaminants into a matrix.

Where there are access restrictions for large vehicles and the use of sucker trucks is not feasible, (the use of sucker trucks from a distance is difficult as pumping efficiency is severely reduced) subsequent formal access points need to be constructed. This may require the purchase of additional land or agreements with adjacent land owners to facilitate access. Removal of wet material, with of-site dewatering, is often required as drying areas are frequently not sufficient.

Depending on regional and district planning requirements resource consents may be necessary for the removal of sludge. This may require erosion and sediment control planning reports.

4.1.2 Vegetation Management

Increasingly vegetation management is an important part of overall pond maintenance. This includes the weeding and monitoring of amenity planting around the pond but more significantly, in terms of capital expense, the removal and control of aquatic weed infestations. These infestations affect water quality, reduce the storage volume of the pond and in some instances block outlet structures increasing the risk of flooding. In some ponds in the North Shore City of Auckland, managers, with the agreement of the Department of Conservation, have released nonbreeding diploid grass carp *Ctenopharyngodon idella L.* to control Parrots Feather *M. aquaticum* and other aquatic species. This action mimics the rabbit and stoat situation, the weeds have taken advantage of the ponds and now the carp have to be released to control the weeds. All this effort is ironically to control contaminants and flooding.

4.2 Cost of Sediment Cleanout

The future costs of pond maintenance in particular for sediment removal should not be underestimated. For example, consider the following scenario, if 10 ponds are constructed in a given year and they have a forebay and main pond cleanout frequency of 5 and 25 years respectively, within the first 5 years all the ponds need forebay cleanouts. Conservatively, assuming $100m^3$ of forebay material each to be removed at current rates for removal and disposal of \$350 per m^3, this would equate to \$350,000 in the first 5 years of operation, simply to clean the forebays.

If the 25 year maintenance cost is considered at today's prices with a very conservative $500m^3$ volume to be removed the total cleanout cost for 10 ponds is a substantial \$1.75 million. Including forebay and main pond cleanout the total is \$3.5 million or \$350,000 per pond over 25 years. If we extrapolate that to the possible 350 ponds in the Auckland region alone the maintenance cost for sediment removal alone is a conservative \$122.5 million as an indicative cost.

Based on the general consensus of stormwater pond managers in the Auckland Region cleanout programmes are well behind scheduled programming, with the prohibitive costs being incurred considered to be the limiting factor. To be meeting water quality objectives as per resource consent requirements these ponds must be cleaned out.

It should be noted that sediment removal costs are associated with many other treatment options; therefore in order to avoid these costs control at source is required.

5 Possible Solutions

5.1 Mitigation Options

There are a number of ways that existing ponds can be retrofitted to improve ease of maintenance and minimise environmental impact, some of which are as follows:

- Construct dry weather baseflow bypass channel,
- Reduce permanent pool area,
- Construct formal access,
- The use of treatment train approach to reduce pond loadings,
- Increase shading through specimen tree planting,
- Align pond in a North to South direction (in new construction) to increase shading,
- Construct a deep water release pipe at the service outlet to avoid thermal impacts,
- Improvements in forebay design to trap more sediment and reduce costs,

- Incorporating floating wetlands in pond treatment systems to increase shading and metals removal,
- Retrofitting fish bypasses to outlets,
- Community education planning to control deliberate and accidental releases of invasive species,
- Include biological monitoring in inspection regimes,
- Existing ponds being redesigned and retrofitted as wetland pond systems.

The mitigation and maintenance options outlined above may go some way in alleviating existing problems. However where possible the use of onsite mitigation options supported by regulatory authorities will facilitate a more sustainable low impact design approach. Avoiding the use of ponds in the first instance, while potentially more challenging, may serve us better in the future.

6 Conclusions

Stormwater ponds are an effective way to reduce flooding from increases in catchment runoff associated with development. At the present time they are often a preferred option in the management of contaminants transported in stormwater. However, there are matters of some significance to consider when choosing them as a stormwater management tool as they can produce a varied assortment of harmful impacts on receiving environments and have long-term cost implications. Some of these impacts which are illustrated in more detail in this paper include the following:

- Increased organic matter content and decreased dissolved oxygen concentration stressing downstream fauna and resulting downstream shifts in stream trophic status.
- Accumulation of persistent pesticides and herbicides and heavy metals can bioaccumulate and impact organisms within the ponds and potentially organisms within the receiving waters.
- High costs of ongoing maintenance are a limiting factor in maintenance frequency and subsequently may reduce water quality treatment and flood control performance.
- Pond thermal heating causes significant increases in water temperature, often for hundreds of meters downstream of the pond discharge point.
- Ponds are prone to aquatic weed and pest fish infestations resulting in further spread of these species.
- Being damming structure ponds can form complete or partial barriers to fish passage.

The great Scottish poet Robert Burns once said “The best-laid plans of mice and men/Go oft awry." There is more than meets the eye when considering stormwater ponds as a stormwater management option. They have certain adverse effects on the environment and have in part shaped our development habits. The consequences on the environment and the public purse should not be underestimated as it will be future generations who will bear the burden of their ongoing care.

The extent and severity of their ecological impact warrants further study, possible changes to policy and communication of the risks both financially and environmentally to the wider public.

Considering once again the Stoat and Rabbit analogy and reflecting on the role Stoats are known to play in our native ecology, the use of ponds to protect the environment from development should at least be further debated; it might be that we need to stop releasing rabbits.

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