

Section 7. Phosphorus Budget

Phosphorus is a macronutrient essential for all plant growth. It is typically found at low concentrations and thus it can limit the productivity of phytoplankton and macrophytes. Quantifying the sources of phosphorus and seasonal loadings from various sources are essential to understand nutrient dynamics and eutrophication processes. Phosphorus loading into Martins Pond includes inputs of phosphorus from many potential sources, including surface runoff from the Skug River, soil erosion, groundwater, septic systems, sediment release and to a lesser extent precipitation and dryfall (aeolian inputs).

To determine both the monthly and annual loading of phosphorus into Martins Pond from the Skug River at the Route 28 inlet (WW-6), a mass balance approach was used to tabulate loadings during the 12 month study period. Phosphorus loadings were determined by calculating the mean monthly flows based on SWMM hydrologic model results or observed continuous flow monitoring values, and multiplying these mean flow values by mean monthly total P concentrations (mg/L). The calculated values represent estimates of the mean monthly P loading or flux into Martins Pond (kg P). The same calculations were performed for all the major subwatersheds analyzed in this study to determine loadings for each sub-basin. A phosphorus budget was then developed to quantify the amount of phosphorus entering and leaving Martins Pond.

7.1 - Phosphorus Loading into Martins Pond

The results of the phosphorus loading analysis are presented in Table 30. Monthly values were summed to determine total annual loadings into Martins Pond as shown at the bottom of the Table. Phosphorus shows monthly variability in flows and estimated loadings into Martins Pond over the course of the study period. Overall, the total yearly inflow (656.7 kg) was only 3.7% more than the yearly outflow total (682.0 kg). These results can be very misleading if the monthly variation is overlooked.

Table 30 includes a column that notes the change in % of inlet loading relative to the P outflow from Martins Pond. Positive (+) values denote outflow > inflow loadings and negative (-) values denote inflow > outflow. In April, August, September, November, December and January there was more P exiting the pond than entering it. Export levels in August and September were especially high, exceeding inputs by 41.2 and 31.9 kg, respectively (corresponding to a 68.7 and 70.6% export 'surplus', respectively). In contrast, inputs in May 2005 (81.7 kg) greatly exceeded outputs (31.1 kg) indicating uptake, assimilation and/or storage of P. The same pattern was observed in June and July 2005, though to a much lesser extent. Overall, the percent of P loading by month into Martins Pond did not show great variability between months, although the lowest contributions were made in August (2.9%), September (2.0%) and February (3.0%). There was increased loadings starting in March (7.5%) that slowly increased into April (10.6%), May (12.4%), June (13.2%) and then decreased slightly in July (11.7%). The contributions from the other months were: October 14.4%; November 8.8%; December 7.3% and January 6.2%.

The seasonal variability in P import and export from Martins Pond points to the importance of both external (watershed) inputs of P and in-pond processes. Figure 29 showed increases in total P concentrations during the summer in Martins Pond and throughout the watershed. The proportionally high P outflows from the pond in August and September 2005 during relatively low flow periods may reflect evapoconcentration and/or internal loading of P from sediments. An external watershed source was not evident due to the relatively low loadings entering the pond during those two months. In contrast, in May there appeared to be a large influx of P from a watershed source that was still evident, though dissipated in extent, into June and July.

Over the course of the year study period, only 25.3 kg more P flowed out of Martins Pond than entered it, representing a net ‘surplus’ outflow of 3.7%. This suggests annual symmetry in P inputs versus outputs. However, in-pond processes, seasonal watershed inputs and/or internal loading are all occurring, just over shorter time spans that balance out when summed over the course of the study period. Thus, simplified annual summaries of the phosphorus loadings while useful, do not provide adequate resolution of the seasonal and monthly P dynamics occurring both in Martins Pond and in the watershed. The high flushing rate of Martins Pond (some 33 times per year) also means that the watershed is an active source of P loading into Martins Brook and the lower Ipswich River Basin.

