PHOSPHORUS BALANCE FOR THE ALBERT LEA REGION

Summary Report to the Shell Rock River Watershed District

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INTRODUCTION

Nutrient impairment of surface waters remains a major environmental challenge. In Minnesota alone there are more than 400 nutrient impaired waters, with very few having been restored as the result of management practices. The slow progress of reducing nutrient pollution of rivers is illustrated by the long-term trend of total phosphorus (TP) in the Mississippi River (Figure 1), which shows virtually no decline to total P loads since 1980.

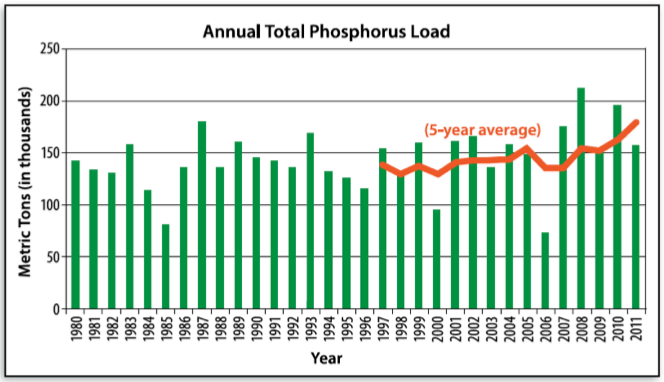

Figure 3. Annual TP loads to the Gulf of Mexico.

Figure 1. Annual total P loads delivered from the Mississippi River to the Gulf of Mexico. Source: (MRGMWNTF 2013)

Widespread utilization of conventional best management practices (BMPs) has not resulted in substantial, widespread declines in P loadings from either urban or agricultural nonpoint sources of pollution, so new approaches are needed.

One major new direction for reducing P loadings is to think more holistically, to bring the overall P balance of a watershed into balance, so that deliberate inputs of P are balanced by deliberate exports. *Deliberate* refers to fluxes (movement of P) controlled by humans. By contrast, P inputs from atmospheric deposition are *inadvertent*, that is, not controlled by humans. Figure 2 illustrates this idea. P inputs to an agricultural watershed might include crop fertilizer, manure (from another watershed), livestock feed, and livestock supplements. Deliberate exports might include animal products (meat, milk, and eggs), crops, and manure (to another watershed). The P flux associated with streams is an important inadvertent P export. When P inputs exceed deliberate P exports, P accumulates in soils, increasing the soil test P (STP). A wealth of evidence shows that when STP levels increase, concentrations of soluble P in runoff also increase. Conversely, if P inputs are lower than deliberate P exports, STP levels will decline, and eventually this will lead to lower stream P concentrations. The stream response will not be immediate because of “legacy” effects of accumulated P (Sharpley et al. 2013, Haygarth et al. 2014), and the actual water quality response (reduced P concentrations) may take decades.

