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Flow model

PLANNING TOOL FOR MANAGING SEWAGE PUMP-OUT STATIONS

BATSECO-BOAT WORK PACKAGE 2, TASK 2.6

Main authors: Fredrik Dunér, Maria Johansson, and Helfrid Schulte-Herbrüggen, Ecoloop AB, Sweden.

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Glossary

Black water	Toilet waste waters generated by humans
Central Baltic	Geographical area which includes land and sea areas around Northern Baltic Sea, southern Bay of Bothnia and Gulf of Finland
Eutrophication	Process of where water is overly enriched mainly by nutrients (P and N) leading to excessive growth of algae and oxygen depletion.
Grey water	Water resulting from washing or cleaning, but does not contain toilet waste
HELCOM	HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area
Holding tank	Fixed tank mounted in a leisure boat where sewage or toilet waste is collected for temporary storage
Leisure boat	Watercraft or recreational craft with hull length commonly less than 24m, that are intended for leisure or sport use
Leisure boat harbour	Refers to home or guest harbour, port or marina
Pump-out station	Device designed to extract and collect sewage (toilet waste) from leisure boats
Sewage collection system	Network of different kind of pump-out stations for the use of boaters
Sludge	Semi-solid matter that is produced by a waste water treatment process or by a sanitation system
Waste water	Water polluted by human waste (incl black and grey waters) or by other human activity, excluding bilge waters generated by the water craft and collected separately

AIS	Automatic identification system (AIS). System by which the position, course and speed of naval vessels can be tracked.
ECA	East coast area (ECA). A grouping of coastal counties in central Sweden
Catchment area	The area surrounding a pump-out station within which leisure boats can be expected to travel in order to empty their holding tank.

S	Volume of sewage added to the pump-out station per day.
B_{catch}	The number of leisure boats present in a pump-out station's catchment area.
AIS_{at}	The number of leisure boats present in a given area, a, during a given time-period, t.
Q_{toilet}	The share of leisure boats in a region that are fitted with a holding tank for toilet waste.
Q_{empty}	The share of boats with a holding tank present in the catchment area of a pump-out station that plan to empty their tank. Expressed in three different ways all estimates are made using one of the three options.
V_{waste}	The amount of waste a leisure boat with a holding tank can be expected to empty.

1. Introduction

1.1. The BATSECO-BOAT project

Visiting leisure boat harbours in the Baltic Sea area fascinates both national and international visitors, many of whom explore the coastal and archipelago areas using small leisure boats. Boat tourism is an important and popular way to spend a summer holiday in archipelagos and coastal areas, which provide beautiful and peaceful maritime nature experiences. Staying and living for weeks in a leisure boat requires similar kind of community services to what we usually have at home but these require a somewhat different organisation. Usually, it is the small boat harbours that provide and sell most of these services to boaters.

The possibility of emptying toilet waste from leisure boats can be considered a fundamental service for boaters, which, when neglected, has a crucial impact on boaters' comfort during their holidays. However, this basic service suffers from problems, such as lack of easily accessible and functional sewage pump-out stations; non-harmonized sewage collection equipment; and lack of easily accessible information regarding location and functionality. It is also important to reduce visitor detours (having to make extra trips to other stations when the nearest station is full or malfunctioning) by improving information regarding the pump-out station network and its' operability. Moreover, it can be difficult for international visitors to know what kind of waste handling and pump-out services that exist. Both Sweden and Finland have an extensive archipelago with an active leisure boat life where boaters commonly cross between the countries. Although toilet waste collection systems have been in place for several years, there is need to address both technical and managerial challenges. In Estonia, where the boating culture is very young, the coastline is open and waters are shallow, the coverage of sewage collection services is low. Thus, it is important to upgrade the service level in Estonia. Cross-border collaboration and exchange of experiences has the potential to facilitate mutual support, good examples, and a more systematic approach to the management of toilet waste from leisure boats across the Central Baltic region.

The BATSECO-BOAT (Best Availabe Technologies of Sewage Collecting for Boat tourism) project is a collaborative project between three countries in the central Baltic region: Finland, Sweden, and Estonia. The aim is to 1) increase tourism across the Central Baltic Region by investing in best available technologies for sewage collection and management and 2) create improved service facilities for leisure boats visiting small harbours in the Baltic Region.

By installing new pump-out stations, the BATSECO-BOAT project also contributes to the objectives of EUSBSR (EU Strategy for the Baltic Sea Region) in keeping the sea cleaner by facilitating collection of nutrients from toilet waste from leisure boats and thereby reducing a source of algal growth and eutrophication. The project supports the tourism industry with a cross-border approach that benefits both entrepreneurs and public authorities, and the Baltic Sea environment as whole.

The main results of the BATSECO-BOAT project include an upgrade of the sewage collection services in 18 leisure boat harbours in Estonia, in Finland and in Sweden. The upgrade is realised by investments into the best available technology of sewage collection, including both new and renovated pump-out stations. This upgrading ensures good level of unified sewage collection services in the participating leisure boat harbours across the Central Baltic region for the next 15-20 years, way beyond the duration of BATSECO-BOAT project.

The BATSECO-BOAT-project continues for three years (2018-2020) and is coordinated by the Brahea Centre at the University of Turku. Other Finnish project partners are Keep Archipelago Tidy, the Swedish partners Ecoloop AB, UCV/Campus Roslagen and Norrtälje municipality and the Estonian partners are Hoia Eesti Merd (Keep the Estonian Sea Tidy) and Viimsi municipality. The BATSECO-BOAT project is funded by EU's Interreg Central Baltic program, the total budget of the project is 1,48 million euro.

1.2. Aim of this report

The goal of this report is to introduce and apply a tool for the management of latrine waste from sewage pump-out stations. The flow-model introduced in subsequent parts is of use both for existing stations that purchase regular emptying services as well as a help in the planning of new ones. Based on data collected as part of the project in addition to generally available information the model is applied to a case study of Norrtälje municipality. Completed using MS Excel the report and model are both easily accessible and can be applied to other municipalities in the Baltic Sea region.

2. Method

This is a short overview of the method; more detailed descriptions follow in the subsections:

A model for predicting the volume of sludge collected in a sewage pump-out station was assumed. The model was based on parameters that the BATSECO-project had collected data on, or parameters for which generally available data could be found. The parameter values where then estimated using this data and the model was tested on statistics from pump-out stations in Norrtälje municipality.

2.1. Purpose of model

The flow model purpose was to be able to plan the emptying of sewage pump-out stations and if possible, also to plan where to place new stations. It was decided that both these purposes could be at least partly achieved by predicting the volume of sewage in a pump-out station during any given time during the boating season. Someone responsible for planning an emptying schedule for sewage stations in an area can use the model to predict how often the stations in the area need emptying and can test a suggested schedule against the model to see if any stations will overflow. Likewise, the model can be used to see how often a hypothetical new station in a given location would need to be emptied.

2.2. Available data

It is assumed that the planner using the flow model will have data on their pump-out stations, such as volumes and location. To be able to predict the flow of sewage into the stations the planner will also need to know how many boat owners are likely to use the station and what volumes these boat owners will empty into the station.

The following datasets were available to us in the development of the flow model:

Data set	**Can be used for**	**Limits and quality of data**	**Availability of the data**
AIS-data – data on boat locations	Predicting the number of boats in an area from traffic in previous seasons.	Not all leisure boats have an AIS-transponder and will therefore not show up in the data set.	Can be recorded for any location in the world, for a fee. The project had access to recorded data in Norrtälje, from the summer season of 2018.
Båtlivsundersökningen 2015	Predicting the number of leisure boats that fit the relevant description, i.e.	The number of respondents relative to the	The report itself can be accessed, in Swedish, from the

	what share of boats that can be assumed to have an AIS-transponder, be fitted with a toilet, make long enough trips to warrant emptying their septic tanks etc.	scope of the survey is relatively low. Thus, some uncertainty regarding how well the results of the survey can be generalized to fit the actual population of boats in Norrtälje.	website of the Swedish transport agency. However, the dataset that the report is based on is owned by the company Point.
Latrin från fritidsbåtar I Stockholms skärgård – innehåll, volym och påverkan på avloppsreningsverk och ekosystem	Predicting the number of leisure boats that are fitted with, and use, their toilet.		Master's thesis by Josefine Klingberg. Available from the website of Uppsala University.

Table 1. The table summarizes the different source material and how to access them.

2.3. Assumed model

The model for predicting volume of sewage in one given pump-out station was assumed as follows:

$S = B_{catch} * Q_{toilet} * Q_{empty} * V_{waste}$

Where:

S = volume of sewage added to the pump-out station per day

B_{catch} = number of boats in the pump-out station's catchment area per day

Q_{toilet} = percentage of boats in the catchment area that have a holding tank for toilet waste

Q_{emtpy} = percentage of boats with a holding tank in the catchment area that plan to empty the tank in the pump-out station

V_{waste} = the volume of waste a boat with a holding tank can be expected to empty

2.4. Case study Norrtälje

As the parameter descriptions above suggests, the final testing was done by fitting the model to the area and activity surrounding each of the pump-out stations currently in use. Since no information was available to suggest otherwise the characteristics and mix of different types of leisure boats in Norrtälje municipality is assumed to be the same throughout. However, to discern how well the datasets Q_{toilet} and Q_{empty} fit the true number of boats active in the area all estimations are made using both the values for Sweden as a whole, as well as the east coast of Sweden, which Norrtälje is part of.

The catchment area for each of the pump-out stations was assigned using AIS data recorded and collected on a weekly basis throughout the summer of 2018. Using geographical information system (GIS) software the routes travelled and locations visited by leisure boat owners as well as an estimate on the number of boats that spend time in a particular area becomes apparent and can be complied. Lacking a more accurate measure great care was taken in attempting to fit a catchment area to each pump-out station as several are placed in relatively proximity to one another along well travelled boating routes, see figure 1.