Table 30. A comparison of phosphorus loading into and out of Martins Pond. Total P loading at the inlet (Skug River at Route 28 [WW-6]) is compared to total P exiting Martins Pond at its outlet (Burroughs Road [MP-3]). Great monthly variation in the total P exiting Martins Pond and/or assimilated is clearly evident. Monthly inflows and outflows are in units of million gallons per day (MGD).

Month	Monthly Mean Inflow MGD	Monthly Mean Outflow MGD	Inlet	Outlet	Outlet minus Inlet kg	% of Inlet Loading Relative to the P Outflow*
			Total P Loading - kg			
03/05	20.08	21.56	49.481	45.555	(-3.926)	- 8.6
04/05	24.47	28.29	69.469	73.892	4.423	6.0
05/05	21.75	24.06	81.655	31.056	(-50.599)	- 162.9
06/05	12.28	14.55	86.476	66.075	(-20.401)	- 30.9
07/05	6.84	7.83	77.021	67.950	(-9.071)	- 13.3
08/05	3.81	4.44	18.793	59.958	41.165	68.7
09/05	3.90	4.37	13.283	45.150	31.867	70.6
10/05	27.72	29.96	94.340	80.854	(-13.486)	- 16.7
11/05	14.98	17.00	57.855	92.640	34.785	37.5
12/05	14.61	16.36	48.011	55.688	7.677	13.8
1/06	16.55	18.65	40.787	45.959	5.172	11.3
2/06	11.51	13.54	19.523	17.221	(-2.302)	- 13.4
Yearly Sum			656.7	682.0	25.3	3.7

* Positive (+) values [in blue] denote outflow > inflow loadings and negative (-) values denote inflow > outflow.

In order to evaluate any changes in P loadings over the past twenty years, a comparison of the annual P loading and budget found in the 1985 D/F Study was made with the current study. A summary of that comparison is presented in Table 31.

The yearly rainfall totals were very similar between the two studies. However, the flux of P entering and leaving Martins Pond has essentially doubled over the 20 year period between studies. Thus, external watershed inputs have apparently dramatically increased over the past two decades. This is reflected in both the overall loadings (327 kg/year in 1985 and 657 kg/yr in 2005-06) as well as the increase in mean concentration of total P shown in Table 31. The relative portion of P leaving the pond was 85.3% of the input in 1985, suggesting some assimilation of P. In the 2005-06 study, however, there was a modest net outflow of P. The current high P loadings and concentrations help explain why P may not always be the limiting nutrient in this system and that Martins Pond is not an effective sink for P inputs.

Table 31. A comparison of P loading estimates from the 1985 and 2005-06 Diagnostic/Feasibility Studies for Martins Pond.

	1985 D/F	2005-06 D/F
Mean annual P inflow concentration	0.032 mg/L	0.040 mg/L
Mean annual inflow	7.4 MGD	15.2 MGD
Total P inflow to Martins Pond	327 kg/yr	657 kg/yr
Total Precipitation	41.18 in	43.78 in
Total P outflow from Martins Pond	279 kg/yr	682 kg/yr
Mean annual P outflow concentration	0.032 mg/L	0.049 mg/L
Mean annual outflow	8.4 MGD	16.7 MGD

Based on use of the NPSLAKE Model (Mattson and Isaac 1999), Martins Pond is predicted to have total P concentrations of 0.029 mg/L. The results of that analysis are presented in Appendix B.

In addition to the results presented in Tables 30 and 31, a simple P budget for Martins Pond was developed to estimate other P sources. This budget includes septic tank inflow/ inputs of 0.5 kg P house⁻¹ yr⁻¹ based on values presented by Mattson and Isaac (1999), atmospheric inputs based on estimates from Reckhow et al. (1980) and internal loadings based on values in Welch and Cooke (1995). The components of the P budget are summarized in Table 32.

Table 32. A phosphorus budget component summary for Martins Pond.

