SMAST University of Massachusetts Dartmouth
The School for Marine Science and Technology

Coastal Systems Program SMAST

---------- **Technical Memorandum** ----------

To: Kim Tower, Environmental Technician, Town of Plymouth

From: Eduard Eichner, TMDL Solutions
Brian Howes, Ph.D., Director, Coastal Systems Program

RE: Great Herring Pond Stormwater Monitoring Project results

Date: February 24, 2016

Overview/Summary

Stormwater sampling at 6 of 13 runoff discharge sites around Great Herring Pond was completed during three storms by CSP/SMAST for the Town of Plymouth. Stormwater sampling consisted of measuring runoff flow and collecting water quality samples that were later analyzed at the CSP/SMAST Analytical Laboratory. Sampling sites were along Herring Pond Road (sites R6, R14), Eagle Hill Drive (sites R7, R10), Carter's Bridge Road (site R8), and Roxy Cahoon Road (site R4). Sites R4 and R8 generally had the highest constituent concentrations with R4 having the highest average total nitrogen (TN) and total suspended solids (TSS) concentrations and R8 having the highest average total phosphorus (TP) concentration. Highest runoff flows were generally measured at sites R7 and R10 and these higher flows meant these sites also had the highest nutrient and TSS loads during each of the measured stormwater events. Based on the combined impacts of the nutrients and TSS, the measured sites would have the following rank from the greatest impact to the lowest: R7>>R10>>R8,R14>R4>R6. Differences in loading between storms showed that precipitation intensity and the length of dry weather prior to a storm impacted loads and concentrations. Project staff reviewed annual precipitation events and used the collected data to estimate annual stormwater contaminant loads from all sites to Great Herring Pond: TP, 5.6 kg; TN, 45 kg; and TSS, 1,800 kg. Additional characterization of the Pond watershed and water quality is necessary to put these loads into further context.

Background

As part of the Plymouth Pond and Lake Stewardship (PPALS) Program, the Town and the Herring Ponds Watershed Association asked Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) staff to review available water quality and ecosystem characterization data for Great Herring Pond and Little Herring Pond.[1] Part of the analysis was to assess gaps in the existing environmental data what would be needed for any future management plan for this system. Based on the review,

[1] Eichner, E.M., B.L. Howes, and S. Horvet. 2015. Town of Plymouth Pond and Lake Atlas. Town of Plymouth, Massachusetts. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 138 pp.

CSP/SMAST staff was asked design a program to collect targeted and baseline data associated with management of these two ponds. The initial tasks identified in the overall program were to:

a) collect, review, and synthesize the available data within the two ponds,
b) complete a watershed delineation and use existing land use and water information to develop initial water, nitrogen, and phosphorus budgets for the ponds,
c) complete stormwater runoff sampling of 6 key sites, and
d) identify data gaps and recommendations for next steps.

The findings from these tasks would be summarized in a baseline water quality assessment report, but the Town had an opportunity to accelerate the overall process by completing the stormwater runoff sampling task first.

During the Fall of 2015, the Town secured to complete the stormwater runoff sampling at six stormwater discharges (of 13 total) to the Herring Ponds System. The Town asked to have this completed in early 2016. CSP/SMST staff completed the sampling in late December and the results of this sampling are provided here and can be used in the future for the anticipated development of a Great Herring Pond and Little Herring Pond water quality assessment report and as a quantification of stormwater inputs to the ponds associated with pond management.

Sampling Approach

Stormwater runoff enters the Great Herring Pond through 13 discharges. Six of these sites were selected for storm discharge measurements by Town of Plymouth staff (Figure 1). CSP/SMAST staff collected time-series stormwater samples and volumetric flows from each of the six discharges during three separate storms. Runoff samples were collected from locations adjacent the pond and just upstream from the pond shore; at some locations samplers were standing in the pond while collecting samples just before entry into pond waters. Data were retrieved by CSP/SMAST staff in accordance with accepted sampling, quality control and quality assurance procedures.

Staff sampled on the following dates in 2015: October 28, December 14/15, and December 17. A threshold of 0.25 inches of precipitation was used to determine a "significant" storm event. This threshold was met for each of the event described in this memo. Staff also mobilized for a December 1 storm event, but the actual rainfall was <0.25 inches and failed to produce adequate runoff. Water quality samples were analyzed at the CSP/SMAST Analytical Laboratory for the following constituents: total phosphorus, total nitrogen, total suspended solids (TSS), pH, alkalinity, ortho-phosphate, and various nitrogen species. Laboratory procedures are the same as those used for pond samples during the Plymouth PALS Snapshots and for the stream/river flow measurements by the Massachusetts Estuaries Project assessment of Plymouth Harbor with the addition of analysis for TSS.

Sampling Sites

Impacts from stormwater runoff are predicated on the land uses within the contributing watershed/capture area to the discharge site and the aspects of the precipitation event (*e.g.*, intensity, magnitude). The details of the Great Herring Pond stormwater contributing areas and discharges are:

- Sites R6 and R14 are 12 inch diameter pipes that discharge runoff collected from roadway catch basins on Herring Pond Road, which appears to have been recently paved, and are located along the eastern edge of the pond.
- Sites R10 and R7 discharge are 15 and 8 inch diameter pipes, respectively, that discharge runoff from Eagle Hill Drive, which is located on a peninsula that extends from the eastern shoreline. The contributing area to R10 includes a large paved circle with inputs from adjacent lots at the end of a long run of older road, while R7 captures runoff from a section of the same road on the other side of a small hill.
- Site R8 is a partially occluded 12 inch diameter pipe that collects runoff from the pond side of Carter's Bridge Road and may also collect some from the wetland system on the other side of the road.
- Site R4 is located at the end of a small path of paving stones that collects runoff from a section of unpaved Roxy Cahoon Road creating a more porous and less well defined contributing area than associated with the other discharges.

Precipitation Events and Timing of Runoff Sampling

Each of the three monitored storms had different characteristics in the timing and amount of precipitation and, as such, had different runoff profiles. Precipitation data from a station in Sagamore Beach (lat 41.800 long -70.536; approximately two miles east of the pond) was used to characterize each storm. Precipitation was measured every 7 to 60 minutes during the first storm and every 5 minutes during the second and third storms.

The October 28 storm recorded initial precipitation at 3:07 PM, reached a rate of 1.2 in/hr at 3:52 PM, declined to 0 in/hr at 7:01 PM, then rose to a rate of 0.33 in/hr by 8:12 PM (Figure 2). First runoff sample was collected at 4 PM (T0 sample at R6) and last sample was collected at 9:50 PM (T3 at R8). Cumulative precipitation during this period was 0.62 inches and there was no measurable precipitation in the 10 days preceding this storm. First flush (T0) samples were collected at all six stations, except R4, between 4 PM and 4:33 PM. R4 did not generate its first runoff sample until 8:25 PM indicating that the initial storm peak wet the surface of the dirt road, but did not generate runoff, consistent with its more porous surface.

