Contribution of Phosphorus from Automatic Dishwasher Detergents (ADDs) to Lake Champlain

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The Lake Champlain Committee
The Lake Champlain Committee (LCC) is a non-profit membership-supported advocacy organization that has worked to protect and restore lake health since 1963.

Introduction

Lake Champlain is considered an impaired water body due to excessively high concentrations of phosphorus. Excess phosphorus can cause extensive algae blooms. Phosphorus pollution in Lake Champlain has prompted many agencies and organizations including the Lake Champlain Committee to explore reduction strategies. The lake wide management plan Opportunities for Action (Lake Champlain Steering Committee, 2003) calls for reduction of phosphorus loading to target levels by 2016, but the Lake Champlain Committee has called for an accelerated clean-up by 2009. This deadline was recently endorsed by Vermont, and Quebec officials in the fall of 2003.

Though large reductions have been made in end of pipe discharges from point sources, little effort has been invested in controlling phosphorus entering sewage treatment plants since the ban on phosphorus in laundry detergents in the mid-1970s. This action led to a 40% reduction in effluent phosphorus concentrations from waste water treatment facilities in Vermont (Van Benschoten and Smeltzer, 1981). Similar reductions have been achieved nationwide (Litke, 1999). If the phosphorus that needed to be removed from waste water were limited, potential savings might accrue in the economics and efficiency of treatment.

Phosphorus from automatic dishwasher detergents (ADDs) represents one example of controllable inputs to waste water treatment facilities. At the time the laundry detergent phosphorus ban was enacted household dishwashers were not common. Today one in every two households in New England has an automatic dishwasher (U.S. Department of Energy, 2001). The purpose of this paper is to examine the relative role of ADDs to phosphorus loading in Lake Champlain and the potential costs and benefits of eliminating this source.

The role of phosphorus in ADDs is to build the surfactant to keep dishes from spotting (Table 1). Phosphorus binds with calcium and magnesium found naturally in hard waters to prevent further interference with surfactant performance and minimize scale build up in the machine. Phosphorus also binds with iron and aluminum to minimize rusting of machine parts, which may increase the lifespan of the machine. Detergents without phosphorus can still have sequestering properties, although they may not be as strong as P-based detergents.

There are many alternative automatic dishwashing detergents available to consumers that do not use phosphorus (Table 2). The P-free detergents still accomplish the task of removing calcium, magnesium, iron, and aluminum out of the water, allowing the surfactant to work effectively. Laboratory testing and consumer purchases of P-free detergents have shown that the products have satisfactory performance and can be successfully substituted for P-based detergents (Wolf, 2003).

Legislation to reduce P in ADDs has been presented in Minnesota, Massachusetts, and Michigan. None of the proposed bills has passed, but public awareness of them has grown. Legislation was proposed in the Minnesota House (H.F. No. 257) and Senate (S.F. No. 203) in January 2003. In the Senate, the bill was sent to the Environment and Natural Resource Committee, and then moved to the Committee on Rules and Administration under Rule 21. The Rules Committee adopted the amendments made by the Environment and Natural Resource Committee and considered the bill passed on March 20, 2003. In the House, the bill was referred to the Environment and Natural Resources Policy Committee. Since that time authors have been added to the bill but it has not moved. In Massachusetts the Senate introduced a bill (No. 1252) and the House presented a petition for the bill (No.

3009). Both bills were sent to the Joint Committee on Natural Resources and Agriculture in January 2003, which is where they currently remain. A public hearing was held on September 18, 2003 for review of the proposed legislation. Michigan is the only other state actively pursuing restrictions on phosphorus in automatic dishwashing detergents. In March, a Senate bill (No. 351) was proposed and referred to the Committee on Natural Resources and Environmental Affairs; nothing further has happened.