<i>Source of P Inputs</i>	<i>kg / year</i>	<i>percent</i>
Watershed Inflow	656.7	89.7
^a Septic Tank Inflow (125 homes)	62.5	7.4
^b Internal Loading (sediment-water transfer)	10.0	1.4
^c Atmospheric Loading	11.1	1.5
Total Load	740.3	100
Outflow	682.0	
Total Available	(58.3)	

^a Based on NPSLAKE model (Mattson and Isaac 1999)

^b Based on estimates from Welch and Cooke (1995)

^c Based on deposition rate of ~0.3 kg ha⁻¹ yr⁻¹ (Reckhow et al. 1980)

The results in Table 32, and those in Tables 30 and 31 indicate that Martins Pond is not acting as a sink for phosphorus. While it may be assimilating some P in the sediments and/or macrophytes (e.g. in May 2005), overall, P inflows are simply being exported. Watershed sources of P are clearly the most important inputs representing 89.7% of the total P inflow budget. Septic system inflows represent only 7.4% of P inputs into Martins Pond.

7.2 - Phosphorus Loading in the Martins Pond Watershed

Mean monthly estimates of phosphorus loadings were conducted at or near outlets of the major subwatersheds delineated for this study. The monthly loading results are presented in Table 33. To compare loadings across different sized basins, normalized kg P/ha were also calculated for each basin. Based on the latter measure, subwatersheds J (reference) and D had the lowest loading rate per hectare. Subwatershed D is a densely residential area with the highest septic density in the entire watershed (see Section 11.2), nonetheless it had a lower P loading than even the reference watershed. The two wetland sites, WW-1 and WW-NB, exhibited relatively high (1.57 kg/ha) and relatively low (0.49) loadings, respectively. Subwatersheds G, F and H combine to drain the northern portion of the Martins Pond watershed at sampling site WW-3. Interestingly, the loadings from that portion of the watershed (904.9 kg) exceeded even the Martins Pond inlet loading (656.7 kg). Thus, some P assimilation must be occurring along the lower Skug River prior to entry into Martins Pond.

Table 33. A monthly comparison of phosphorus loading in different subwatersheds, at the two wetland sites in the study, and at the Martins Pond inlet and outlet in the Martins Pond Watershed.

	Subwatershed(s)								
	J	G	WW-NB	C	D	F	G, F, H	Entire Skug River at Route 28	Martins Pond Outlet
	Reference	Wetland	Wetland	Sub-Shed	Sub-Shed	Sub-Shed	Sub-Sheds	Sub-Sheds	
Month	Total P in kg								
03/05	1.995	6.090	0.902	2.894	2.177	0.948	11.187	49.481	45.555
04/05	4.191	12.189	1.386	3.930	4.134	7.951	26.051	69.469	73.892
05/05	1.475	11.166	1.830	12.340	1.571	25.713	23.643	81.655	31.056
06/05	3.299	34.665	3.096	10.277	5.094	14.036	30.596	86.476	66.075
07/05	3.455	21.514	4.528	5.220	3.404	9.220	6.905	77.021	67.950
08/05	1.391	15.779	1.552	1.248	1.713	5.190	16.714	18.793	59.958
09/05	0.161	9.284	1.130	7.359	0.176	5.407	49.975	13.283	45.150
10/05	7.483	91.481	3.701	57.391	4.643	17.923	209.899	94.340	80.854
11/05	1.587	52.941	2.524	4.681	0.985	7.706	15.657	57.855	92.640
12/05	2.291	21.950	2.649	3.048	1.736	5.266	35.880	48.011	55.688
1/06	5.034	14.976	1.544	5.397	3.427	4.663	185.468	40.787	45.959
2/06	1.439	7.734	0.402	1.156	1.252	1.025	292.960	19.523	17.221
Kg P/year	33.8	299.8	25.245	114.9	30.3	105.0	904.9	656.7	682.0
ha	188.6	191.1	52.1	303.4	189.1	193.7	690.3	1709.7	1993.9
kg P/ha	0.179	1.569	0.485	0.379	0.160	0.542	1.311	0.384	0.342