The December 14/15 storm recorded initial precipitation at the Sagamore Beach rain gauge at 9:27 PM, but the first runoff sample was collected at 7:46 PM. This difference accentuates how slight differences in storm tracks can alter where it is raining even in the same general area. The storm continued with relatively low rates (0.12 to 0.48 in/hr) until approximately 11:30 PM when the rate increased to 0.73 in/hr, jumped again at 11:47 PM to a high of 1.56 in/hr, declining to 0.48 in/hr at 12:22 AM and 0.12 in/hr five minutes later (see Figure 2). The first runoff sample was collected at 7:46 PM (T0 sample at R10) and last sample was collected at 12:18 AM (T4 at R4). Precipitation during this period was 1.3 inches. First flush (T0) samples were collected at six stations between 7:46 PM and 10:00 PM depending on when runoff flow started. There was no precipitation for three days prior to this storm and there was a total of only 0.2 inches of precipitation during the 10 days prior to this storm.

The December 17 storm recorded initial precipitation at the Sagamore Beach rain gauge at 2:37 PM, with the first runoff sample collected at 3:15 PM. In this case, the difference between the beginning of rain and the first runoff accentuates the time required to completely saturate a surface before runoff is generated. This storm had relatively low precipitation rate throughout

the sampling period with frequent momentary stoppages; maximum rate during the sampling period was 0.24 in/hr (see Figure 2). First runoff sample was collected at 3:15 PM (T0 sample at R6) and last sample was collected at 6:35 PM (T4 at R4). Precipitation during this period was 0.32 inches. First flush (T0) samples were collected at six stations between 3:15 PM and 4:00 PM. There was no precipitation for one day prior to this storm and there was a total of 0.52 inches of precipitation in the 10 days prior to this storm (including the December 14/15 storm).

Stormwater Runoff Rates

Runoff flows were measured at the end of each of the stormwater discharge pipes along the shoreline (sites R6, R7, R10, R14) or at locations just before runoff entered Great Herring Pond (sites R4, R8). Sites had a wide range of runoff volumes per storm due to different contributing areas, characteristics (*e.g.*, paved, unpaved), and how storms passed through the area. Discharge sites R7 and R10 consistently had the highest runoff rates, with maxima 5 to 10 times higher than the other sites (Figure 3; Table 1). Both R7 and R10 discharges collect runoff from Eagle Hill Drive. Among the three storms measured, runoff rates were highest during the December 14/15 storm, although the differences in the average runoff were generally not proportional to the differences in the precipitation amounts. Further evaluation of the stormwater collections areas contributing to each of these discharge points would be necessary to understand the relationship between discharge volume and precipitation rate at each site and between the sites.

Stormwater Runoff Contaminant Concentrations

Runoff samples were collected at the same time as runoff flows were measured during each of the three storms. These samples were analyzed at the CSP/SMAST Analytical Laboratory for a number of constituents including total phosphorus, total nitrogen, and total suspended solids (TSS). Flow weighted average concentrations were determined for each storm event (see Table 1). Among the storms and runoff sites, total phosphorus concentrations ranged from 0.07 to 0.54 mg/L, total nitrogen concentrations ranged from 0.63 to 5.15 mg/L, and total suspended solids ranged from 14 to 1324 mg/L. Average concentrations were: 0.26 mg/L TP, 2.07 mg/L TN, and 234 mg/L TSS. Sites R4 and R8 generally had the highest constituent concentrations with R4 having the highest average TN and TSS concentrations and R8 having the highest average TP concentration.

The October 28 storm had the highest average nutrient concentrations, while the December 14/15 storm had the highest average TSS concentration. This finding suggests that the 10/28 storm mobilized stored contaminants from the road surfaces because of the long period without rain that preceded this storm, while the greater precipitation amount in the December 14/15 storm mobilized solids sources that were not activated by the October 28 storm. Further evaluation of the stormwater collections areas contributing to each of these discharge points would be necessary to understand the relationship between discharge volume and precipitation rate at each site and between the sites.

Review of the time-series concentrations show the importance of capturing the initial runoff samples (*e.g.*, the first flush). The initial samples (T0) generally had the highest concentrations of contaminants; total nitrogen concentrations are shown as an example in Figure 4. It should also be noted that changes in storm intensity can alter the general decline in contaminant concentrations as a storm progresses; the increase in the precipitation rate later in the December

14/15 storm (see Figure 2) mobilized more contaminants and led to an increase in TN concentrations in the later time-series samples (see Figure 4).

Stormwater Runoff Contaminant Loads

Pairing the stormwater runoff flows with the contaminant concentrations allows constituent loads to be determined. This information can then be used with annual or seasonal precipitation to establish nutrient and other contaminant budgets for development of water quality management strategies for Great Herring Pond.

As with the flows, sites R7 and R10 generally had the highest nutrient loads during each of the measured stormwater events. However, the loads associated with the each site varied with each storm. For example, the total phosphorus load at R7 during the December 14/15 storm was the largest individual site load during a storm and the load at R10 was approximately 30% of the R7 load (Figure 5). But during the October 28 storm R7 and R10 had approximately the same TP load and flow. Some of the differences at the smaller flow sites were even more pronounced: flow at R6 during the October 28 storm was 64% of the December 14/15 storm, but the TP load during the October 28 storm was nearly 4X the December 14/15 storm. Total nitrogen (TN) generally followed similar patterns as TP, though the sum of TN loads at all stations were generally 7X to 9X larger than the TP loads (Figure 6).

Comparison of relative TP loads and runoff flows show that the October 28 storm had higher load amounts than expected based only on runoff flows at 4 of the 5 stations with measurements; the December 17 storm had loads roughly in line with comparisons of flow. This comparison suggests that TP loads from storms preceded by long periods without rain will be much higher than storms that had previous storms in the preceding few days.

Total suspended solids (TSS) generally followed the same patterns as the nutrients: the R7 and R10 sites generally had the highest loads during each of the storms (Figure 7). TSS load was highest during the December 14/15 storm, followed by the October 28, and then the December 17 storm. The total load across all stations was proportional greater than flow in the October 28 storm and proportionally less than flow during the December 17 storm, again reinforcing the potential impact of previous storms on storm-specific loads.

Calculating contaminant loads means bringing flow information together with contaminant concentrations and these results can show the importance of measuring these factors through the course of a storm. Incorporating flow information with the concentrations has shown that greater flows later in storms can also result in higher loads.[2] Using TN as an example, initial runoff contaminant concentrations at the Great Herring Pond sites are generally the highest during the initial runoff (see Figure 4), but the higher runoff flows during the later parts of the storm cause TN loads greater than the initial runoff loads (Figure 8).

