Concawe
Environmental Science for European Refining

Report

Report no. 10/20

2016 Survey of Effluent Quality and Water Use at European Refineries

ISBN 978-2-87567-121-9

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2016 Survey of Effluent Quality and Water Use at European Refineries

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Thanks for their contribution to:

- Members of WQ/STF-34
- NewFields Consultants: L. Hall and A. Mianzan

Brussels
June 2020

ABSTRACT

Since 1969, Concawe has been gathering and compiling data on aqueous effluents from European oil refinery installations. Surveys have been completed at 3-5 yearly intervals and the survey design has been updated over time to address various scientific and legislative developments. Since 2010, for example, the data collection also focused on water uses within the installations. This report presents the findings of the survey completed for the 2016 reporting year of European refineries' effluent quality and water use. Compared to previous surveys, the 2016 survey design had improved Quality Assurance and Quality Control (QA/QC) and data integrity.

A total of 72 refineries from the EU-28 countries, Norway and Switzerland participated in the survey from 98 potential respondents (73% response rate). A statistical assessment of site water use is presented, including aggregated data on intake and effluent volumes, water treatment processes, and costs associated with water use. In addition, annual average concentration and discharged mass for a number of chemical substances and parameters regulated at EU level are compared with survey data from previous years. The data returned from these surveys provides perspective on historic trends in refinery water use and effluent discharge and insight into the recent refinery sector performance. The data also allows Concawe to assess the potential impact of proposed changes to existing European legislation.

All 72 refineries were included in the 2016 record of water intake, showing a total of 2.9 billion m^3 of water being withdrawn in 2016 (vs 3.5 billion m^3 for 78 refineries included in the 2013 survey analysis). Out of the total water withdrawn, 80% represented by once-through cooling water, which was primarily salt/brackish surface water (97%). The water withdrawn excluding once-through cooling water and pass-through waters (non-harvested rainwater) was 475 million m^3, out of which 352 million m^3 was fresh water (average 4.8 million m^3 fresh water withdrawn per refinery).

Of the total intake used for site purposes, most was used for recirculating cooling purpose (44%), followed by use in demineralised water production and/or steam/boiler (25%), and use in flue gas scrubbers (7 %). Water losses by use type was reported to be dominated by losses in recirculating cooling use (76 %), followed by steam/boiler use (10%) and demineralised water production (7%).

An average of 0.65 m^3 of treated effluent water was discharged from the reporting refineries per tonne of annual feedstock throughput, which is lower than that reported in the previous two Concawe surveys (0.90 in 2013; 0.94 in 2010). With regard to process effluents, over 90% of the reporting refineries in 2016 applied three-stage biological waste water treatment, or transferred their process water effluent to an external facility applying three-stage biological waste water treatment. This clearly illustrates that the vast majority of the reporting refineries utilised the provisions of the Best Available Techniques (BAT) Reference document (BREF) for the Refining of Mineral Oil and Gas (REF BREF)[1] and its BAT Conclusions (2014/738/EU[2]) for treatment of effluents.

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[1] Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas; European Commission Joint Research Centre, 2015.
https://eippcb.jrc.ec.europa.eu/reference/BREF/REF_BREF_2015.pdf

[2] 2014/738/EU: Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas.

With regard to effluent quality, the results of the 2016 survey are consistent with the long-term trend towards reduced discharge loads of oil (reported as Oil in Water (OiW) or Total Petroleum Hydrocarbons (TPH)). Moreover, the total and relative load (i.e. normalised to throughput) are lower relative to the 2013 and 2010 survey years, being at 262 tonnes and 0.51 g/tonne throughput, respectively, for 2016. The decrease was confirmed by looking at the median relative TPH load for only the 46 refineries that reported under all surveys form 2010 to 2016.

For other effluent quality parameters, taking 2010-2016 data into account, reductions in relative load was observed for 12 of the analysed quality elements (various organics and heavy metals such as Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and cadmium) in 2016. Whereas three were kept at constant levels (total nitrogen, phenols and total phosphorus) and two increasing (mercury and vanadium) in 2016.

KEYWORDS

Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Oil in Water (OiW), Total Petroleum Hydrocarbon (TPH), phenols, water intake, water withdrawal, water discharge, effluents, water consumption, water use, waste water treatment, water costs, refinery, survey.

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SUMMARY

Since 1969, Concawe has been gathering and compiling data on aqueous effluents from European oil refinery installations. Surveys have been completed at 3-5 yearly intervals and the survey design has been updated over time to address various scientific and legislative developments. Since 2010, for example, the data collection also focused on water uses within the installations. This report presents the findings of the survey completed for the 2016 reporting year of European refinery effluent quality and water use.

A total of 72 refineries from the EU-28 countries, Norway and Switzerland participated in the 2016 survey from 98 potential respondents (73% response rate). The total number, capacity and throughput of refineries reporting under the surveys from 1969 to 2016 are presented in the **Table 1** below. The data returned provides perspective on historic trends in refinery water use and effluent discharge, as well as insight into the recent refinery sector performance. The data also allows Concawe to assess the potential impact of proposed changes to existing European legislation.

All 72 refineries were included in the 2016 record of water intake, showing a total of 2.9 billion m^3 of water being withdrawn in 2016 as presented in **Table 1**. Out of the total water withdrawn, 80% represented by once-through cooling water, which was primarily salt/brackish surface water (97%). The water withdrawn excluding once-through cooling water and pass-through waters (non-harvested rainwater) was 475 million m^3, out of which 352 million m^3 was fresh water (average 4.8 million m^3 fresh water withdrawn per refinery). The relative (i.e. normalised to throughput) freshwater withdrawal was 690 m^3/kilotonne. Out of the captured total rainwater volume (35 million m^3), most went directly to discharge and only 3 % was harvested for a subsequent use.

By way of comparison to the most recent surveys, 2013 data (78 refineries) indicated a total of 3.5 billion m^3 water being withdrawn, a total freshwater withdrawal (for purposes other than once-through cooling but including pass-through waters) of 5.3 million m^3 per refinery on average and a relative freshwater withdrawal of 742 m^3/kilotonne.

Of the total intake used for site purposes, most was used for recirculating cooling purpose (44%), followed by use in demineralised water production and/or steam/boiler (25%), and use in flue gas scrubbers (7 %). Water losses by use type was reported to be dominated by losses in recirculating cooling use (76 %), followed by steam/boiler use (10%) and demineralised water production (7%).

Also presented in **Table 1** are summary data for aqueous effluent volumes by refineries reporting under the survey from 1969 to 2016. In 2016, discharge quantity data recorded 2,693 million m^3 of total aqueous effluents, and 5.3 m^3/tonne relative to total throughput. Considering only treated effluents the corresponding numbers were 330 million m^3 and 0.65 m^3/tonne, respectively. The latter being lower than that reported in the previous two surveys (0.90 m^3/tonne in 2013; 0.94 m^3/tonne in 2010).

With regard to process effluents, over 90% of the 2016 reporting refineries applied three-stage biological waste water treatment, or transferred their process water effluent to an external facility applying three-stage biological waste water treatment. Assuming that the refineries which reported using three-stage biological waste water treatment on their process water in 2010 and 2013 continued to do so in 2016, the total percentage of refineries utilising three-stage biological waste water treatment on their process water is over 97%. This clearly illustrates that the

vast majority of the reporting refineries utilise the provisions of the Best Available Techniques (BAT) Reference document (BREF) for the Refining of Mineral Oil and Gas (REF BREF)[3] and its BAT Conclusions (2014/738/EU[4]) for treatment of effluents.

Using the IPIECA definition for freshwater consumption (indicator E6; IPIECA, API and IOGP, 2015), it was shown that refineries consumed 246 million m^3 of fresh water in 2016 with an average of 3.4 million m^3 per year. When comparing the freshwater consumption with the freshwater intake (excluding once-through cooling) it was shown that country groups having a high freshwater consumption within the facility also had a high freshwater intake.

The freshwater consumption in 2016 was lower compared to 2013 (271 million m^3) and 2010 (282 million m^3). The average relative freshwater consumption was lower in 2016 at 482 m^3/kilotonne compared to 2013 (598 m^3/kilotonne), but slightly higher compared to 2010 (467 m^3/kilotonne). Total and relative freshwater consumption was also calculated utilising only the sites reporting for all three surveys 2010, 2013 and 2016 (48 refineries); it showed that the relative freshwater consumption was similar in 2016 and 2010 (494-501 m^3/kilotonne), whereas it was higher in 2013 (618 m^3/kilotonne). Total freshwater consumption showed the same pattern. The reasons for the difference in 2013 was not evident, although it may be due to the way of collecting the data on intakes and uses in the different surveys.

From the high-level information collected on costs associated with refinery water use, it was observed that the relative intake costs exceeded relative discharge costs independent of the country croup. Compared to 2013 not all regions exhibit the same trend, whereas in 2016 it was true for all. Also, relative treatment costs exceeded relative discharge costs independent of the country croup, whereas different country groups showed different patterns in comparing relative treatment costs and relative intake costs.

With regard to effluent quality, the results of the 2016 survey was consistent with the long-term trend towards reduced discharge loads of oil (reported as Oil in Water (OiW) or Total Petroleum Hydrocarbons (TPH)), as shown in **Figure 1**. Moreover, the total and relative load are lower compared to the 2013 and 2010 survey years, being at 262 tonnes and 0.51 g/tonne, respectively, for 2016. The decrease was confirmed by looking at the median relative TPH load for only the 46 refineries that reported under all surveys form 2010 to 2016.

For other effluent quality parameters, taking 2010-2016 data into account, reductions in relative load was observed for 12 of the analysed quality elements (various organics and heavy metals, such as Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and cadmium) in 2016. Whereas three were kept at constant levels (total nitrogen, phenols and total phosphorus) and two increasing (mercury and vanadium) in 2016.

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[4] 2014/738/EU: Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas.

Table 1. Number of refineries reporting for each survey year, together with their reported capacity, annual feedstock throughput and aqueous effluent discharge data.

Year of survey	Number of refineries reporting [response rate in %]	Reported capacity (million tonne/year)	Reported throughput[1] (million tonne/year)	Freshwater withdrawal (million m3/year)	Relative freshwater withdrawal (m3/tonne throughput)	Total aqueous effluent[2] (million m^3/year)	Relative total aqueous effluent[2] (m^3/tonne throughput)	Treated effluent[3] (million m^3/year)	Relative Treated Effluent[3] (m^3/tonne throughput)
1969	82 [n.d.]	400	n.a.	n.d.	n.d.	3,119	n.d.	n.d.	n.d.
1974	112 [n.d.]	730	n.a.	n.d.	n.d.	3,460	n.d.	n.d.	n.d.
1978	111 [n.d.]	754	540	n.d.	n.d.	2,938	5.4	n.d.	n.d.
1981	105 [n.d.]	710	440	n.d.	n.d.	2,395	5.4	n.d.	n.d.
1984	85 [n.d.]	607	422	n.d.	n.d.	1,934	4.6	n.d.	n.d.
1987	89 [n.d.]	587	449	n.d.	n.d.	1,750	3.9	n.d.	n.d.
1990	95 [n.d.]	570	511	n.d.	n.d.	1,782	3.5	n.d.	n.d.
1993	95 [n.d.]	618	557	n.d.	n.d.	2,670	4.8	n.d.	n.d.
1997	105 [n.d.]	670	627	n.d.	n.d.	2,942	4.7	n.d.	n.d.
2000	84 [n.d.]	566	524	n.d.	n.d.	2,543	4.9	n.d.	n.d.
2005	96 [85 %]	730[4]	670	n.d.	n.d.	790[5]	1.2[5]	790	1.2
2008	125 [100%]	840	748	n.d.	n.d.	1,112[6]	1.5[6]	612	0.82
2010	98[9] [87 %]	720	605	713 (420)[10]	1.2 (0.69)[10]	1,583[7]	2.6[7]	569[8]	0.94
2013	78[9] [76 %]	507[4]	500	491 (371)[10]	0.98 (0.74)[10]	2,370 (465)[10]	4.7 (0.92)[10]	451[8]	0.90
2016	72 [73 %]	585	510	509 (352)[10]	1.0 (0.69)[10]	2,693 (371)[10]	5.3 (0.73)[10]	330	0.65

n.a. = not available

n.d. = not determined

[1] Throughput refers to total throughput, i.e. including both crude oil and other feedstocks

[2] Until 2000 the total aqueous effluent in the table refers to the sum of process effluents, cooling water and other flows such as lightly contaminated rain water. For the 2008, 2010 and 2013 surveys, there is the distinction between treated process water and other streams that are discharged at the same or separate emission points. The values between brackets are based upon the sum of all reported discharges, excluding once-through cooling water

[3] Including treated transfer streams

[4] Some refineries reported throughput but did not report capacity. This capacity number represents the total capacity reported and may be under-represented

[5] 2005 data only consider the treated effluents and no longer included once-through cooling water from closed systems.

[6] For 2008 data, many sites only reported treated effluent volumes and not all the effluent waters. When looking at treated effluent volumes, the 2008 data appears to be in line with other years.

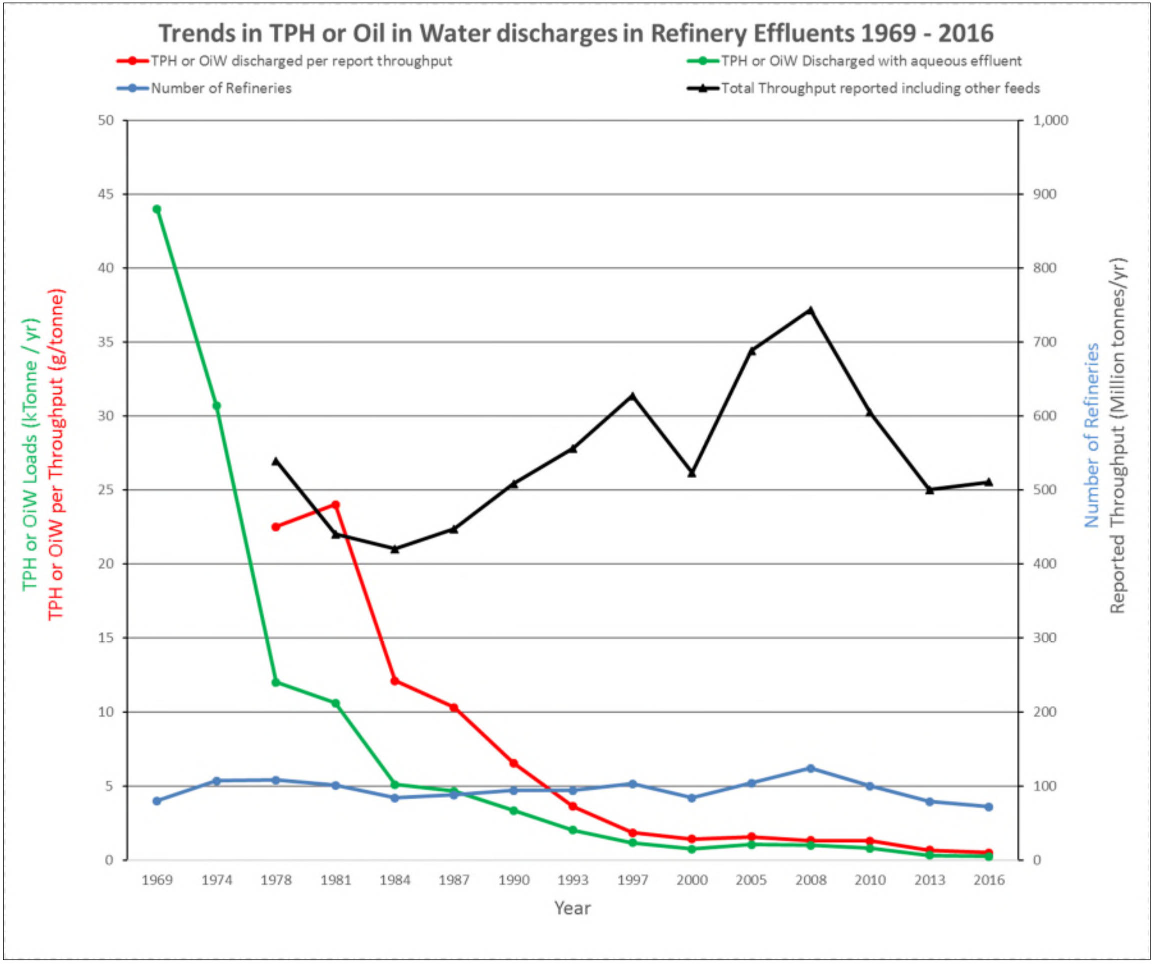
[7] When comparing sites that responded in both 2010 and 2013, there were 5 sites that indicated once-through cooling waters in their effluent volumes in 2013 (total 1,702 million m3), but indicated 0 m3 once-through cooling waters in their effluents in 2010. Therefore, if the sites had similar volumes in 2010 as they reported in 2013 the total effluent volumes in 2010 would add up to 3,285 million m3

[8] Re-evaluated since Concawe Report 12/18 (Concawe, 2018), see **Table 10**

[9] Revised number compared to Concawe Report 12/18 due to reporting entity definition (decreased by 3 for 2010, and decreased by 1 for 2013).

[10] Number in parenthesis is excluding once-through cooling waters

Figure 1. Trends in Total Petroleum Hydrocarbons (TPH) or Oil in water (OiW) loadings in effluents, reported throughput and number of refineries reporting in Concawe surveys from 1969 to 2016[1].



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[1] OiW was the main reporting metric until 2000 (including) for reporting hydrocarbon discharges, from 2005 it was replaced by TPH.

1. INTRODUCTION

Since 1969, Concawe has been gathering and compiling data on water use and effluent quality for European refineries. Surveys have been completed at 3-5 yearly intervals and the survey design has been updated over time to address various scientific and legislative developments. This report presents the findings of a Concawe survey completed for the 2016 reporting year. The data returned from the surveys provides historic trends in refinery water use and effluent discharge and insight into the recent refinery sector performance. The data also allows Concawe to assess the potential impact of proposed changes to existing European legislation.

1.1. PROJECT DESCRIPTION AND EXECUTION

The water/effluent survey for the 2016 reporting year was initiated in November 2017 with the launch of a web-based survey tool to Concawe member company refineries. The 2016 survey design had improved Quality Assurance and Quality Control (QA/QC) and data integrity compared to previous surveys.

A total of 72 responses of 98 potential respondents[1] (73% response rate) were collected from refineries of varying type and complexity across Europe[2]. For comparison, 78 refineries out of a potential of 104 responded to the 2013 survey (75% response rate). The numbers of refineries which have reported refining capacity and total annual feedstock throughput data in each survey year are given in **Table 2**.

Table 2. Refining capacity and throughput for each survey year

Year of survey	Number of refineries reporting in each survey	Reported capacity (million tonne/year)	Reported throughput (million tonne/year)[1]
1969	82	400	Not available
1974	112	730	Not available
1978	111	754	540
1981	105	710	440
1984	85	607	422
1987	89	587	449
1990	95	570	511
1993	95	618	557
1997	105	670	627
2000	84	566	524
2005	96	730[2]	670
2008	125	840	748
2010	97[3]	720	605
2013	78[3]	507[2]	500
2016	72	585	510

[1] Throughput refers to total throughput, i.e. including both crude oil and other feedstocks.
[2] Some refineries reported throughput but did not report capacity. This capacity number represents the total capacity reported and may be under-represented.
[3] Revised number compared to Concawe Report 12/18 due to reporting entity definition (decreased by 3 for 2010, and decreased by 1 for 2013).

