4 Kittridge Road, Buzzards Bay, Massachusetts 02542

Green Center Two-Month Urine Diversion Project Final Report

March 13, 2024

Introduction

Surface water bodies and groundwater aquifers across Cape Cod have become increasingly polluted with nutrients due to the combination of overdevelopment and inadequate wastewater management practices. When added to freshwater and marine surface waterbodies via groundwater flow, excess nutrients (nitrogen and phosphorus) degrade water quality, damage natural habitat, fuel harmful algal blooms, and threaten public health. Interestingly, human urine has been identified as the leading source of these excess nutrients in wastewater. This realization has stimulated growing interest in an innovative nutrient management strategy called urine diversion or UD. UD is a practice where urine is separated from the conventional waste stream using specialized toilet and urinal fixtures to prevent water pollution at the source, reduce water usage, and capture nutrients that are valuable as fertilizer for farms and gardens. The Rich Earth Institute[1], a non-profit organization based in Brattleboro, Vermont, has been successful in developing a community wide UD program where urine is collected, processed and distributed to local farmers to offset or replace their need for conventional fertilizers. Many Cape Cod residents see UD as an opportunity to reduce pollution at lower cost than conventional approaches and with the added benefits of nutrient recycling and overall improved ecological sustainability.

Project Overview

The non-profit Green Center of Falmouth, MA[2] is a long-time proponent of sustainable living practices including, most recently, a concerted effort to promote and implement urine diversion. Beginning in August of 2023 the Green Center initiated this project to assess how much urine volume could be collected and what amount of nutrients could be diverted from residential wastewater flows using UD. With this information, potential watershed-scale nutrient pollution reduction benefits of UD could be better understood.

To collect the necessary data, the Green Center identified a group of project participants and distributed portable collection containers called "cubies," (pictured) which were developed by the Rich Earth Institute. These simple UD devices consist of a cube shaped plastic container, usually of 2.5 or 5-gallon capacity, and fitted with a funnel for urine collection. The opening inside the funnel is valved by a plastic ball that serves to allow urine in but keep odors from leaving the container.

With approval from the Falmouth Board of Health the Green Center also distributed plastic 55-gallon drums where participants transferred their collected urine from the cubies for

[1] https://richearthinstitute.org/
[2] https://newalchemists.net/

longer term storage. Storage drums were typically located outside adjacent to households or inside garages.

Participants were instructed to divert as much of their urine into these systems as possible for a 2-month period. Following recommendations from the Rich Earth Institute they were also advised to add a cup of white vinegar to their cubies before usage and after each emptying to acidify the urine, which helps to stabilize the nitrogen and prevent odors from ammonia off-gassing. Cubie funnels could also be cleaned by spritzing with a white vinegar filled spray bottle after each usage.

The Green Center contracted with the Massachusetts Alternative Septic System Technology Center (MASSTC) to conduct volume measurements and sampling and to collect and manage all diverted urine at the completion of the project.

Discussion and Results

At the 41 participating households an average of 1.5 people diverted their urine (62 people total) about 80% of the time they were at home. Participants collected their urine in cubies and transferred to their storage drums repeatedly as needed during the study period. A few participants required additional storage barrels to contain their full volume during the test period. All participants successfully collected urine throughout the study period and many plan to continue indefinitely.

MASSTC Environmental Project Assistant, Bryan Horsley, completed all volume measurements and sample collections per the following process. All applicable MASSTC Standard Operating Procedures were adhered to throughout the effort.

1. **Measure Volume**: The volume of each storage barrel was documented by measuring the depth of urine in inches and then converting to gallons using a conversion guide made by the Green Center. All storage barrels used in this project were of the same geometry allowing this simple depth to volume conversion except for one site where collected urine was stored in smaller containers with clearly marked volume graduations.
2. **Mix**: Before collecting samples, each storage barrel was thoroughly mixed using a combination of tipping the barrel back and forth and circulating urine inside the barrel using a small electric pump. This procedure seemed effective at producing a well-mixed sample as indicated by consistent color and cloudiness passing through the clear pump tubing while circulating and sampling.
3. **Sample**: Once the barrel was well mixed samples were collected into prelabeled sample bottles using a small electric pump. Each sampling event required three bottles as follows: Nitrate and Nitrite in a plastic 250mL bottle with no preservative, Total Kjeldahl Nitrogen in a 250mL plastic bottle with sulfuric acid, and Total Phosphorus in a 250mL plastic bottle with sulfuric acid. Once collected, the bottles were capped and placed in a cooler with ice and delivered to the Barnstable County Water Quality Lab for analysis. Chains of custody were completed to document proper sample handling, storage and hold times.