Estimates of Annual Stormwater Contaminant Loads to Great Herring Pond

Using the information gathered during this project, staff developed annual estimates of the contaminant loads from stormwater runoff to Great Herring Pond. Based on review of past

[2] Stenstrom, M.K. and M. Kayhanian. 2005. First Flush Phenomenon Characterization. CTSW-RT-05-73-02.6. California Department of Transportation. Sacramento, CA. 81 pp.

stormwater monitoring for Great Herring Pond, there are approximate 13 sites around the pond that discharge of collected stormwater runoff; six of these were measured during this project.

Based on the nearest long-term precipitation station[3], the average annual precipitation in the area was 47.02 inches between 1893 and 2014. Precipitation at the nearest station with a complete annual record (Plymouth Airport) totaled 36.48 inches in 2015.[4] Of that total, 86% was deposited in daily precipitation amounts of 0.2 inches or more and 26% was deposited in daily amounts of 1.0 inch or more.

Based on all of this information, an estimate of the annual loads of nutrients to Great Herring Pond was developed. For the estimates, it is assumed that:

a) only storms greater than 0.2 inches generate runoff to the pond,
b) storms during 2015 are representative of usual storms in the area,
c) average runoff characteristics at the six monitored sites are representative of the other non-measured discharge sites, and
d) storms greater than 1 in are represented by the December 14/15 storm and storms greater than 0.2 inches are represented by averages of the October 28 and December 17 storms.

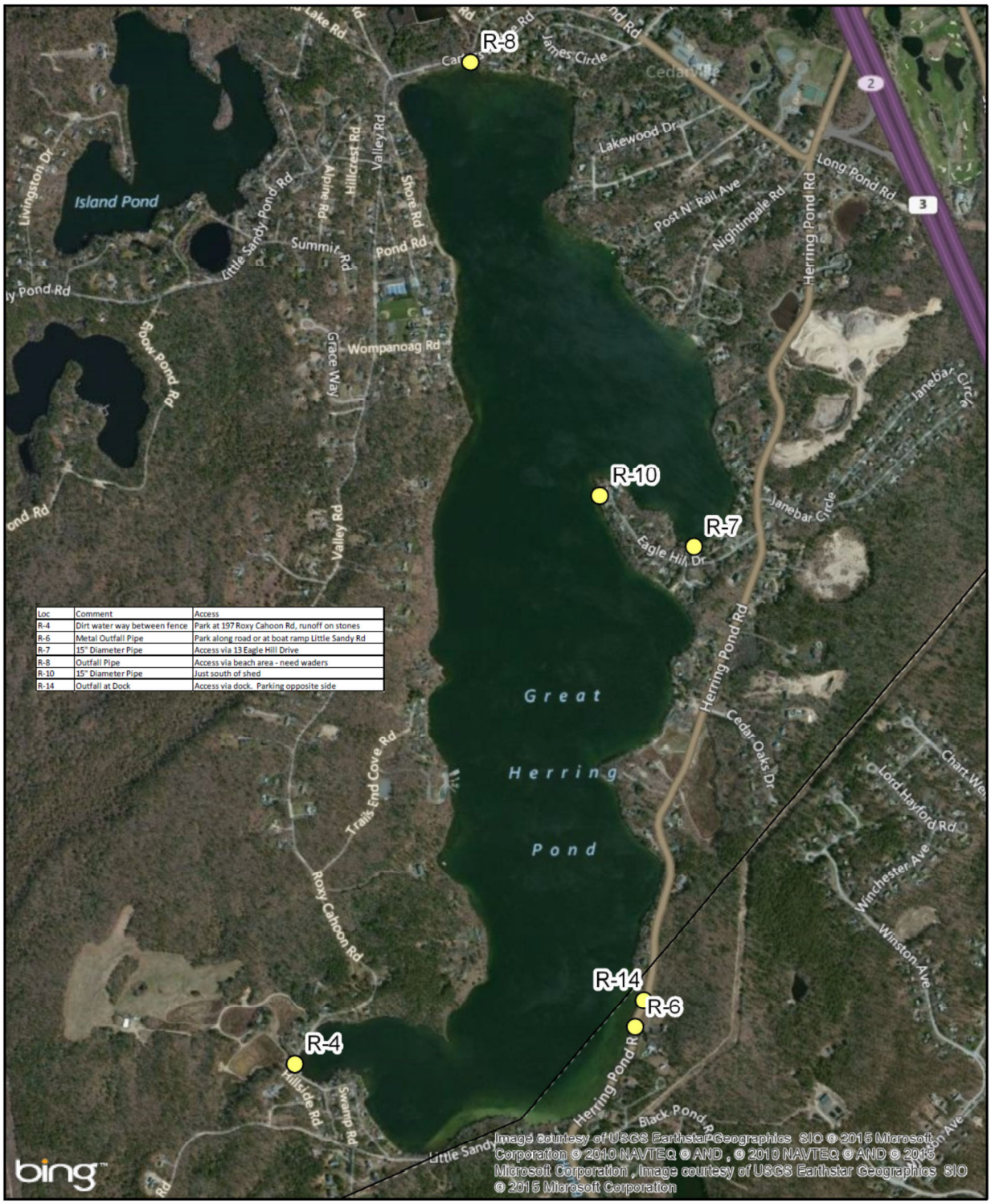
Based on these assumptions, using the measured data from the 2015 stormwater monitoring, and adjusting precipitation for an average year, the following annual stormwater runoff contaminant loads to Great Herring Pond were estimated: TP, 5.6 kg; TN, 45 kg; and TSS, 1,800 kg. Additional assessment of water quality in the pond, contaminant sources in its watershed, and how water flows in and out of the pond are needed in order to put these estimates into a meaningful context.

Summary

Overall, the stormwater flow and contaminant load information gathered during this project will provide site-specific information for the Town of Plymouth to develop pond water quality management and stormwater management strategies. Collected readings show that sites R7 and R10 generally had the highest flows and contaminant loads to the pond, while sites R4 and R8 generally have the highest contaminant concentrations. Impacts from large storms (>1 inch) generally have much more significant impacts than smaller storms, although readings show that storms during periods of regular precipitation have less impact than storms during predominantly drier periods. Readings also show that while the initial runoff will have higher contaminant concentrations, contaminant loads later in storms can be larger than the initial loads. CSP/SMAST staff looks forward to continuing to work with the Town of Plymouth to further assess and restore acceptable water quality in Great Herring Pond.

[3] NOAA Kingston/Plymouth station (lat 41.982, long -70.696) with precipitation records from 1893 to present.

[4] NOAA, National Centers for Environmental Information. http://www.ncdc.noaa.gov/ accessed 2/3/16.