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[1] The number of potential respondents represent the number of crude oil refineries within the EU-28 countries + Norway and Switzerland that were declared to be operational in 2016.

[2] Complexity groups were derived for each site using their Nelson Complexity index from 2013 (Oil & Gas Journal, December 2, 2013). Complexity groups are categorized using these complexity indexes for analyses: Class 1 <4; Class 2 4-6; Class 3 6-8; Class 4 8-10; Class 5 >10

Table 3 shows a breakdown of survey response by refinery type. Bio-refineries, i.e. refineries that do not process any crude oil, were not included in the survey since they, at the time of the survey, were too few (≤ 3) to be of statistical relevance.

Table 3. Summary of collected responses by refinery site type in 2016

Type of Site	Response spilt by percentage
Refinery with or without a crude oil terminal	62%
Combined refinery and chemical plant	19%
Other[1]	19%

[1] Other includes bitumen plants, lubricant plants, bigger complexes (e.g. combined refinery, chemical plant, bitumen plant and crude oil terminal) and non-specified.

Survey findings are presented for the refinery sector in Europe as a whole, as well as for refineries in different geographic regions. The geographic regions have been created to facilitate regional comparisons, while maintaining the anonymity of individual refineries. Findings are also presented for refineries grouped by complexity. The geographic extent of country groupings, summary of responses collected by country groups and site complexity, respectively, in 2013 and 2016 can be found in **Appendix 1**.

To facilitate comparison between the 2016 and previous survey findings, key metrics have been normalised to refinery throughput.

1.2. QUALITY CONTROL AND QUALITY ASSURANCE (QA/QC)

Prior to data analyses, the data were subjected to QA/QC checks and corrections including:

- Automated QA/QC built into the survey tool for identification of outliers and unit consistencies flagged for validation and correction during form finalization by respondents;
- Once forms were completed additional checks were conducted;
    - Reviewing respondent notes to clarify or complete questionnaire data entries;
    - Sites were identified that had data incongruities to receive follow-up; examples include:
        - Data compared with data entered in 2010 and 2013 for magnitude and type;
        - Made-water scenarios on nodes (e.g. waste water treatment plant; WWTP) or site as a whole;
        - Receiving basin designated as marine but classified as a “Fresh” water type;
        - Once-through cooling water with an up-stream use (i.e. likely not a once-through use).

The QA/QC checks result in a limited number of follow-up from respondents. After confirmation, some of the reported values were then updated in the database. All changes were documented along with valid reasoning for each change and preservation of the original respondents’ input.

2. WATER INTAKE, DISCHARGE AND CONSUMPTION IN THE EUROPEAN REFINING INDUSTRY

This section provides summaries and graphics on the characteristics and quantities of water intakes and discharges. The consumption of fresh water based on the IPIECA definition of their indicator E6 (IPIECA, API and IOGP, 2015) is also presented in this section. Due to the increased refinements made in the 2016 survey tool for water quantities and usage, as well as different number of respondents, the total volumes in 2016 are more exact than historical reported water quantities. **Table 4** and **Table 5.** present the total water intake and discharge for the reporting industry, respectively. The intake numbers and discharged numbers does not completely match (total discharge volume is 7 % lower than total intake), which is expected due to water evaporation and other losses.

Table 4. Total water intake

Intake type	Once-through volume (m^3/y)	Onsite utilized volume (m^3/y)	Pass-through volume [1] (m^3/y)	Total (m^3/y)
Fresh water	63,567,000	352,108,000	93,809,000	**509,484,000**
Brackish/salt	2,262,545,000	122,803,000	282,000	**2,385,630,000**
Total	**2,326,112,000**	**474,911,000**	**94,091,000**	**2,895,114,000**

[1] Pass-through volume includes water that is directly discharged without being utilized for site purposes. Examples include unharvested rainwater, hydraulic control water, and waters immediately transferred to third parties without being used.

Table 5. Total water discharged grouped by receiving body water classification.

Receiving water body type	Discharge due to once-through cooling (m^3/y)	Other site discharge volumes (m^3/y)	Total discharge volumes (m^3/y)
Fresh water	63,674,000 [1]	171,096,000	**234,770,000**
Brackish/salt	2,257,144,000	170,162,000	**2,427,306,000**
Transfer	259,000	30,510,000	**30,769,000**
Total	**2,321,077,000**	**371,768,000**	**2,692,845,000**

[1] Once-through cooling discharge volumes is slightly higher than corresponding intake (**Table 4**) due to “created water” scenarios for a few sites (i.e. more water reported leaving than entering a site).

2.1. WATER INTAKES[3]

In the 2016 survey, respondents were asked to classify their water intake streams by water supply, source, as summarised in **Table 6**. This classification system allowed fine granularity in parsing and grouping data according for analysis. For each classified water intake stream, respondents provided total volumes withdrawn on an annual basis, as well as subsequent water use as appropriate. Aggregated sourwater and other recycled/reused water flows were also reported.

Classifications of water types for water intake streams were classified as either fresh or salt/brackish. Fresh water was defined based on the IPIECA limit of 2000 mg/L total dissolved solids[4]. This criterion was used by all respondents but one.

Table 6. Classifications of water sources

Water Intake Source
Groundwater
Purchased demineralised water
Purchased potable water[1]
Purchased raw water[2]
Purchased recycled water
Purchased steam
Remediation/hydraulic control
Storm/rain water
Surface water
Tank bottom draws

[1] Purchased potable water was defined as water that is supplied by a vendor of water that is fit for consumption without any further treatment (i.e. tap water).
[2] Purchased raw water was defined as water that is supplied by a vendor that is not fit for human consumption.

For the 72 refineries included in the analyses, a total of 2.9 billion m^3 (2,895,115,000 m^3) of water was withdrawn in 2016 for use in the European refining industry (vs 3.5 billion m^3 in 2013 for the 70 refineries included in the analysis). Out of the total water withdrawn, 80% is represented by once-through cooling water, which is primarily salt/brackish surface water (97%). The water withdrawn excluding once-through cooling water and pass-through waters (non-harvested rainwater) was 579 million m^3, 352 million m^3 was fresh water (average 4.8 million m^3 per refinery).

As indicated in **Figure 2**, the majority of water intakes not associated with once-through cooling were derived from surface water (46%), followed by groundwater (17%). In fact, 17% should be considered the minimum threshold for groundwater use as it is more than likely that water purchased from external sources also were originally derived from groundwater sources. When considering all the purchased water categories, purchased water accounted for 31% of the total intake volume. The reliance on purchased water highlights the potential vulnerability of European refineries on water pricing initiatives.

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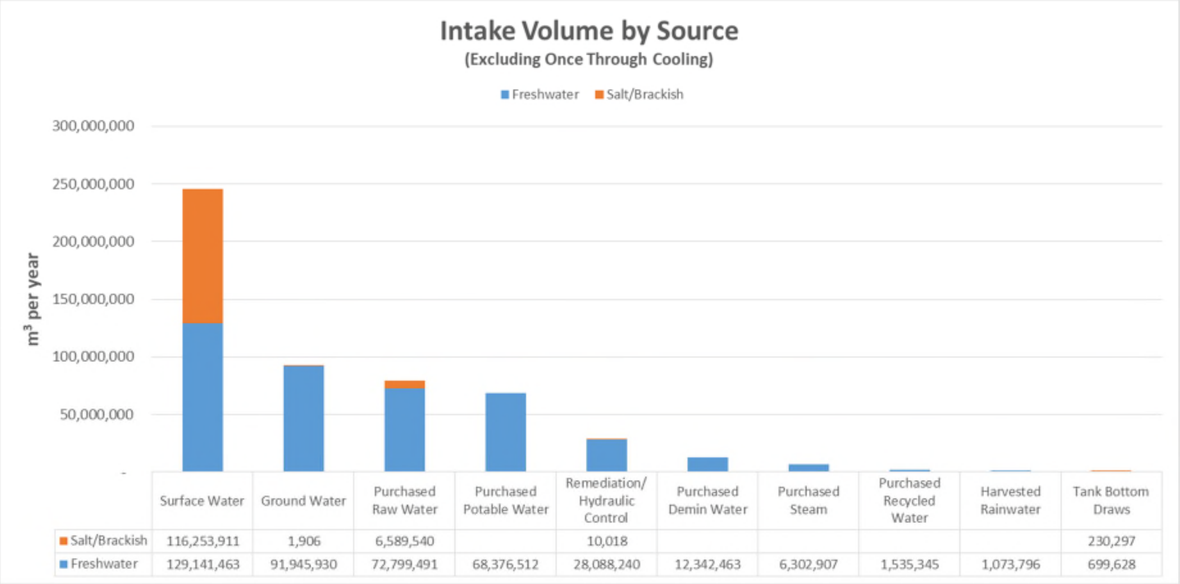
[3] The definition of water intake used the definition of water withdrawal of IPIECA (http://www.ipieca.org/resources/good-practice/efficiency-in-water-use-guidance-document-for-the-upstream-onshore-oil-and-gas-industry/), with the addition of remediation/hydraulic control and tank bottom draws. The two additional intakes compared to the IPIECA definition were believed to potentially be significant.

[4] http://www.ipieca.org/resources/good-practice/efficiency-in-water-use-guidance-document-for-the-upstream-onshore-oil-and-gas-industry/

Out of the captured total rainwater volume (35 million m^3), most went directly to discharge and only 3.1% was harvested for a subsequent use. Only the harvested rainwater portion is utilised in intake analyses, as shown in **Figure 2** and subsequent figures.

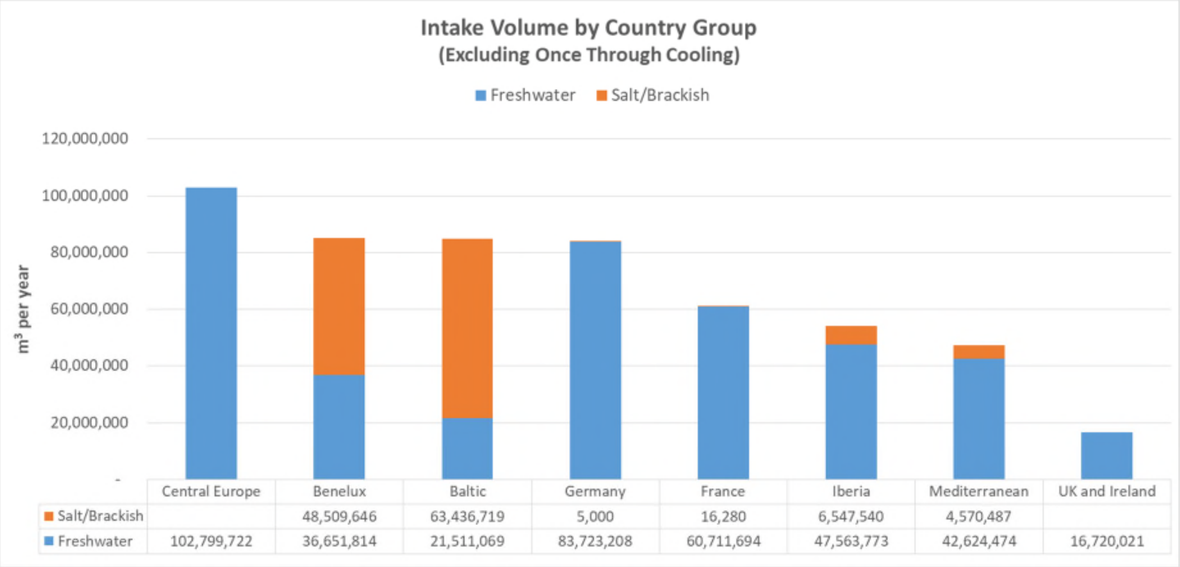
Figure 2. Total water intake by water source. (Once-through cooling volumes have been excluded).



	Surface Water	Ground Water	Purchased Raw Water	Purchased Potable Water	Remediation/ Hydraulic Control	Purchased Demin Water	Purchased Steam	Purchased Recycled Water	Harvested Rainwater	Tank Bottom Draws
Salt/Brackish	116,253,911	1,906	6,589,540		10,018					230,297
Freshwater	129,141,463	91,945,930	72,799,491	68,376,512	28,088,240	12,342,463	6,302,907	1,535,345	1,073,796	699,628

Total water intakes by country group without once-through cooling are summarised in **Figure 3.** Most country groups primarily utilise fresh water, except for the Baltic and Benelux regions.

Figure 3. Total water intake by country group. (Once-through cooling volumes have been excluded)



	Central Europe	Benelux	Baltic	Germany	France	Iberia	Mediterranean	UK and Ireland
Salt/Brackish		48,509,646	63,436,719	5,000	16,280	6,547,540	4,570,487	
Freshwater	102,799,722	36,651,814	21,511,069	83,723,208	60,711,694	47,563,773	42,624,474	16,720,021

The total freshwater intake in 2016 was 509 million m^3. Of this volume, 64 million m^3 was used for once-through cooling and an additional 94 million m^3 was directly discharged without being used directly for site purposes. The latter waters included rainwater, water pumped for hydraulic control/remediation and not used directly on site, or water sent to a third party prior to being utilized on site. The remaining volume of 352 million m^3 represents the total fresh water intake that was used directly for site purposes other than once-through cooling.

Figure 4 shows a summary of freshwater intake across each country group excluding once-through cooling as well as direct discharges.

Figure 4. Total fresh water intake by country group. (Once-through cooling volumes as well as pass through waters have been excluded)

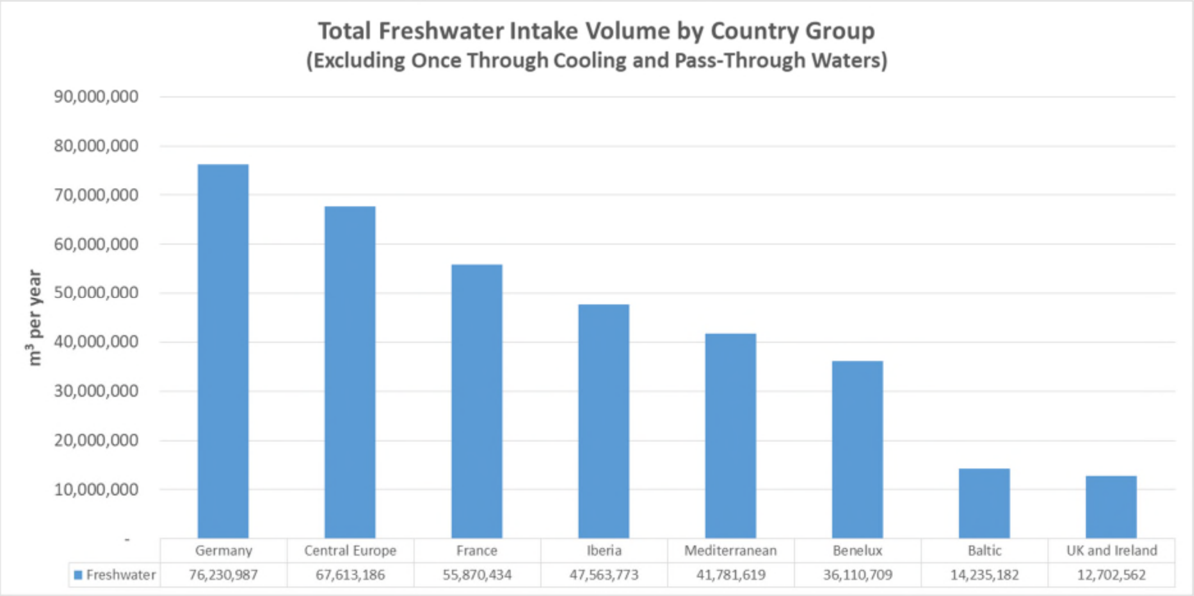


Figure 5 and **Figure 6** presents the freshwater intake relative to total throughput for each country group excluding and including once-through cooling and direct discharges, respectively.

Figure 5. Fresh water intake relative to the total throughput of each country group. (Once-through volumes and pass-through waters have been excluded).

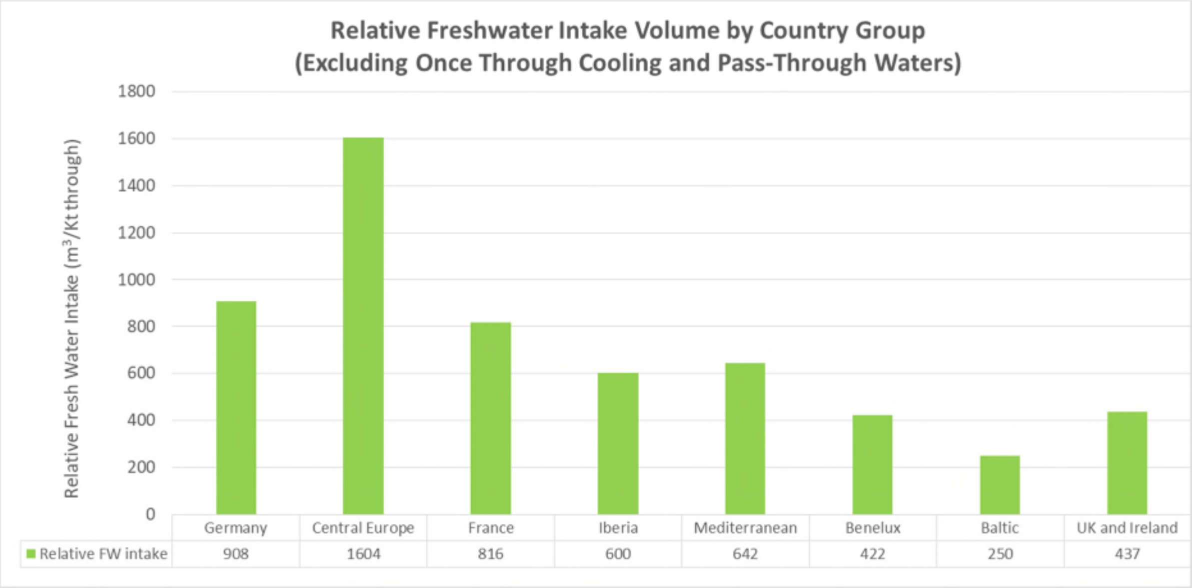


Figure 6. Fresh water intake relative to the total throughput of each country group (once-through volumes and pass-through waters included).