4. **Measure Field Parameters**: At the same time as sampling, field parameters were measured using a YSI ProDSS handheld instrument which analyzed in-situ for temperature, pH, conductivity, and dissolved oxygen.

Volume measurement and sampling of storage tanks was completed between October 5, 2023, and February 5, 2024 as close as possible to exactly 2-months (62-days) after the start of collection. Participants began collecting at different dates which allowed sampling to spread over multiple months. Volume measurements for those sites that were collected before or after the 2-month mark were adjusted by calculating daily average collection volume (days since start divided by total volume measured) and multiplying by 62 days to estimate the urine volume collected at the 62-day project end date as accurately as possible.

The total volume of urine collected at the 2-month mark across all participants was calculated at 1,003 gallons (avg. per house: 29-gals, max: 71-gals, min: 9-gals). See Graph 1. below for volumes collected at each of the 41 households.

Concentrations of total nitrogen (TN) and total phosphorus (TP) were analyzed from samples collected. TN was found by adding results of Nitrate, Nitrite and Total Kjeldahl Nitrogen analyses. The average concentration of TN across all households was 7,267 mg/L and TP was 469 mg/L confirming that urine is a highly concentrated nutrient source. For comparison, average nitrogen concentration in residential wastewater is typically in the range of 40 to 100 mg/L.

The total nutrient load (concentration x volume) collected across all sites at the 2-month date was 30.2 kg TN and 2.0 kg TP. The average nutrient load diverted per household at the 2-month date was 0.74 kg TN and 0.05 kg TP. Graphs 2 and 3 below offer visual depiction of these nutrient analyses at the 2-month date.

Per conversations during sampling visits and review of pH data, participants seemed to vary in their completion of vinegar addition recommendations with some adding a cup to the cubie before adding urine, some just spritzing the funnel after usage, and others using no vinegar at all. This variable likely had a minor effect on volume and nutrient concentration results due to dilution but not on the total nutrient load collected considering that all stored urine was sealed in air-tight containers and thus potential ammonia off gassing and associated nitrogen loss was minimized. pH field measurement results were likely affected by variable vinegar (acetic acid) addition. Fresh urine is typically close to neutral acidity (pH 7) but over time in storage it naturally increases in pH as urea is converted to ammonia and reaches basic conditions in excess of pH 9. The addition of vinegar acidifies the urine, which prevents the urea to ammonia conversion and results in pH values below 7. Stored urine from this study ranged in pH from minimum 4.4 (assume vinegar addition) to maximum 9.8 (assume no vinegar addition) with an average of 8.3.

See Table 2. below for complete project data.

Of the 41 participating locations 26 requested to have their stored urine and storage barrels removed at the end of the study. MASSTC worked with the for-profit company Wasted[3] to pick up and transport all collected urine

[3] https://wasted.earth/

to MASSTC at the end of January 2024. As most participants continued to collect urine beyond the 2-month project end date there was considerably more urine stored at each location at the pump out dates. Approximately 1,000 gallons of urine was delivered to MASSTC, where it is currently stored for future usage in research and testing applications. The remaining 15 participants opted to keep their urine and storage tanks for continued collection and usage on their properties. Many participants have indicated that they intend to continue diverting their urine with this method as a means of source pollution control within their respective watersheds. Many more participants indicated they would continue the practice of UD if there were a service available to complete tank pump outs and system maintenance on a regular basis.

Conclusions

To assess the potential nutrient management benefits of UD at watershed scale implementation we can compare our findings with the proposed sewer expansion project described in the Great Pond Targeted Watershed Management Plan (TWMP) for the nitrogen impaired Great Pond watershed in Falmouth, MA. In section 4.2.2 Project Phasing of the Great Pond TWMP Final Report it is stated that Phase 1 will entail the extension of sewer connections to approximately 811 dwelling units in the Teaticket Acapesket Sewer Service Area.[4] Table ES.2 Nitrogen Budget for Great Pond to Achieve Nitrogen TMDL Compliance in the Great Pond TWMP Executive Summary indicates that sewer connections to these 811 units in Subarea 1 would remove an estimated 2,890 kg/year of TN.[5] In comparison with the rate of nitrogen load removal we documented during this UD study, implementing UD at 811 parcels would result in diversion of 3,578 kg/year, roughly 30% more than the projected nitrogen removal by the planned sewer expansion. See Table 1 below outlining how this number was calculated.