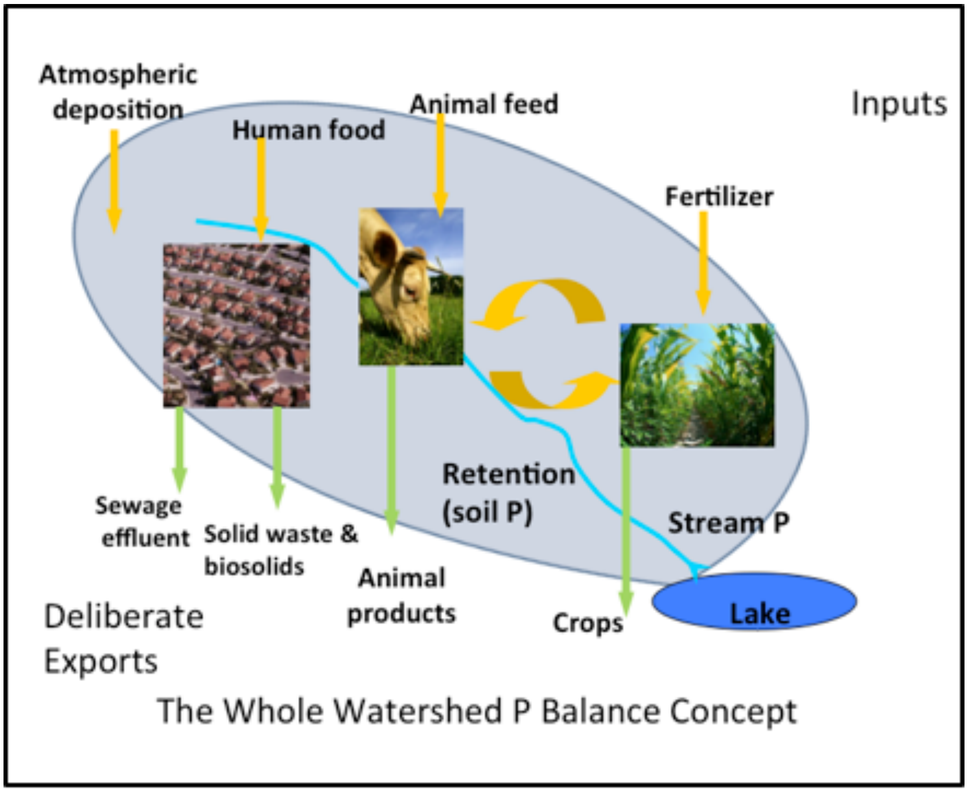

Figure 2. Schematic of the watershed P balance concept.

The same principle applies to urban landscapes. If more P is added to urban landscapes, in the form of fertilizer, pet wastes, atmospheric deposition, and other inputs, stream P levels increase. Over the long term, reducing P inputs to a point that they are less than deliberate P exports (a negative P balance) will reduce STP levels and, eventually, stream P export

One problem with using P balances is that we have not had an actionable tool for developing watershed P balances. An *actionable* tool would is one that is easy to use, reasonably accurate, and politically acceptable. This study developed actionable watershed P balance tools, one for urban systems and one for agricultural systems. Both tools are easy-to-use, open-source spreadsheet calculators, designed for use by small teams of watershed experts. We hope that these calculator tools will be used to develop P balances for other watersheds, and are used to guide P management.

Our intent was to develop spreadsheet calculator tools that could be used throughout Minnesota. To do that, we developed a P balance for three agricultural watersheds near Albert Lea and the City of Albert Lea itself, using these findings to develop the P calculator tools. This report focuses on the P balances for both the agricultural watersheds near Albert Lea and the city itself. Other products from this study include a **Users Manual: Phosphorus Balances and Hydrologic Tools For TMDL Planning**, and **a** journal article, **Agricultural System Phosphorus Balance for Addressing Watershed TMDL Goals** (Peterson et al. 2014).

The Shell Rock River Watershed District was a partner in this effort, providing us with monitoring data, organizing meetings of the Technical Advisory Group (TAG) held in Albert Lea, and participating in TAG meetings held at the University of Minnesota, and providing us with a wealth of on-the-ground information regarding livestock practices, and other management practices that affect P balances. The City of Albert Lea's Public Works Department supplied us with data from their wastewater treatment plant, for which we are grateful. Finally, we thank the managers of Select Foods (Jeff Woodside), Mrs. Gerry's (Dave Vanderploeg), and Merrick's (Jon Hedlund) for allowing us to visit their facilities and providing us with data on their operations, and Colin Whitmer, the Freeborn County feedlot officer, for helping us understand local animal operations.

WATERSHED DESCRIPTION

We developed the agricultural P balance for the three main agricultural watersheds in the region, the watersheds of Bancroft Creek, Peter Lund Creek, and Wedge Creek (Figure 3), and an urban P balance for the City of Albert Lea.