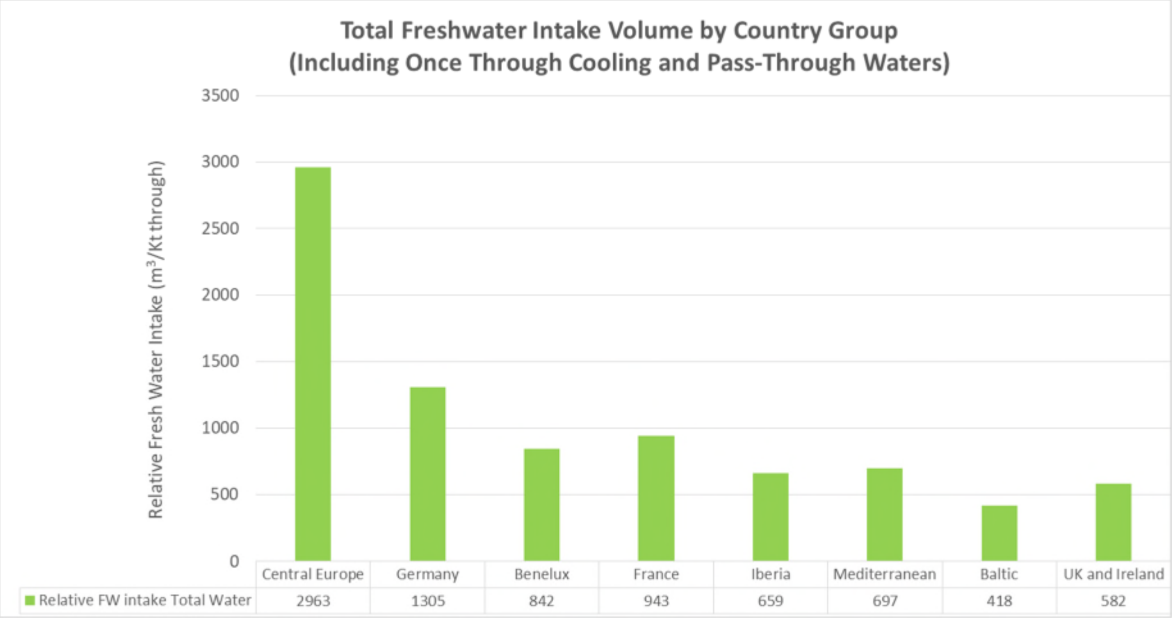
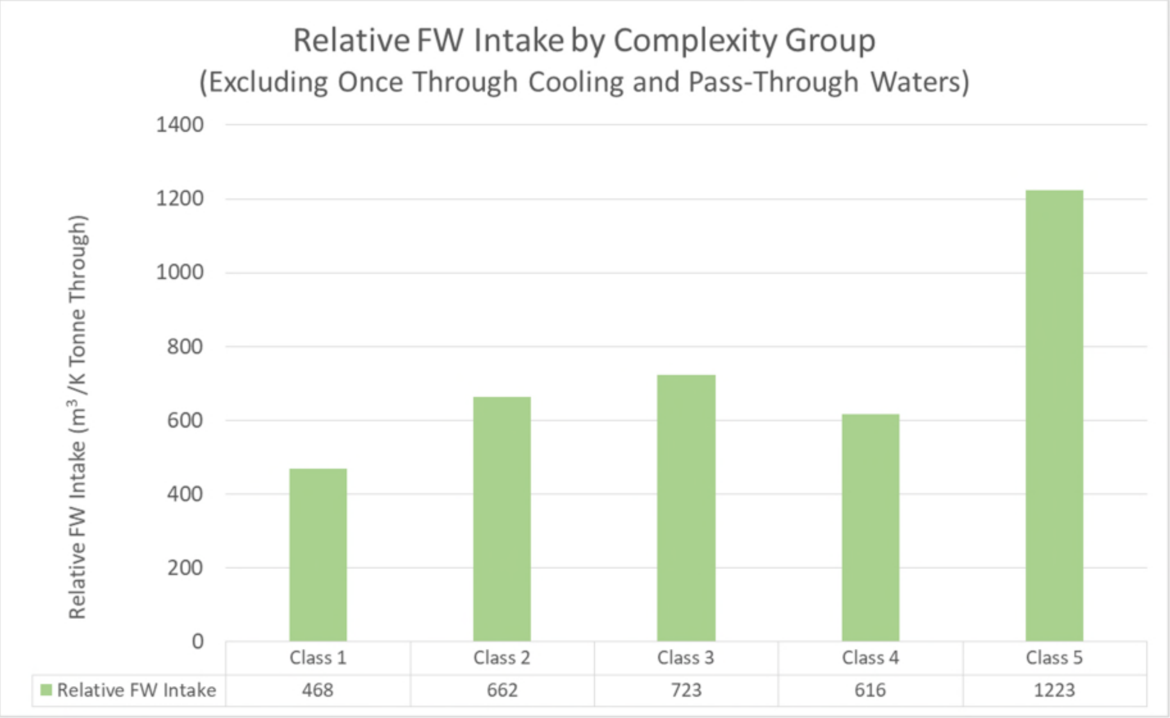


Figure 7 presents the relative freshwater intakes by complexity group excluding once-through cooling as well as direct discharges.

Figure 7. Relative freshwater intakes by complexity group. (Sites without complexity index classification have been removed).



By way of comparison (**Table 7**), the 2013 survey (78 refineries) and 2010 survey (98 refineries) indicated a total freshwater intake of 371 million m^3 and 419 million m^3 for purposes other than once-through cooling, respectively. However, comparison with 2010 and 2013 data could reflect the different population of refineries reported under the surveys, or differences in the way that the 2016 survey definition (volumes defined as the sum of intakes vs. volumes defined as the sum water uses in 2013 and 2010). Presenting the numbers relative to throughput decreases this bias, and it shows that 2010 and 2016 are comparable (690-693 m^3/kilotonne), whereas there was a higher freshwater intake reported in 2013 (742 m^3/kilotonne).

Table 7. Freshwater withdrawal data from 2010 to 2016 (excludes water withdrawn for once-through cooling)

Year of survey	Number of reporting refineries	Freshwater withdrawal (million m^3/year)	Relative freshwater withdrawal (m^3/kilotonne throughput)
2010	98	419	693
2013	78	371	742
2016	72	352	690

2.2. USES

The 2016 web form survey considered the water use classifications shown in **Table 8.** For the analysis, the demineralised water plant use and steam/boiler use were merged into one use, as it in most cases is the same water being used, with the exemption being the few cases when demineralised water is purchased.

Table 8. Classifications of water uses.

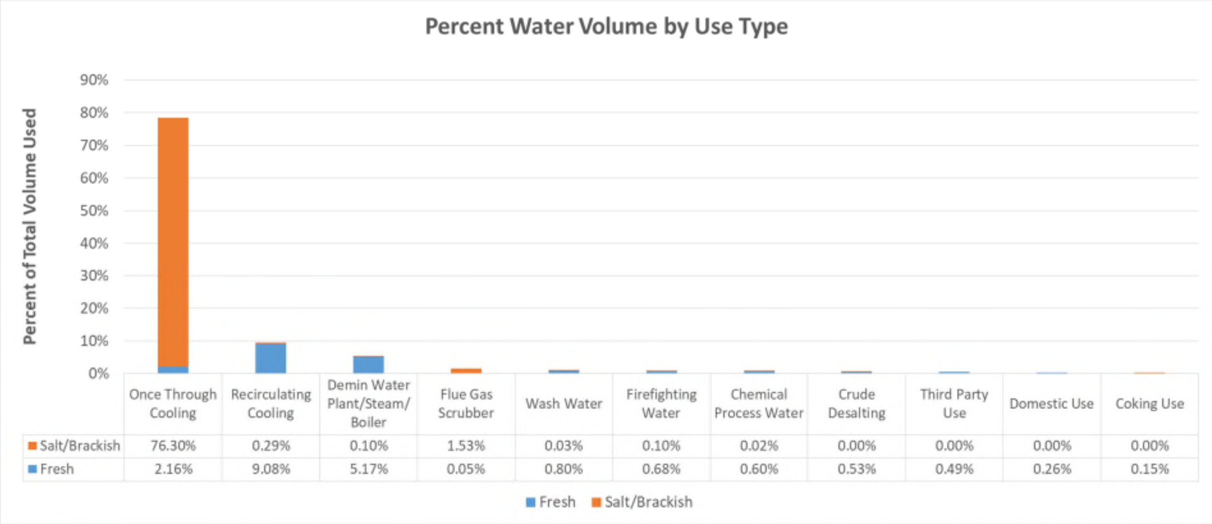
Water Uses
Chemical process water
Coking
Crude desalting
Demineralised water plant
Direct through discharge[1]
Domestic use
Firefighting Water
Flue gas scrubber
Once-through cooling
Recirculating cooling
Steam/boiler
Third party use
Wash water

[1] Direct through discharge has been included for information purposes but is not strictly a use. It includes rainwater, water derived from remediation/hydraulic control.

The water uses by percent of water used is shown in **Figure 8**. The water usage is shown by percentage to provide a relative breakout of the water utilized for each use, considering not all respondents provided volumes for water use (67 sites out of 72 provided water use data with a volume >0 m^3). The uses also contain reused water, which represents 96 million m^3. For this purpose, reused water is defined as water that is discharged from one use and is utilized in a different subsequent use prior to being discharged from the site. Under this definition, reused water does not refer to water that is cycled multiple times through the same use (i.e. recirculating cooling).

As shown in **Figure 8**, the vast majority (76%) of water used was salt/brackish water for once-through cooling purposes. When plotted in the same graph, the high volumes of water used for once-through cooling relative to other use volumes had the effect of dominating the scale of the graphs and therefore occluding meaningful analyses of other water use types in which contaminants are added and discharged. Therefore, in most subsequent analyses, once-through cooling waters have been removed and, where useful, have been included in stand-alone graphs.

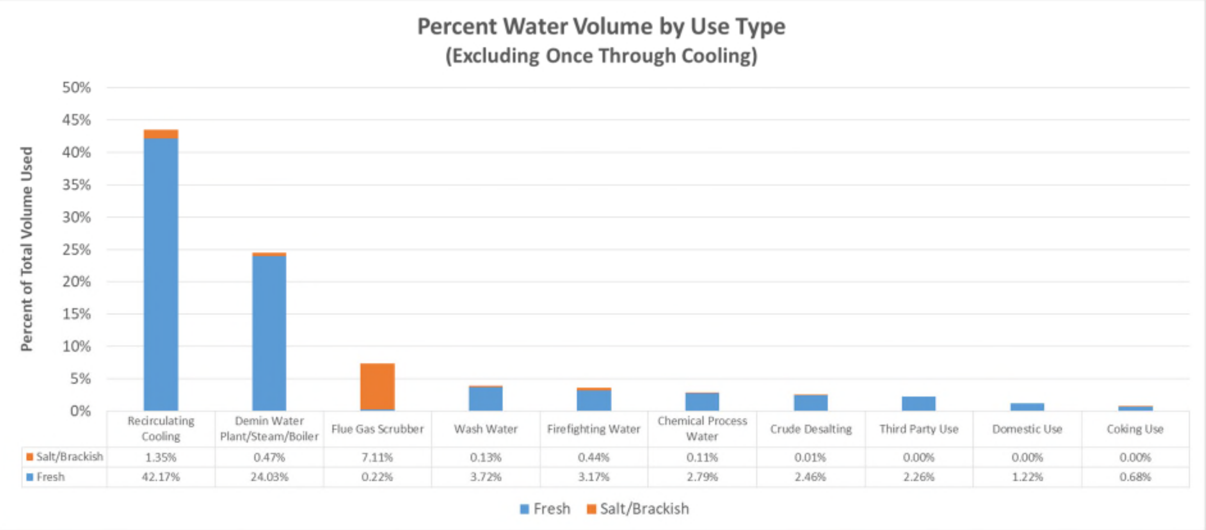
Figure 8. Total water use split by type.



	Once Through Cooling	Recirculating Cooling	Demin Water Plant/Steam/Boiler	Flue Gas Scrubber	Wash Water	Firefighting Water	Chemical Process Water	Crude Desalting	Third Party Use	Domestic Use	Coking Use
■ Salt/Brackish	76.30%	0.29%	0.10%	1.53%	0.03%	0.10%	0.02%	0.00%	0.00%	0.00%	0.00%
■ Fresh	2.16%	9.08%	5.17%	0.05%	0.80%	0.68%	0.60%	0.53%	0.49%	0.26%	0.15%

Figure 9 shows the volume of water uses per type with once-through cooling water removed, and showed that most water was used for recirculating cooling. For water used in the refineries 67 sites were included in the analysis. Of the total intake used for site purposes, most was used for recirculating cooling purpose (44%), followed by use in demineralised water production and/or steam/boiler (25%), and use in flue gas scrubbers (7 %).

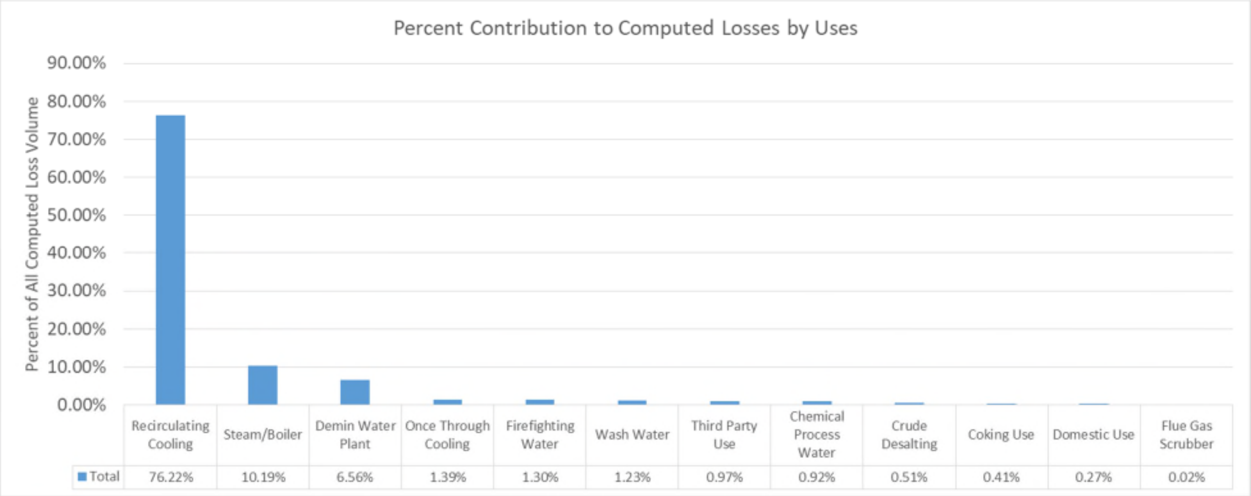
Figure 9. Total water use split by type. (Once-through cooling volumes excluded).



	Recirculating Cooling	Demin Water Plant/Steam/Boiler	Flue Gas Scrubber	Wash Water	Firefighting Water	Chemical Process Water	Crude Desalting	Third Party Use	Domestic Use	Coking Use
■ Salt/Brackish	1.35%	0.47%	7.11%	0.13%	0.44%	0.11%	0.01%	0.00%	0.00%	0.00%
■ Fresh	42.17%	24.03%	0.22%	3.72%	3.17%	2.79%	2.46%	2.26%	1.22%	0.68%

Respondents defined water uses and provided the volume directed into the use and leaving it, then being directed to subsequent uses or effluent streams. In some cases, specific volumes were not reported but an estimate of the loss occurring in the use was provided. The data made it possible to compute relative loss of each use. Since not all respondents provided loss data on each use, the specific volumes computed was not fully representative. Therefore, loss values are presented in terms of percent of all computed losses (**Figure 10**). Recirculating cooling represents the vast majority of computed loss volumes across all uses (76 %). This is not surprising considering the recirculating cooling process circulates the same water through the cooling system multiple times and has substantial evaporative loss and relatively minimal blowdown volumes. Other significant losses were reported for steam/boiler use (10%) and demineralised water production (7 %).

Figure 10. Percent of all computed loss water by use type.



As shown in **Table 9**, the percentage of fresh water intake used for recirculating cooling across country groups appeared highest in country groups with limited access to brackish/salt water sources, such as Germany or Central Europe. Conversely, the percentage is lowest in those regions with relatively easy access to saltwater sources, such as in the Baltic or Benelux country groups. Baltic and Benelux sites also had the highest number of sites utilising once-through cooling water.

Table 9. Percent of fresh water intake used for recirculating cooling across country groups.

Country Group	Percent fresh water intake used for recirculating cooling	Number of sites within each country group that utilises once-through cooling water
Baltic	0.2%	7
Benelux	12.9%	5
Central Europe	34.7%	3
France	17.8%	1
Germany	48.7%	2
Iberia	35.7%	1
Mediterranean	38.2%	3
UK and Ireland	10.5%[1]	1

[1] One site had a created water scenario on their recirculating water use (i.e. higher volume coming out of the use than coming in). This site was removed from the UK and Ireland country group for this analysis to not to distort the statistics.

Of the total fresh water intake used for site purposes (352 million m^3), 76% was being utilized for recirculating cooling purpose as reported by 42 refineries (an additional 3 refineries indicated recirculating cooling using brackish water). The percentage of fresh water utilized for recirculating cooling was calculated separately for each of these 42 refineries, which indicated use of fresh water for this purpose. The percentages ranged from 8% up to 100% as shown in Figure 11. The four sites which had > 80% was further examined in order to further understand the reason for the high percentages. All were suspected to be artificially high and the examination confirmed that[5], although a revised figure was not obtained.

The 30 refineries that did not report fresh water utilized for recirculating cooling either used once-through cooling water (12 sites), used non-fresh recirculating cooling (5 sites), did not report any cooling uses (8 sites), or did not provide any water use data (5 sites).

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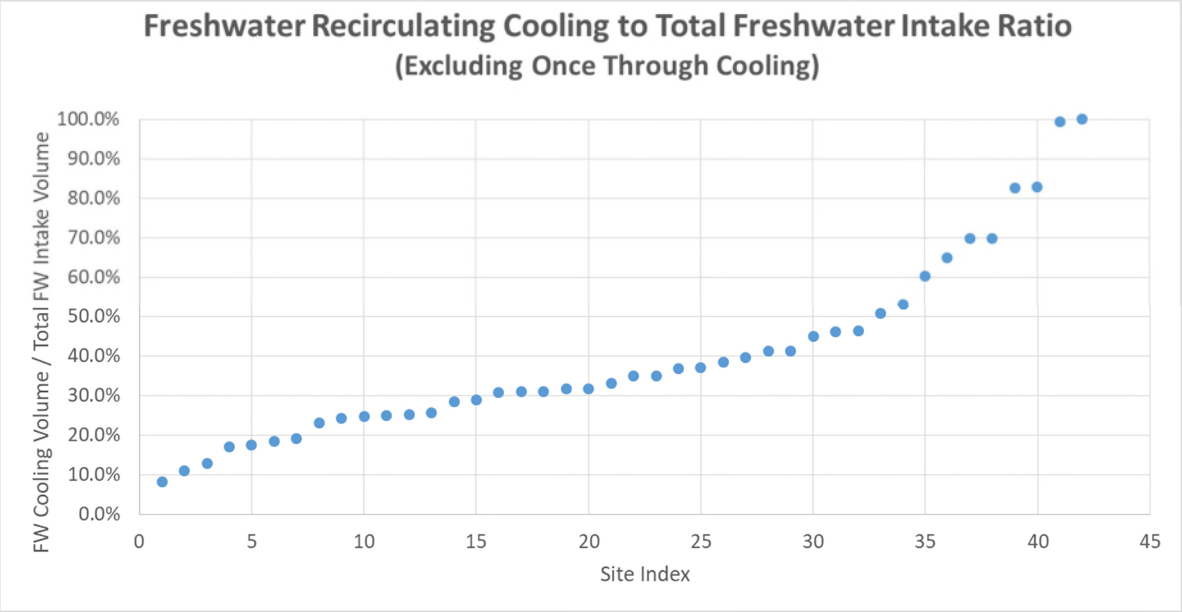
[5] the site at 100% had created water scenarios (i.e. higher volume coming out of the use than coming in); the site at 99% only reported three uses in total; the first site at 83 % (82.9 %) labelled one of their large uses (> 20 million m^3) as “Cooling water and other internal use” but classified the full volume as recirculated cooling; and the second site at 83 % (82.7 %) had a large portion of its freshwater use labelled as “Demi plant use” but classified it as recirculating cooling use.