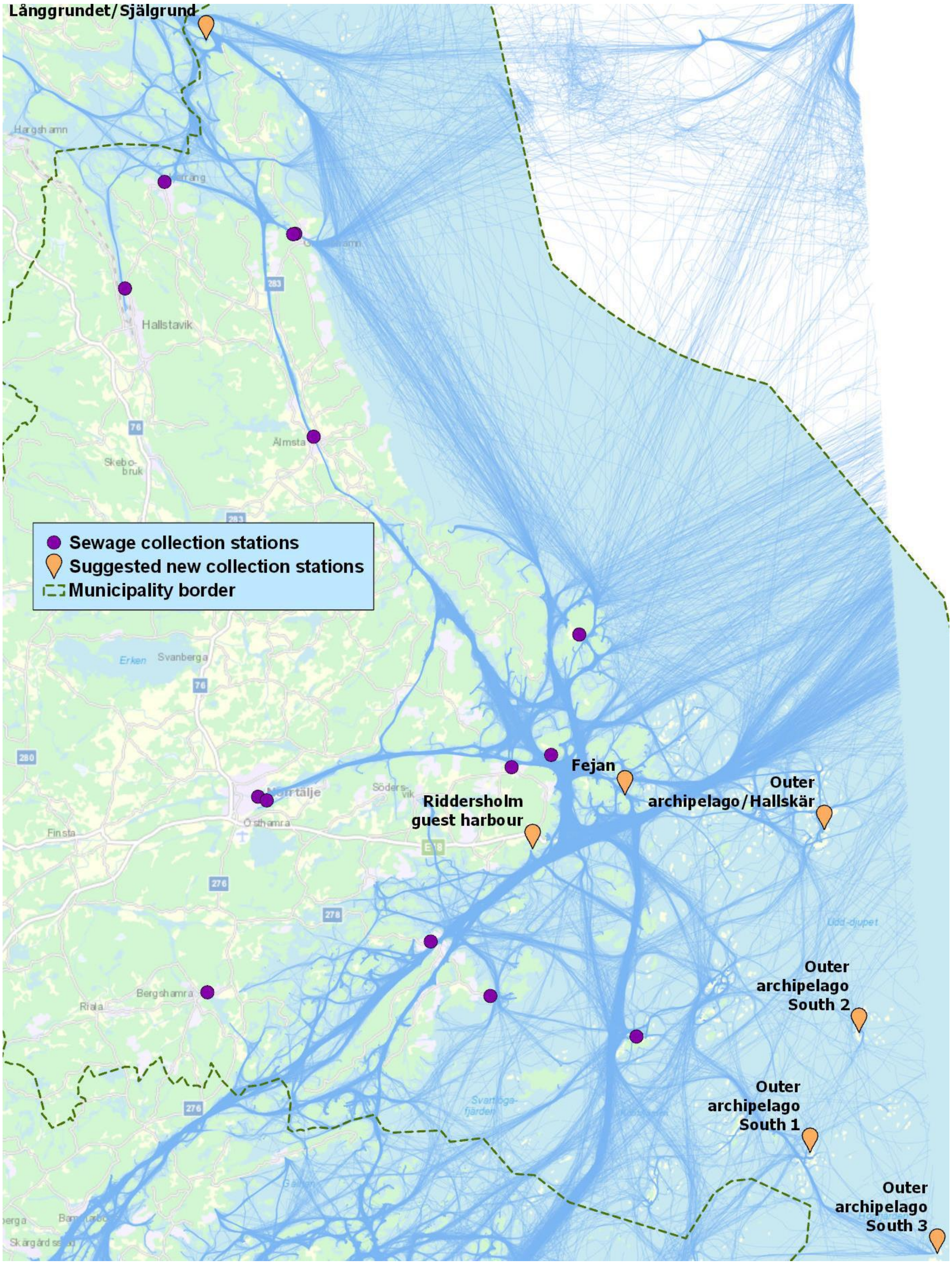

Figure 1. Existing collection points for sewage from small boats (purple dots) and suggestions for localization of new sewage collection points (orange tear-shaped markers). Blue lines represent boat movements recorded from AIS-transponders during the summer of 2018.

3. Results

3.1. Parameter values

The model parameters B_{catch}, Q_{toilet} and Q_{empty} for Norrtälje were estimated using data from the 2015 survey by the Swedish transport agency on the behavior and characteristics of Swedish boatowners, a thesis by Josefine Klingberg, and available AIS-data.

The 2015 survey asks its respondents questions such as what type of boat they own, the equipment fitted to it and the way it is used. The survey divides Sweden into five regions and Norrtälje municipality is assumed to share the characteristics of the east coast of Sweden, as they appear in the survey. Thus, the results can provide an estimate of what share of boats in the Norrtälje area are of a relevant size, are fitted with toilets, are a part of the AIS-network and are used in a way that warrants the need to visit one of the municipality’s pump-out stations. In the following table some of the general statistics for the east coast area (ECA) used to estimate the model parameters are presented alongside Sweden as a whole. The east coast area includes four counties, Stockholm, Södermanland, Östergötland and Gotland. The data has been sorted to exclude leisure boats in need of repair or refurbishment and at the time of survey where not fit for use.

	ECA	**Sweden**
Average number of people per boat.	2,7	2,4
Average days of use may-aug.	18,1	17,0
Share of all leisure boats that fit one of the following categories: motorboats with a cabin and facilities for staying overnight (1), sailboats with a cabin and facilities for staying overnight (2), sailboats with a cabin and limited facilities for staying overnight (3).	25,5%	17,5%
Share of all leisure boats that are fitted with a toilet that can be emptied using a pump-out station.	6,2%	3,4%
Share of all leisure boats that are fitted with a toilet that can be emptied using a pump-out	88,9%	87,0%

station that are of type 1, 2 or 3.		
Share of leisure boats that are fitted with an AIS-transponder.	2,1%	1,8%
Share of all leisure boats that are fitted with an AIS-transponder that are of type 1,2 or 3.	100,0%	75,0%
Share of leisure boat owners that go on trips lasting a full weekend or longer.	17,2%	9,3%

Table 2. The table summarizes some general statistics for the east coast area as well as for Sweden as a whole.

Using the information on the share of boats that are a part of the AIS system, as presented above, together with the AIS-data for Norrtälje, which provides information on the number of boats active in an area during a given period of time the parameter B_{catch} can be estimated. The AIS data available for Norrtälje was compiled on a weekly basis throughout the summer of 2018. Only 2,1% of all leisure boats are fitted with an AIS-transponder, but all that are active in the east coast region can be expected to be of a relevant type. As such there exists a further 48 boats for every one that is part of the AIS-network and the final value of B_{catch} is a function of the assumed number of boats, AIS, in a given area, a, during a specific period of time, t, and can be described as follows:

$$B_{catch} = \left(\frac{All\ active\ leisure\ boats\ in\ the\ ECA}{Active\ leisure\ boats\ in\ the\ ECA\ fitted\ with\ an\ AIS\ transponder}\right) * AIS_{at}$$

The catchment area for any of the considered pump-out stations, defined in the above equation as the “a” parameter, is exemplified in the map below. It shows the amount of traffic in the area surrounding Rödlöga throughout week 31 of 2018. It is assumed that boatowners at any time will look to empty their toilet tank in the pump-out station closest to them. As such, the catchment area for Rödlöga roughly extends up until boatowners are closer to the pump-out stations at Blidö and Lidö.

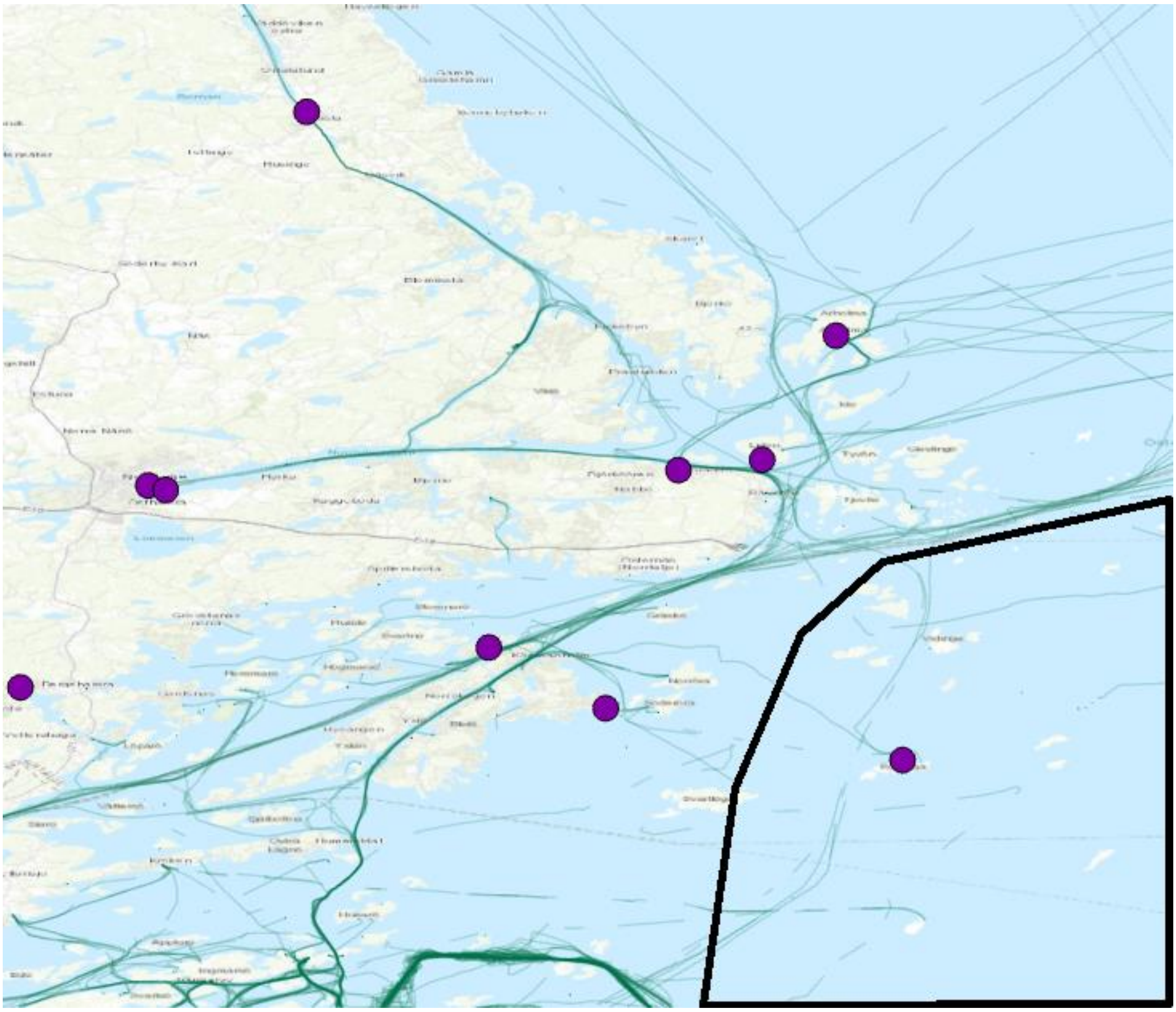

Figure 2. Catchment area for the pump-out station at Rödlöga, delimited by the black polygon. The green lines indicate boat traffic during week 31 of 2018 while the purple dots represent pump-out stations.

