An assessment of the cost-effectiveness of vegetation harvesting as a means of removing nutrient and metals from ponds

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ABSTRACT
This paper reports on an investigation to quantify the mass of pollutants removed from a stormwater retention pond by routine vegetation harvesting. The amount of plants can increase the costs of ponds, and the increased costs of plant maintenance may not be justified by enhanced pollutant removal. This study provides some of the basic information, previously lacking, which is needed to come to such decisions. The study facility was La Costa pond, a retention pond in California used to treat highway runoff. Water quality monitoring data indicate that the pond removed 43 percent of the total nitrogen entering the facility, with 5 to 7 percent directly attributable to harvesting the vegetation – in this case cattails (*Typha)*. The data also indicate that 48 percent of the total annual phosphorus was removed from the runoff, with the harvested vegetation responsible for between 3 and 8 percent. Metal uptake by the vegetation was substantially less than nutrients. Total removal of copper, lead and zinc by the pond varied between 57 and 93 percent, with the harvested vegetation accounting for less than 2 percent of removal. Issues addressed in the paper include the cost implications of harvesting and ways of improving vegetative pollutant removal.

KEYWORDS
Vegetation; Retention pond; Harvesting; Pollutant removal; Stormwater

INTRODUCTION
Retention ponds, where stormwater undergoes treatment by a number of natural processes resulting in an improvement in water quality are one of the most commonly employed best management practices (BMPs) used to mitigate the negative impact of stormwater runoff. Removal processes include sedimentation, biomass uptake, sorption, precipitation and transformation. While guidelines for retention pond design vary, most recommend a certain percentage of the pond be vegetated. Plants are desirable in ponds for several reasons. They add aesthetic and amenity value to ponds, making them more acceptable to the public. They also allow the establishment of ecosystems, which support other forms of aquatic life such as fish populations – vital for vector and algae control. Established vegetation can also be advantageous from a safety point of view, preventing easy access to deeper water, especially the larger emergent macrophytes such as reeds (*Phragmites*) and cattails (*Typha*).

It is also generally asserted that pond vegetation will assimilate nutrients and certain pollutants, and that the harvesting of this vegetation will permanently remove these constituents from the pond (Hansson and Fredriksson 2004, Hosoi, *et al*. 1998, Martín and

Fernández, 1992). However, little hard data are available to quantify just how much of any given pollutant is actually removed by vegetation harvesting, and how this compares to the total amount removed by all processes within a pond. This information is important, since the presence of vegetation potentially increases the maintenance costs associated with ponds.

METHODOLOGY

The study objectives were achieved by carrying out a chemical mass balance for various constituents in a pond treating urban runoff using data gathered from a number of published studies. A literature search quickly identified two types of study which were useful in this context: those providing concentrations which could be used in mass balance calculations, and those which could be used to make more general observations on the practice of harvesting.

There were several specific data requirements that defined whether results from a particular study would be suitable for use in the mass balance calculations:

1. Data had to be available for an in-situ pond which: 1. had established vegetation, and 2. received urban/highway runoff;
2. Values were required for nutrient levels in flow entering and leaving the pond;
3. There had to be a known weight of vegetation removed during a routine harvesting of the pond;
4. Values were needed for nutrient and metal concentrations in *Typha* plants exposed to levels of nutrients and metals within the range normally found in urban/highway runoff.

The literature review failed to identify a single study which fulfilled all requirements, so a combination had to be used. The studies used are described in the next section and are listed in Tables 3 and 4.

Studies used

La Costa Pond. Only one source was identified which could provide a weight for harvested cattail biomass – La Costa Pond. The La Costa pond (Figure 1) is situated on Interstate 5 in California (Caltrans, 2004). It receives flow from a 1.7 ha watershed with 48% impermeable cover, which includes the northbound lanes of the highway. The pond contains numerous plant species, including *Typha*. The data analysed were gathered during a water quality monitoring program over three years of wet and dry weather measurements to characterize the reduction in nutrients and metals in the pond. The vegetation in the pond was harvested annually and the volume and mass of vegetation removed was quantified.

The pond was closely monitored for both water quality and quantity during the growing period of the harvested plants, and reliable results were available for the volume of dry weather flow and storm events, along with the corresponding pollutant concentrations for inflow and outflow. Those relevant to this study are shown in Table 1.

Miao (2004) investigated rhizome growth and nutrient resorption in cattails and sawgrass. The plants were grown in mesocosms for one year, and exposed to different nutrient regimes during this time. At the end of the test period, the plants were harvested and analysed for nitrogen and phosphorus accumulation. The results used here were those from the nutrient regime corresponding to urban/highway runoff values.