Figure 11. Fraction of fresh water intake utilised for recirculating cooling purposes. (Graph only shows sites with fresh water used for recirculating cooling).



2.3. EFFLUENT DISCHARGE VOLUMES

This section provides an overview of the quantities and types of effluent discharges. Also provided are information on the water body types receiving the effluent and a summary of water treatment types. With respect to refinery effluent volume, Concawe has been collecting data from their membership regularly since 1969.

The 2016 discharge quantity data (72 refineries) showed slightly higher levels with 2013 data when it comes to total aqueous effluent volumes including once-through cooling (**Table 10**). 2016 comparisons with 2010, 2008 and 2005 data was difficult given the way 2005-2010 data was reported (2005 not including once-through cooling volumes, whereas 2008 and 2010 contains some but not all once-through cooling volumes). Excluding once-through cooling showed a reduction in 2016 compared to 2013, and even further so compared to 2005.

Comparing 2016 to 2013, the potentially most meaningful indicator is the volume of effluent per tonne of throughput, which indicated that the relative total effluents have increased in 2016 (5.3 m^3/tonne vs. 4.7 m m^3/tonne) but decreased when excluding once-through cooling volumes (0.92 m^3/tonne vs. 0.73 m m^3/tonne).

Table 10. Effluent discharge data from 1969 to 2016

Year of survey	Number of reporting refineries	Total aqueous effluent [1] (million m^3/yr)	Relative Aqueous effluent (m^3/tonne throughput)
1969	80	3,119	n.a.
1974	108	3,460	n.a.
1978	111	2,938	5.4
1981	104	2,395	5.4
1984	85	1,934	4.6
1987	89	1,750	3.9
1990	95	1,782	3.5
1993	95	2,670	4.8
1997	105	2,942	4.7
2000	84	2,543	4.9
2005	96	790 [2]	1.2 [2]
2008	125	1,112 [3]	1.5 [3]
2010	98	1,583 [4]	2.6 [4, 5]
2013	78	2,370 (465) [6]	4.7 (0.92) [6]
2016	72	2,693 (371) [6]	5.3 (0.73) [6]

n.a. = not applicable

[1] Until 2000, the total aqueous effluent in the table refers to the sum of process effluents, cooling water and other flows such as lightly contaminated rainwater. For the 2008, 2010 and 2013 surveys, there is the distinction between treated water and other streams that are discharged at the same or separate emission points.

[2] 2005 data only consider the treated effluents and no longer included once-through cooling water from closed systems.

[3] For 2008 data, many sites only reported treated effluent volumes and not all the effluent waters. When looking at treated effluent volumes (**Table 10**), the 2008 data appears to be in line with other years.

[4] When comparing sites that responded in both 2010 and 2013, there were 5 sites that indicated once-through cooling waters in their effluent volumes in 2013 (total 1,702 million m^3), but indicated 0 m^3 once-through cooling waters in their effluents in 2010. Therefore, if the sites had similar volumes in 2010 as they reported in 2013 the total effluent volumes in 2010 would add up to 3,285 million m^3

[5] Error corrected compared to 2010 survey report (Concawe, 2012).

[6] In parenthesis, excluding once-through cooling volumes.

In contrast to total aqueous effluent volumes, treated effluent volume data for 2016 could be compared with 2005-2010 data and this also showed a decrease as shown in **Table 11**.

Table 11. Treated effluent discharge data from 2005 to 2016

Year of survey	Number of reporting refineries	Treated Effluent[1] (million m^3/year)	Relative Treated Effluent (m^3/tonne throughput)
2005	96	790	1.2
2008	125	612	0.82
2010	98	569[2]	0.94
2013	78	451[2]	0.90
2016	72	330	0.65

[1] Including treated transfer streams

[2] Re-evaluated since Concawe Report 12/18 (Concawe, 2018) as follows:

- 2010 data: Previous number only considered an estimate of treated process water (241 Mm3) and reports on other water (328 Mm3) that was treated before discharge or transfer. From the notes provided by the survey respondents, it is evident that these other waters are mixes of process, cooling and storm water. Therefore, it was assumed that 50% of these effluents comprise process water, and 405 Mm^3 was estimated. In this report, 100 % of all treated effluents are included.
- 2013 data: Previous number only considered an estimate of treated process water, which was based on the reported treated process water (170 Mm^3) and reports on other water (136 Mm^3) that was treated before discharge or transfer. From the notes provided by the survey respondents, it is evident that these other waters are mixes of process, cooling and storm water. Therefore, it was assumed that 50% of these effluents comprise process water, and 238 Mm^3 was estimated. In this report, 100 % of all treated effluents are included.

Figure 12 present a summary of discharge quantities by country group type and partitioned by receiving environment (fresh, salt/brackish, transfers) including once-through cooling. In the Baltic and Benelux regions, a limited number of refineries contributed to the high discharge volumes observed. These refineries are all located adjacent to an ocean shore and are equipped with a once-through cooling system that discharges either in harbours/estuaries or directly in the marine environment.

Figure 12. Annual discharge volumes, plotted according to salinity of receiving environment. (Once-through cooling volumes excluded).

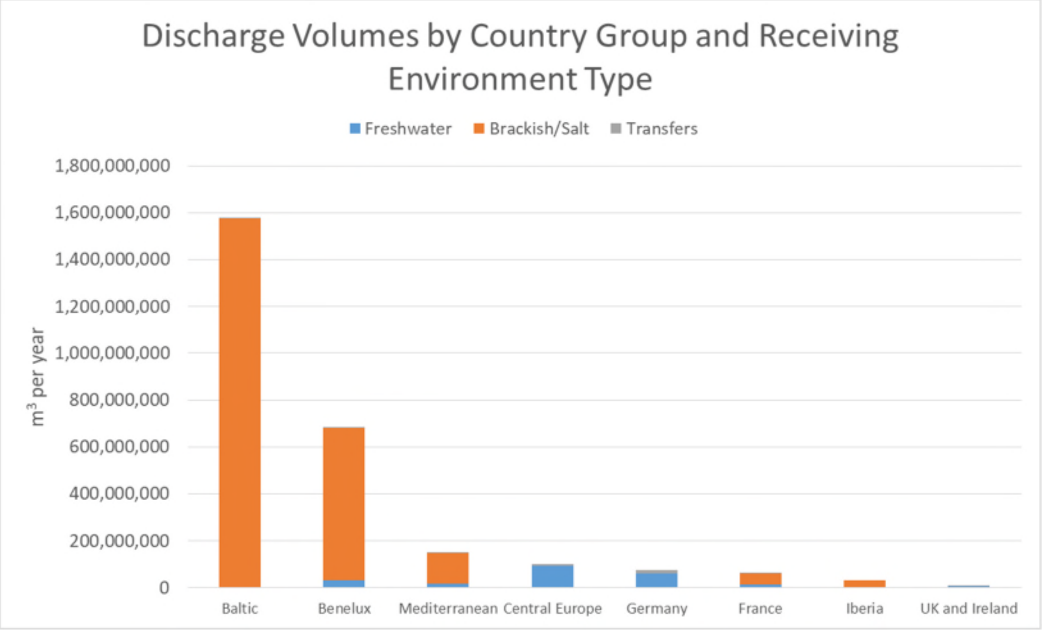


Figure 13 shows discharge quantities by country group and partitioned by receiving environment type excluding once-through cooling. Excluding once-through cooling made it apparent that one site in the Baltic region with a large volume of scrubber water (> 40 million m^3), being discharged without requiring treatment, had a major impact on the Baltic region data. This volume could be considered for exclusion in the dataset since it is a very specific circumstance. The corresponding relative discharge volumes gives a more balanced picture (**Figure 14**). However, Central Europe stands out with high volumes. In addition, excluding the large volume of scrubber water in the Baltic region, as mentioned above, makes Baltic comparable to Benelux and Iberia.

Figure 13. Annual discharge volumes, plotted according to receiving environment. (Once-through cooling volumes excluded).

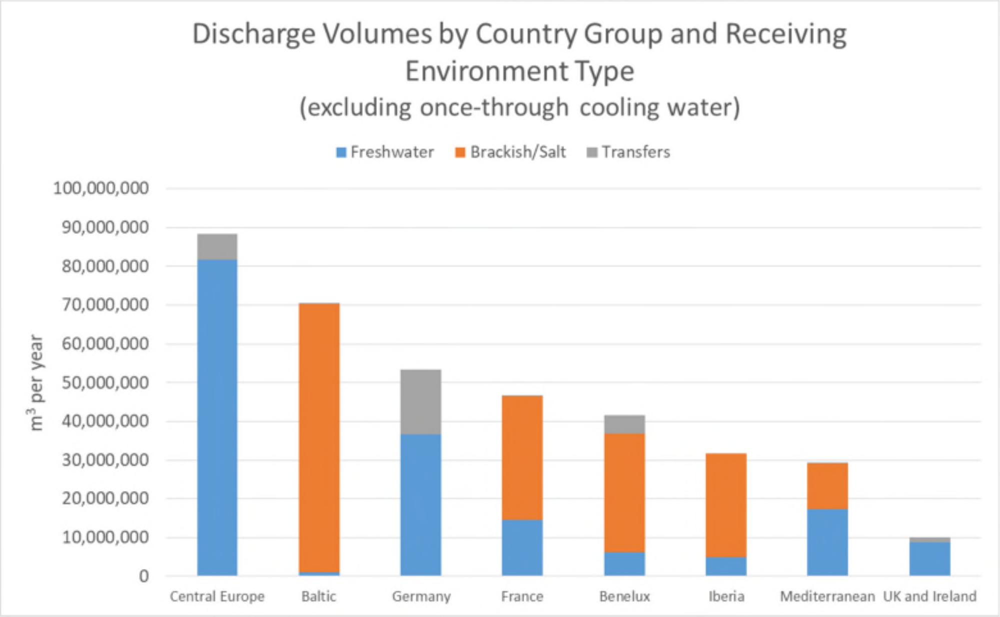


Figure 14. Annual discharge volumes relative to the total throughput, plotted according to salinity of receiving environment. (Once-through cooling volumes excluded).

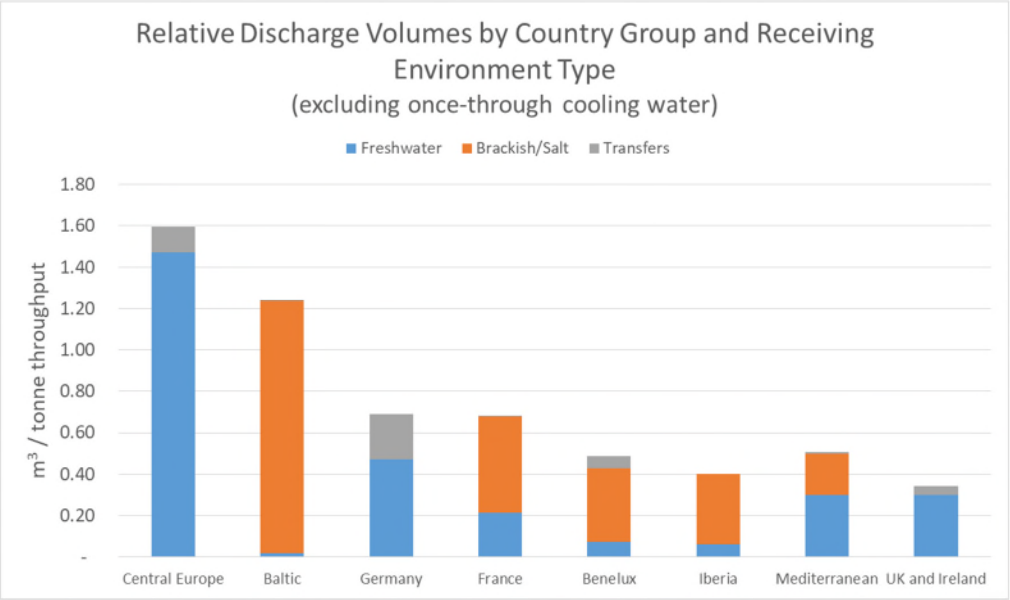


Figure 15 and **Figure 16** shows discharge quantities by country group discharged into fresh water environments in total and relative volume, respectively. Country groups that are more land-locked, such as Central Europe and Germany, understandably have higher volumes of discharge to fresh water environments than country groups such as Baltic that have ready access to the sea.

Figure 15. Annual discharge volumes into freshwater. (Once-through cooling volumes and waters ultimately discharged into a freshwater environment are included).

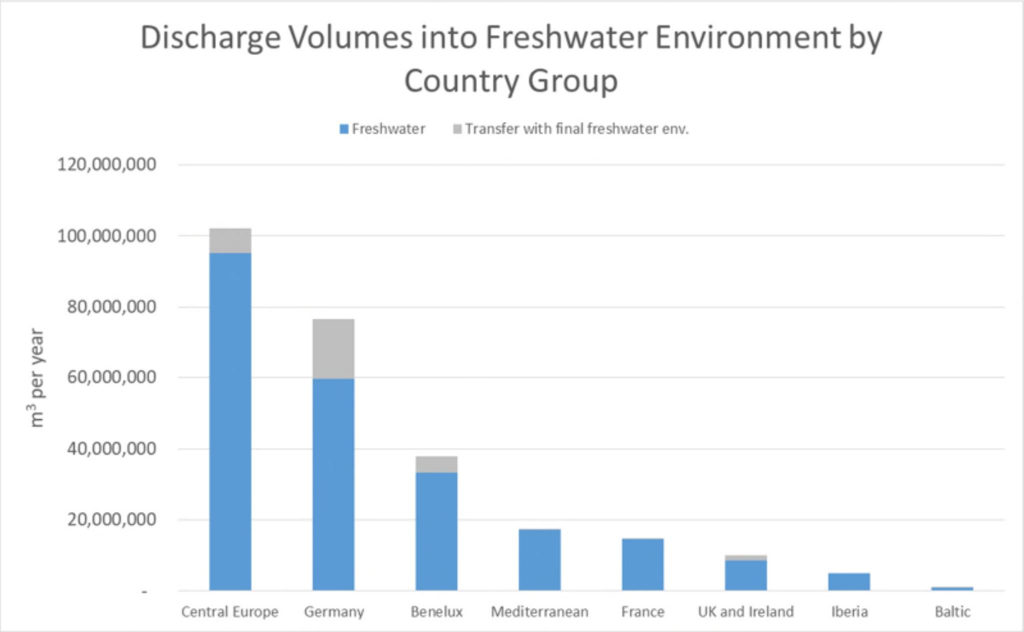


Figure 16. Annual discharge volumes into freshwater relative to the total throughput. (Once-through cooling volumes and waters ultimately discharged into a freshwater environment are included).

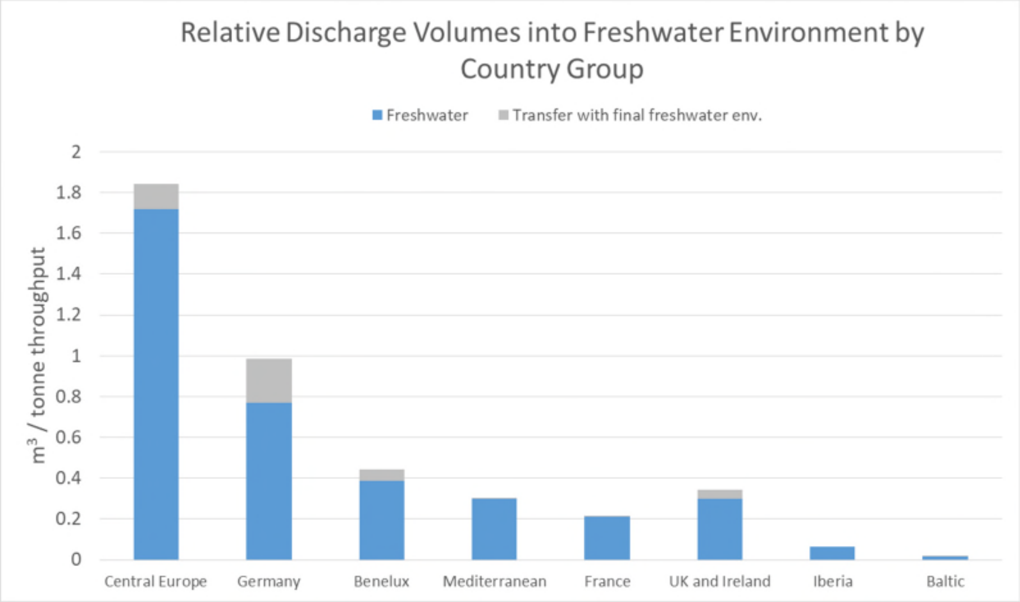
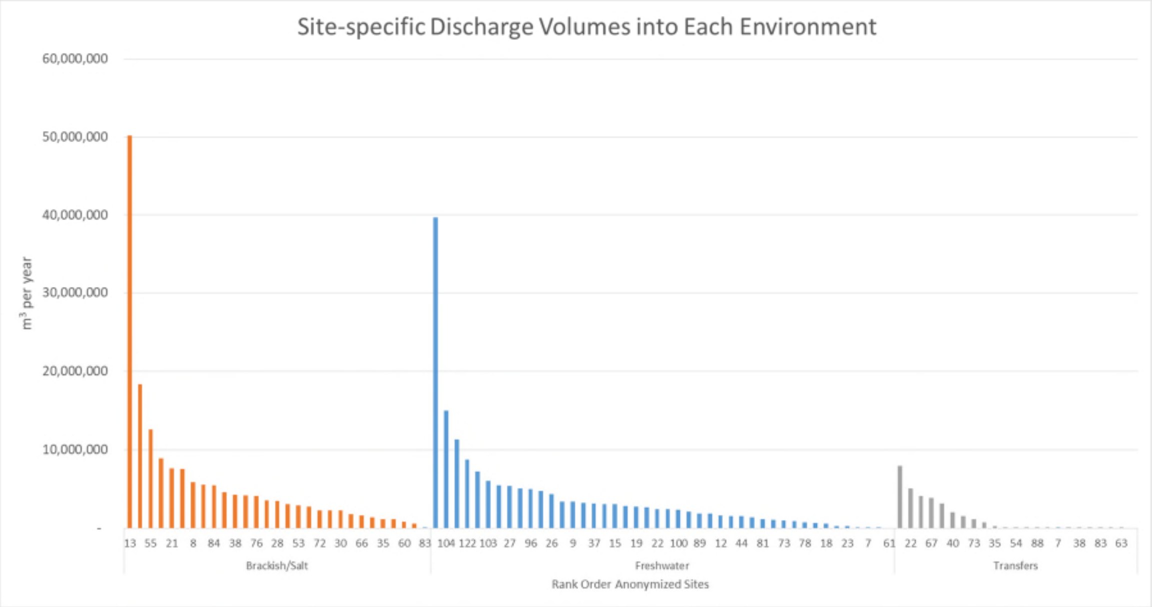


Figure 17 shows sites effluent quantities, in a descending rank order, for different receiving environment bodies and transfers, excluding once-through cooling volumes. The outlier in discharging to salt/brackish is again the site mentioned above in the Baltic area, which has a large volume of scrubber water (> 40 million m^3) being discharged without requiring treatment. The outlier in discharging to fresh water is located in Central Europe and is not an outlier in terms of water consumption (**Section 2.4**), therefore, again, illustrating a feature of a country group being land-locked.