The parameter Q_{toilet} is estimated as the share of all boats in the region that are in usable condition, fitted with a toilet that can be emptied using a pump-put station and that are of one of the following types: motorboats with a cabin and facilities for staying the night (1), sailboats with a cabin and facilities for staying the night (2) or sailboats with a cabin and limited facilities for staying the night (3). Of the total number of boats active the region 5,5% are estimated to have a toilet with a holding tank that can be emptied in a pump-out station and fit the description.

$$Q_{toilet} = \frac{\sum_{i=1}^{3} Active\ leisure\ boats\ in\ the\ ECA\ fitted\ with\ a\ tank\ that\ can\ be\ emptied_i}{All\ active\ leisure\ boats\ in\ the\ ECA}$$

Finally, the share of boats with a holding tank that plan on emptying it in one of the pump-out stations is estimated in a few different ways in an effort to find the instrument that best represents the behavior of those agents. The first is based on the type of travel that can be expected to result in a need for emptying the tank and includes those leisure boat owners that go on trips lasting either a full weekend or longer who own a boat with a toilet tank.

$$Q_{empty1} = \frac{\sum_{i=1}^{3} Active\ leisure\ boats\ in\ the\ ECA\ fitted\ with\ a\ tank\ used\ for\ trips\ lasting \geq 2\ days_i}{All\ active\ leisure\ boats\ in\ the\ ECA}$$

The second attempt is based on willingness to use the stations. This is estimated using the frequency by which owners of boats with tanks for toilet waste claim that they use a pump-out station when emptying their tanks. Respondents range from those who never use a pump-out station to those who use one every time. To simplify the summation of answers four boat owners who use a pump-out station one out of four times are counted as being equal to one boat owner who use the station every time that they empty their tank etc. On average 55% of those who own a boat with a tank visit one of the pump-out stations when it is time to empty it. Important to note is that the sample size is very small on a regional level, and only slightly larger on a national one. For that reason, the values presented and used are for all leisure boat owners in Sweden.

Frequency by which the tank is emptied using a pump-out station	**Share of all leisure boat owners with a tank**
Never	19,0%
1/4	9,5%
1/2	9,5%
3/4	19,0%
Always	33,3%

Table 3. The table summarizes the frequency by which boat owners of boats fitted with toilet tanks claim that they use pump-out stations to empty them.

$$Q_{empty2} = \frac{\sum_{i=1}^{3} Share\ of\ all\ leisure\ boat\ owners\ who\ empty\ their\ tank\ using\ a\ station_i}{\sum_{i=1}^{3} Share\ of\ all\ leisure\ boat\ owners\ who\ own\ a\ boat\ with\ a\ tank_i}$$

The third attempt is based on the average number of times leisure boat owners with a toilet tank empty their tank, as reported by Klingberg (2017). A survey conducted as part of her paper indicates that the average boat owner empties their tank eight times every year. The probability that a boat owner will empty their tank any given week can be estimated to 15%.

$$Q_{empty3} = \frac{Number\ of\ times\ boat\ owners\ empty\ their\ tanks\ per\ year}{Number\ of\ week\ per\ year}$$

The parameter values used throughout estimations for individual pump-out station catchment areas are summarized in the table below.

	B_{catch}	Q_{toilet}	Q_{empty1}	Q_{empty2}	Q_{empty3}
Norrtälje/ECA	$48*AIS_{at}$	0,06	0,17	0,55	0,15
Sweden	$43*AIS_{at}$	0,03	0,09	0,55	0,15

Table 4. The table summarizes the parameter values used in estimating the number of boats that can be expected to visit one of the pump-out stations in Norrtälje.

The model parameters together give a measure of the number of boats that can be expected to visit either of the pump-out stations in Norrtälje. To estimate the average amount of waste that each boat will empty when visiting one of the stations, V_{waste}, two different methods are used based on either the average amount of waste produced by a person, the average amount of water used when flushing the toilet, the time spent at sea and the number of people on each boat or the survey responses collected by Klingberg (2017) on the average toilet tank size, 51 liters, and to which extent it is full when emptied, 66%.

$$V_{waste1} = Persons\ per\ boat * Waste\ per\ person\ per\ day * Time\ spent\ at\ sea$$

$$V_{waste2} = Average\ toilet\ tank\ size * Average\ percentage\ when\ emptied$$

The average Swedish person produces 140 grams of feces and 1500 milliliters of urine per day (Vinnerås et al. in Maurya, 2012). Assuming the average person uses the toilet four to eight times every day and that the average amount of water consumed when flushing a typical boat toilet is 1,7 liters, see appendix for a cross-section of common boat toilets, the total volume of waste per person per day can vary between 8,8 and 15,6 liters. However, some uncertainty exists regarding the extent to which those who own a boat with a toilet choose to use it instead of one on land. The model is initially estimated using the average volume per person per day, 12,2 liters. To test how the model performs when the assumption of how often people use their boat toilet changes it is re-run again for all estimates with the assumption that it is used one quarter of the times, half the time and three quarters of the time, the results are available in the appendix.

Combining all the various parameters the results presented in the following parts are based on the following two models:

$$S = B_{catch} * Q_{toilet} * Q_{emptyi} * V_{waste1} \quad (1)$$

$$S = B_{catch} * Q_{toilet} * Q_{emptyi} * V_{waste2} \quad (2)$$

3.2. Testing against statistics from Norrtälje

To determine how well the model describes the volume of sewage that is produced as a consequence of leisure boating in Norrtälje the results are compared to available data from a subsection of the municipality's pump-out stations on how much and how often they are emptied. Most stations are directly connected to local treatment plants and as such do not have readily available data on what volume they process but there are a few exceptions.

3.2.1. Arholma and Rödlöga

The two floating pump-out stations at Arholma and Rödlöga are both emptied "by hand" and as such the model can be compared against them. Information provided by the contractor charged with emptying them points towards a consistent issue with both being prone to overflowing before emptied. The pump-out station at Arholma was emptied three times at capacity, 6 m^3, and the one at Rödlöga four times, also when full at 6 m^3. This is equivalent to a total amount of waste per year of 18m^3 and 24m^3 respectively. The table below presents the model results. The first column lists the names of the respective pump-out stations, the second the amount of waste emptied per year and the third, fourth and fifth the results of model (1) and (2) using either Q_{empty1}, Q_{empty2} or Q_{empty3} as a measure for the share of boatowners who plan on emptying their tank. The model is estimated using values for the ECA, as described above, with results using parameter values for Sweden being available in the appendix.

Pump-out station	**Waste per year (m^3)**			
	2018	$S = ..* Q_{empty1} * V_{waste1} / S = ..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1} / S = ..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1} / S = ..* Q_{empty3} * V_{waste2}$
Arholma Österhamn	18	38,98/30,75	126,1/99,5	34,39/27,14
Megelskär, Rödlöga	24	36,77/29,02	118,98/93,88	32,45/25,6

Table 5. The table summarizes the amount of waste emptied at the pump-out stations at Arholma and Rödlöga during 2018 alongside the different estimates of the flow-model for that same period.

Instantly noticeable is the marked difference between the model using Q_{empty2} as a measure for the willingness of boatowners to empty their toilet tanks in a pump-out station and the two other estimates. The survey question on which the parameter is based suffers from a lack of respondents in comparison to the others, only consisting of 22 actual answers. Because of that and the outlying results the second model, while still presented alongside the two others, will not be interpreted as a measure of actual activity in the regions considered. However, it still serves as a useful starting point for further discussion as it both indicates a greater need for collection points and the capacity of them as well as how the model can potentially be enhanced and what information would be needed to improve it. The model values using parameters based on data for Sweden are, unsurprisingly, significantly lower. This reflects the differences in types of boats, the equipment they are outfitted with and way in which they are used compared to the ECA, as reported in table 2. As the predicted values are so markedly lower than the amounts reported for the same period the parameter values can be expected not to represent the agents active in Norrtälje.

The following figures illustrate the amount of weekly waste as well as accumulated waste throughout the season as predicted by the flow-model for the pump-out stations at Arholma and Rödlöga respectively.

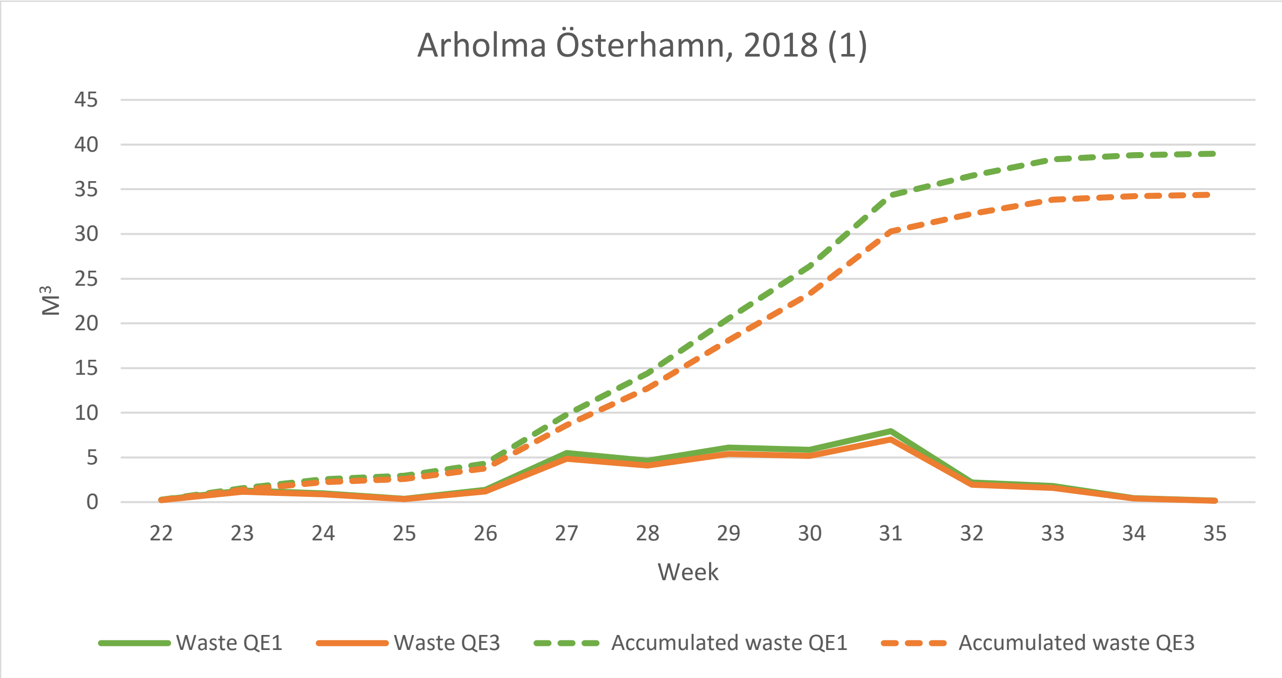

Figure 3. Amount of waste predicted at Arholma during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste1}.