Table 1. Use of phosphorus in automatic dishwashing detergents

Phosphates are used as "builders" meaning they:

- *Soften water by forming complexes with calcium and magnesium ions*
- *Reduce spotting on dishes through calcium and magnesium sequestering*
- *Reduce rusting by chelating iron and aluminum*
- *Keep food particles in suspension*
- *Produce an alkaline environment necessary for surfactant performance*

Table 2. Alternatives for phosphorus in ADDs (usually used in combination)

- polycarboxylates
- Zeolite A (a crystalline sodium aluminosilicate)
- sodium citrate
- sodium silicate
- sodium carbonate
- poly (acrylic acid)
- nitriloacetic acid (NTA)

Note: *NTA is not used in the United States due to safety and ecological reasons. All other listed alternatives have no reported environmental or human health impacts (Great Lakes Science Advisory Board, 1980; 1983)*

Determining Phosphorus Loading

To estimate the amount of phosphorus generated by automatic dishwashers in the Lake Champlain Basin (Table 3) two questions must be answered: how often are dishwashers used in the Lake Champlain Basin; and how much phosphorus is used per wash cycle. To answer the first question requires determining the number of dishwashers in the Basin and a daily or weekly use pattern. The second question depends on the amount of phosphorus in the detergent used and on the amount of detergent used per wash.

For our calculations we determined there were over 111,000 dishwashers in the Lake Champlain Basin. There are around 221,000 households in the Basin. We arrived at this number by dividing the population of the Basin (571,000 - LCBP, 1999) by the average number of people per household (2.58 – U.S. Census Bureau, 2002). Approximately 50% of households in New York and New England have automatic dishwashers according to the United States Department of Energy (2001). We have used this figure though it may be low. Phone surveys of 384 households in South Burlington, VT and 306 households in Lolo, MT suggest about 75% of residents in these locations owned automatic dishwashers (Alm, 1998; Burnside and McDowell, 2001).

Dishwashers are used once every other day in our analysis. This is consistent with use in South Burlington (Alm, 1998), but slightly lower than results from Montana (Burnside and McDowell, 2001).

We determined that each dishwasher generates 10.2 grams (g) of phosphorus per week. This is less than results from phone surveys of household dishwasher use. Alm (1998) suggested phosphorus contribution for South Burlington households was between 12.53 and 16.03 g/week. In Montana, phone surveys led to a mean phosphorus contribution of 10.98 g/week (Burnside and McDowell, 2001).

Average weekly household phosphorus contributions will be strongly affected by assumptions about the amount of detergent used per wash. Dishwashers typically have two detergent cups, a pre-rinse cup and a time-released cup. The pre-rinse cup holds between 1.0 and 1.5 tablespoons (TBSPs) of detergent while the time-release cup holds between 2.5 and 3 TBSPs (Burnside and McDowell 2001). However, it is unclear whether both cups are completely filled for a typical wash. Alm (1998) suggested that reservoirs were 81-89% filled on average, but it is unclear how this average was calculated. We have chosen to analyze phosphorus contributions to Lake Champlain based on use of 3 TBSP/wash, which may be quite low.

In our analysis, the average ADD contained 0.976 g P/TBSP. We arrived at this quantity by averaging the manufacturer's reported phosphorus concentrations and weighting them based on sales figures for the Hannaford's Supermarket in Burlington for the three week period between December 7th and December 27th, 2004. In the absence of weighting based on sales, the mean phosphorus concentration was 1.10 g/TBSP.

Determining Costs and Benefits

The cost of eliminating phosphorus in ADDs will accrue principally to consumers since non-phosphorus ADDs are currently more expensive. Financial benefits may be realized by municipal wastewater treatment facilities (WWTF) that currently must remove phosphorus.

To determine the average cost to consumers of switching to non-phosphorus detergent we compared prices of detergents at the City Market in Burlington during the week of December 7, 2004. The average ADD with phosphorus cost $0.0288/oz. less than the Seventh Generation phosphorus-free detergent. Multiplying the price difference by the average detergent use calculated earlier leads to a per-household cost increase of between $6.30 and $10.90 annually with an average of $8.65. Of course, the cost increases would only accrue to households currently using ADDs with phosphorus.

Since dishwasher detergent is sold by weight but we have estimated use based on volume, we needed to determine the volume of detergent in each container. We determined that there are 0.55 ounces/TBSP of detergent. To do so, the number of TBSPs in a 50 oz. box were measured and a TBSP of detergent was weighed from a separate container. The results were consistent.

In estimating the cost of removing phosphorus from wastewater we have used a cost of biological treatment plus alum of $969/mt P. The annual costs associated with treating phosphorus from automatic dishwashing detergents vary depending on treatment method. The most typical treatment methods include either chemical additions such as sodium aluminate to precipitate phosphorus, or biological aids to consume phosphorus in solution.