Figure 17. Descending rank order of sites for the effluent quantities for different receiving bodies and transfer. (Once-through cooling volumes excluded).



In the 2016 survey, a new question was asked concerning the receiving basin flow and/or the known dilution factor applied to the receiving basin. However, the response rate to this question was low as only 16% of all the defined outfalls were provided with defined or calculable dilution factors. Within country groups, it ranged from 40% of the outfalls being provided with dilution factors (France) to 8% (Baltic country group). The lack of dilution factors for the latter area is presumably because many of the discharges are directly into marine/sea environments where dilution is difficult to compute without extensive modelling. Overall, the average dilution factor for discharged waters was 2,833. However, it varied significantly by receiving basin category, e.g. up to 15,138 for estuaries, between 218 and 11,520 for rivers and between 1 and 102 for canals, respectively. The data indicated that canals may be more heavily influenced by refining industry discharges in both their relative volume as well as potentially mass loadings.

Figure 18 and **Figure 19** shows water effluent quantities with respect to treatment types, excluding once-through volumes but including untreated uncontaminated water in total and relative volumes, respectively. Three-stage biological (primary separation, biological treatment and secondary separation) WWTP was the most commonly used treatment type, and comprised of over 178,000,000 m^3/year and about half (51%) of all water effluent volumes across all treatment types. Physical (e.g. oil-water separation or settling) and/or chemical (e.g. chemical precipitation) installation was the second most common treatment type, with approximately 59,000,000 m^3/year and 17% of total water effluent volume. Less abundant treatment types included external facility transfer (8.8%), and uncontaminated water not requiring treatment (22%). It should be noted that the effluent volumes plotted in **Figure 18** comprise waste waters with variable treatment requirements, including process effluents and less contaminated waters (e.g. rainwater water runoff).

With regard to process effluents, over 90% of the reporting refineries in 2016 applied three-stage biological waste water treatment, or transferred their process water effluent to an external facility applying three-stage biological waste water treatment. Assuming that the refineries which reported using three-stage biological waste water treatment on their process water in 2010 and 2013 continued to do so in 2016, the total percentage of refineries utilising three-stage biological waste water treatment on their process water is over 97%. This clearly illustrates that the vast majority of the reporting refineries utilise the provisions of the Best Available Techniques (BAT) Reference document (BREF) for the Refining of Mineral Oil and Gas (REF BREF)[6] and its BAT Conclusions (2014/738/EU[7]) for treatment of effluents.

Figure 18. Water effluent volumes by treatment type. (Once-through cooling volumes excluded).

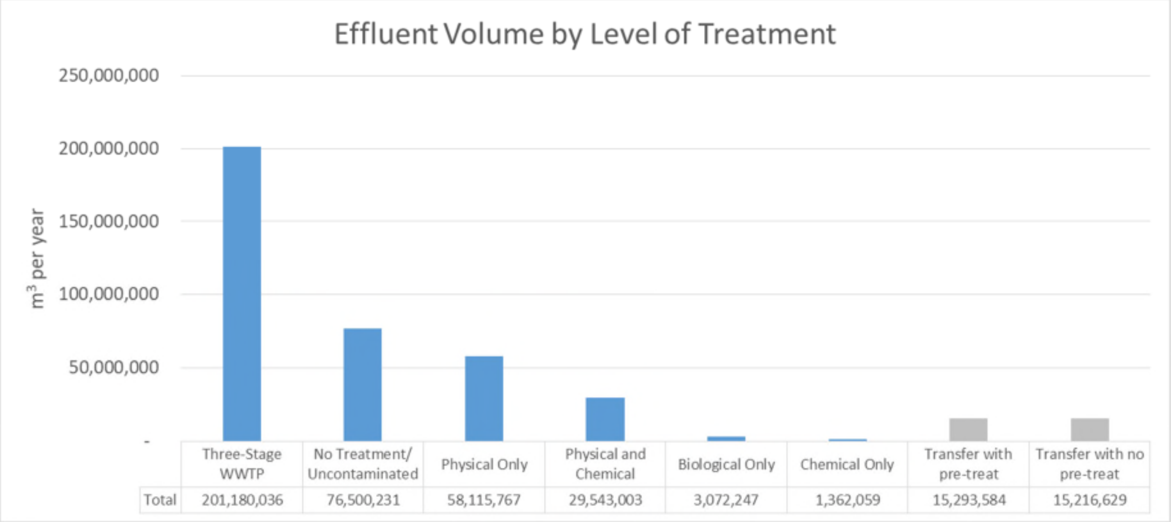
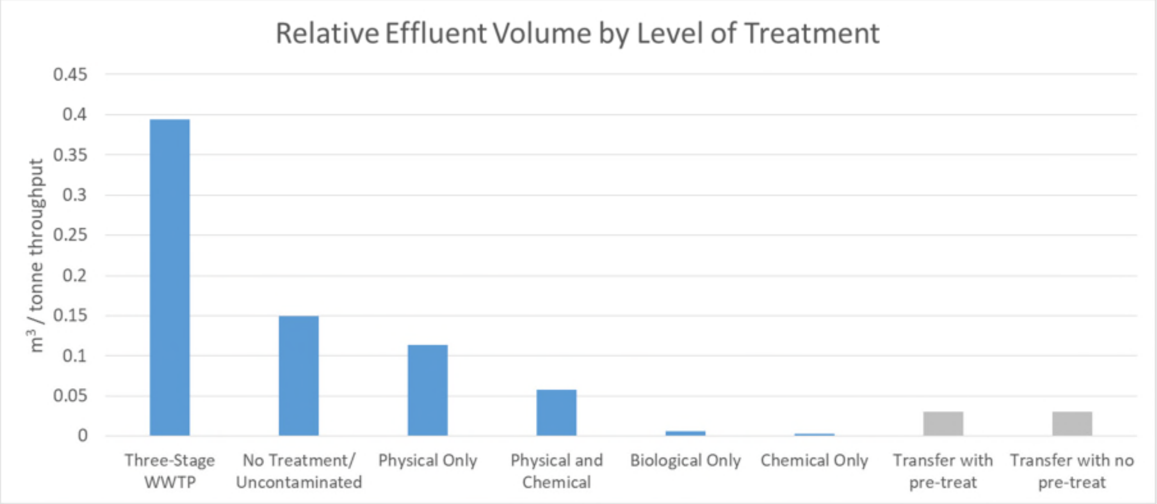


Figure 19. Water effluent volumes by treatment type relative to the total throughput (Once-through cooling volumes excluded).



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[6] Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas; European Commission Joint Research Centre, 2015.
https://eippcb.jrc.ec.europa.eu/reference/BREF/REF_BREF_2015.pdf

[7] 2014/738/EU: Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas.

Figure 20 and **Figure 21** presents the volume of transfer water by final treatment type and discharge environment in total and relative volumes, respectively. Approximately 94% of transfer volume was for treatment purpose.

Figure 20. Volume of transfer water split by transfer purpose and final treatment applied to the transferred water.

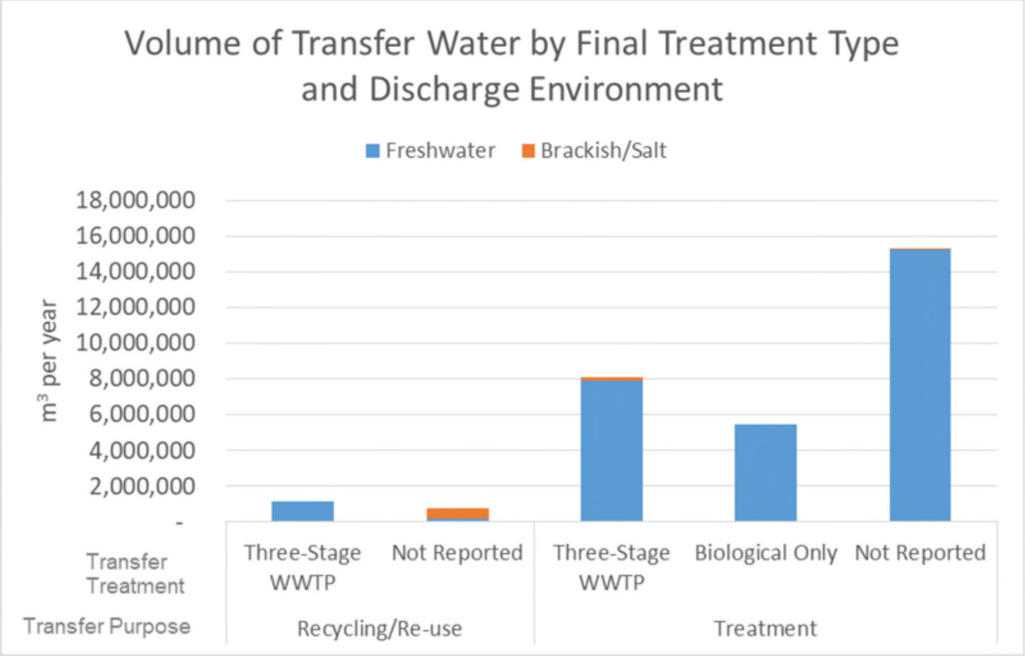


Figure 21. Normalised volume of transfer water split by transfer purpose and final treatment applied to the transferred water.

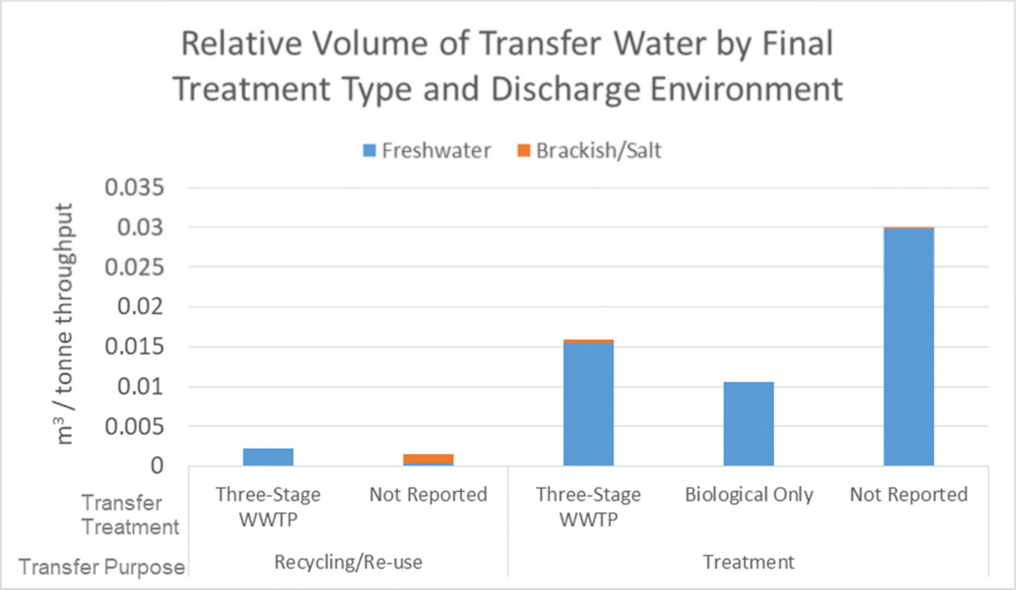
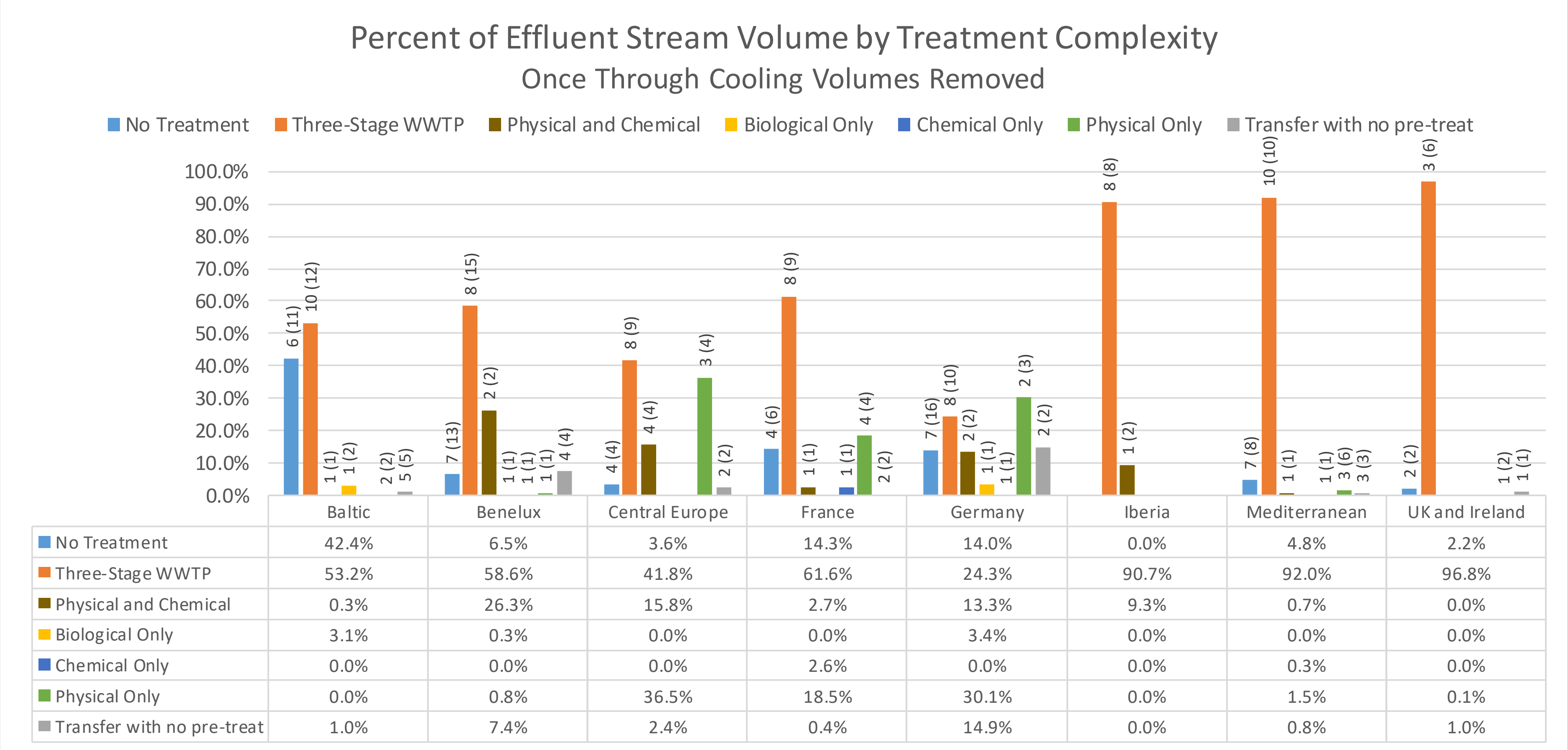


Figure 22 presents the percent of effluent stream volumes by treatment type/complexity from all 72 refineries. Once-through cooling volumes have been removed. Transferred waters that were pre-treated have been included in their respective pre-treatment category.

Initially, there was a very high “no treatment”-percent for Baltic due to a site that has a large volume of scrubber water (> 40 million m^3) that was mixed with cooling water prior to discharge. It was confirmed with site that this water did not require treatment. In order not to skew the statistics, this stream was omitted from the figure, if included the Baltic percentages would have been 75 % having no treatment and 23 % treated in a three-stage WWTP. Nevertheless, the Baltic country group showed the highest percentage of water requiring no treatment by far.

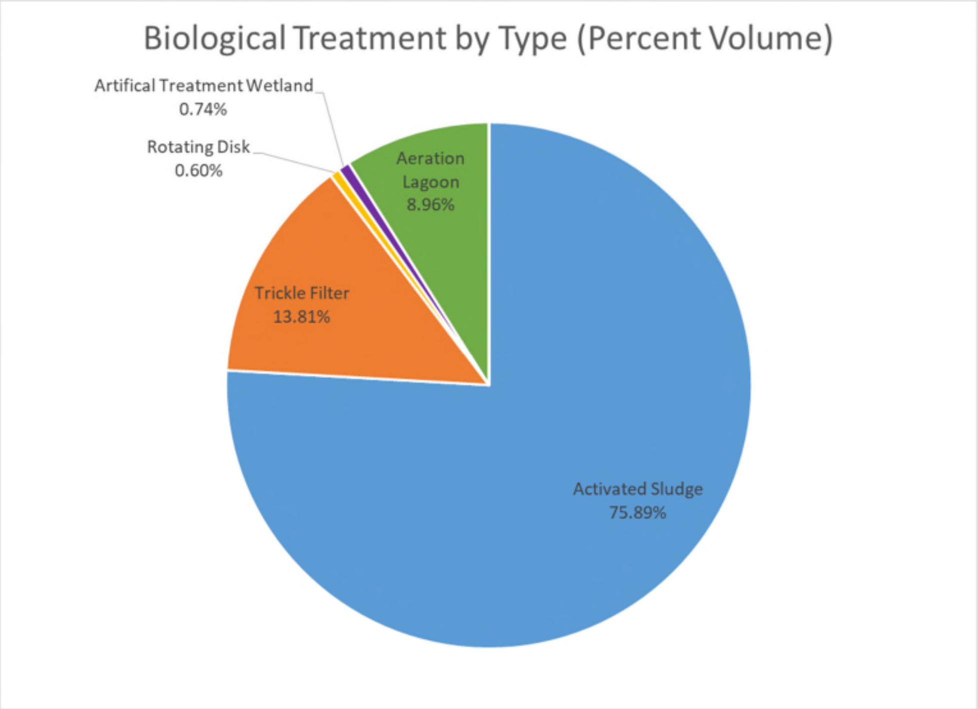
Figure 22. Percent of effluent stream volumes by treatment type/complexity. Once-through cooling volumes have been excluded. Transferred waters that were pre-treated have been included in their respective pre-treatment category. Numbers above each bar represent the number of unique sites per treatment/country group as well as number of unique effluent streams in parentheses. Note that some sites may have multiple effluent streams with different treatment types. Therefore, the sum of site counts may exceed total number of sites in the survey.



	Baltic	Benelux	Central Europe	France	Germany	Iberia	Mediterranean	UK and Ireland
No Treatment	42.4%	6.5%	3.6%	14.3%	14.0%	0.0%	4.8%	2.2%
Three-Stage WWTP	53.2%	58.6%	41.8%	61.6%	24.3%	90.7%	92.0%	96.8%
Physical and Chemical	0.3%	26.3%	15.8%	2.7%	13.3%	9.3%	0.7%	0.0%
Biological Only	3.1%	0.3%	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%
Chemical Only	0.0%	0.0%	0.0%	2.6%	0.0%	0.0%	0.3%	0.0%
Physical Only	0.0%	0.8%	36.5%	18.5%	30.1%	0.0%	1.5%	0.1%
Transfer with no pre-treat	1.0%	7.4%	2.4%	0.4%	14.9%	0.0%	0.8%	1.0%

Figure 23 presents the percent of effluent stream volumes receiving biological treatment segregated by biological treatment type. The activated sludge process is by far the most common biological treatment technique applied (76% of treated volume), followed by trickling filter (14% treated volume).