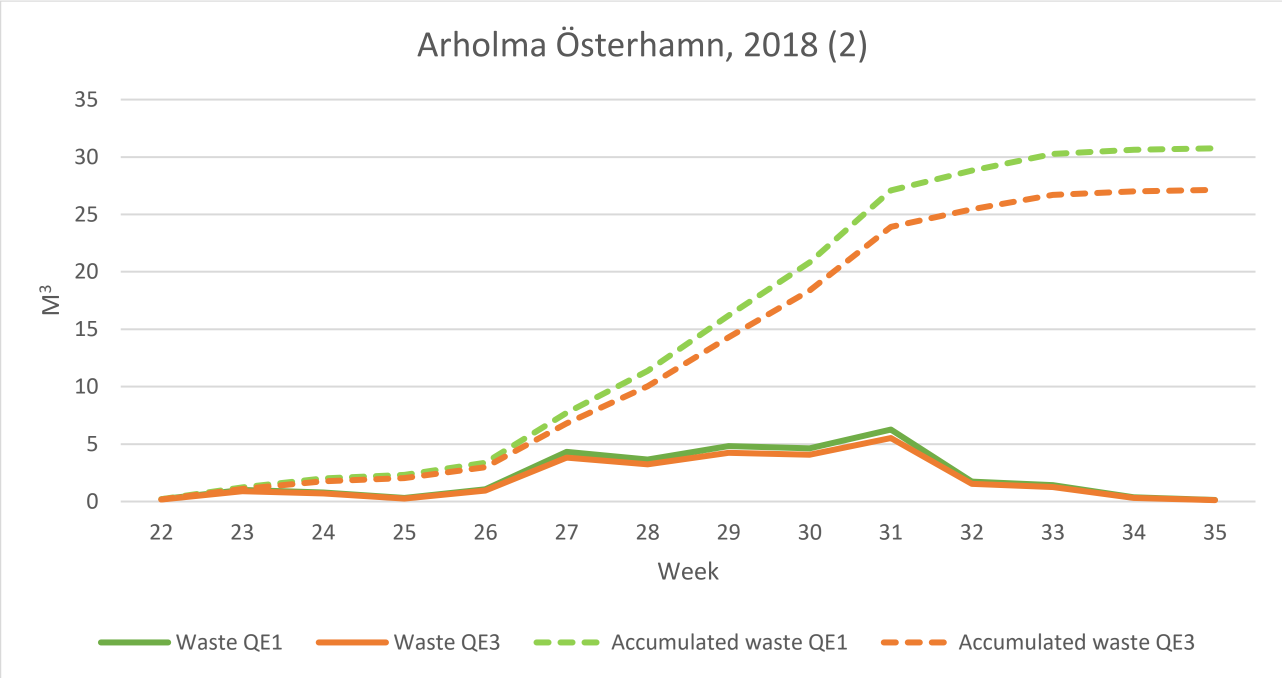

Figure 4. Amount of waste predicted at Arholma during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste2}.

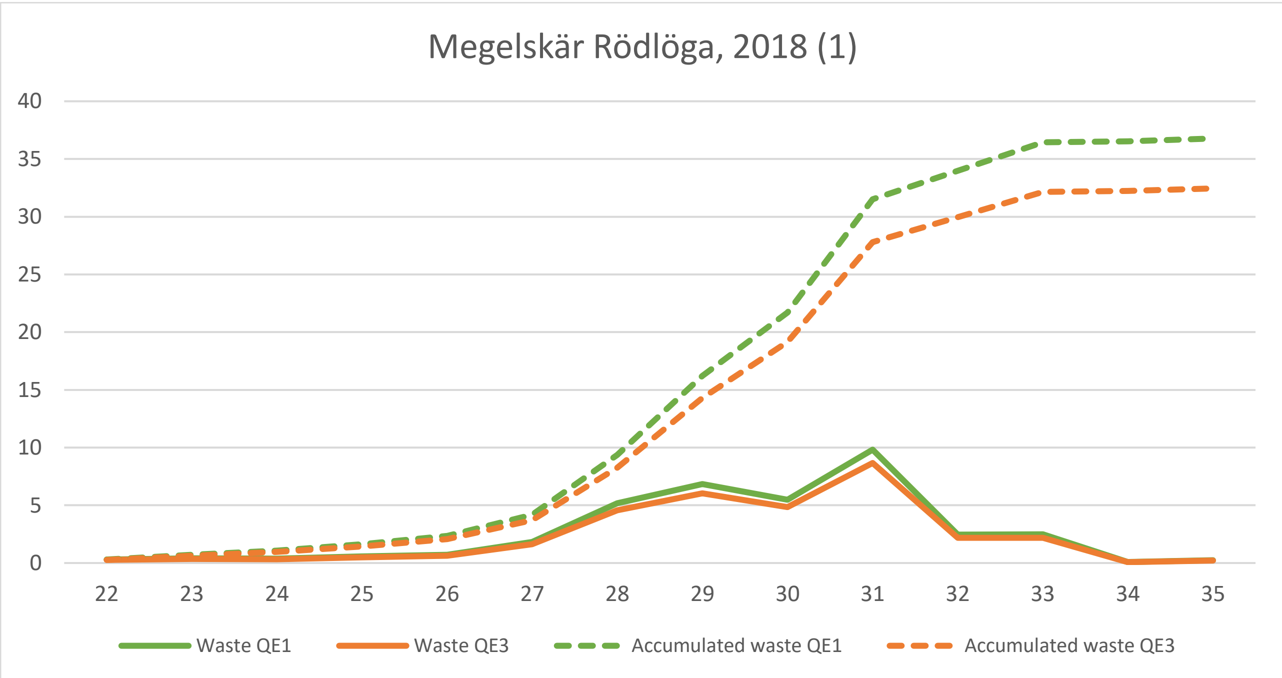

Figure 5. Amount of waste predicted at Rödlöga during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste1}.

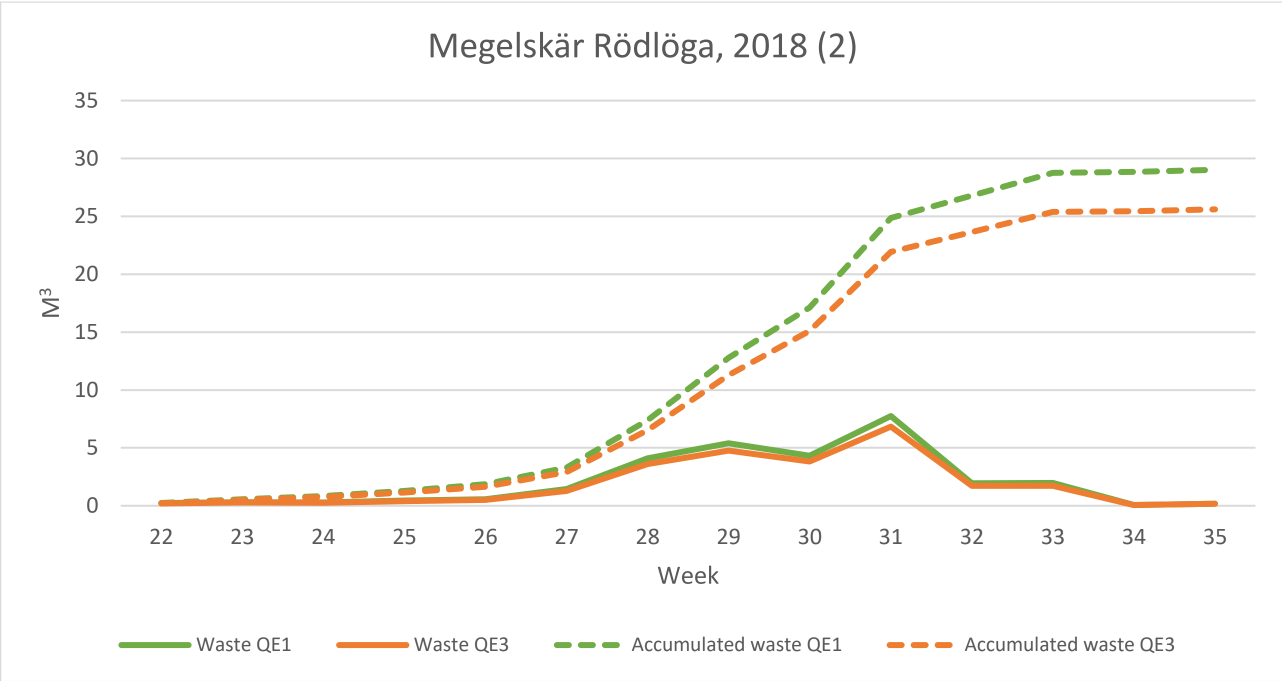

Figure 6. Amount of waste predicted at Rödlöga during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste2}.

The model predicts greater volumes of waste generated during 2018 than the amount that was collected. Another point of note is the relatively short peak, week 27 until 31, during which most of the waste is generated. Changing the assumption on how frequently the average individual uses their boat toilet to three quarters of the time the results of model 1 align with those of model 2, these results can be seen in the appendix.

It is possible that the discrepancy between the model results and the volumes that were emptied in 2018, rather than being dependent on some inherent flaw of the model, is the result of "overcrowding" and as described by the contractor point towards a greater demand for accessible options for emptying waste tanks than what is currently available. Similarly, it could suggest that problems encountered where the tanks overflow are due to them being emptied too infrequently during that specific period as opposed to a lack of capacity.