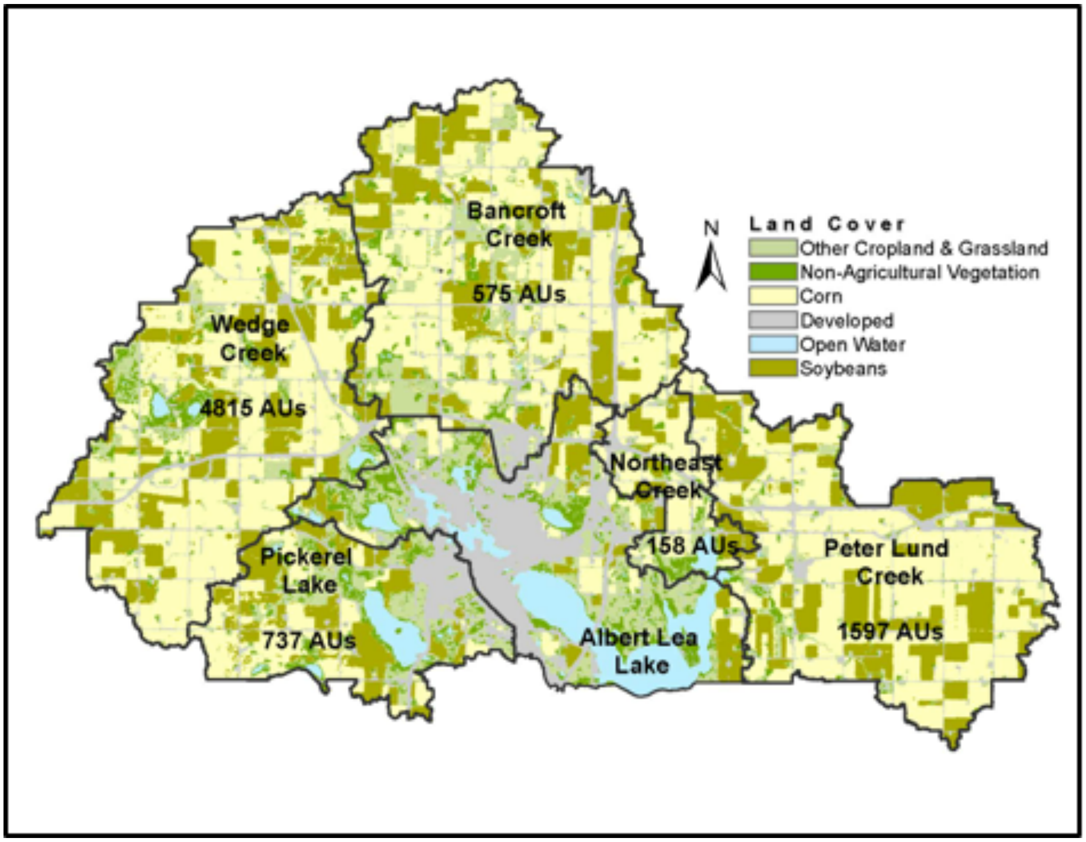

Figure 3. The Albert Lea Lake watershed, showing subwatersheds, cropping pattern, and total animal units.

The agricultural watersheds are nearly all cropland, dominated by corn and soybeans (Table 1). The main animal production system is hogs, which comprise 27% of the animal units in the three watersheds. All three streams discharge to Albert Lea Lake, either directly (Peter Lund Creek) or indirectly (Bancroft Creek and Wedge Creek) through Fountain Lake, which then drains to Albert Lea Lake.

The City of Albert Lea has a population of 18,000, of which 12,575 live in single-family homes. The city is entirely sewered. In addition to household sewage, the wastewater treatment plant receives effluent from several food processing facilities. Effluent from the wastewater treatment plant enters the Shell Rock River just below Albert Lea Lake.

Table 1. Land cover and crop types in the three agricultural watersheds. Note: One hectare (ha) = 2.47 acres.

	Peter Lund Creek	Wedge Creek
Total watershed area, ha	7,597	8,978
Corn + soybeans, %	81.6	73.6
Other crops, %	2.0	4.5
Total cropland, %	84	78
Developed (low/medium/high)	1.3	1.2
Developed open+barren	8.2	8.5
Forest	1.1	2.5
Grassland	5.1	7.1
Lakes and wetlands	0.8	2.7

APPROACH

The general approach for developing P balances is discussed briefly below. Details of the approach for developing P balances for the agricultural and urban systems are presented in our **Users Manual: Phosphorus Balances and Hydrologic Tools to Support TMDL Plans** (Baker et al., 2014). Details regarding P balances for the agricultural system are presented Peterson et al. (2014).

AGRICULTURAL SYSTEM

The watershed's agricultural system P balance was calculated using the general equation of:

P Imports = Deliberate P Exports + Stream P Exports + P Storage equation 1

Imports include any livestock, feed or supplements, and fertilizers brought into the watershed boundary. Deliberate exports include meat and dairy products, harvested crops not consumed as livestock feed, and livestock mortalities that are exported to landfills or rendering plants. Manure is not considered a watershed export since it is applied onto the watershed cropland as P fertilizer.

The P use efficiency ($P_{efficiency}$) of the Albert Lea Lake watershed agricultural system was determined using the following equation:

$$\text{Agricultural } P_{\text{efficiency}} = \frac{\text{Total deliberte P Exports}}{\text{Total P Imports}} \qquad \text{equation 2}$$

If the agricultural $P_{efficiency}$ is greater than 1, P exports are leaving the watershed at a mass greater than imported and STP levels will decrease. If the $P_{efficiency}$ is less than 1, P will accumulate in soils, raising the STP.

The following types of data were used to develop the watershed P balances:

Farm interviews

Denton Bruening, Minnesota Department of Agriculture, conducted 88 on-farm, personal interviews. P management data was collected for 111 corn, 80 soybean, 4 sweet corn, and four alfalfa fields, covering 80% of the corn land area and 84% of the soybean land area within the Albert Lea Lake watershed. The interviews included review of farm records to determine crop harvests, fertilizer and manure applications, feed purchases, etc. In addition, 20 personal interviews of permittees were collected with a focus on the livestock systems, including swing, sheep, dairy and beef cattle. These purpose of these interviews were solely to compare permitted livestock numbers to actual onsite numbers.