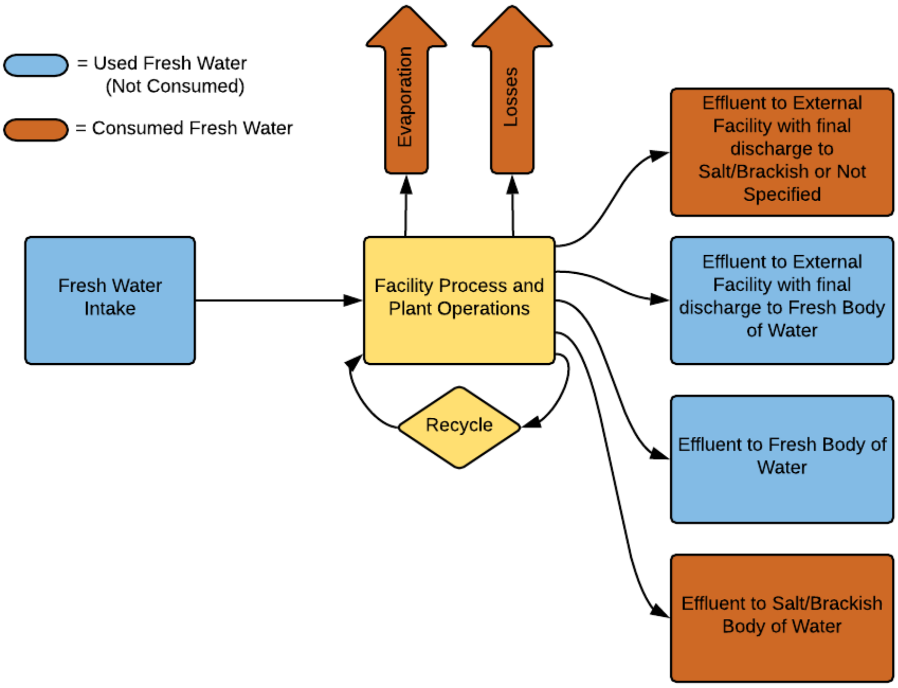
Figure 23. Percent of effluent stream volumes with Biological treatment by biological treatment type



2.4. FRESHWATER CONSUMPTION

The refining industry handles substantial quantities of water of various types and from various sources. Of particular interest is the amount of fresh water that is utilized in the industry and ultimately consumed because of operations. This freshwater consumption metric provides a relevant parameter for assessing resource efficiency. However, solely relying on freshwater intake volumes does not provide an accurate picture of the actual water consumed as some intake water is passed through the facility without being depleted. In practice, fresh water is consumed directly through evaporation and losses or indirectly through discharge to salt/brackish water bodies, as shown in **Figure 24.**

Figure 24. Flow diagram of freshwater consumption accounting



Freshwater consumption was calculated as the amount of fresh water withdrawn by the refining industry not including once-through cooling volumes and subtracting out the amount of fresh water that is returned to a freshwater body, as per the IPIECA definition of freshwater consumption, indicator E6 (IPIECA, API and IOGP, 2015). The rationale for this approach is that fresh water that is returned to freshwater bodies is not taken out of the regional water cycle, remaining available to other users downstream. In the calculations, the freshwater consumption was computed as the difference between site freshwater intake and site discharge to freshwater volumes. In addition, fresh water withdrawn for once-through cooling purposes but subsequently discharged to a salt/brackish body was also included in the freshwater consumption computation, as shown below:

$$FW_{consumption} = \left(FW_{intake} - Disch_{FW\ body}\right) + FW_{once\ thru\ disch\ to\ brackish}$$

To provide an accurate accounting of freshwater consumption, the freshwater intakes not utilized for processing and not in contact with refinery product or intermediate streams were excluded, as follows:

- Fresh water, used for once-through cooling water, returned unchanged, excluding thermal effects, to a freshwater source. The large volumes often used in cooling do not represent consumption since the water is returned and are therefore removed as they would otherwise distort freshwater withdrawal data;
- Fresh water already quantified as an intake stream but utilized in other intakes at the site (e.g.: internal recycles are only accounted on primary intake); and
- Fresh groundwater extracted solely for flood control, hydraulic control, or remediation.

In some cases, fresh intake water was discharged to an external facility for treatment (waste water treatment plant) or reuse (recycling). In the 2016 survey, responders were asked to provide data on the final discharge of transferred waters, if known. As a result, the transferred water volumes from fresh water sources could be tracked to the final destination type and fresh water consumption could be more accurately computed, a marked improvement over previous survey results.

The freshwater consumption was calculated for each refinery individually and subsequently aggregated across the entire industry. If effluents related to fresh water exceeded the freshwater intake for the given refinery, it was assumed that fresh water being discharged was equal to the intake and therefore evaporation and losses were set to zero for the given refinery. This conservative approach prevented scenarios of "created fresh water" (where a refinery discharged more fresh water than it withdrew) from being included in the freshwater consumption values.

In previous surveys, the presence of non-harvest rainwater at a refinery often caused issues related to accurate calculation of total freshwater consumption since many refineries would include the volume of rainfall in their reported mixed effluent volumes, but not account for that rainfall on their intake volumes. As a result, it was difficult to remove the unharvested rainfall portion when computing the freshwater consumption. In the 2016 reporting, direct discharge rainwater is measured on the intake and outfalls and can therefore be excluded from the consumption calculations

2.4.1. Statistical analysis of 2016 freshwater consumption

The industry-wide freshwater consumption aggregated from all considered sites was calculated to be 246 million m^3, as summarised in **Table 12**.

Table 12. Summary of industry-wide refinery fresh water consumption for 2016

Consumption type	Freshwater consumption (m^3/year)	Relative freshwater consumption (m^3/kilotonne throughput)
Freshwater effluent to brackish/salt water body	87,036,000	171
Fresh water consumption within facility (evaporation and losses)	159,108,000	312
TOTAL	**246,144,000**	**483**

Figure 25 presents the freshwater consumption aggregated by country group, whereas **Figure 26** presents the same relative to throughput and indicated that relative freshwater consumption (within the facility) varied up to five-fold by country group. It may be surprising that the UK and Ireland sites did not show any consumption due to freshwater discharge to salt/brackish environments, however no discharges to any saltwater body were reported[1].

Figure 25. Freshwater consumption by country group

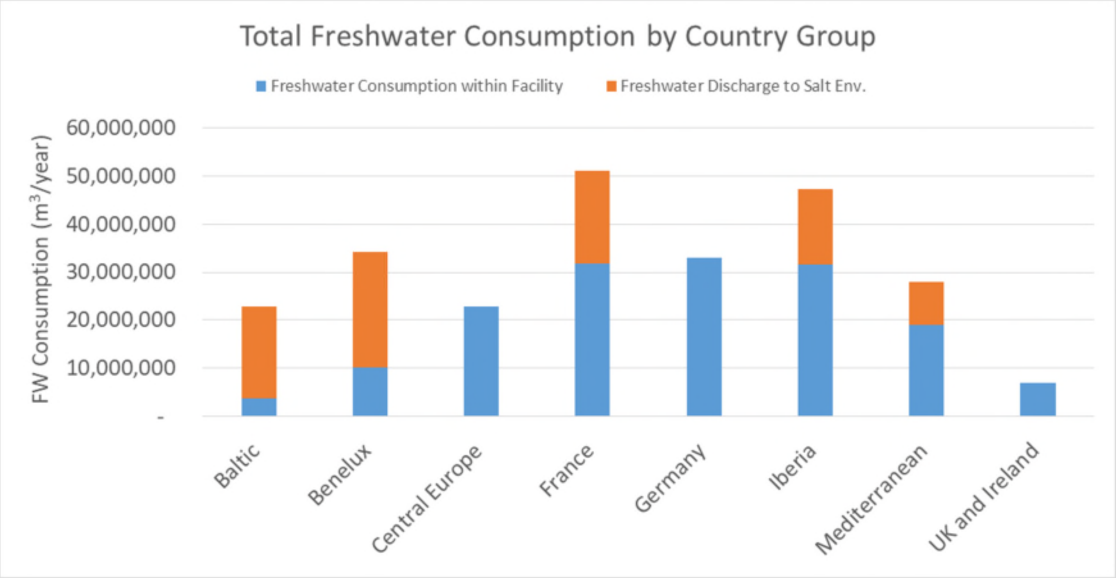
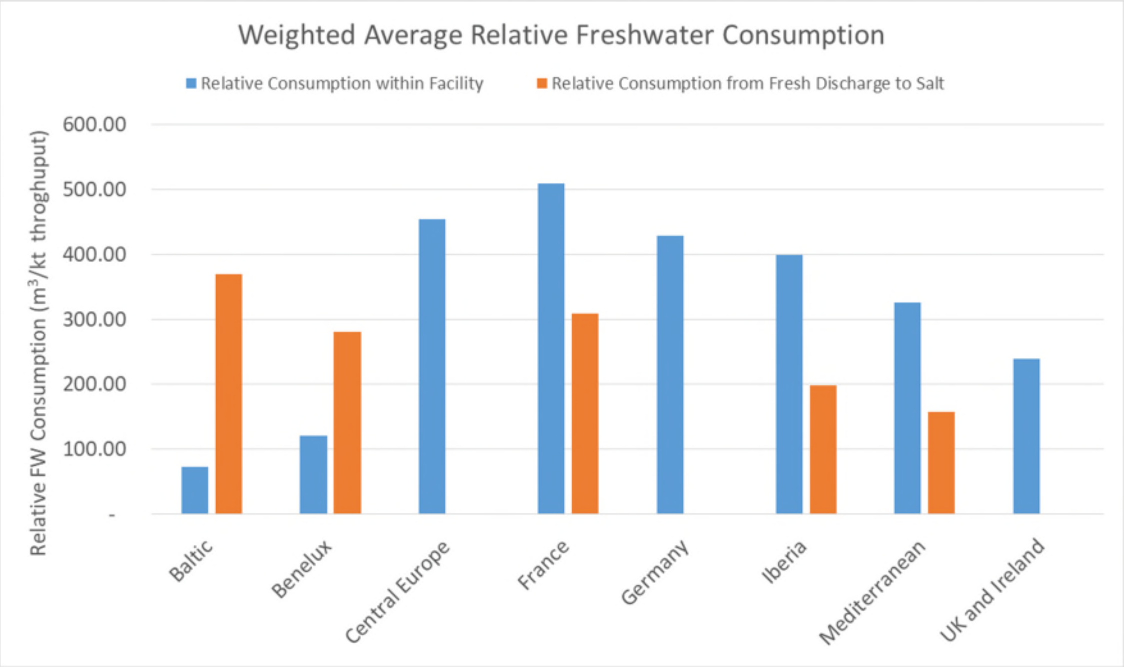


Figure 26. Average relative freshwater consumption by country group



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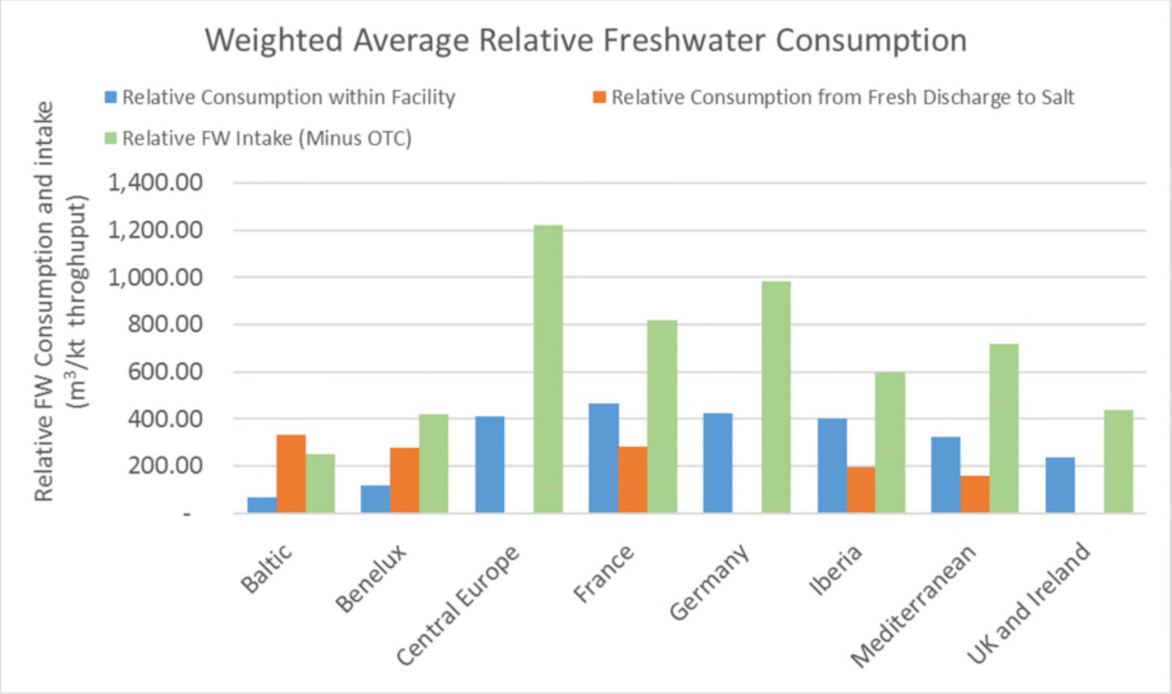
[1] Out of four UK/Ireland sites reporting, two sites reported having transfer streams with final receiving environment being a river, one site discharging to an estuary classified as freshwater, and the remaining discharges were all to canals which were classified as freshwater

When comparing the freshwater consumption with the freshwater intake (excluding once-through cooling) that country groups having a high freshwater consumption within the facility also had a high freshwater intake (**Figure 27**).

Figure 27. Average relative freshwater consumption by country group including metric not considering once-through cooling waters.



Relative freshwater consumption generally increased with increasing refinery complexity, (**Figure 28**). This increase with complexity is, however, not linear which suggests that more parameters than refinery complexity should to be taken into account when assessing relative freshwater consumption.

Figure 28. Average relative freshwater consumption by complexity group. Not available

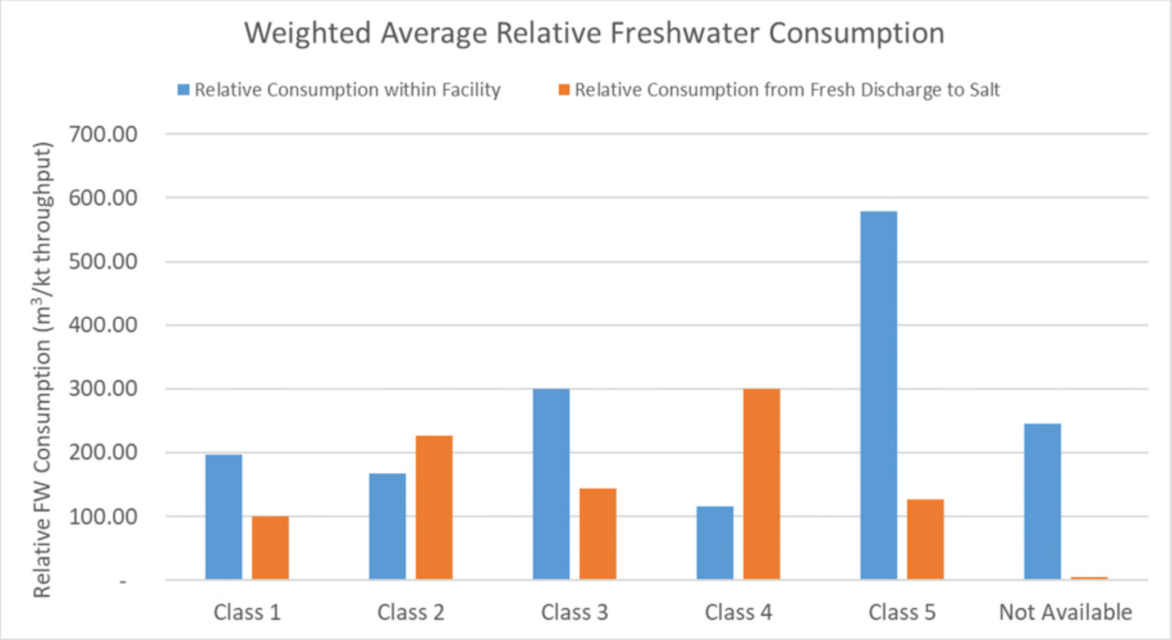


Figure 29 presents the consumption of fresh water per site in rank order. The average consumption of fresh water per refinery site was 3.4 million m^3 per year.