3.2.2. Norrtälje

As described, most pump-out stations are connected to local treatment plants and do not collect information on the amount of waste they process. Lacking data for the actual values processed at the remaining ten pump-out stations the predicted values for each are reported on their own in table 6 below. Free of a value to compare the model results with the outputs should be regarded as a general indication of how great the need for pump-out stations and waste collection is, rather than how well the need is met. Both Grisslehamn and Norrtälje harbor areas house two separate pump-out stations and to avoid issues in defining the catchment area for each they are combined into a single entity. Values estimated using parameter values for Sweden are available in the appendix.

Faced with a similar issue, Klingberg (2017) was able to access information on the number of boats that had connected to few of the pump-out stations in Norrtälje municipality until and during 2016 and, using estimates on the amount of waste typically emptied, assess the total amount of waste. These include the pump-out stations at Härräng, Älmsta, Gräddö and Furusund. To give some context to the results of the flow-model they are, to the extent possible, compared to the volumes in 2016 in table 7.

Pump-out station	**Waste per year (m³)**		
	$S = ..* Q_{empty1} * V_{waste1} / S =..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1} / S =..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1} / S =..* Q_{empty3} * V_{waste2}$
Hallsta Båtklubb	33,54/26,46	108,5/85,62	29,59/23,35
Herrängs Båtklubb	38,37/30,28	124,14/97,96	33,86/26,72
Grisslehamn	38,29/30,21	123,86/97,74	33,78/26,66
Grisslehamns Marina			
Grisslehamn, Västra hamnen			
Älmsta Gästhamn	33,97/26,8	110,0/86,72	29,97/23,65
Lidö Gästhamn	20,65/16,3	66,82/52,73	18,22/14,38
Gräddö Hamn	75,43/59,52	244,03/192,56	66,6/52,52
Furusunds Gästhamn	76,03/59,99	245,98/194,1	67,09/52,94
Blidö Bromskär	18,91/14,92	61,16/48,26	16,68/13,16

Bergshamra Båtklubb	44,78/35,34	144,88/114,32	39,51/31,18
Norrtälje	155,38/122,61	502,71/396,68	137,1/108,19
Norrtälje Gästhamn			
Norrtälje Seglarsällskap			

Table 6. The table summarizes the estimates of the flow-model for the pump-out stations in Norrtälje municipality, excluding those at Arholma and Rödlöga.

Pump-out station	**Waste per year (m³)**			
	2016	$S = ..* Q_{empty1} * V_{waste1}$/ $S = ..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1}$/ $S = ..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1}$/ $S = ..* Q_{empty3} * V_{waste2}$
Herräng	17,1	38,37/30,28	124,14/97,96	33,86/26,72
Älmsta	35,3	33,97/26,8	110,0/86,72	29,97/23,65
Gräddö	50,0	75,43/59,52	244,03/192,56	66,6/52,52
Furusund	66,2	76,03/59,99	245,98/194,1	67,09/52,94

Table 7. The table summarizes the amount of waste collected at four locations in Norrtälje municipality, as described by Klingberg (2017), throughout 2016 alongside the results of the flow-model.

Important to note when attempting to compare the results of Klingberg (2017) with those of the flow-model is both the large increase between 2015 and 2016 in the number of boats connecting to the different pump-out stations, ranging from 33% to almost 100%, and the fact that the flow-model is greatly affected by how the catchment area is defined for the respective pump-out station. It is not certain if the great increase in the use of these stations as reported by Klingberg is evidence of a general trend, the seasonal effects of weather or some other temporary effect. Barring those caveats the results are still interesting, with the flow-model predicting relatively similar volumes of waste.

3.2.3. New locations

As a part of work package two of the BATSECO project several suggestions for the location of new pump-out stations in Norrtälje municipality was presented. The locations pinpointed are the result of the AIS data collected during the summer of 2018 as well as a number of interviews conducted with boat owners throughout the same period (Mustonen & Johansson, 2019). The locations suggested are shown in figure 1. The following section applies the flow-model to the areas surrounding each of the suggested locations. The results serve as an indication on the need for new pump-out stations with the table below showing the yearly amounts of waste that can be expected to have been produced during the period.

Pump-out station	**Waste per year (m³)**		
	$S = ..* Q_{empty1} * V_{waste1}$/ $S =..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1}$/ $S =..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1}$/ $S =..* Q_{empty3} * V_{waste2}$
Långgrundet/Sjögrund	25,68/20,26	83,09/65,56	22,66/17,88
Fejan	22,55/17,8	72,96/57,57	19,89/15,7
Riddersholm Gästhamn	23,97/18,92	77,57/61,21	21,16/16,69
Outer archipelago	61,85/48,81	200,11/157,9	54,58/43,06
Outer archipelago South 1	102,94/81,23	333,05/262,8	90,83/71,67
Outer archipelago South 2	85,2/67,23	275,66/217,51	75,18/59,32
Outer archipelago South 3	47,93/37,82	155,07/122,37	42,29/33,37

Table 8. The table summarizes the estimated amount of waste that would have been generated at either of the suggested locations for new pump-out stations in Norrtälje municipality during 2018.

The results show greater unmet needs in the outer parts of the Norrtälje archipelago when compared to the suggested locations closer to the coast.

Additionally, the rate at which waste can be expected to have been produced is shown in the figures below. The figures depict the amount of waste produced in the "inner", Långgrundet, Fejan and Redderholm, as well as "outer", Outer archipelago, Outer archipelago south 1, Outer archipelago south 2 and Outer archipelago 3, locations suggested which can be seen in figure 1.

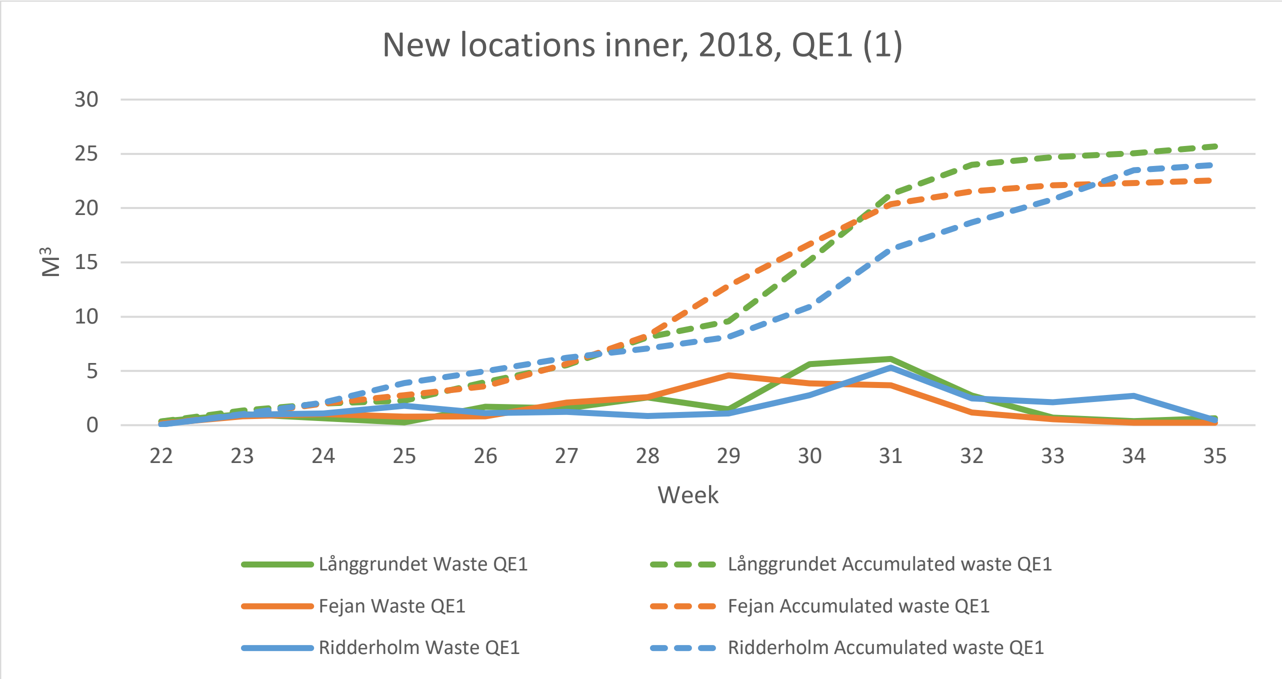

Figure 7. Amount of waste predicted at each of the new inner locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste1}.

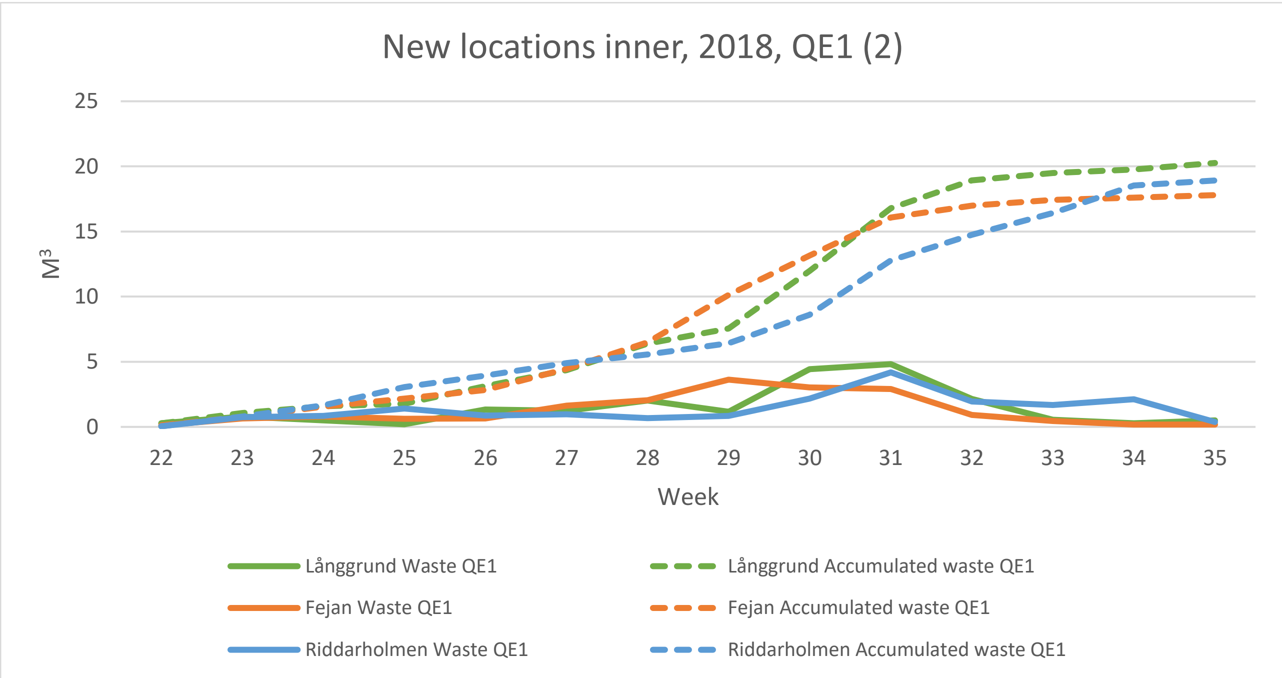

Figure 8. Amount of waste predicted at each of the new inner locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste2}.