Location and size of livestock operations

We used feedlot permit data from the Minnesota Pollution Control Agency feedlot permit data, including the geospatial location of farms, to determine the numbers and types of animals in each operation. We conducted “drive-by” screenings with the Colin Whitmer, the Freeborn County feedlot officer, to verify actual numbers of animal in livestock operations not included in the farm survey. This verification revealed that the actual numbers of animal units were always lower than the permitted numbers (Table 2). Overall, only 47% of permitted animal units (AUs) actually lived in the watershed. A major reason for this is that several hog barns were destroyed by a tornado the previous year.

3. P balances for animal operations. To estimate the P balance for each type of animal operation, we first constructed a herd structure, estimating the numbers of imported animals, reproducing animals, animals at each growth stage, and export of animals from the herd by death or sale. This was done using data from our farm

Table 2. Animal units in the agricultural watersheds of Albert Lea Lake. One AU is the equivalent of one dairy cow.

Livestock system	Permitted	Actual	Percent of permitted	AU conversion
Beef	2,223	829	37%	0.70
Dairy	218	218	100%	1.0
Horses	245	43	18%	1.0
Sheep	398	95	24%	0.10
Swine	12,824	6,157	48%	0.3
Turkey	445	440	99%	0.02
Multi Animal	434	98	23%	--
Watershed Total	16,787	7,880	47%	

survey, county-level animal production statistics, and especially, expert knowledge from local producers and University experts[1]. Once the herd structure for each type of operation was established, we used recommended nutrient intakes from National Research Council reports for each type of animal operation, and then estimated the composition of diets that would provide these nutrients. The specific composition of diets to achieve dietary requirements varies among years and location, so we developed typical diets based on Extension publications, University animal science experts, and local producers. For example, in Minnesota, common protein sources are soybean meal and Distiller Dry Grain with Solubles (DDGS), so most of the protein in our constructed diets included these feedstocks. The final diets for each type of animal operation always met NRC recommendations.

Animal manure production was based on the University of Nebraska's Manure Nutrient and Land Requirement Estimator (Koelsch, 2006), which is based on the sizes of animals in each type of operation, the P intake for each size of animal in the herd, and the use of phytase, which improves availability of P in grains.

Finally, export of P in animal products was based on the P content of whole animals and the P content of milk and eggs.

Table 3 shows the P balance for the major animal operations. As a check on our methodology, we computed the P balance error, the difference between P inputs (feed, supplements, and young animals) and P outputs (animals, milk, and eggs),

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[1] We thank the following University of Minnesota Animal Science professors for contributing their expert knowledge to this analysisRr Gerald Shurson (swine nutrition), Alfredo DeCostanza (dairy), and Sally Noll (poultry).

which should be 0. The fact that our error was < 10% for all animal operations modeled indicates that our methodology was robust.

Table 3 also shows that the most efficient operations, with respect to P, were pork and turkey, followed by dairy and beef. The pork P use efficiency was somewhat higher than values reported in the literature in part because most piglets were imported into the watershed, rather than born there. Hence, the P cost of reproduction was encountered outside the watershed.

Table 3. P balances of each major animal operation in the case study watersheds. See also Peterson et al. (2014).

Table 5. Phosphorus efficiency of individual livestock systems. Note: 1 Mg = 1000 kg = 1.1 T.

	P Input	Product P Export	P Efficiency	Balance Error†
	------Mg/yr------			
Beef	16.4	4.5	28%	-7.4%
Pork	81.8	45.3	55%	2.1%
Dairy	3.3	1.2	37%	-2.1%
Turkey	20.6	11.2	54%	5.7%

Crops

Crop P balances were computed from inputs of P fertilizer and manure and from outputs as crops. Overall, 412,013 kg of P in the form of fertilizer and manure P was applied, and 734,054 kg of P was removed as crops, resulting in a P use efficiency of 1.78.

Summary: Overall Agricultural P Balance

The overall agricultural P balance is shown in Figure 4. Overall, 442,000 kg P/yr was imported to the watershed, mostly as fertilizer (352,000 kg P/yr) and animal feed (66,490 kg). Deliberate exports included crops (684,000 kg P/yr) and animal products (56,340 kg P/yr). The P in recycled manure was equivalent to 17% of the imported fertilizer P. Overall, the P use efficiency of agriculture was 1.7.