TN load diverted/41 homes/2 months	30.15	kg
TN load diverted/home/2 months	0.74	kg
Potential TN load/ home/year	4.41	kg
Potential TN load/811 homes/year	3,578.36	kg

Table 1. Data of Nitrogen Removal

It's important to note that greater nutrient removal performance from UD as compared with sewering is impossible given that sewering would effectively remove all residential wastewater from the watershed including 100% of the urine plus additional black and grey water, which UD would not remove. The higher UD performance results identified in this study can be explained by the fact that the projected sewering nutrient removal performance is based on models that often significantly underestimate the nutrient concentration in residential wastewater. This means that the actual nutrient removal performance of sewering these 811 parcels would be higher than the TWMP projected amount noted above.

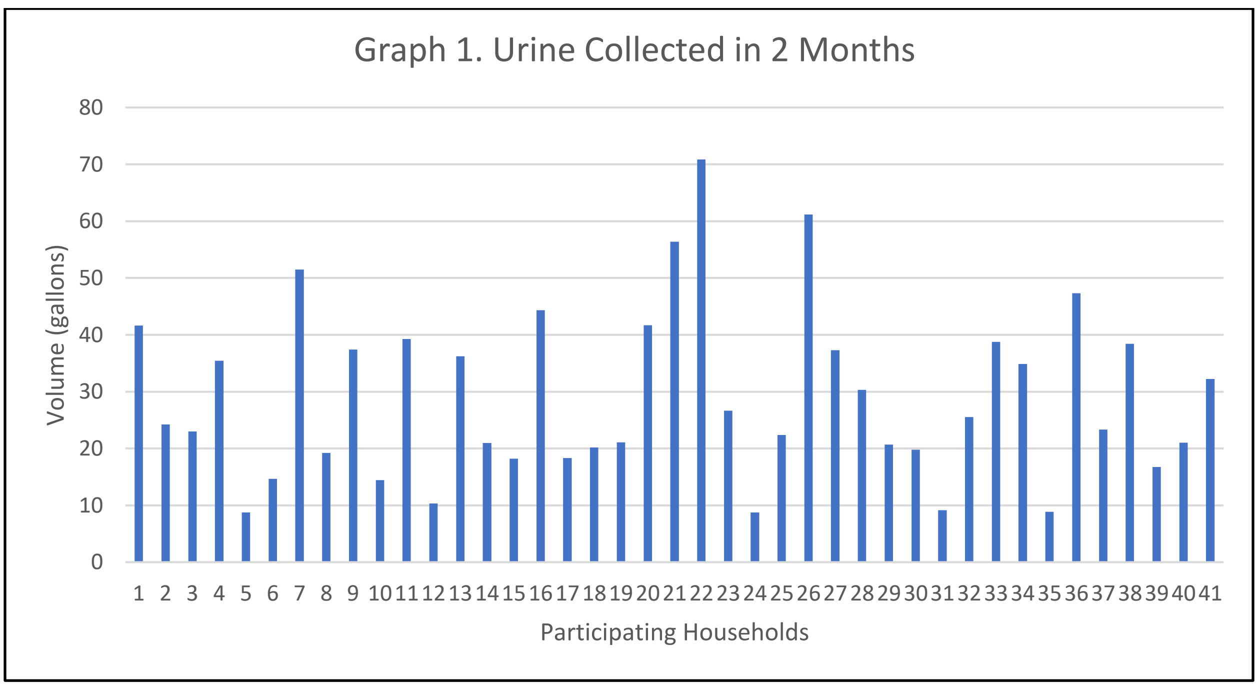
In contrast with the modeled performance projections of the sewering project, the urine diversion nutrient concentrations measured in this study are real values which is why UD appears to perform better than the