Loc	Comment	Access
R-4	Dirt water way between fence	Park at 197 Roxy Cahoon Rd, runoff on stones
R-6	Metal Outfall Pipe	Park along road or at boat ramp Little Sandy Rd
R-7	15" Diameter Pipe	Access via 13 Eagle Hill Drive
R-8	Outfall Pipe	Access via beach area - need waders
R-10	15" Diameter Pipe	Just south of shed
R-14	Outfall at Dock	Access via dock. Parking opposite side

Figure 1. Great Herring Pond Stormwater Runoff Sampling Sites 2015. These six sampling sites were selected by Town of Plymouth staff. There are a total of 13 stormwater runoff discharge sites around the pond.

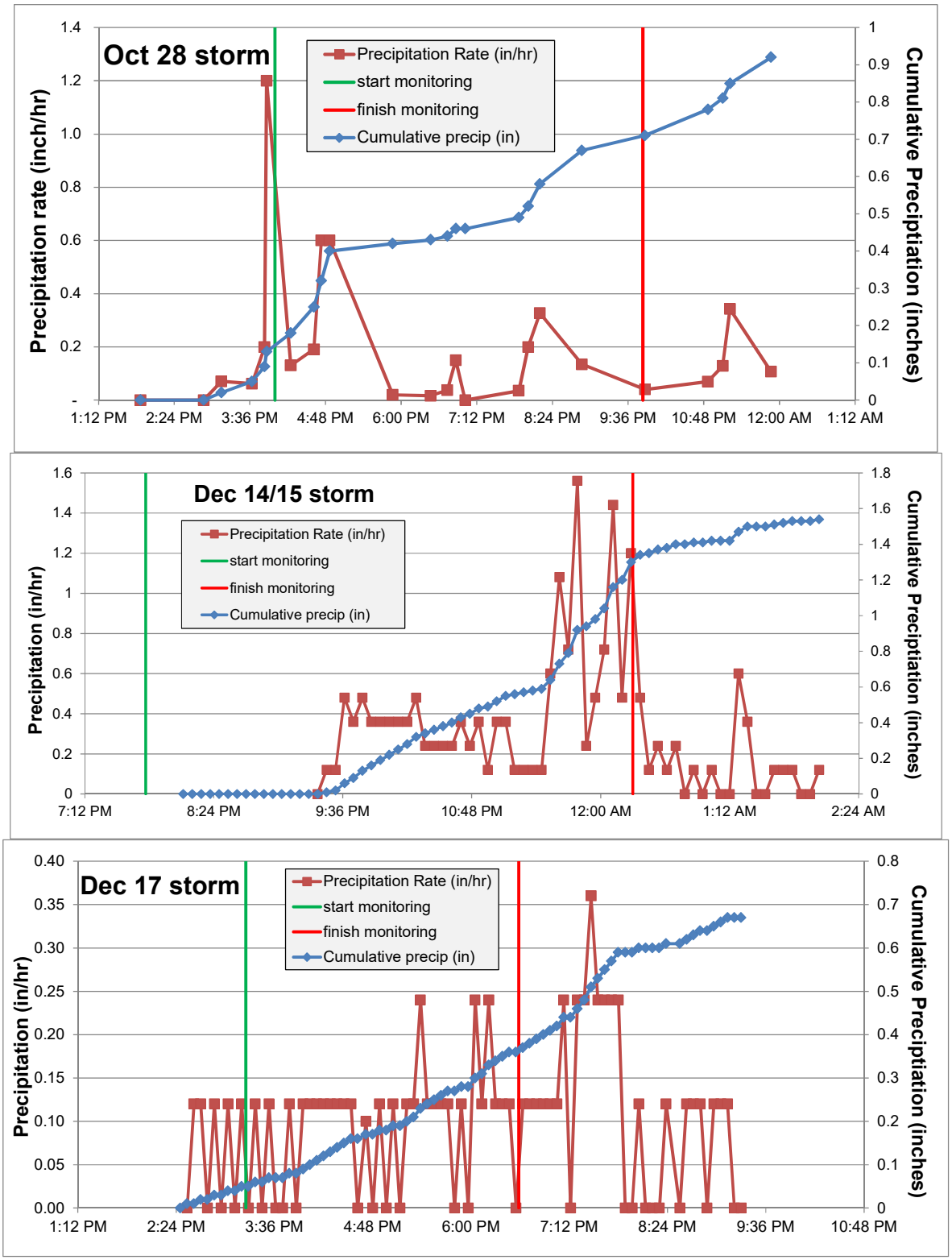


Figure 2. Precipitation during Great Herring Pond 2015 Stormwater Runoff Sampling. Stormwater measurements were reported from a station near Sagamore Beach. Precipitation during the runoff measurement periods for each storm was: 0.62 in, 1.3 in, and 0.32 in, respectively.