Although this seems impossible that exported P could be greater than imported P, this imbalance is possible, at least for the short term, because crops can “mine” available P from soils, which decreases the STP. By our estimate, cropland soils in the watershed would have lost about 6 mg P/kg during the modeling year (2010). Over time, this imbalance would continue to reduce STP levels, and would probably reduce stream P levels. Although this imbalance probably does not occur every year, Fixen (2010) reported the overall P use efficiency for crops in Minnesota was 1.1 in 2007.

Based on our observations, discussions with farmers, and our data, some factors that have led to efficient use of P in this watershed include: management of animal nutrition, including reductions in the use of P supplements and increasing use of phytase, which enables animals to utilize P more efficiently, a move toward manure application based on P (rather than N), GPS-guided tractors and manure injection systems, and increasing use of soil P testing.

Despite the high P use efficiency, stream P export was about 5,000 kg P/yr. This seemingly incongruous fact is possible because there may be hot spots of elevated P in the watershed, or simply, a lag period period between improving efficiency and declining stream P (the so-called "legacy effect").

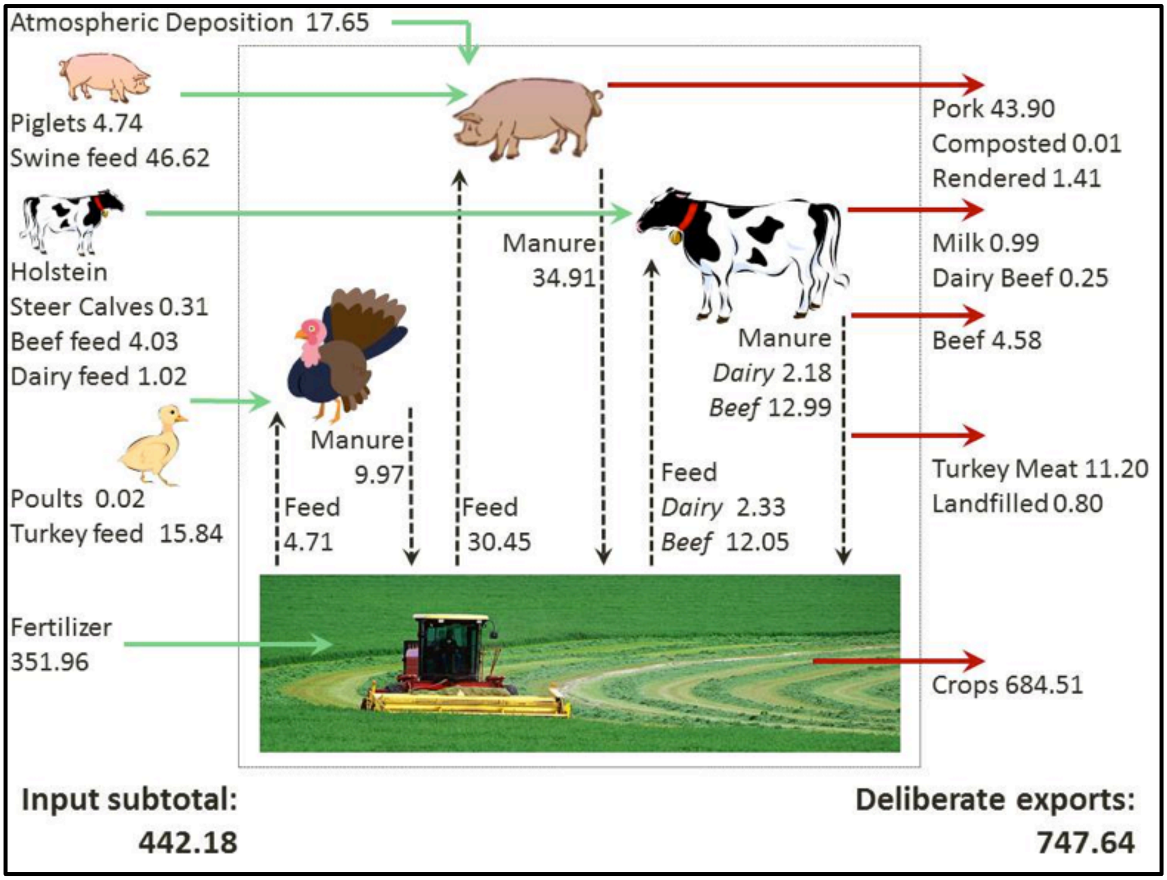

Figure 4. Summary P balance for the agricultural watersheds. Units are thousands of kg/yr.