Figure 29. Freshwater consumption per site in rank order

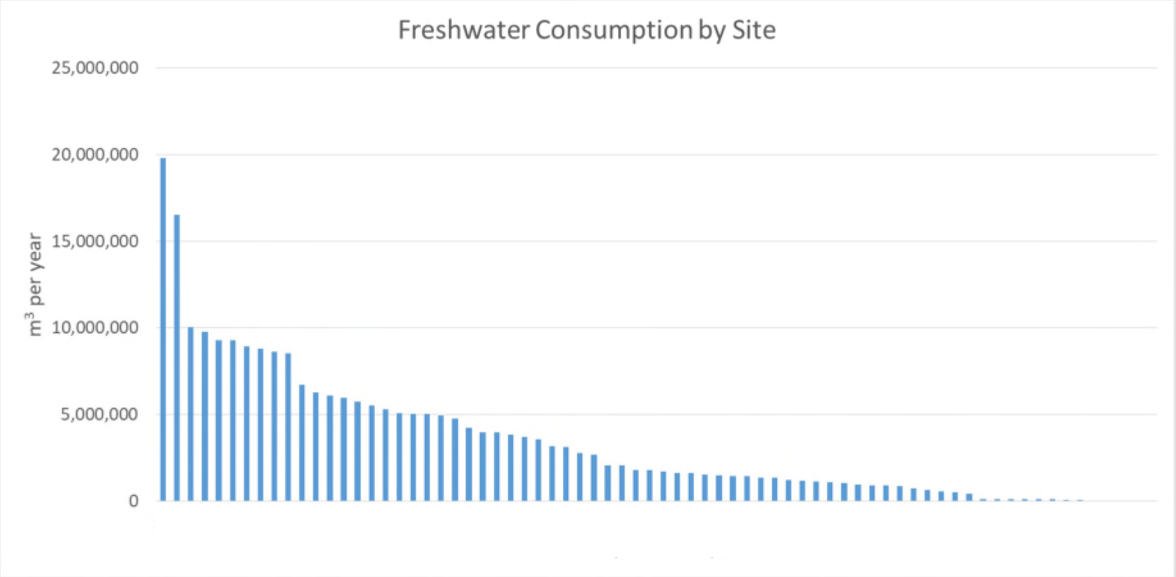
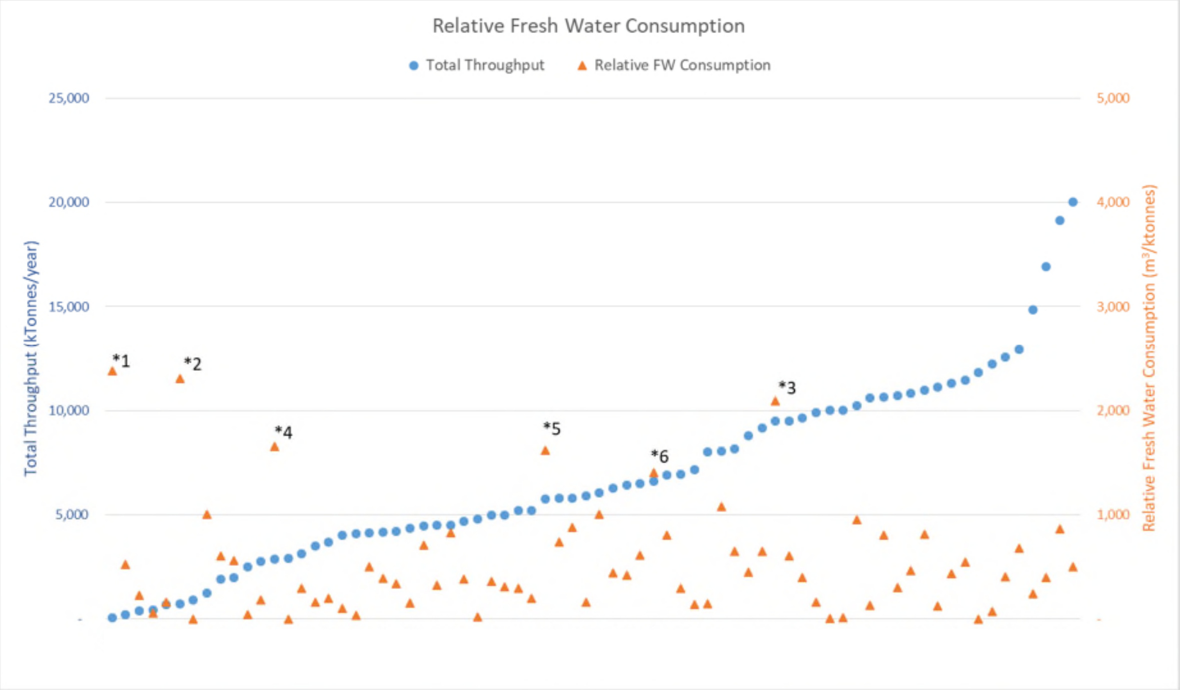


Figure 30 presents the relative freshwater consumption to throughput for each site. Outside a handful of high values (indicated with *), the relative freshwater consumption was rather consistent across refineries with the vast majority of sites (87 %) being in the range of 0-1000 m^3/kilotonne.

Figure 30. Freshwater consumption by refinery relative to total throughput



The outliers in **Figure 30** (indicated with ***1**, ***2**, ***3**, ***4**, ***5**, and ***6,** respectively) were further investigated to better understand the reasons for relative freshwater consumption being high. ***1** relies on recirculating cooling which has freshwater consumption through evaporation. In addition, this site has relatively low throughput so any consumption has a high relative impact; ***2** was an outlier also in 2013, however it had a decreased throughput in 2016 (43% of its 2013 value). Moreover, in 2013 the site did not include rainwater in their intake but did include it in 2016 with similar output volumes resulting in a slight increased consumption. The combination of these two factors results in the higher relative consumption; ***3** is located near the mouth of a river and is considered brackish. Thus, this site has fresh water discharge to a brackish environment, which is considered consumption and therefore reflecting location more than process losses. (It is the same site being the biggest outlier in **Figure 28**); ***4** has a large steam production component that was used for site purposes, but does not appear to be captured in any discharge. Therefore, the full amount of produced appeared to be consumed. This site had similar relative consumption levels in 2013; ***5** has a large loss on recirculating cooling use, which increases its relative consumption; ***6** has a relatively large losses on a recirculating cooling as well as in its demineralised water plant.

2.4.2. Comparison of 2010, 2013 and 2016 freshwater consumption data

Figure 31 presents the total freshwater consumption between the 2010, 2013 and 2016 survey years. It shows that refineries consumed 246 million m^3 of fresh water in 2016 vs. 271 million m^3 in 2013 and 282 million m^3 in 2010.

Figure 31. Total Freshwater Consumption in 2010, 2013, and 2016 survey years

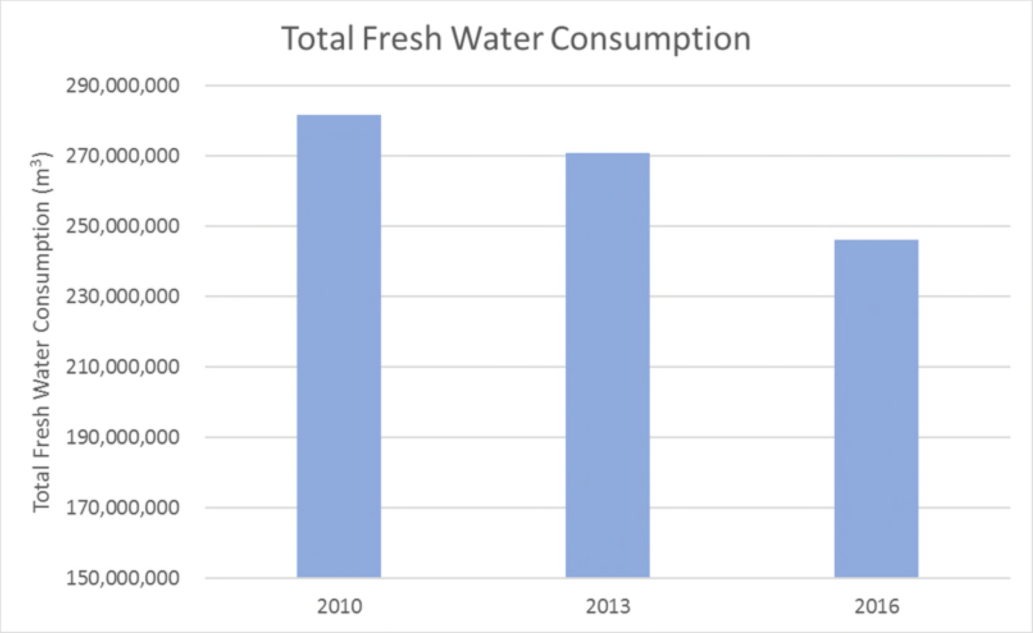
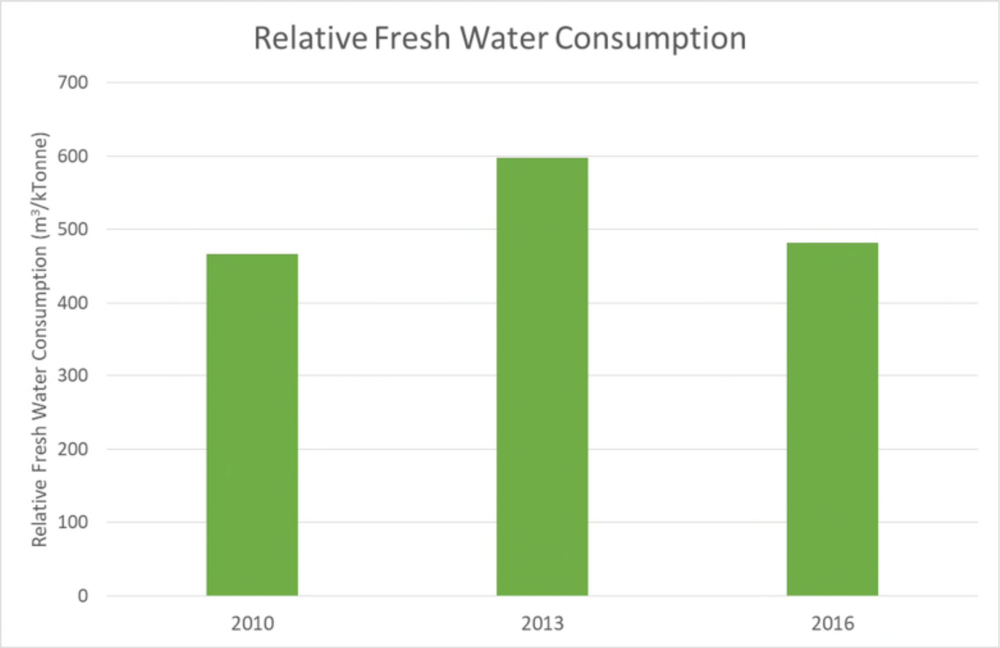


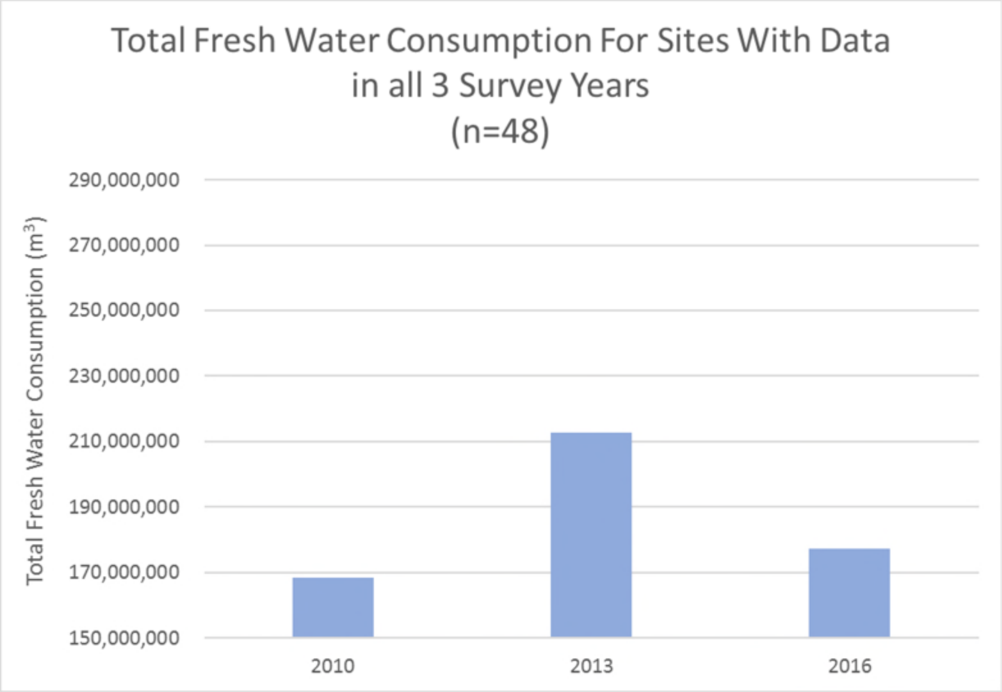
Figure 32 shows the relative freshwater consumption of the 2010, 2013 and 2016 survey years. The average relative freshwater consumption was lower in 2016 at 482 m^3/kilotonne compared to 2013 (598 m^3/kilotonne), but slightly higher compared to 2010 (467 m^3/kilotonne).

Figure 32. Relative Freshwater Consumption in 2010, 2013, and 2016 survey years.



In order to further remove the bias of different populations of refineries reporting under the different survey years, the freshwater consumption were compared utilising only sites reporting in all three surveys. The analysis (48 sites) showed that the total freshwater consumption was similar in 2016 and 2010 (168-177 million m^3), whereas it was higher in 2013 (213 million m^3) (**Figure 33**).

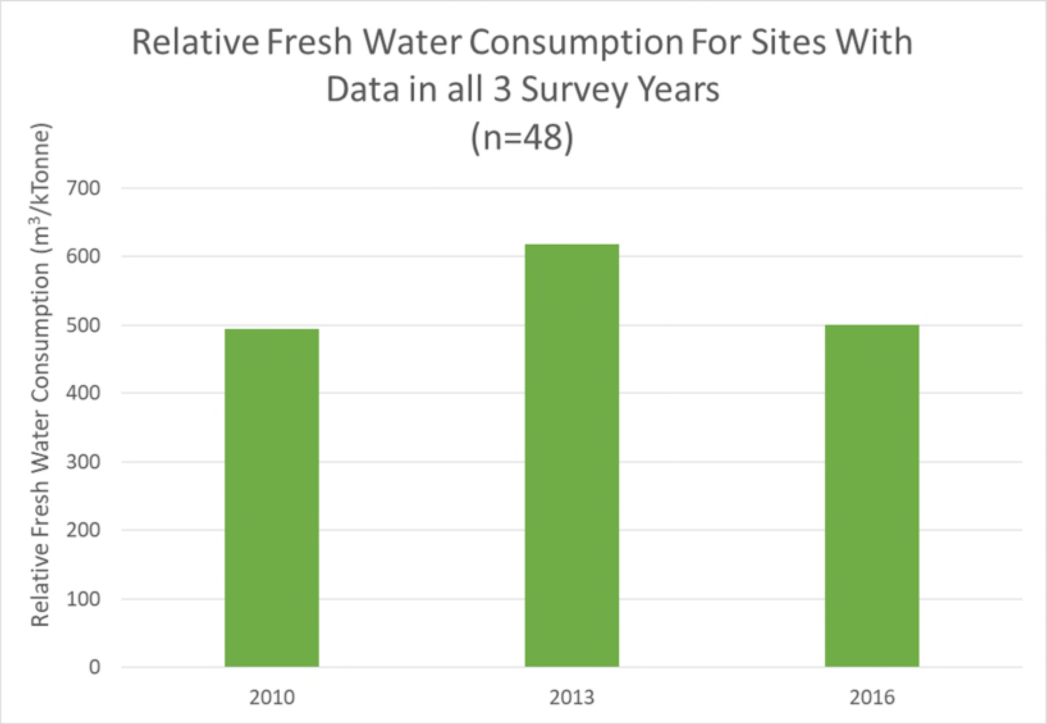
Figure 33. Total Freshwater Consumption utilising sites with data in all 2010, 2013, and 2016 survey years.



Looking at relative freshwater consumption utilising only the sites measured in all three survey years showed the same pattern as for total consumption; being similar in 2016 and 2010 (494-501 m^3/kilotonne) and higher in 2013 (618 m^3/kilotonne) (**Figure 34**). Therefore, the decrease in total freshwater consumption utilising the complete datasets (**Figure 31**) appears to be related to: 1) changes in the number of sites reporting, 2) different sites reporting between the survey years, and 3) decreased overall throughput per site.

The reasons for the difference in 2013, especially when looking only at sites reporting for all three surveys, was not evident. It may be due to the way of collecting the data on intakes and uses in the different surveys. The decrease in 2016 compared to 2013 could therefore be because rainwater volumes was better captured in 2016 survey (see **Section 2.4**).

Figure 34. Relative Freshwater Consumption utilising sites with data in all 2010, 2013, and 2016 survey years.



2.5. WATER COSTS

Following 2013 survey, which included a section pertaining to the costs of water, respondents were asked to identify the components included in the costs in order to make improved comparisons in water costs between the refineries. The 2016 survey water cost section were divided into three categories: intake, treatment, and discharge costs. From these three categories, the following sub-categories could be selected to define the basis for the costs:

- Intake:
  - Water supply costs (e.g. third party supply, onsite production of demineralised water, permitting/tax)
  - Intake monitoring costs (e.g. lab costs, online systems)
  - Pre-treatment costs (e.g. pumping, filtration, chemicals)

- Treatment:
  - Water supply costs (e.g. third party supply, onsite production of demineralised water, permitting/tax)
  - Intake monitoring costs (e.g. lab costs, online systems)
  - Pre-treatment costs (pumping, filtration, chemicals)
  - WWTP plant monitoring costs (e.g. lab costs, online systems)
  - Water treatment costs (energy costs, chemicals, waste disposal, equipment cleaning)
  - Third party on-site effluent treatment costs
- Discharge:
  - Discharge costs (e.g. permitting/tax)
  - Effluent monitoring costs (e.g. lab costs, online systems)
  - Third party off-site effluent treatment costs

Water costs related to intake, treatment discharge were normalized to a relative volume basis[2], as shown in **Figure 35**. In order to more accurately compare water costs across the industry, comparisons were subsequently made when refineries had selected the same sub-types for each cost item (**Figure 36**; **Figure 37; Figure 38**). For this purpose, the most commonly selected sub-types were used to confirm observations made from the overall cost analyses. It should be noted that the basis of cost figures differed between refineries (e.g. tax and/or monitoring costs may vary greatly), so the water costs presented here can only be considered as best estimates of the industry

On an overall industry level, it can be observed that the relative intake costs exceeded relative discharge costs independent of the country croup. Compared to 2013 not all regions exhibit the same trend, whereas in 2016 it was true for all. Also relative treatment costs exceeded relative discharge costs independent of the country croup, whereas different country groups showed different patterns in comparing relative treatment costs and relative intake costs. E.g. in the Baltic region, Central Europe, and UK and Ireland the relative intake cost was >3 times higher than the treatment costs, whereas in Iberia, Germany, and Mediterranean region the treatment costs were clearly higher than the intakes.

Overall, looking on both the overall costs and the most commonly selected sub-types, the highest water intake costs were observed in Central Europe, and the lowest in France and Germany. The highest water discharge costs were observed in Iberia and Mediterranean, and the lowest in Benelux and Central Europe. When including monitoring within the discharge costs, the Baltic region reported a much higher cost than any other country group. The highest water treatment costs were observed in Mediterranean, Germany and Benelux. When only looking at the WWTP plant costs, Iberia had the highest costs, together with Mediterranean and Benelux.

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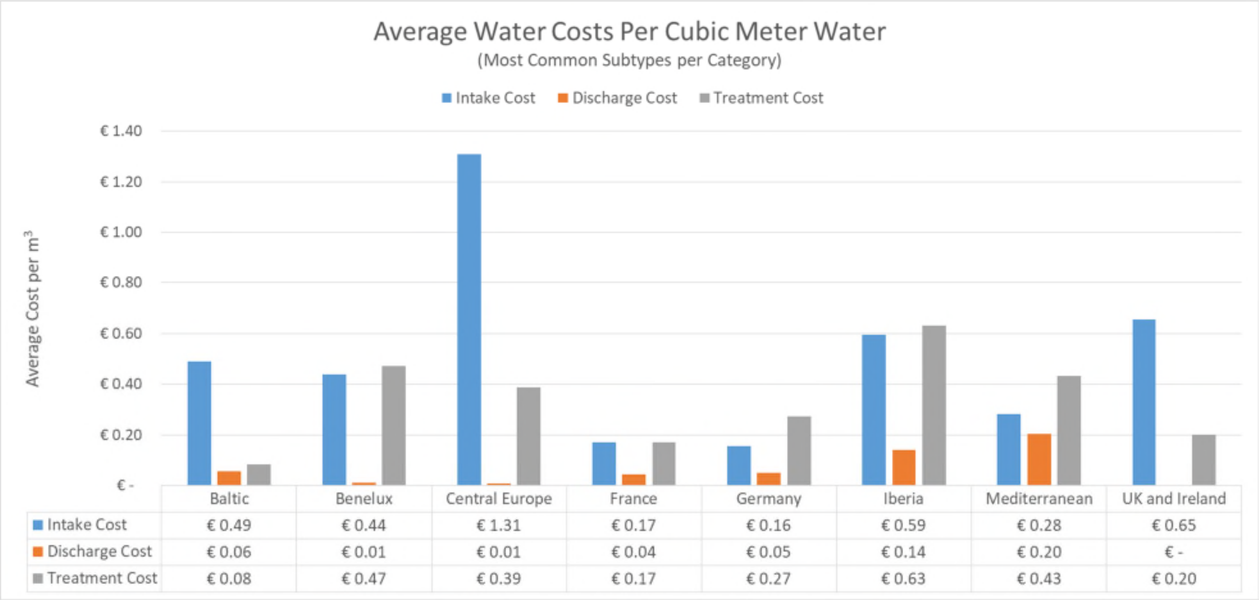
[2] Once-through cooling water intake volumes are included for the relative cost calculations.