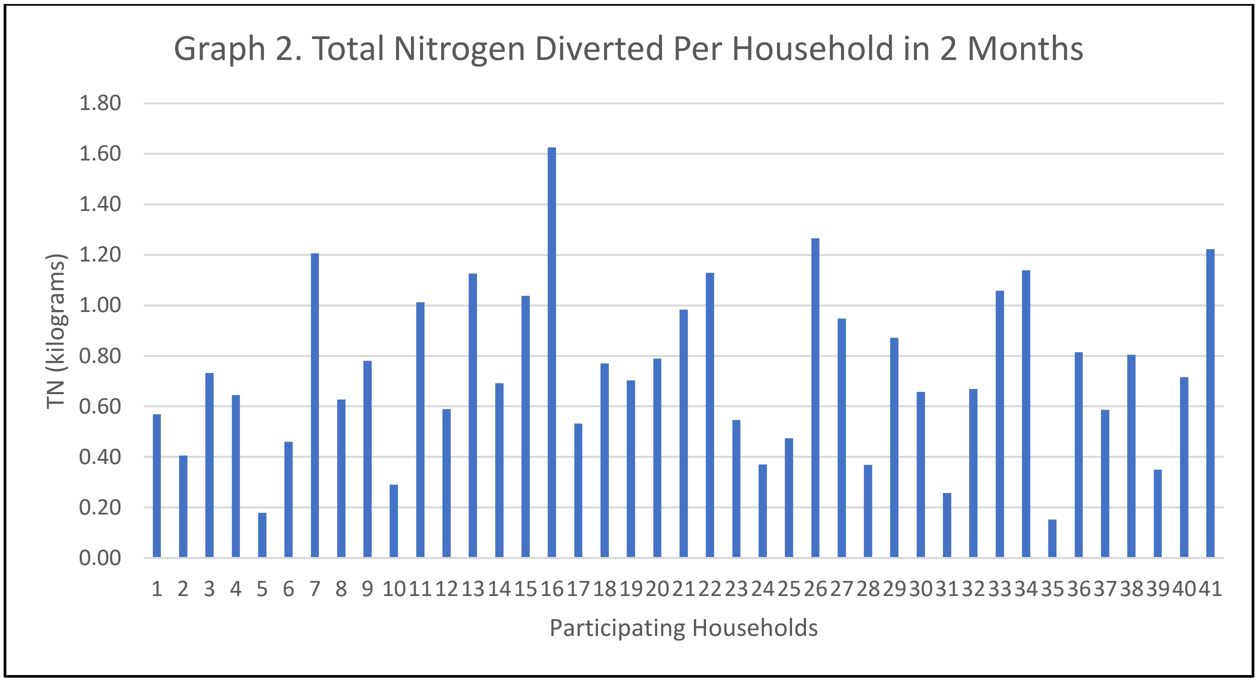
[4] https://www.falmouthma.gov/DocumentCenter/View/13256/Great-Pond-TWMP-Final-Report---Section-4
[5] https://www.falmouthma.gov/DocumentCenter/View/13248/Great-Pond-TWMP-Final-Report---Executive-Summary

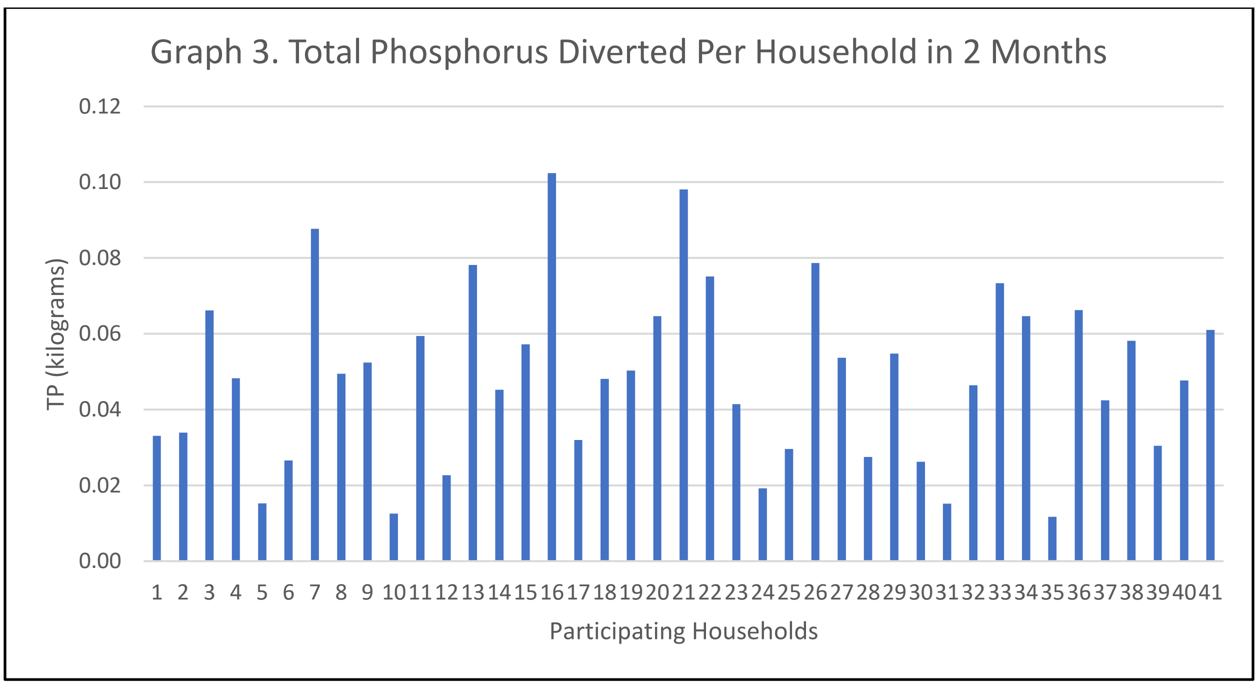
proposed sewering project we are comparing with. It is also important to note that the results of this study were based on approximately 80% UD participation and thus if all conventional toilet fixtures were replaced with UD fixtures, 100% participation could be achieved, which would result in greater nutrient removal performance with UD. Despite these inconsistencies the findings in this report show that UD can produce very high-performance nutrient removal likely at lower cost, lower energy usage and lower greenhouse gas emissions and with the added benefits of water conservation and reclamation of nutrients as beneficial fertilizer products. These results and added benefits indicate that UD is a valuable tool for municipalities to utilize in their watershed management planning process and deserves further consideration for widespread implementation.