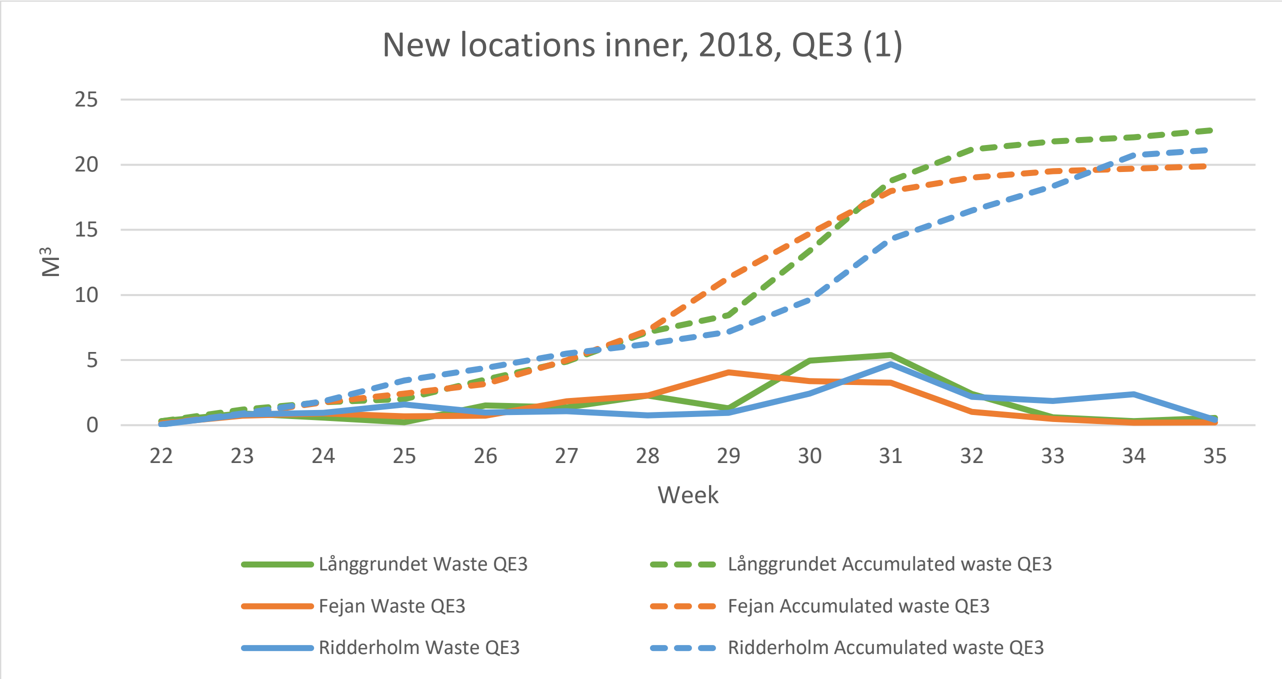

Figure 9. *Amount of waste predicted at each of the new inner locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using* V_{waste1}.

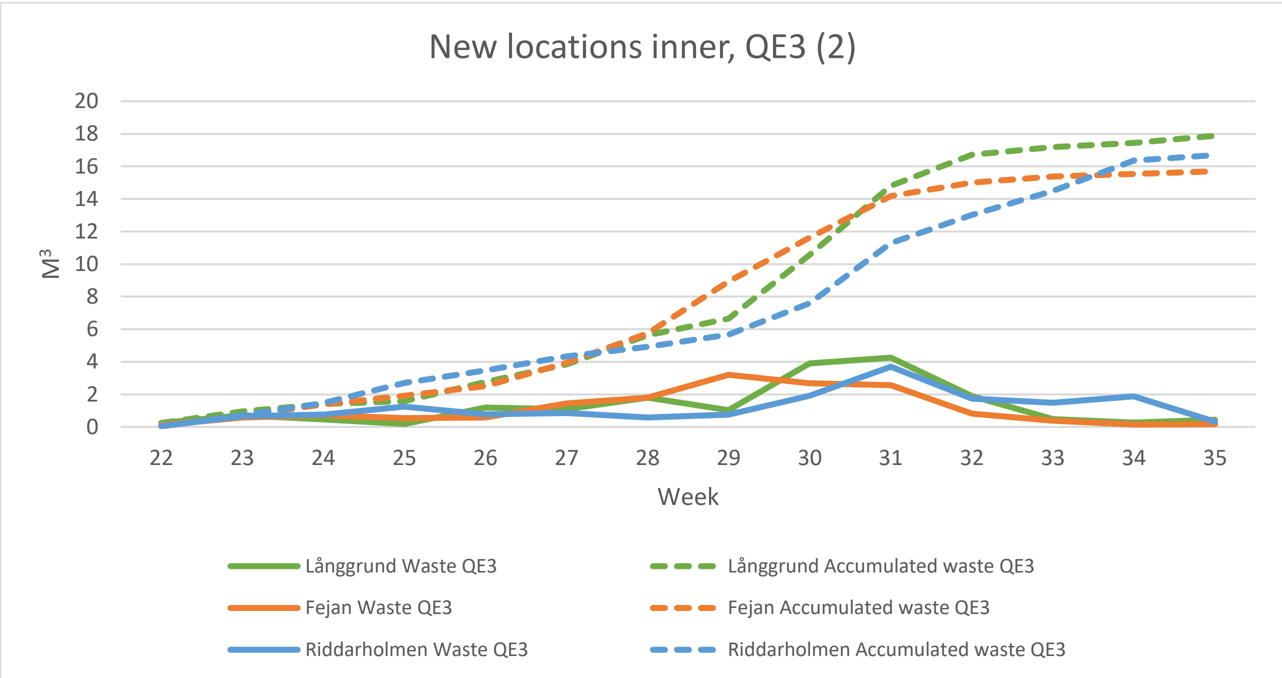

Figure 10. *Amount of waste predicted at each of the new inner locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using* V_{waste2}.

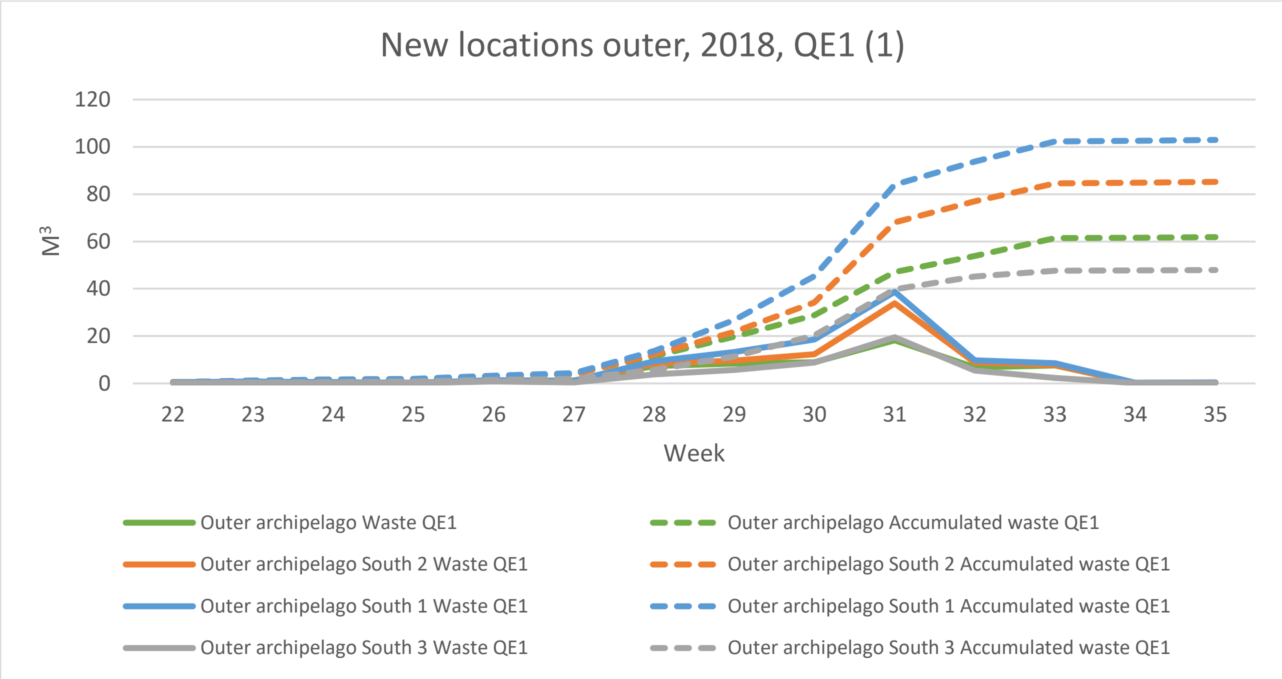

Figure 11. *Amount of waste predicted at each of the new outer locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using* V_{waste1}.