South Base Pond (SBP) is a former dry detention basin which was converted to a constructed wetland in order to increase the treatment given to the received runoff (Municipality of Metropolitan Seattle, 1993). The pond receives stormwater runoff from 18.5 ha of impervious surfaces at a coach maintenance and repair facility. Once completed, the pond was monitored to appraise its performance. The plants were harvested after 6 months growth, and analysed for nitrogen, phosphorus, lead and zinc accumulation.

Figure 1. La Costa pond pre- and post- harvesting (Caltrans 2004).

Table 1. La Costa data used in mass balance calculations (all concentrations mg/l).

	Wet weather flow	Dry weather flow
Total volume (m³)	1300	17800
N conc. inflow	4.65	17.19
N conc. outflow	2.85	9.7
P conc. inflow	0.93	2.23
P conc. outflow	0.88	1.13
Pb conc. inflow	0.295	0.004
Pb conc. outflow	0.006	0.001
Zn conc. inflow	0.056	0.072
Zn conc. outflow	0.033	0.028
Cu conc. inflow	0.097	0.063
Cu conc. outflow	0.010	0.029

A Minnesota wetland was used as the third vegetation study. This was a particularly comprehensive *Typha* study carried out over two years, observing seasonal patterns of nutrient accumulation in the biomass of three different strains (Garver 1988). Results were reported for nitrogen and phosphorus accumulation in each *Typha* species at seven points throughout each of two consecutive growing seasons. With such a wealth of data to choose from, it was decided to also attempt to identify the optimum harvesting time to remove the maximum amount of nutrients in addition to using data from a harvesting period chosen to fit with the other two studies.

Constructed wetland systems were studied by Karpiscak *et al.* (2001), looking at nutrient and metal uptake and storage by a variety of plants exposed to differing types of effluent. The data most useful was for systems treating secondary wastewater effluent, which had metal levels comparable with highway runoff.

Calculations

Using La Costa data, a mass balance was carried out for nutrients and metals entering and leaving the pond. The mass balance used Equation 1 to calculate loads, and the results are presented in Table 2. In September 2000, the *Typha* population at the pond was harvested, giving a known weight of biomass removed. However, there was no subsequent analysis of the harvested biomass, and no information on nutrient and metal concentrations in the plant material. This information was gleaned from the studies discussed in the previous section (Miao, 2004; Municipality of Metropolitan Seattle, 1993; Garver, 1988; Karpiscak, 2001) and used with the La Costa data to calculate the percentage of each pollutant removed by vegetation.

$$L = QC \qquad \text{(Equation 1)}$$

Where: L = pollutant load (kg)
Q = flow (m^3)
C = pollutant concentration (mg/l)

The *Typha* harvest at La Costa yielded a wet biomass weight of 12000lbs (5443kg). Assuming a moisture content of 87.7% (Dubbe D.R. 1988; Lorenzen, *et al*. 2001), this equates to a dry weight of 664kg, and this mass was used in the mass balance calculations.

RESULTS

Table 2 shows the total amount of the measured constituents relevant to the study removed by all mechanisms within La Costa pond. Tables 3 and 4 show the total amounts of each constituent calculated to have been removed by the vegetation, using biomass nutrient values gathered from the studies indicated. Table 5 compares the percentages removed by the vegetation to the total removed by all mechanisms within the pond.

Table 2. Total amounts of nutrients and metals removed from flow in La Costa pond

	N in (mg/l)	Total N in (kg)	N out (mg/l)	Total N out (kg)	% removed from flow
Wet weather	4.65	6.045	2.85	3.705	
Dry weather	17.19	305.982	9.7	172.66	
Totals for all flow		312.027		176.365	43.48
	P in (mg/l)	Total P in (kg)	P out (mg/l)	Total P out (kg)	
Wet weather	0.93	1.209	0.88	1.144	
Dry weather	2.23	39.694	1.13	20.114	
Totals for all flow		40.903		21.258	48.03
	Cu in (mg/l)	Total Cu in(kg)	Cu out (mg/l)	Total Cu out(kg)	
Wet weather	0.097	0.126	0.010	0.013	
Dry weather	0.063	1.120	0.029	0.514	
Totals for all flow		1.246		0.527	57.66
	Pb in (mg/l)	Total Pb in (kg)	Pb out (mg/l)	Total Pb out(kg)	
Wet weather	0.295	0.384	0.006	0.008	
Dry weather	0.004	0.068	0.001	0.026	
Totals for all flow		0.451		0.034	92.51

Table 2. (Continued)

	Zn in (mg/l)	Total Zn in kg)	Zn out (mg/l)	Total Zn out(kg)	
Wet weather	0.056	0.073	0.033	0.043	
Dry weather	0.072	1.283	0.028	0.490	
Totals for all flow		1.356		0.532	60.74