Despite these very promising performance results there remain challenges to overcome before UD can be deployed beyond pilot scale, most notably including regulatory approvals and development of infrastructure for collection, transport, processing, and distribution. While these are not insignificant challenges there is a growing base of support and example implementation projects across the U.S. and internationally indicating that they can be overcome. In Massachusetts, state regulators are actively assessing UD's potential as a nutrient management approach and identifying pathways for approval. Research is underway to further assess efficacy and safety, multiple processing facilities are in development, and there is interest among the business community to mobilize and provide the needed infrastructure and workforce components.

The findings of this project indicate that UD has great potential to serve as an efficient and sustainable nutrient management approach for watersheds impacted by nutrient pollution and should be considered an important tool to meet nutrient management goals.




Graph 2. Total Nitrogen Diverted Per Household in 2 Months
TN (kilograms)
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Participating Households


Graph 3. Total Phosphorus Diverted Per Household in 2 Months
TP (kilograms)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
Participating Households

MASSTC

The Massachusetts Alternative Septic System Test Center

4 Kittridge Road, Buzzards Bay, Massachusetts 02542

Table 2. Green Center UD Project Data

Site ID	Collection Start Date	Sample Date	# Days	Volume at sample date (gals)	Volume/day (gals)	Volume at 2 months (62 days)(gals)	Volume at 2 months (L)	TN (mg/L)	TP (mg/L)	TN/2 months (kg)	TP/2 months (kg)	TN/year (kg)	TP/year (kg)	pH
1	2-Aug	5-Oct	64	43	0.67	42	158	3608	210	0.57	0.03	3.41	0.20	9.4
2	2-Aug	5-Oct	64	25	0.39	24	92	4420	370	0.41	0.03	2.43	0.20	7.1
3	4-Aug	5-Oct	62	23	0.37	23	87	8408	760	0.73	0.07	4.39	0.40	6.6
4	9-Aug	11-Oct	63	36	0.57	35	134	4808	360	0.64	0.05	3.87	0.29	7.2
5	9-Aug	11-Oct	63	9	0.14	9	33	5380	460	0.18	0.02	1.07	0.09	9.3
6	10-Aug	11-Oct	62	15	0.24	15	55	8308	480	0.46	0.03	2.76	0.16	9.2
7	10-Aug	11-Oct	62	52	0.83	52	195	6189	450	1.21	0.09	7.24	0.53	9.4
8	10-Aug	12-Oct	63	20	0.31	19	73	8612	680	0.63	0.05	3.76	0.30	9.3
9	11-Aug	12-Oct	62	37	0.60	37	142	5516	370	0.78	0.05	4.69	0.31	8.9
10	12-Aug	12-Oct	61	14	0.23	14	55	5319	230	0.29	0.01	1.74	0.08	9.3