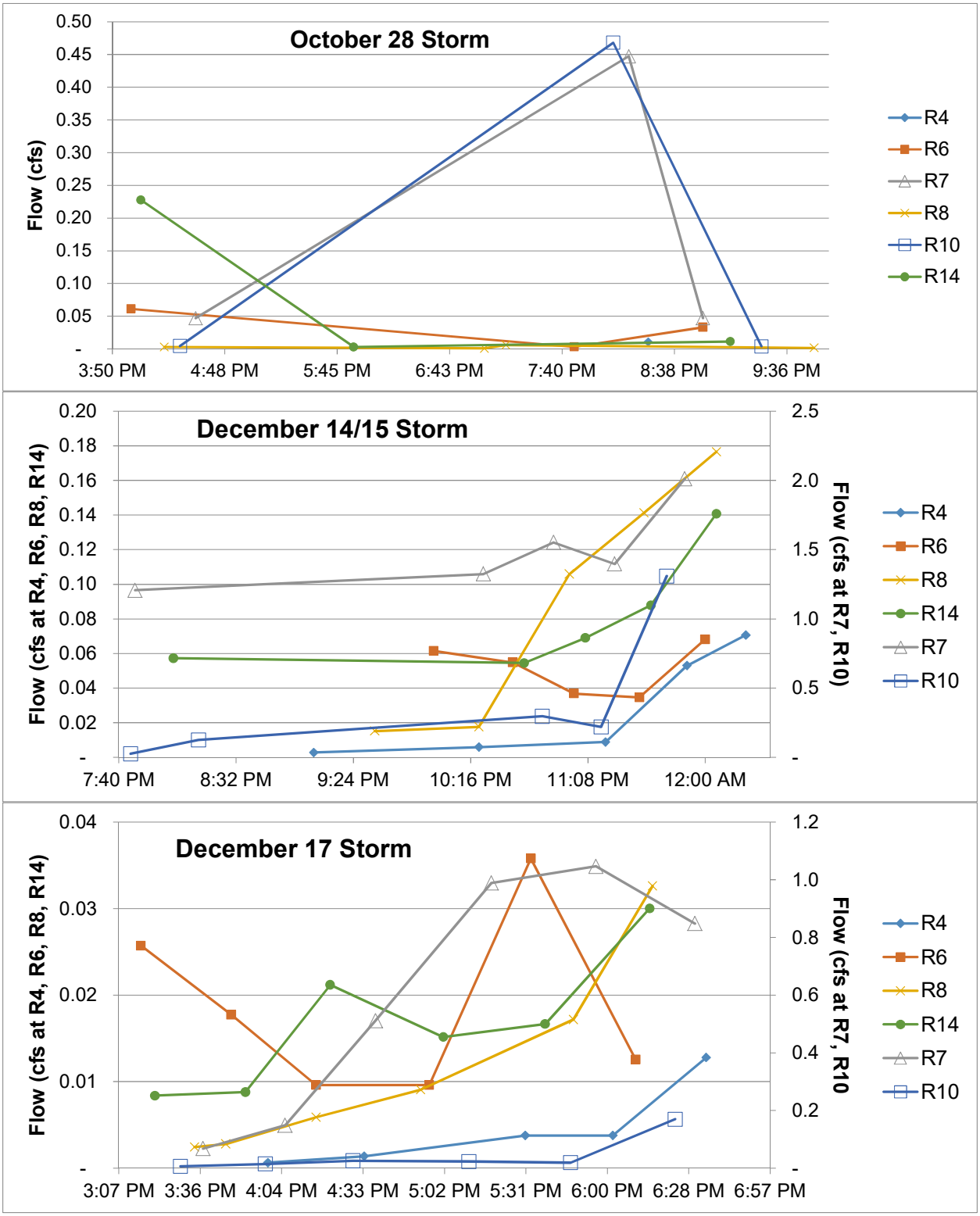


Figure 3. Great Herring Pond 2015 stormwater runoff flows: October 28, December 14/15, and December 17 storms. Measured flows at all six stations are shown. All flows are in cubic feet per second.

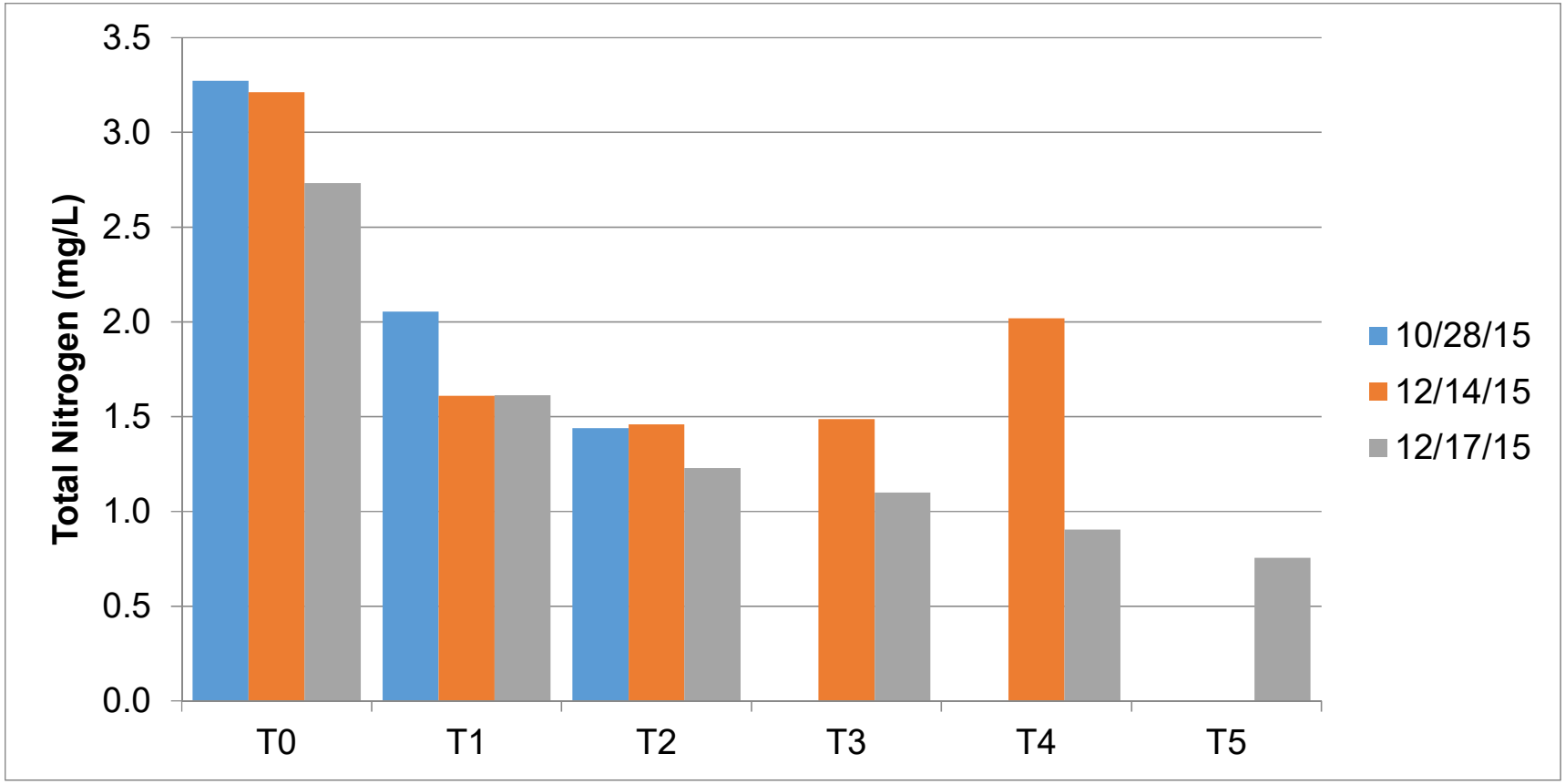


Figure 4. Average Total Nitrogen concentrations in stormwater runoff during three 2015 storms at Great Herring Pond. Concentrations for time-series samples during the respective storms are shown. T0 was the initial "first flush" sample. All concentrations are in mg/L TN. Readings show that initial runoff concentrations were generally highest during each storm with each progressive sample having a lower concentration. The increase in late storm concentrations for the 12/14-12/15 storm show the importance of incorporating samples throughout storms.