URBAN SYSTEM P BALANCE

We also developed a P balance for the City of Albert Lea. To do this we divided the city into two systems: an *engineered system* and an *urban landscape* system. P enters the engineered urban system via food and various chemicals (industrial and household cleansers, etc.), is transmitted via sewers to wastewater treatment plants, and disposed as effluent (entering rivers or lakes) or biosolids. The urban system is further divided into *households* and *industries*. Our conceptualization of households includes all food consumption, and production of wastes, by individuals. This definition therefore includes some commercial P fluxes, for example, food consumed at restaurants. The engineered system also includes industrial facilities, which in Albert Lea include several major food processing facilities. The other part of the urban system is *urban landscapes*, where P enters the watershed via green landscapes, such as lawns, parks, and golf courses; and leaves the watershed via stormwater drains and streams.

Household P fluxes

Household P inputs were calculated using our Urban System Spreadsheet Calculator. P inputs entering households include human food that is consumed, wasted food (about one-third of the total), and household chemicals. Table 5 shows coefficients for each of these inputs. P fluxes leaving households include sewage and solid waste (garbage). Sources of P to sewers include human excretion (which is nearly identical to P consumed in food), household chemicals that are flushed down the drain, and food wastes processed by garbage disposals. The presence of garbage disposals increases the amount of P in sewage (by 0.05 kg P/capita-yr) and decreases the amount of P going to solid waste by the same amount. Based on data from the Twin Cities, we estimated that one-half of households in Albert Lea had garbage disposals.

Table 5. Summary of coefficients used in the household component of the Urban Spreadsheet Model. Note: 1 kg = 2.2 lbs.

Flux term	Coefficient, kg P/capita-yr	Total P flux for Albert Lea, in kg P/yr
Human food	0.6	10,800
Food brought into households that is wasted	0.24	4,320
Pet food	0.13	2,340
Household chemicals	0.61	10, 980
Total P input, kg P/yr		28,522
Flux to garbage disposals (if present)	0.05	
Flux to sewage, with garbage disposal present	1.26	11,340
Flux to sewage, without garbage disposal	1.21	10,800
Flux to solid waste, with garbage disposal	0.19	1,710
Flux to solid waste, without garbage disposal	0.24	2,160
Total P to sewage treatment, kg P/yr	--	22,248
Exported biosolids, kg P/yr	--	8,009

To landfill, kg P/yr	--	6,274
Sewage effluent to Shell Rock River, kg P/yr		14,239
Total P exported, kg P/yr		28,522

Industrial P balances

We surveyed the three major food processing industries in Albert Lea. Select Foods processes prime cuts of pork into retail cuts, Mrs. Gerry's Foods processes vegetables to make salads, and Merrick's produces food powers (mustard, etc.) and calf milk replacement. We visited each to learn about the industries, and to quantify the movement of raw products, by-products, solid waste, and sewage wastes, to the extent possible. We then converted the movement of these materials, in pound per day, into phosphorus fluxes, in kg P/yr. Details about these calculations are in our Urban P Spreadsheet Calculator. Table 6, below shows the P fluxes into and out of each industry.

Table 6. Partial P balance for the three major food processing industries in Albert Lea. Data are for 2011. Values are in kg P/yr (= 2.2 lbs).

	Merrick's	Mrs. Gerry's	Select Foods	Total industrial
Inputs				
Raw food products	14,871	5,321	1,750,036	1,770,228
Cleansers and chemicals	3,691	30.8		
Outputs				
Food products	14,838	4,798	19,636	39,272
Chemicals	3,691	31	0	3,722
By-products	16	0	1,617,082	1,617,098
Solid waste	16	478	0	494

Select Foods has by far the largest P input, because the primal cuts brought into the plant contain P-rich bones. Most of these bones are removed during processing and shipped to rendering plants to produce meat and bone meal and other products. On a weight basis, bone products weigh only 14% as much as the meat produced (mostly bone-out cuts), but because bones are rich in P, bone by-products account for over 90% of the P exiting the plant. In addition to bone, Merrick's utilized about half of its food scraps for hog feed. The solid waste produced by two plants were < 1% of the P entering the industrial system.

We could not reliably estimate P entering sewage "by difference", because it is a small quantity relative to inputs and outputs. However, we estimated an overall P load from industries by subtracting household P (about 22,248 kg/yr; see above) from the measured total P entering the wastewater treatment plant (44,115 kg/yr), yielding an estimate of 21,967 kg P/yr. This quantity, though about half of the sewage P, is only about 1% of the total quantity of P entering the food industries.