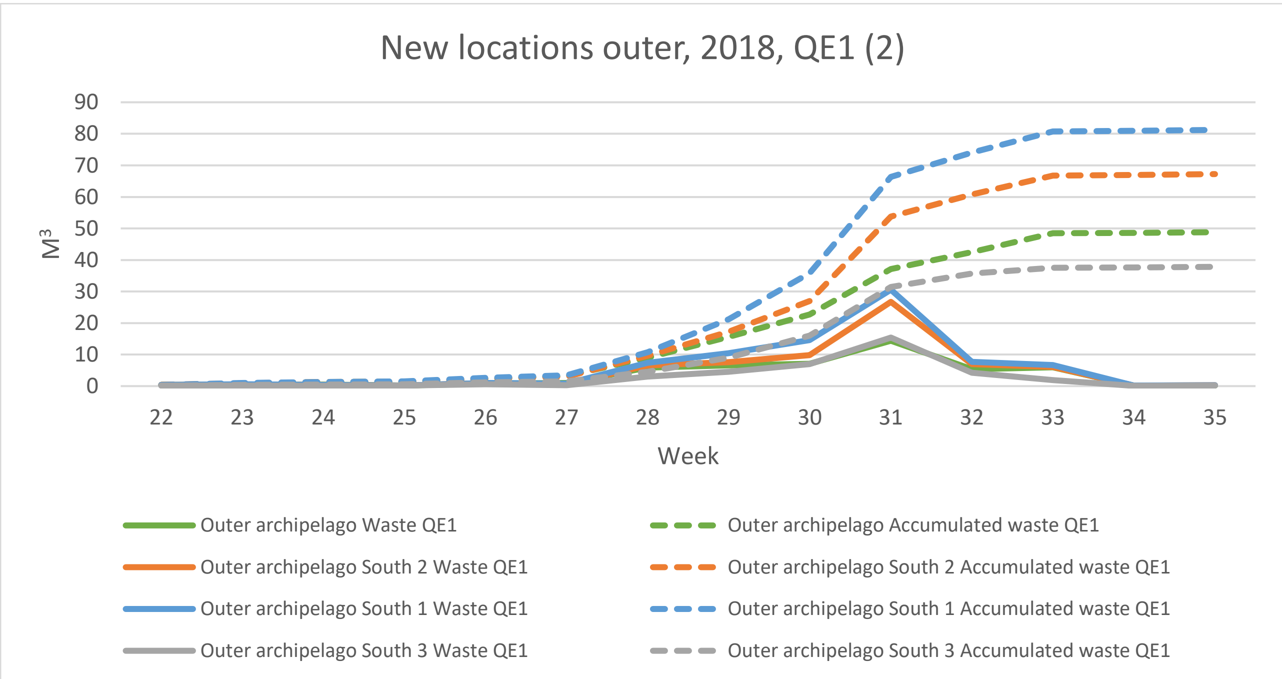

Figure 12. Amount of waste predicted at each of the new outer locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste2}.

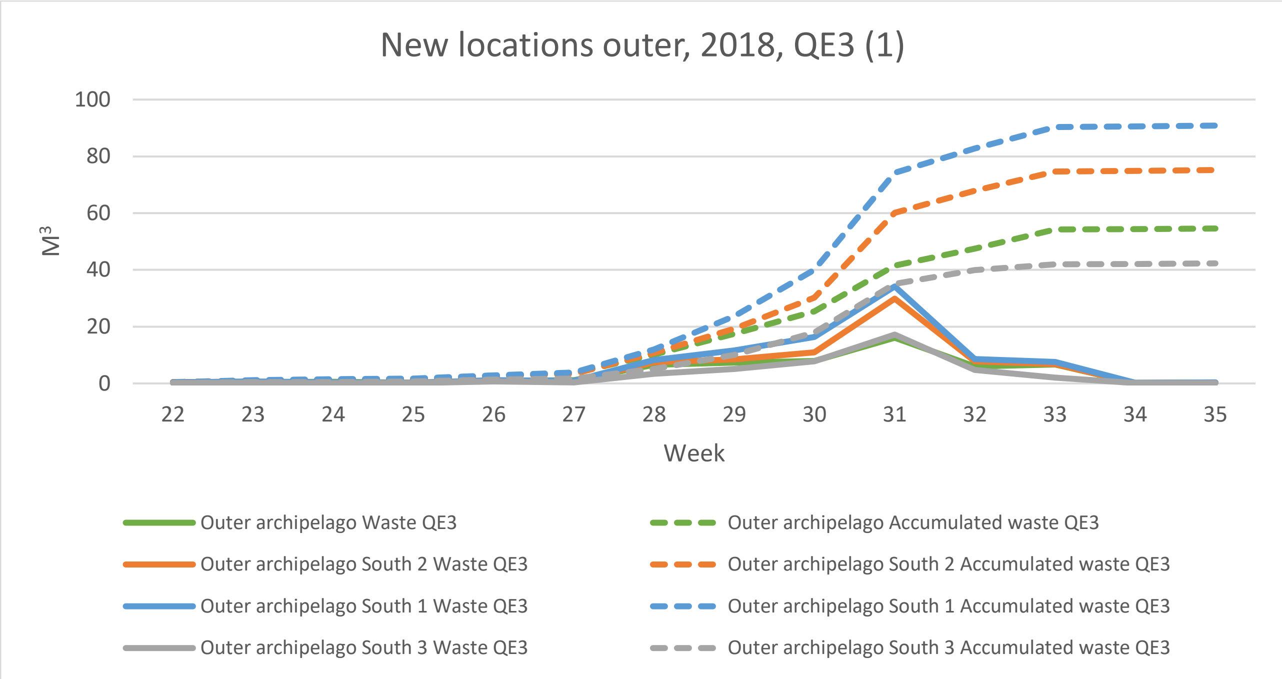

Figure 13. Amount of waste predicted at each of the new outer locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste1}.

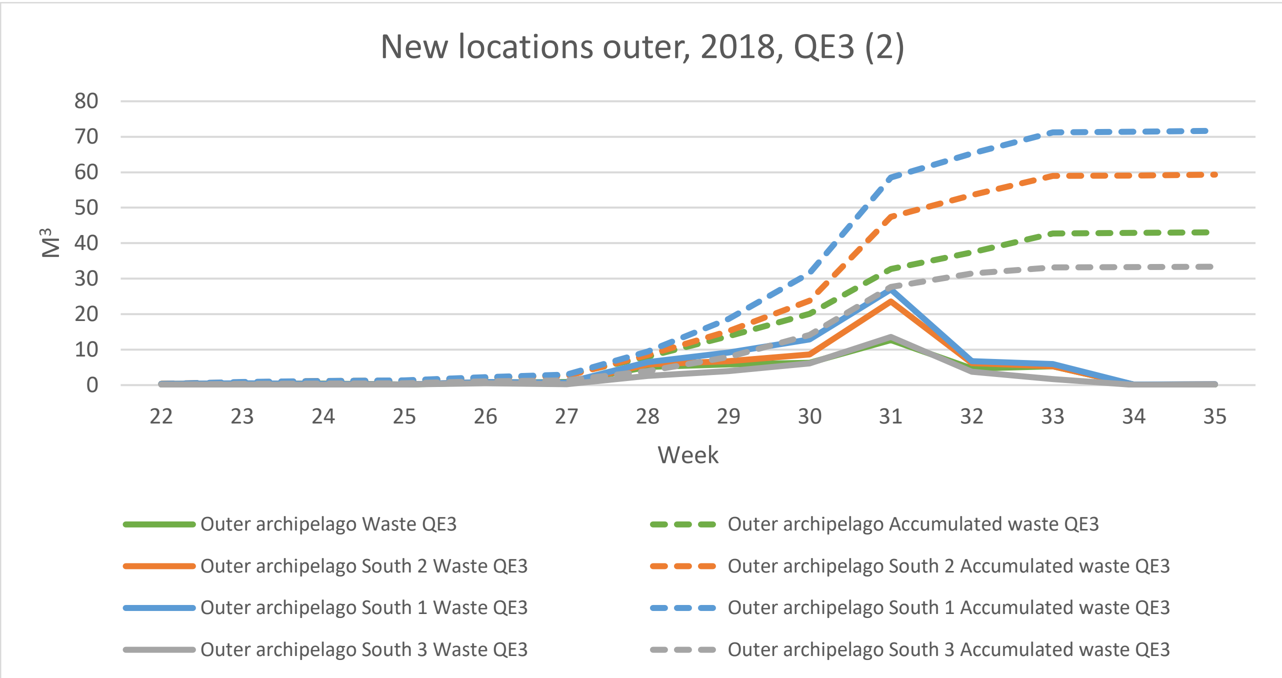

Figure 14. Amount of waste predicted at each of the new outer locations during each week of the summer of 2018 and the accumulated amount throughout the season. Model estimated using V_{waste2}.

4. Analysis and discussion

4.1. What can the flow model results be used for?

The apparent benefits of the model are similar to those set out at the beginning of the study and while it is difficult to determine the exact validity of the model it should still serve as a useful tool in future planning of both when, and how often, existing stations should be emptied as well as where new ones are installed. Whether the model predictions are exactly accurate or not they illustrate similar issues as reported by the company in charge of emptying the two floating tanks in Norrtälje municipality of greater volumes of waste than the stations are capable of handling. In combination with the "timeline" of the rate at which waste is generated it should serve as a useful tool in planning and scheduling when the stations need to be emptied to ensure full functionality while still maintaining as much efficiency in terms of avoiding unnecessary trips.

Assuming that the model predictions are not overly optimistic they also allow for, as described in previous parts, estimates of where further pump-out stations are needed. In the effort to make more areas accessible to leisure boat tourism further options for disposing waste are crucial. By estimating the volumes of waste generated the model can thus help in determining where new pump-out stations would be the most useful, avoiding potential overlap with current ones while serving the greatest number of people.

Finally, given the discrepancy between the amount of waste that is collected and the results of the model it could serve as an indicator on the prevalence of illegal emptying of toilet waste in the region.

4.2. Applicability to other municipalities

The generalizability of the results and model is dependent on the input factors used in estimating the model parameters. As such it is possible to fit the model, and estimate the need for pump-out stations, to any municipality given that the assumptions made on the behavior of boat owners can be expected to be similar or otherwise adapted for local, regional or national differences. This is more readily done for municipalities in Sweden as the data used from the survey by the Swedish transport agency is available for all parts of the country. For municipalities in other countries that are part of the Baltic Sea region it is likely necessary to find comparable data relevant to specifically that region or country. As described in the summary of available data a similar study on boating is available for Finland.

4.3. Data availability, resources needed

The validity of the model parameters given all assumptions made, as stated above, and by extension the accuracy of the model itself is dependent on the available data. Information on the behavior of boat owners in specific regions, municipalities and Sweden as a whole is limited with the regular survey conducted by the Swedish transport agency perhaps giving the best overall view on the many facets of boat ownership. Another benefit is the easy access it allows for anyone interested in conducting a similar study along with information on further aspects that potentially could be used to enhance the flow model. The one caveat to it important to take note of is the limited number of actual respondents for some questions. Given the general lack of in-depth information it still serves as a useful reference in this study, and should be consulted in similar ones for other municipalities, but any results based on it should be viewed with a measure of caution. The two parts of additional information needed for a similar study, AIS data on leisure boat traffic and data on the extent pump-out stations are de facto used, should be available for any given municipality; AIS data for a specific area can be purchased from any number of companies and information on the use of pump-out stations, to the extent that it exists, is typically held by the respective owner.