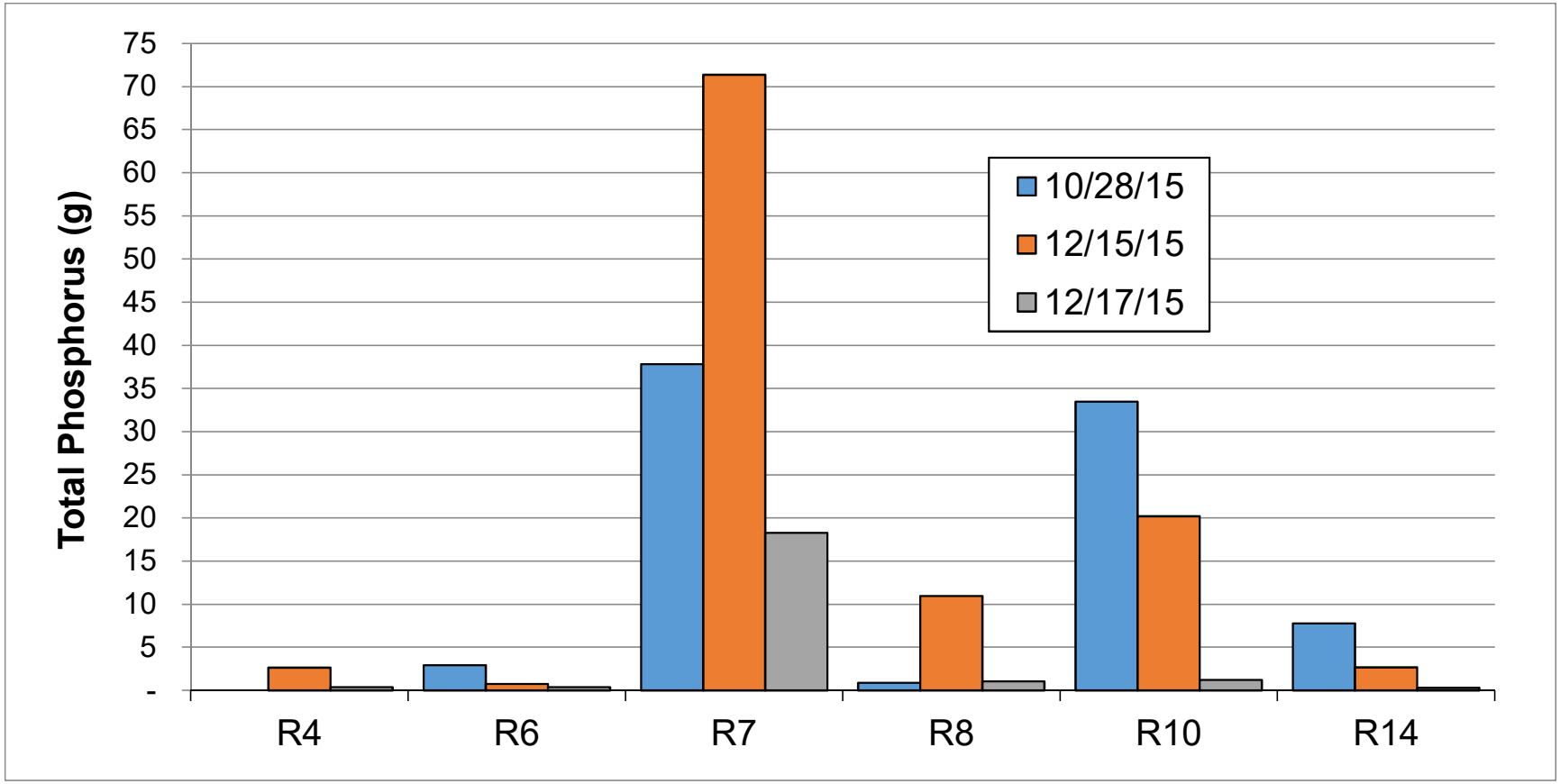


Figure 5. Total Phosphorus loads in stormwater runoff at six sites during three 2015 storms at Great Herring Pond. Loads are all in grams. R7 and R10 sites generally had the highest loads during all three storms. R7 and R10 are located off Eagle Hill Drive on a peninsula extending into the pond from the eastern side. Based on this data and annual precipitation, the overall estimated annual stormwater runoff TP load to Great Herring Pond was 5.6 kg.