Wastewater treatment

Some of the phosphorus in sewage is removed from the influent and converted to biosolids and the rest remains in the effluent, which is discharged to the Shell Rock River. Using monthly data provided by the Albert Lea Public Works Department for 2009, we calculated a P removal rate of 36%, which meant that 64% of the influent P entered the Shell Rock River. The 36% removal rate corresponded to a P flux to biosolids of 15,870 kg P/yr. To verify this value, we also calculated the amount of P entering biosolids, which is measured separately and is therefore an independent check. This value, 15,926 kg P/year, was within 0.4% of our calculated P removal rate, confirming the accuracy of the P balance. Biosolids from the Albert Lea plant are utilized for agricultural fertilizer.

Urban landscape

P enters the urban landscape of Albert Lea in the form of atmospheric deposition, fertilizer, pet waste, fertilizer, and polyphosphates (Table 7).

Our estimate of P input from atmospheric deposition to urban landscapes, based on Barr Engineering (2007), assumed that deposition inputs occur over the entire area of Albert Lea. Fertilizer inputs were probably near zero, because Minnesota's Lawn Phosphorus Law prohibits using fertilizers containing P, except for "starter" fertilizers for lawns and garden fertilizer. In the absence of lawn P fertilizer inputs, pet waste – mainly from dogs – has become a major form of P input to urban landscapes in Minnesota. We estimated the flux of P in dog wastes indirectly, by estimating how much P is consumed as dog food (Baker et al. 2007, Fissore et al. 2011). Although all P in dog food is excreted, only about 75% is in solid feces. Moreover, dog owners pick up a large fraction of dog excrement. We used a value of 60% pickup, based on a study in Rhode Island (RDEQ 2003). We assume that pet waste that is picked up ends up in the garbage can, and have adjusted our inputs to garbage in the interior of households to account for this. Finally, polyphosphates, which are used to prevent corrosion of water pipes containing lead and copper, is added to the drinking water. The City of Albert Lea uses polyphosphates in their water supply, and some of this ends up on lawns, via irrigation. To estimate this P flux, we computed the amount of irrigation water used in Albert Lea, which was 31% of the total (see the Urban P Balance Calculator), along with the average P concentration contributed by polyphosphates (0.4 mg P/L).

Potential exports of P from Albert Lea's urban landscape include stormwater and landscape wastes. Landscape wastes hauled to the transfer station are composted and made available to city residents as compost and wood chips. Hence there is little or no export of landscape wastes from the city. Stormwater does exit the city. In the absence of other information, we used a value of 0.5 kg P/ha-yr, based on a study of six similar urban watersheds in the St. Paul region (Janke et al. 2013).

Table 7. P fluxes into and from Albert Lea's urban landscape. Note: 1 kg = 2.2 lb.

Inputs	Flux, kg P/yr
Lawn P fertilizer	0
Atmospheric deposition	1,799
Dog waste	1,288
Polyphosphates in water supply	136
Total input	**3,223**
Outputs	
Stormwater	1,771
Total output	**1,771**
Accumulation	**1,452**

The P balance indicates that there is accumulation of P within Albert Lea. This accumulation occurs mainly in soils. Over time, P accumulation increases the available P in soils, measured as soil test phosphorus (STP). There is fairly strong evidence that stream P concentrations increase as STP levels increase, so shifting the P balance in a negative direction – so that P outputs are greater than P inputs, would, over many years, reduce stormwater P loads.

One of the most direct ways to do this would be to reduce inputs of dog waste. To illustrate the potential of reducing dog waste on the P balance, when we set dog waste to "0" in the Urban P Spreadsheet Calculator, P accumulation was reduced to 164 kg/yr – a reduction of 89%.

A second approach to reducing outputs from stormwater would be to engage in enhanced street sweeping. In a parallel EPA "319" project (Baker et al., 2014), we studied nutrient removal by enhanced street sweeping and developed a spreadsheet calculator for estimating nutrient removal by street sweeping under various user-defined sweeping scenarios. Briefly, we found that quantities of N and P removed by street sweeping increased with increasing tree canopy over streets and with increased sweeping. We also found that street sweeping can be very cost effective if sweepings are targeted (high canopy streets during the spring and fall. Presentations, handouts, and the Street Sweeping Planning Calculator are on the University of Minnesota's Stormwater U website (http://www.extension.umn.edu/environment/stormwater/stormwateru.html) We were not able to estimate potential P removal from sweeping for Albert Lea because our Street Sweeping Planning Tool was completed very recently, but the City of Albert Lea might consider using this tool to estimate potential P removal in the future.