11	13-Aug	12-Oct	60	38	0.63	39	149	6812	400	1.01	0.06	6.07	0.36	9.4
12	13-Aug	18-Oct	66	11	0.17	10	39	15069	580	0.59	0.02	3.54	0.14	9.6
13	14-Aug	18-Oct	65	38	0.58	36	137	8208	570	1.13	0.08	6.76	0.47	9.4
14	14-Aug	18-Oct	65	22	0.34	21	79	8715	570	0.69	0.05	4.15	0.27	4.6
15	14-Aug	18-Oct	65	19	0.29	18	69	15053	830	1.04	0.06	6.23	0.34	5.9
16	15-Aug	19-Oct	65	47	0.72	44	168	9681	610	1.63	0.10	9.75	0.61	9.5
17	20-Aug	19-Oct	60	18	0.30	18	69	7661	460	0.53	0.03	3.19	0.19	9.0
18	20-Aug	19-Oct	60	20	0.33	20	76	10085	630	0.77	0.05	4.62	0.29	9.5
19	20-Aug	19-Oct	60	20	0.34	21	80	8808	630	0.70	0.05	4.22	0.30	9.2
20	21-Aug	26-Oct	66	44	0.67	42	158	5006	410	0.79	0.06	4.74	0.39	5.2
21	21-Aug	26-Oct	66	60	0.91	56	213	4611	460	0.98	0.10	5.90	0.59	5.6
22	21-Aug	26-Oct	66	75	1.14	71	268	4206	280	1.13	0.08	6.77	0.45	4.4
23	21-Aug	26-Oct	66	28	0.43	27	101	5412	410	0.55	0.04	3.28	0.25	9.5
24	21-Aug	26-Oct	66	9	0.14	9	33	11151	580	0.37	0.02	2.22	0.12	9.3
25	23-Aug	26-Oct	64	23	0.36	22	85	5600	350	0.47	0.03	2.84	0.18	9.3
26	24-Aug	26-Oct	63	62	0.99	61	231	5467	340	1.27	0.08	7.59	0.47	9.5
27	29-Aug	27-Oct	59	36	0.60	37	141	6711	380	0.95	0.05	5.69	0.32	9.4
28	12-Aug	31-Oct	80	39	0.49	30	115	3211	240	0.37	0.03	2.21	0.17	4.8
29	23-Aug	31-Oct	69	23	0.33	21	78	11141	700	0.87	0.05	5.23	0.33	9.3
30	23-Aug	31-Oct	69	22	0.32	20	75	8791	350	0.66	0.03	3.95	0.16	9.1
31	24-Aug	31-Oct	68	10	0.15	9	35	7446	440	0.26	0.02	1.54	0.09	9.5
32	24-Aug	31-Oct	68	28	0.41	26	97	6922	480	0.67	0.05	4.01	0.28	9.2
33	28-Aug	31-Oct	64	40	0.63	39	147	7211	500	1.06	0.07	6.35	0.44	9.4
34	28-Aug	31-Oct	64	36	0.56	35	132	8631	490	1.14	0.06	6.84	0.39	9.4
35	6-Sep	15-Nov	70	10	0.14	9	34	4518	350	0.15	0.01	0.91	0.07	5.2
36	31-Aug	15-Nov	76	58	0.76	47	179	4547	370	0.81	0.07	4.89	0.40	4.5
37	30-Aug	15-Nov	77	29	0.38	23	88	6639	480	0.59	0.04	3.52	0.25	9.7
38	6-Sep	16-Nov	71	44	0.62	38	145	5529	400	0.80	0.06	4.82	0.35	9.3
39	3-Sep	16-Nov	74	20	0.27	17	63	5523	480	0.35	0.03	2.10	0.18	7.1
40	6-Sep	5-Feb	152	60	0.33	21	79	9004	600	0.72	0.05	4.29	0.29	9.8
41	29-Aug	5-Feb	160	60	0.52	32	122	10017	500	1.22	0.06	7.33	0.37	9.6
Max			**160**	**75**	**1**	**71**	**268**	**15069**	**830**	**2**	**0**	**10**	**1**	**9.8**
Min			**59**	**9**	**0.14**	**9**	**33**	**3211**	**210**	**0.15**	**0.01**	**0.91**	**0.07**	**4.4**
Sum			**2870**	**1042**		**1003**	**3798**			**30.15**	**2.0**	**180.9**	**12.0**	
Average			**70**	**31**	**0.47**	**29**	**110**	**7267**	**469**	**0.74**	**0.049**	**4.41**	**0.29**	**8.3**