These two methods are used at two of the Burlington treatment plants, while a third plant uses both in combination. Biological treatment alone costs $881/mt P; biological treatment plus alum costs $969/mt P; and sodium aluminate treatment costs $2,390/mt P (Roy, 2003). It is important to note that these estimates do not include the cost of sludge removal which can be substantial.

Table 3: Calculations used in determining the costs and benefits of eliminating phosphorus in dishwasher detergents in the Lake Champlain Basin. All calculations have been rounded to three significant digits for reporting which accounts for discrepancies in the table.

Row #	Category	Value	Justification/Formula
1	g P/ TBSP ADD	0.976	weighted average based on three weeks of sales at Hannafords in Burlington - see text
2	% households w/ dishwashers	50%	(USDOE 2001)
3	Basin population	571,000	(LCBP 2002)
4	people / household	2.58	(USCB 2002)
5	households in Basin	221,000	Row 3/Row 4
6	dishwashers in Basin	111,000	Row 2*Row 5
7	TBSP/ wash	3	(Burnside and McDowell 2001) see also text
8	washes/ week	3.5	(Alm 1998)
9	% WWTF	43%	(http://www.anr.state.vt.us/champ/lakefax.htm)
10	% septic	55%	*ibid*
11	Weeks/year	52	
12	metric tons/g	0.000001	
13	g/metric ton	1,000,000	
14	metric tons/dishwasher/year	5.33E-04	Row 1*Row 7*Row 8*Row 11*Row 12
15	**Annual P release from dishwashers (mt)**	**59.0**	Row 6*Row 14
16	P entering WWTF	25.4	Row 9*Row 15
17	Treatment efficiency of WWTF	90.70%	see text
18	**Annual ADD P release from WWTF (mt)**	**2.36**	Row 16*(1-Row 17)
19	ounces/TBSP	0.55	see text
20	ounces/ dishwasher/year	300	Row 7*Row 8*Row 11*Row 19
21	Average difference in cost/ounce between phosphorus and non-phosphorus detergents	$0.0288	see text
22	**Average cost/yr. per dishwasher owner**	**$8.65**	Row 20*Row 21
23	$/mt of P removal at WWTF using alum	$969	(Roy 2003)
24	**Annual cost to WWTFs of removing ADD P**	**$24,600**	Row 16*Row 23
25	**Total cost of eliminating P in ADDs**	**$932,000**	(Row 6*Row 22)-Row 24
26	Cost/mt P reduction in Lake Champlain TMDL	$950,000	(VT DEC and NYS DEC, 2002)
27	**Cost/mt P reduction from dishwashers**	**$395,000**	Row 25/Row 18

Conclusions

Based on our analysis, the cost of eliminating phosphorus from ADDs is lower than other means of reducing phosphorus loading to Lake Champlain. If ADDs with phosphorus were eliminated, Basin consumers would pay at least $958,000 more per year for these products which equates to an average per household cost between $6 and $11. In exchange for this cost, phosphorus loading to Lake Champlain from wastewater treatment facilities would be reduced by 2-3 mt/yr. The cost per metric ton of phosphorus removed is about $395,000. This is 58% less than the cost per metric ton of phosphorus removed outlined in the Lake Champlain TMDL ($139 million for 145.8 metric tons or $950,000 per metric ton – VT DEC and NYS DEC, 2002) and 51% less than an earlier minimum estimated cost of achieving a reasonable approximation of the in-lake phosphorus standards ($808,0000/mt – Holmes and Artuso, 1995). **This comparatively low cost per metric ton of phosphorus removed makes limiting phosphorus in automatic dishwashing detergents an economically sound option to pursue.**

We have been very conservative in our estimates of the phosphorus load generated from ADDs at waste water treatment facilities. We have extrapolated the phosphorus removal efficiency for all WWTFs based on data from Burlington facilities. However, the Burlington facilities must discharge P at a concentration less than 0.8 mg/L based upon their state permits. The Lake Champlain TMDL lists 19 WWTFs in Vermont that have no concentration limits in their permits and thus may not remove any phosphorus (VT DEC and NY DEC, 2002). ADDs could account for 1.5 mt/yr of phosphorus discharged from these facilities alone if they discharge at their full permitted load and 8% of the influent phosphorus to these plants comes form ADDs, the low end of reported estimates (Barr Engineering, 1993; Burnside and McDowell, 2001; Isaac, personal communication). Furthermore, since the Burlington facility is among the largest in the Basin, the cost of phosphorus removal there is likely to be cheaper than at other WWTFs due to economies of scale.