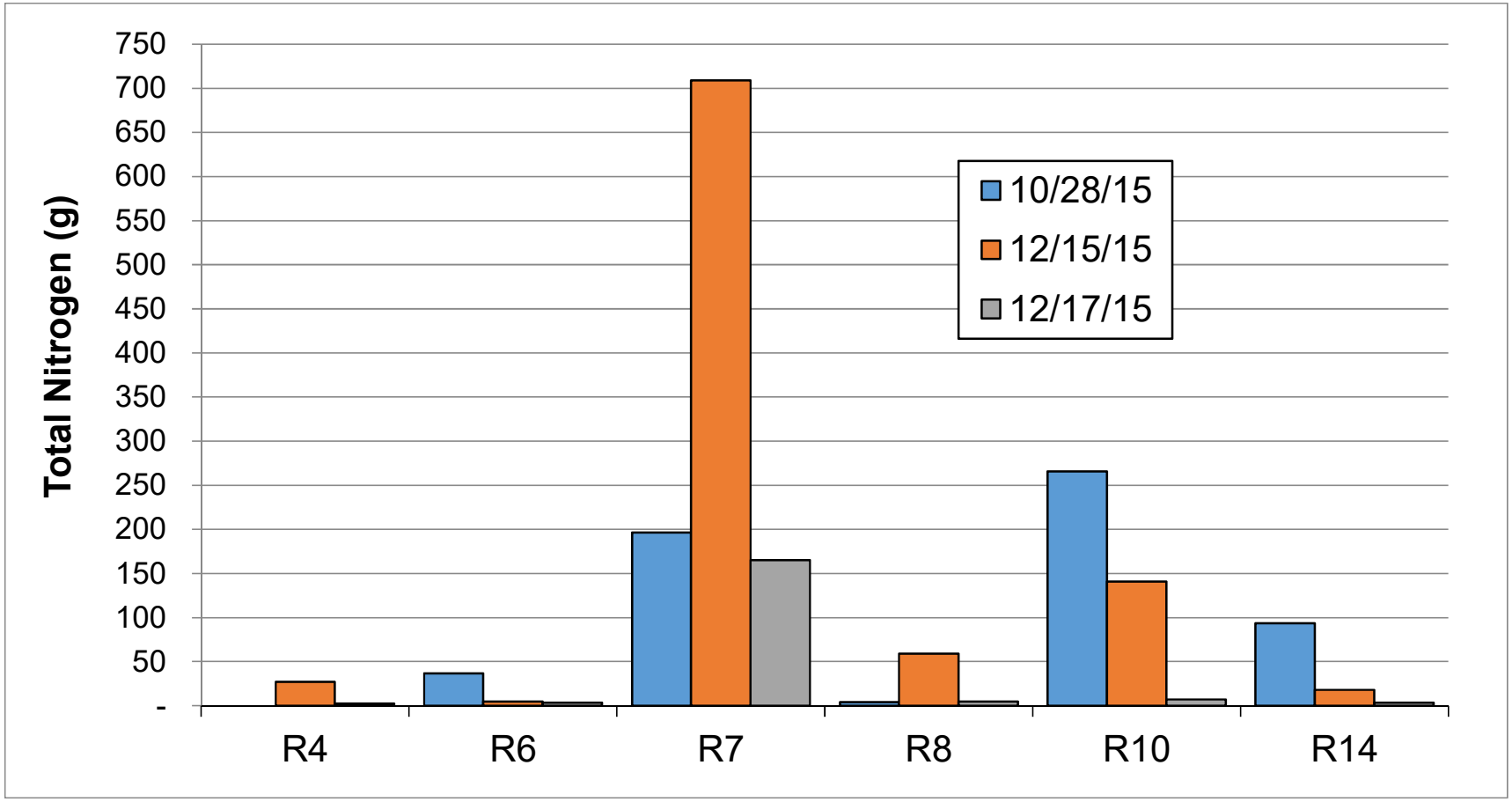


Figure 6. Total Nitrogen loads in stormwater runoff at six sites during three 2015 storms at Great Herring Pond. Loads are all in grams. R7 and R10 sites generally had the highest loads during all three storms. R7 and R10 are located off Eagle Hill Drive on a peninsula extending into the pond from the eastern side. Based on this data and annual precipitation, the overall estimated annual stormwater runoff TN load to Great Herring Pond was 45 kg.

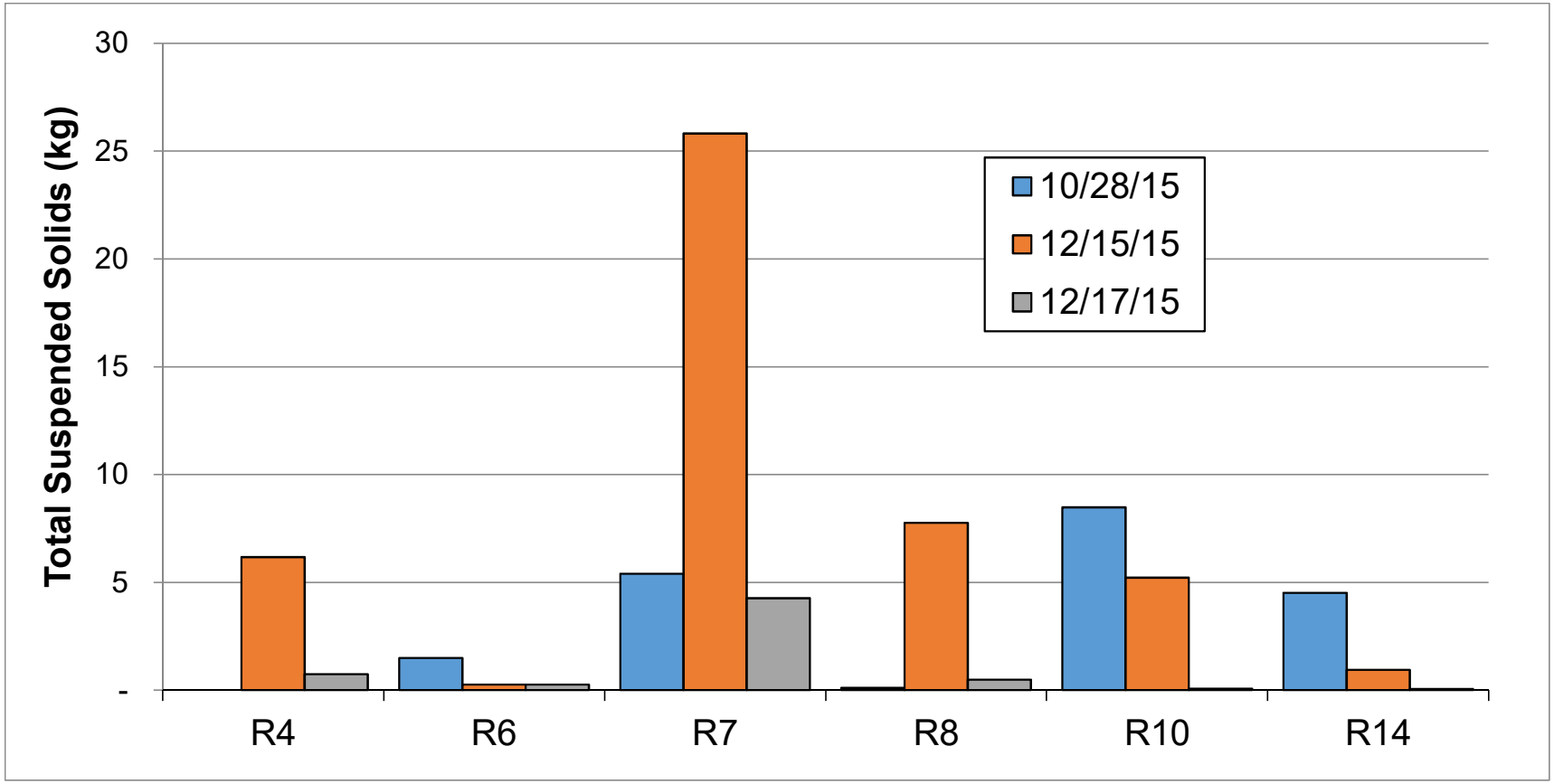


Figure 7. Total Suspended Solids loads in stormwater runoff at six sites during three 2015 storms at Great Herring Pond. Loads are all in kilograms/storm. Differences in loads between stations and events is more variable than the nutrient loads suggesting different mobilization factors; for example, R10 had a higher TSS load during the October 28 storm than during the December 14/15 storm, but the December 14/15 storm had runoff flows that were more than double the October 28 storm. Based on this data and annual precipitation, the overall estimated annual stormwater runoff TSS load to Great Herring Pond was 1,800 kg.