Table 3. Total nutrient content of harvested biomass

		Nutrient content of biomass (mg/kg)		Biomass harvested (La Costa)	Total nutrient content of biomass (kg)	
Study	Plant	N	P	(kg)	N	P
Miao (2004)	T. domingensis Pers.	11000	850	664	7.30	0.56
Municipality of Metropolitan Seattle (1993)	T. latifolia	14386	2514	664	9.55	1.67
Garver *et al.*, (1988)	T. latifolia	10191	2229	664	6.77	1.48
	T. angustifolia	11560	2312	664	7.68	1.54
	T. X glauca	8772	1754	664	5.82	1.16

Table 4. Total metal content of harvested biomass

		Metal content of biomass (mg/kg)			Biomass harvested (La Costa)	Total metal content Of biomass (kg)		
Study	Plant	Cu	Pb	Zn	(kg)	Cu	Pb	Zn
Karpiscak et. al (2001)	T. domingensis	3.54	1.44	21.7	664	0.002	0.001	0.014
Municipality of Metropolitan Seattle (1993)	T. latifolia		1.14	24.9	664		0.001	0.017

Table 5. Percentage of constituent removal in La Costa pond attributable to harvested vegetation

	% constituent removed				
Data source	N	P	Cu	Pb	Zn
La Costa – all mechanisms	43.48	48.03	57.66	92.51	60.74
Miao (2004)	6.36	2.87			
SBP biomass	7.04	8.50		0.18	2.00
Garver *et al.* (1988)* biomass	4.98	7.08			
Karpiscak *et al.* (2001)biomass			0.33	0.24	1.75

*Average of three *Typha* species (standard deviation in brackets)

VEGETATIVE POLLUTANT REMOVAL

The percentage of nutrient and metal removal calculated to be directly attributable to removing the harvested pond vegetation (5-7% for N, 3-8% for P, 0.3-2% for metals) was low when compared to the *total* amount removed from flow in the pond by all mechanisms.

A literature search showed this study to be the first to calculate the actual mass of nutrients and metals removed during routine maintenance of an insitu retention pond. However, there have been numerous studies undertaken to determine the ability of plants to accumulate nutrients and metals, and some of these studies provide data used below to explore the possibility of improving pollutant removal rates.

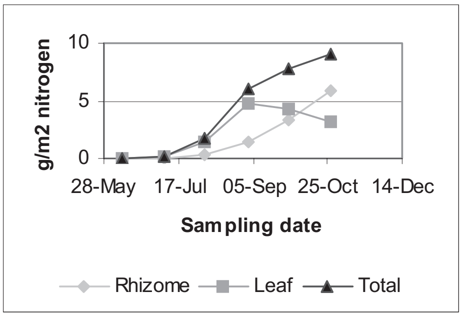
Improving pollutant removal

The results show only a very small percentage of metal removal attributable to cattail harvesting. This is confirmed by the findings of two other studies (Manios *et al.*, 2003; Scholz *et al*., 2002), both of which show the partitioning of accumulated metals within *Typha* plants following the pattern sediments»roots/rhizome»leaves/shoots, with by far the greatest accumulation in the sediments. However, a recent study by Fritioff and Greger (2003) identified that some submersed and free-floating aquatic plants have a higher metal accumulation capacity in their shoots than emergent species such as *Typha*, while emergent species facilitate the binding of metals in the sediments. Using *both* types of plants would presumably improve the treatment capacity of the pond by increasing metal removal by all mechanisms.

On a different theme, Martin *et al.* (2003) showed that the greater the rate of plant transpiration, the more nitrate is removed from an aquatic system. As harvesting vegetation was shown to reduce transpiration rates, then harvesting could actually *reduce* nitrate removal within a system, and this could be seen as a negative impact, However, the same study showed that harvested systems were assimilating more *total* nitrogen than un-harvested systems. Based on this information, it can be said that the choice of plants grown in a pond and the subsequent harvesting regime can be tailored to achieve the optimum attenuation of the pollutant species or nutrient of greatest concern.

Timing of harvest

Garver *et al.* (1988) showed that nutrient accumulation and partitioning in *Typha* varied throughout the growing season, as shown in Figure 2. This thorough study was conducted over two growing seasons, and the data gathered identified July in the second growing season as being the point over the two-year study period at which the maximum level of nutrients could be removed with the minimum weight of biomass. Based on this, a two-year harvesting cycle would be more effective in terms of man-hours than an annual harvest, although the release of nutrients during senescence would have to be taken into account. As most of the nutrients assimilated during the growing season have been transported to the rhizomes by senescence, it is possible that the amount released back into the aquatic environment might not greatly affect the overall quantity ultimately removed, but this would have to be explored further. As the study was terminated after two growing seasons, it is not possible to tell whether the increased accumulation is a reflection of typical behaviour over time, i.e. would there be even greater accumulation over three or four growing seasons?