Overall P Balance for Albert Lea

The overall P balance for the City of Albert Lea, including the industrial, household, and landscape components, is presented in Figure 5. Inputs of P, shown in blue, are dominated by raw food inputs to the three food processing industries. Within the food processing industry, inputs of primal meat cuts to the Select Foods facility dominates, because of the large amount of P in animal bones.

On the output side, deliberate exports – products that can be used – are shown in green. On a P basis, Albert Lea produces about twice as much food as it consumes (humans + pets). By far the largest P export is food by-products. By far the largest flux of by-products P is – again – *bones*! These are sent to rendering plants, where they are processed into mineral supplements (especially P and calcium), meat and bone meal, and other products, much of it returned, indirectly to agriculture. Biosolids from the wastewater treatment plant are returned to agriculture.

Finally, there is discharge of P to the environment. In Albert Lea, food waste is exported from the city to a landfill and buried. Both stormwater and the sewage treatment plant discharge P to the Shell Rock River, but the sewage treatment P discharge is about 16 times greater.

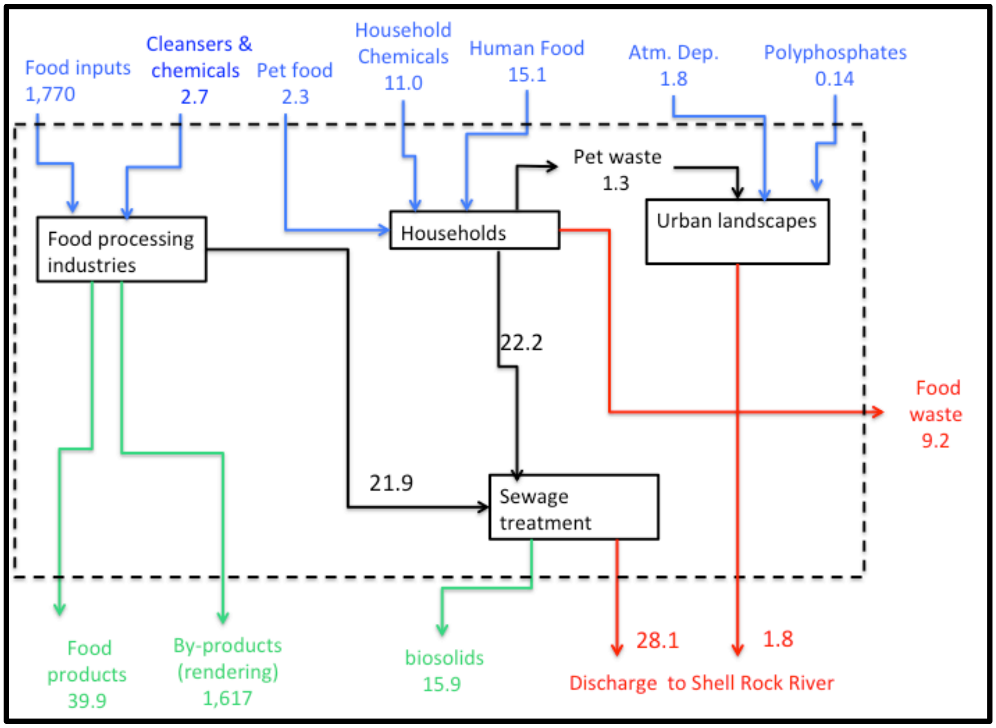

Figure 5. P fluxes through Albert Lea in 2010, in thousands of kg/yr.

Table 8 summarizes the relationship between P inputs to each system in relation to P exports to surface waters. For the household and industrial systems, export to surface waters is based on a treatment efficiency of 36%. For the household system, about 50% of total P input ends up in the Shell Rock River. The movement of animal bones dominates the P flux of the industrial system, so the percentage of P input that is exported to the Shell Rock River (via the sewage treatment plant) is less than 1%. The urban landscape accumulates P, but more than half of P input to the urban landscape is exported via stormwater. Nevertheless, P export from the urban landscape is about an order of magnitude smaller than from other sectors. Finally, agriculture exports only 5% of input P to streams.

Table 8. P inputs and stream P exports for the engineered system, urban landscapes, and the agricultural watershed, in thousands of kg P/yr (lb P/yr).

	P input to city	P export to river	% of P input exported to surface water
Household system	28.5 (62.7)	14.2 (31.2)	50 (110)
Industrial system	1,770 (3,894)	14.1 (31.0)	0.8 (1.76)
Urban landscape	3.2 (7.0)	1.8 (4.0)	56 (123)
Agriculture	442 (972)	24 (53)	5 (11)

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