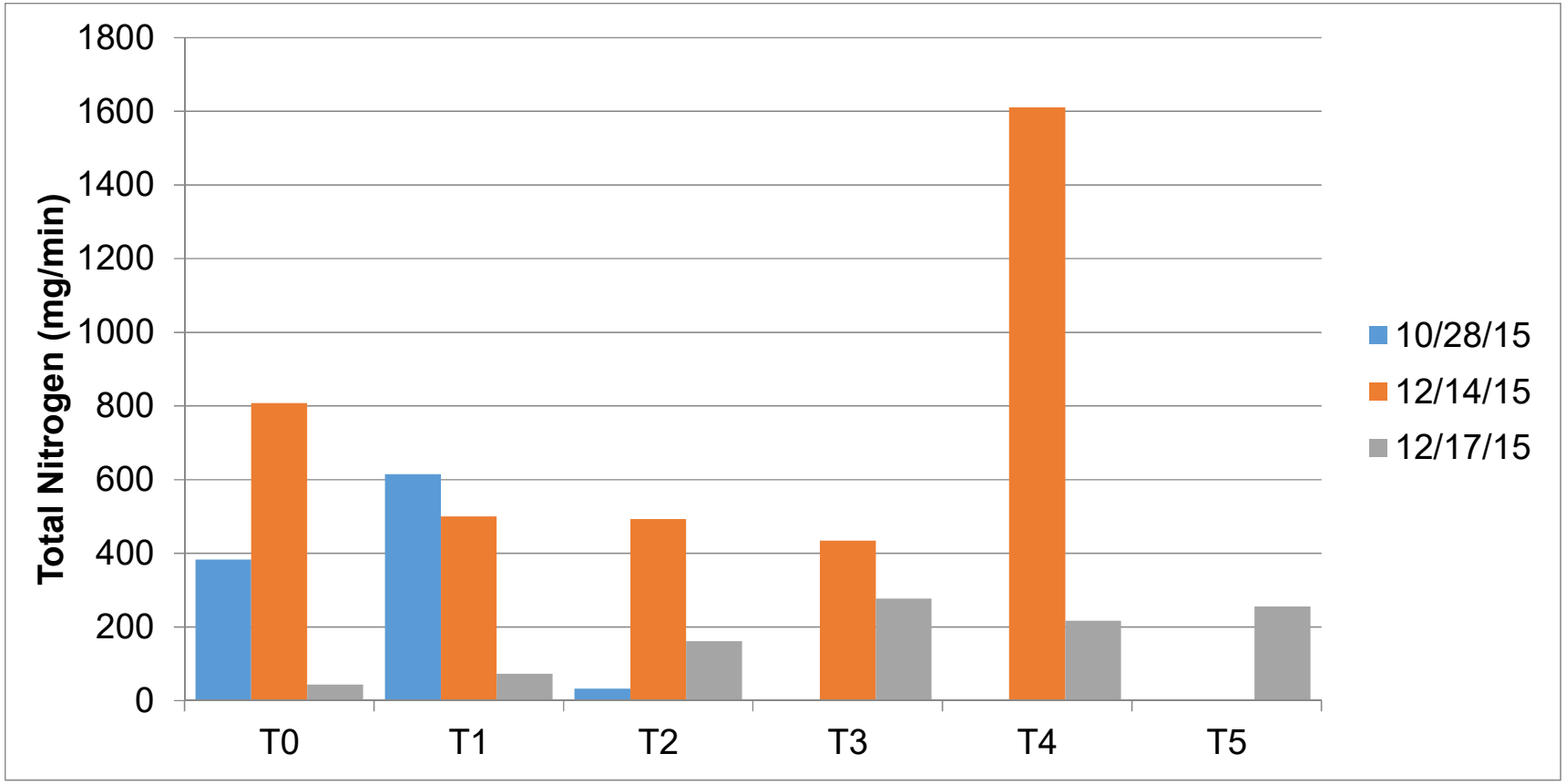


Figure 8. Average Total Nitrogen Loading Rates in stormwater runoff during three 2015 storms at Great Herring Pond. Loading rates are based on combining flow rates with concentrations during the time-series monitoring for the three measured storms. T0 was the initial "first flush" sample. All concentrations are in mg/min. While initial runoff concentrations were generally highest during each storm followed with each progressive sample having a lower concentration (see Figure 4), this shows that larger flows with lower concentrations can result in greater loads later during the course of a storm (*e.g.*, the fourth sampling during the December 14/15 storm had the highest TN loading rate for that storm).

Table 1. Summary of Great Herring Pond 2015 Stormwater Sampling.
Arithmetic means are presented for the concentrations, but not the loads or flows. Given the differences in the storm runoff, means of the loads and flows are not appropriate.

	Storm			
Parameter	10/28	12/14-12/15	12/17	Mean
Precipitation during sampling period (inches)	0.62	1.3	0.32	
Discharge: R4 (Roxy Cahoon Road)				
Total Flow (m3)		5.86	0.87	
TN [mg/L] flow weighted	2.70	5.15	3.22	3.69
TP [mg/L] flow weighted	0.22	0.52	0.47	0.40
TSS [mg/L] flow weighted	508	1,324	815	882
TN Load (g/storm)		27.1	2.6	
TP Load (g/storm)		2.7	0.4	
TSS Load (kg/storm)		6.2	0.7	
Discharge: R6 (Herring Pond Road)				
Total Flow (m3)	14.50	9.60	4.60	
TN [mg/L] flow weighted	2.69	0.63	0.88	1.40
TP [mg/L] flow weighted	0.20	0.10	0.11	0.14
TSS [mg/L] flow weighted	111	37	66	71
TN Load (g/storm)	36.9	4.8	3.3	
TP Load (g/storm)	3.0	0.8	0.4	
TSS Load (kg/storm)	1.5	0.2	0.3	
Discharge: R7 (Eagle Hill Drive)				
Total Flow (m3)	109.2	549.8	162.4	
TN [mg/L] flow weighted	1.88	1.30	0.88	1.35
TP [mg/L] flow weighted	0.35	0.12	0.10	0.19
TSS [mg/L] flow weighted	50	57	23	43
TN Load (g/storm)	196.2	708.8	165.3	
TP Load (g/storm)	37.8	71.4	18.3	
TSS Load (kg/storm)	5.4	25.8	4.3	
Discharge: R8 (Carter's Bridge Road)				
Total Flow (m3)	1.6	19.4	2.4	
TN [mg/L] flow weighted	3.02	2.95	1.48	2.48
TP [mg/L] flow weighted	0.54	0.51	0.34	0.47
TSS [mg/L] flow weighted	69	490	205	255
TN Load (g/storm)	4.3	58.9	4.5	
TP Load (g/storm)	0.9	11.0	1.0	
TSS Load (kg/storm)	0.1	7.8	0.5	
Discharge: R10 (Eagle Hill Drive)				
Total Flow (m3)	119.6	103.6	8.5	
TN [mg/L] flow weighted	2.22	1.93	0.71	1.62
TP [mg/L] flow weighted	0.28	0.26	0.12	0.22
TSS [mg/L] flow weighted	71	113	14	66
TN Load (g/storm)	265.9	140.8	7.2	
TP Load (g/storm)	33.5	20.2	1.2	
TSS Load (kg/storm)	8.5	5.2	0.1	
Discharge: R14 (Herring Pond Road)				
Total Flow (m3)	23.7	26.5	4.2	
TN [mg/L] flow weighted	4.25	0.63	0.77	1.88
TP [mg/L] flow weighted	0.35	0.10	0.07	0.17
TSS [mg/L] flow weighted	210	39	19	89
TN Load (g/storm)	93.5	17.9	3.2	
TP Load (g/storm)	7.8	2.7	0.3	
TSS Load (kg/storm)	4.5	0.9	0.1	