Even if our estimated annual per household use of ADD is low (as it may be if we have underestimated the number of TBSP per wash), the cost benefit ratio would remain the same. The cost to consumers would increase, but so would the amount of phosphorus prevented from entering our waterways. If we doubled our assumption about the number of TBSPs used per wash, the cost per household increases to $12 to $22 with an average of $17.30. At the same time, the reduction in phosphorus entering Lake Champlain through wastewater treatment facilities increases to 4.7 mt/yr.

There are additional assumptions built into these cost estimates that generally improve the economic viability of this option. The comparisons made here do not consider the economies of scale that will likely occur if all ADDs were required to be P-free. Specifically, the price differential between current P-free and P-based detergents would likely decline if all detergents were P-free. In addition, the estimated reductions in phosphorus loading to Lake Champlain do not include reductions in loading from on-site septic systems. Budd and Meals (1994) estimated between 7,629 and 15,259 failed septic systems in the Lake Champlain Basin. Thus ADD discharge to failed septic systems could account for an additional two to four metric tons of phosphorus per year if half of the failed systems have dishwashers and using the annual contribution of phosphorus per dishwasher from Table 3. Lastly, the Soap and Detergent Association has argued that phosphorus-free detergents will increase wear and tear on dishwashers (SDA, 2001), but these hypothetical costs have not

been quantified and are contested by P-free ADD manufacturers, thus they are excluded from our analysis.

In estimating the cost to consumers, there are two critical assumptions with potential opposite effects. The average household cost would be less than what we have calculated if the price of non-phosphorus detergents decreases. A large part of the existing price difference is due to price increases by retailers and costs associated with using distributors. Seventh Generation estimates a 5% reduction in price when product distribution is increased and the products are sold through wholesalers and directly to stores (Wolf, 2003). On the other hand, if the non-phosphorus detergents are less effective than phosphate detergents, consumers may use more of the product.

The Soap and Detergent Association claimed that phosphorus is essential to the performance of automatic dishwashing detergents (SDA, 2001). However, several companies are currently producing P-free products and customers are continuing to purchase them. To refute the claim that P-free detergents do not work as well, Seventh Generation® had Shuster Laboratories test several different ADDs to determine performance qualities (Appendix A). The results suggested that Seventh Generation® USA Auto Dish Gel is comparable to Cascade® Gel after five wash cycles typical of household dishwashing machines; also Seventh Generation® Automatic Dishwashing Powder is comparable to Cascade® Pure Rinse.

Based on our estimates, ADDs represent a fairly small contribution to the overall phosphorus loading to Lake Champlain, but they are a source that can be controlled cost-effectively. Based on our initial conservative estimates, ADDs account for 0.55% of the total load allocation in the Lake Champlain TMDL. The percentage may be as high as 1.76% if contributions from failed septic systems and WWTFs that do not treat for phosphorus are included in the total loading. These results are consistent with preliminary reports from a Minnesota study suggesting that ADDs may account for 0.9% to 1.9% of statewide phosphorus loading (Runke, personal communication).

However achieving phosphorus loading targets established in the Lake Champlain TMDL will require reduction in phosphorus loading from a wide variety of sources. Eliminating phosphorus from ADDs would be 50 to 60% less expensive than eliminating an equivalent quantity of phosphorus through non-point source controls. Additionally, targeting ADDs provides a quantifiable reduction in phosphorus-loading to Lake Champlain, while the efficacy of non-point source measures is sometimes suspect.

Since eliminating phosphorus from ADDs us a cost-effective means of managing eutrophication in Lake Champlain the effort should begin in Vermont. More than half of all Basin residents live in Vermont (68% - LCBP ATLAS-CD, 1999) and Vermont bears the greatest burden of reducing phosphorus loading to Lake Champlain (VT DEC and NY DEC, 2002). Furthermore, while the Lake Champlain Basin includes nearly half the state of Vermont including most of the state's population, it is only a small, relatively less populated portion of New York and Quebec it is appropriate that Vermont should take a leadership role in initiating new reduction efforts.

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