The obvious and perhaps easiest to implement investments municipalities could take to facilitate more accurate and reliable estimates of their needs, in lieu of a statistical survey on the behaviour of its boat owners, is the installation of some form of tracking mechanism on pump-out stations already in use to help understand to which extent they are used. Knowing how frequently boats empty their waste in a station would allow for direct comparisons between the predicted volumes of the flow model and directly show the lack, or overabundance, of service provided in an area. Additionally, such information would greatly aid any future attempts to refine the flow model.

Along with a cursory understanding of MS excel, or another similar software, and information available as described above the model can be fitted to any region or municipality.

5. How to use the flow model

The ambition of this study is to allow for similar surveys to be conducted with other municipalities in mind. To that end, what follows is a stepwise instruction on how to best go about any such attempt.

1. Define the area or region for which the study is to be made.
2. Assemble the necessary data in order to define the relevant parameters:
    a. AIS-transponder data for the region in question during a full boating season or some other period of interest.
    b. Information regarding some of the behavior and characteristics of boat owners in the region. At a minimum this includes the share of boatowners who are part of the AIS-transponder network (B_{catch}), own and use a boat with a toilet installed (Q_{toilet}), some measure on the frequency that toilet tanks are emptied (Q_{empty}) and the volume of waste each boat can be expected to empty when visiting a pump-out station (V_{waste}). If such data proves hard to find this study provides templates that can be used, applicable primarily to other coastal municipalities in the centre of Sweden. However, some caution is advised as it is important when attempting to describe a certain region not to accidentally disregard regional characteristics that would greatly alter either parameter and subsequently the model outputs.
3. Define the catchment area for each pump-out station. As described earlier boat owners are assumed to choose the station closest to them. This assumption and how to implement it in practice can be seen in figure 2.

4. Finally, the model can be applied using MS-excel, or another similar software. In this study the results are reported for the full 2018 season as well as weekly, but the model can easily be adapted to fit any time-period of interest. The only limiting factor is the way AIS-transponder data is collected.

6. Suggestions moving ahead

The flow-model introduced is intended to serve as a helpful and easy-to-use aid in the planning and management of sewage latrine pump-out stations. Used alongside the knowledge and tools already available it should allow for more well-informed decisions to better serve the boating community and help make tourism in the Baltic Sea area more sustainable.

As in many other fields of study the main hinderance to further model development is the lack of data. Knowing more about the usage of pump-out stations would allow for model optimization and more accurate estimates. Setting such issues aside, additional benefits would be gained from applying the model to other region and conducting more case studies. Any such effort would indicate not only the effects of leisure boating in that region but also point towards the general applicability of the model, or lack thereof.

Data availability on leisure boat traffic and use of facilities could help not only planning of waste management but overall planning of services in the archipelagos of the Central Baltic region. Municipalities working together in each country and internationally within the Central Baltic region could collect such data and make it available in a standardized format adhering to formats used in municipal planning. Providing accessible and standardized data would increase the efficiency and reach of initiatives to improve services in the archipelago from private as well as public actors.

7. Appendix

7.1. Boat toilet water usage

The following table summarizes the amount of water consumed when flushing a small subsection of boat toilets.

Product name	Water usage – High	Water usage – Low	Average
Jabsco 37045	1	1	1
Jabsco 37055	2	1	1,5
Jabsco 37255	2	1	1,5
Sanimarin Toalett SN31	2,2	1,2	1,7
Masterflush Färskvatten	2,5	1,2	1,85
Johnson Aquat El Compact	2,5	2,5	2,5
Average			1,675

Table 9. The table summarizes the amount of water used when flushing a subsection of boat toilets.

7.2. Flow-model Arholma and Rödlöga

Model results using parameter values for Sweden.

Pump-out station	Waste per year (m^3)			
	2018	$S = ..* Q_{empty1} * V_{waste1} / S =..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1} / S =..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1} / S =..* Q_{empty3} * V_{waste2}$
Arholma Österhamn	18	8,45/8,0	51,63/48,88	14,08/13,33
Megelskär, Rödlöga	24	7,97/7,55	48,72/46,12	13,29/12,58

Table 10. The table summarizes the results of the flow-model for Arholma and Rödlöga pump-out stations using parameter values for Sweden.

7.3. Flow-model Norrtälje

Model results using parameter values for Sweden.

Pump-out station	Waste per year (m^3)		
	$S = ..* Q_{empty1} * V_{waste1}$/ $S = ..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1}$/ $S = ..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1}$/ $S = ..* Q_{empty3} * V_{waste2}$
Hallsta Båtklubb	7,27/6,88	44,43/42,06	12,12/11,47
Herrängs Båtklubb	8,32/7,87	50,83/48,12	13,86/13,12
Grisslehamn	8,3/7,86	50,72/48,02	13,83/13,1
Grisslehamns Marina			
Grisslehamn, Västra hamnen			
Älmsta Gästhamn	7,36/6,97	44,99/42,6	12,27/11,62
Lidö Gästhamn	4,48/4,24	27,36/25,9	7,46/7,06
Gräddö Hamn	16,35/15,48	99,91/94,6	27,25/25,8
Furusunds Gästhamn	16,48/15,6	100,72/95,35	27,47/26,01
Blidö Bromskär	4,09/3,88	25,04/23,71	6,83/6,47
Bergshamra Båtklubb	9,71/9,19	59,32/56,16	16,18/15,32
Norrtälje	33,68/31,89	205,84/194,88	56,14/53,15
Norrtälje Gästhamn			
Norrtälje Seglarsällskap			

Table 11. The table summarizes the results of the flow-model using parameter values for Sweden.

7.4. Flow-model new locations

Model results using parameter values for Sweden.

Pump-out station	Waste per year (m³)		
	$S = ..* Q_{empty1} * V_{waste1}$/ $S = ..* Q_{empty1} * V_{waste2}$	$S = ..* Q_{empty2} * V_{waste1}$/ $S = ..* Q_{empty2} * V_{waste2}$	$S = ..* Q_{empty3} * V_{waste1}$/ $S = ..* Q_{empty3} * V_{waste2}$
Länggrundet/Sjögrund	5,57/5,27	34,02/32,21	9,28/8,78
Fejan	4,9/4,63	29,88/28,28	8,15/7,71
Riddersholm Gästhamn	5,2/4,92	31,76/30,07	8,66/8,2
Outer archipelago	13,41/12,69	81,94/77,57	22,35/21,16
Outer archipelago South 1	22,32/21,13	136,37/129,11	37,19/35,21
Outer archipelago South 2	18,47/17,49	112,87/106,86	30,78/29,14
Outer archipelago South 3	10,39/9,84	63,5/60,11	17,32/16,39

Table 12. The table summarizes the results of the flow-model for each of the suggested locations for new pump-out stations using parameter values for Sweden.

7.5. Flow-model water consumption

Results for model (1) assuming the average person uses their boat toilet three quarters of the time, half the time or one quarter of the time. Model estimated using parameter values for the ECA.

7.5.1. Arholma and Rödlöga

Pump-out station	**Waste per year (m^3), ¾ use**		
	$S = ..* Q_{empty1} * V_{waste1}$	$S = ..* Q_{empty2} * V_{waste1}$	$S = ..* Q_{empty3} * V_{waste1}$
Arholma	29,23	94,57	25,79
Rödlöga	27,58	89,23	24,34

Table 13. The table summarizes the results of the flow model when adjusting the frequency by which boat toilets are used.

Pump-out station	**Waste per year (m^3), ½ use**		
	$S = ..* Q_{empty1} * V_{waste1}$	$S = ..* Q_{empty2} * V_{waste1}$	$S = ..* Q_{empty3} * V_{waste1}$
Arholma	19,49	63,05	17,2
Rödlöga	18,39	59,49	16,22

Table 14. The table summarizes the results of the flow model when adjusting the frequency by which boat toilets are used.

Pump-out station	**Waste per year (m^3), ¼ use**		
	$S = ..* Q_{empty1} * V_{waste1}$	$S = ..* Q_{empty2} * V_{waste1}$	$S = ..* Q_{empty3} * V_{waste1}$
Arholma	9,74	31,52	8,6
Rödlöga	9,19	29,74	8,11

Table 15. The table summarizes the results of the flow model when adjusting the frequency by which boat toilets are used.

7.5.2. Norrtälje

Pump-out station	**Waste per year (m³), ¾ use**		
	$S = ..* Q_{empty1} * V_{waste1}$	$S = ..* Q_{empty2} * V_{waste1}$	$S = ..* Q_{empty3} * V_{waste1}$
Hallsta Båtklubb	25,15	81,38	22,19
Herrängs Båtklubb	28,78	93,11	25,4
Grisslehamn	28,71	92,9	25,34
Grisslehamns Marina			
Grisslehamn, Västra hamnen			
Älmsta Gästhamn	25,48	82,42	22,48
Lidö Gästhamn	15,49	50,11	13,67
Gräddö Hamn	56,57	183,02	49,91
Furusunds Gästhamn	57,02	184,49	50,31
Blidö Bromskär	14,18	45,87	12,51
Bergshamra Båtklubb	33,59	106,66	29,63
Norrtälje	116,54	377,04	102,83
Norrtälje Gästhamn			
Norrtälje Seglarsällskap			

Table 16. The table summarizes the results of the flow model when adjusting the frequency by which boat toilets are used.

7.5.3. New locations

Pump-out station	**Waste per year (m^3), ¾ use**		
	$S = ..* Q_{empty1} * V_{waste1}$	$S = ..* Q_{empty2} * V_{waste1}$	$S = ..* Q_{empty3} * V_{waste1}$
Långgrundet/Sjögrund	19,26	62,32	17,0
Fejan	16,91	54,72	14,92
Riddersholm Gästhamn	17,98	58,18	15,87
Outer archipelago	46,39	150,08	40,93
Outer archipelago South 1	63,90	206,74	56,38
Outer archipelago South 2	77,21	249,79	68,12
Outer archipelago South 3	35,95	116,31	31,72

Table 17. The table summarizes the results of the flow model when adjusting the frequency by which boat toilets are used.

Main authors: Fredrik Dunér, Maria Johansson, and Helfrid Schulte-Herbrüggen, Ecoloop AB, Sweden.