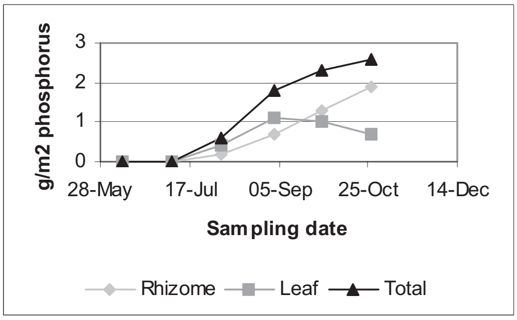


Figure 2. Nutrient accumulation and distribution in *Typha*. (from Garver *et al.* (1988)

COSTS IMPLICATIONS OF HARVESTING

Figure 3 gives a breakdown of the time spent on individual maintenance activities at La Costa, and shows just how labor intensive vegetation maintenance activities are - greatly increasing monetary costs. Out of a total of 436 man-hours on various activities, 319 (>70%) were spent on removing vegetation. Based on the labor rate for maintenance workers, this puts the cost of harvesting at approximately $14,000 per year. Caltrans (California Department of Transportation) was forced to adopt an annual harvesting program for its ponds because of vector concerns by Vector Control Districts and the local Departments of Health. From a monetary point of view, highway authorities would probably be better off if there were no emergent plants, especially as the relatively small amounts of nutrients and metals removed with the harvested vegetation indicate very poor value for the associated monetary cost. Avoiding planting emergent vegetation would reduce whole life costs associated with ponds, and the ancillary benefits added by vegetation are of little interest to the highway department.
However, vegetation is normally required for a range of reasons and an alternative outcome of this study is that the cost effectiveness of harvesting could possibly be improved by some of the measures discussed.

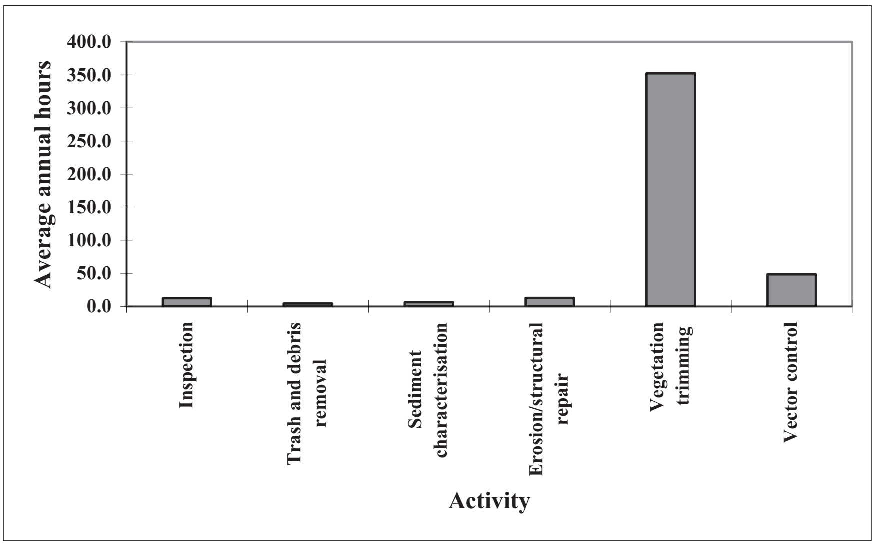


Figure 3. Field maintenance activities at La Costa pond (Caltrans 2004)

CONCLUSIONS

Of the total amount of nitrogen, phosphorus and metals removed by all mechanisms within La Costa pond, this analysis showed between 5-7% of nitrogen, 3-8% phosphorus and less than 2% of metals being removed via harvested vegetation. Harvesting vegetation was the most labour intensive and expensive maintenance activity carried out at La Costa, costing approximately $14000 per year. Consequently, vegetation harvesting for enhanced pollutant removal alone is not likely to be cost effective. Where vector concerns or other factors require annual harvesting of emergent vegetation, it may be beneficial from a cost stand point to minimize planted areas in ponds. In other locations, including emergent vegetation as a standard design feature in ponds may still be desirable based on other attributes such as habitat, bank stabilization, safety, and aesthetics. In view of the role played by pond vegetation in nutrient and pollutant cycling within aquatic systems, it is perhaps necessary to take a more holistic view of the role of plants in ponds before coming to conclusions on the cost effectiveness of harvesting based solely on the figures presented here.

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