Figure 35. Average Intake, Discharge, and Treatment Water Costs per Cubic Meter of Water by Country Group



	Baltic	Benelux	Central Europe	France	Germany	Iberia	Mediterranean	UK and Ireland
Intake Cost	€ 0.49	€ 0.44	€ 1.31	€ 0.17	€ 0.16	€ 0.59	€ 0.28	€ 0.65
Discharge Cost	€ 0.06	€ 0.01	€ 0.01	€ 0.04	€ 0.05	€ 0.14	€ 0.20	€ -
Treatment Cost	€ 0.08	€ 0.47	€ 0.39	€ 0.17	€ 0.27	€ 0.63	€ 0.43	€ 0.20

Figure 36. Intake Cost Sub-Categories and Average Water Intake Costs by Country Group

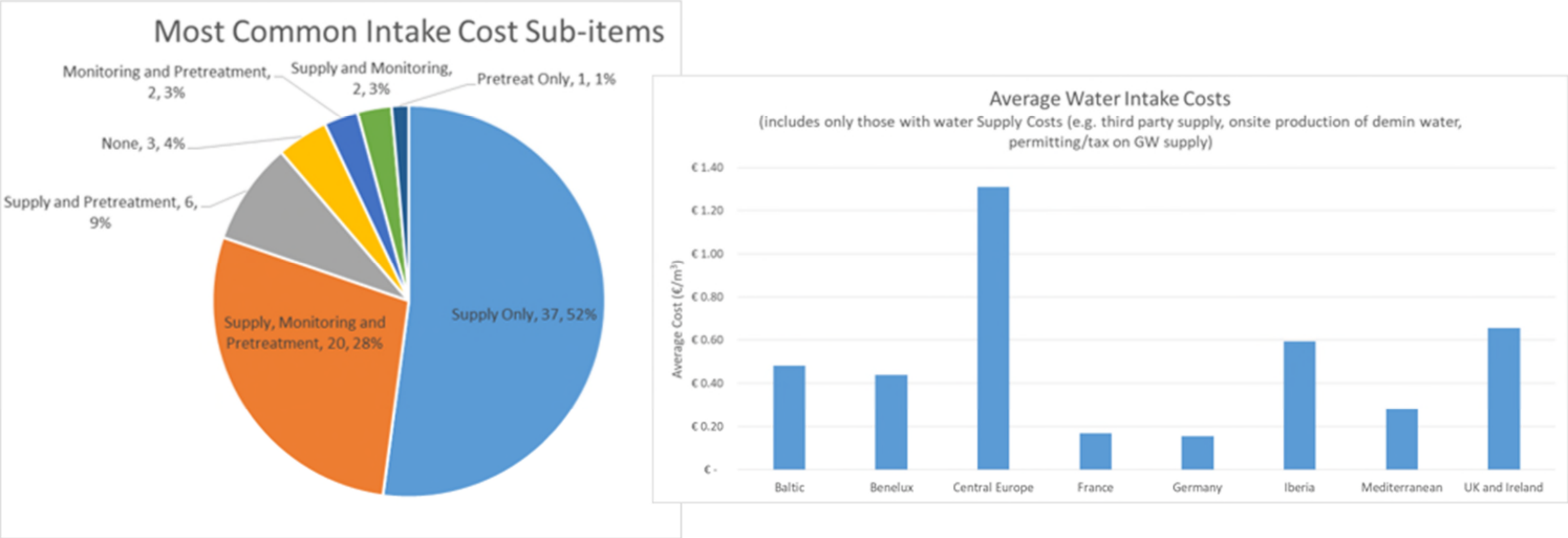


Figure 37. Discharge Cost Sub-Categories and Average Water Discharge Costs by Country Group

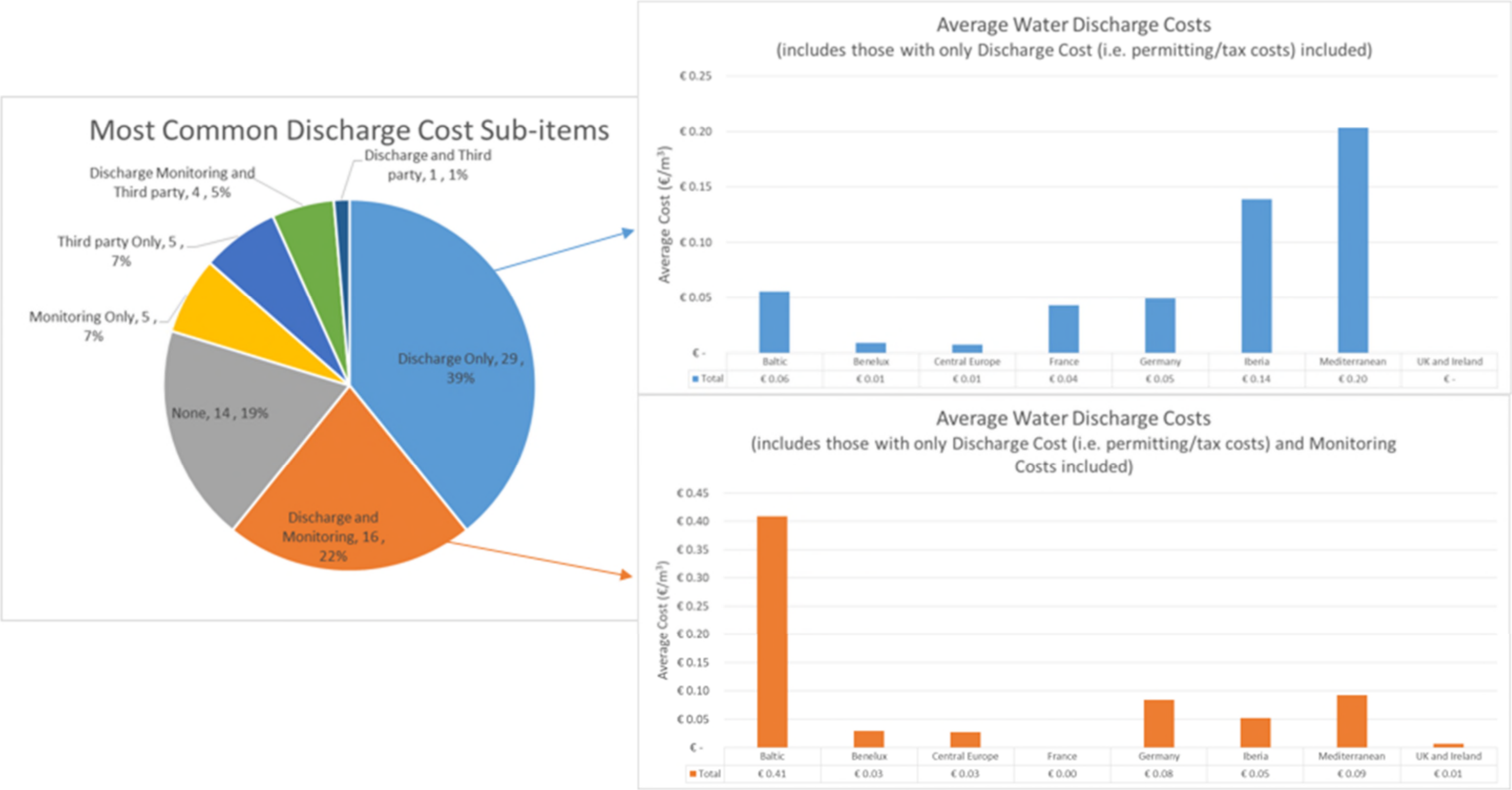
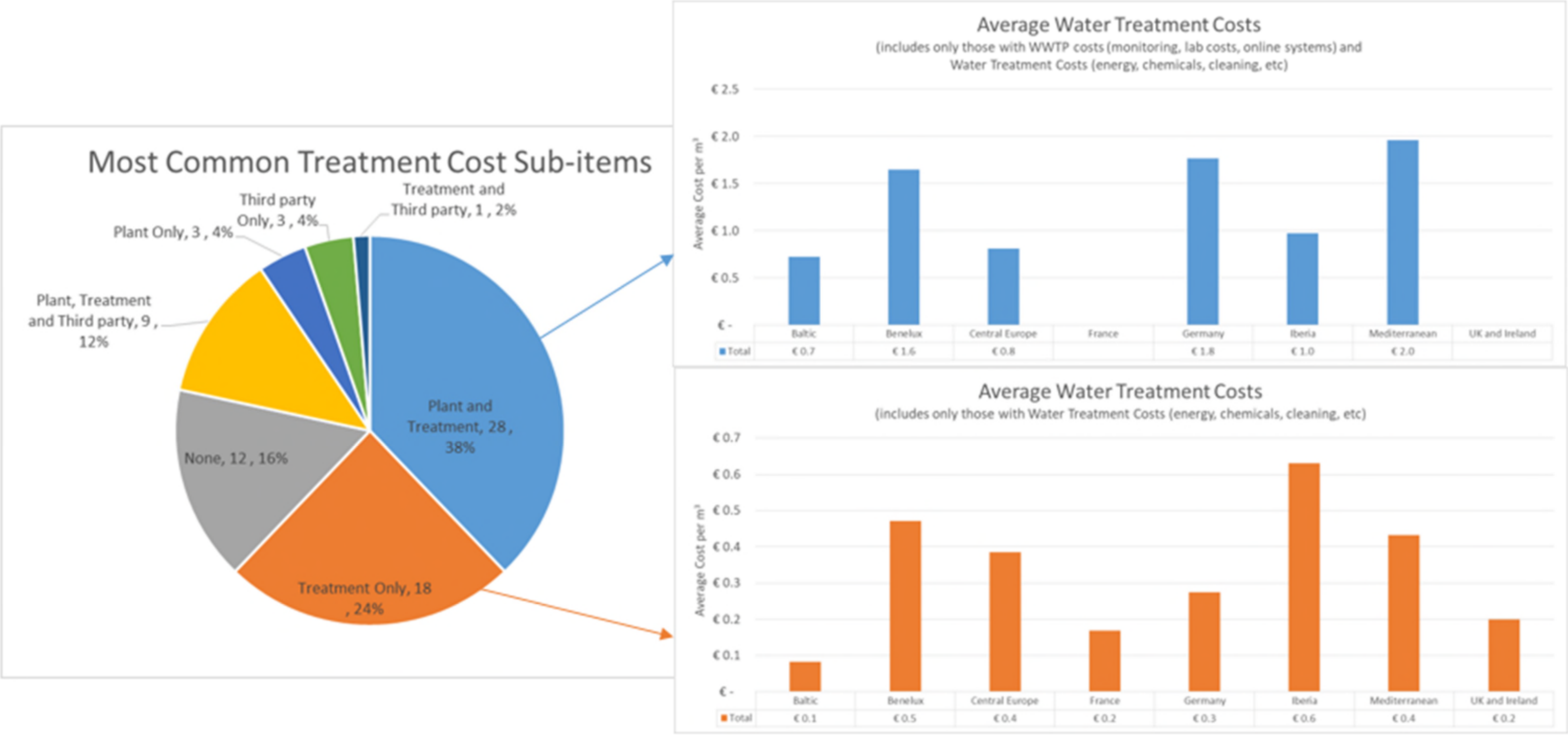


Figure 38. Treatment Cost Sub-Categories and Average Water Treatment Costs by Country Group



3. REFINERY EFFLUENT QUALITY

Reporting of contaminant concentrations and loadings of refinery discharges are presented in this section. With respect to the quality of refinery effluents, Concawe has been collecting data from its membership regularly since 1969. For 2016, key parameters reported are summarised in **Table 13** which presents the total loading (kg/year), the relative loading (g per ton of feedstock throughput/year), the average concentration (mg/L), and the maximum concentration (mg/L) for all refineries reporting. In the calculation of the parameters shown in **Table 13**, the following conventions were used:

- Transferred discharges are not included (this data is presented separately in Table 14);
- For all analytical survey data, an entered value of 0 is treated as a non-detect;
- Results greater than 0 but below the specified Limit of Quantification (LOQ) for an analyte are treated as a reportable results;
- For non-detects, if an LOQ is entered, ½ of the corresponding LOQ is utilised as the value for non-detects;
- For non-detects where no LOQ is entered, ½ of the median of non-zero LOQs for that analyte in the 2016 survey is used;
- Concentrations for facilities with multiple effluent streams were calculated by weighting the concentration values according to the effluent volumes;
- The average relative load is the total annual effluent load divided by the total annual feedstock throughput.

Table 13. Summary of parameters monitored in the refinery effluents. Effluents transferred to external facilities are not included in these values.

Analyte	Direct Discharges		
	Number of Sites (Distinct)	Total Mass (kg)	Avg. Conc.[1] (mg/L)
Organics			
Oil in Water (OiW) or Total Petroleum Hydrocarbons (TPH)	61	257,105	1.42
Phenols	54	29,629	0.084
Benzene, Toluene, Ethylbenzene, Xylene (BTEX)	44	6,604	0.023
Total Polycyclic Aromatic Hydrocarbons (tPAHs[2])	28	39	0.0004
Inorganics			
Total Nitrogen (TN)	51	1,855,833	8.57
Total Phosphorus (TP)	52	157,938	0.78
General parameters			
Biological Oxygen Demand (BOD)	54	2,396,624	14.7
Chemical Oxygen Demand (COD)	64	16,150,908	64.0
Total Organic Carbon (TOC)	39	1,499,603	13.1
Total Suspended Solids (TSS)	62	4,098,377	15.1
Metals			
Cadmium	48	618	0.003
Lead	47	1,123	0.006
Mercury	45	386	0.004
Nickel	47	2,870	0.012
Vanadium	27	8,092	0.05

[1] Average concentration is based on individual outfalls measured for the given parameter. Some sites may have more than one outfall with measurements for the given parameter.

[2] Total PAH values in this table include the total PAH value given by responders. When total PAH value was not provided, it was calculated as the sum of individual PAHs using 0 for non-detects. If all individual PAHs were reported as 0, then ½ of the LOQ for the highest LOQ value reported was used. Individual PAHs included Anthracene, Benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, Fluoranthene, and Indeno(1,2,3-cd)pyrene.

In total 19 refineries transferred some of their effluent water to an external facility for the purpose of treatment. Of these, six refineries monitored the effluent streams for at least one analytical parameter prior to transfer. The final treatment efficiency at these external locations was not known. To account for the loading associated with the transfer streams and to stay consistent with previous reporting (Concawe, 2012), it was assumed that the treatment efficiency for each substance was 95% within the external facility. Using this assumption, the total tonnes discharged to the environment via the transfer streams was approximated and a summary of the estimated additional tonnes discharged per substance in transfer streams is provided in **Table 14**.

Table 14. Summary of parameters monitored in the refinery effluents. Effluents transferred to external facilities are not included in these values.

Analyte	Transfers with 95% Reduction		
	Number of Sites (Distinct)	Total Mass (kg)	Avg. Conc. (mg/L)
Organics			
Oil in Water (OiW) or Total Petroleum Hydrocarbons (TPH)	5	4,506	0.22
Phenols	3	585	0.029
Benzene, Toluene, Ethylbenzene, Xylene (BTEX)	5	317	0.051
Total Polycyclic Aromatic Hydrocarbons (tPAHs[2])	3	2	0.0001
Inorganics			
Total Nitrogen (TN)	4	18,061	1.12
Total Phosphorus (TP)	5	490	0.04
General Parameters			
Biological Oxygen Demand (BOD)	1	3,073	4.35
Chemical Oxygen Demand (COD)	6	995,226	133.5
Total Organic Carbon (TOC)	5	56,732	3.33
Total Suspended Solids (TSS)	5	257,253	44.2
Metals			
Cadmium	3	0.09	0.0001
Lead	3	10.47	0.005
Mercury	3	0.05	3E-05
Nickel	3	1.32	0.0009
Vanadium	3	1.0	0.0005

[1] Some sites may have both a direct discharge outfall as well as a transfer that was measured for a particular parameter. As a result, the total number of distinct sites may be less than the sum of direct discharge sites and transfer sites per analyte.
[2] Total PAH values in this table include the total PAH value given by responders. When total PAH value was not provided, it was calculated as the sum of individual PAHs using 0 for non-detects. If all individual PAHs were reported as 0, then ½ of the LOQ for the highest LOQ value reported was used. Individual PAHs included Anthracene, Benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, Fluoranthene, and Indeno(1,2,3-cd)pyrene.

3.1. TRENDS REFINERY WATER DISCHARGES

Results for all parameters listed in **Table 13** were analysed and this section presents 2016 data together with historical data and the graphics including box and whisker plots for total discharge load, relative discharge load per throughput, and average discharge concentration (**Figure 39** shows the definition of the box and whisker plot components). It should be noted that the population of reporting sites differs between survey years, and so not all metrics are strictly comparable when expressed as discharges for the sector.

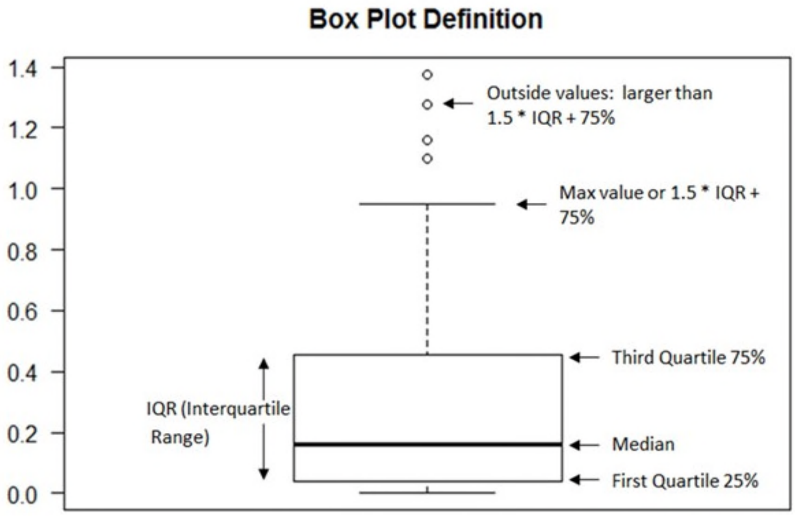
With regard to the plots shown, the following conventions were used:

- Data associated with transferred stream discharges are not included;
- Non-quantified concentration values are replaced with ½ the LOQ value. In a few cases, the concentration was reported as zero but a LOQ was not provided. In these instances, the reported value was utilized;

- The total effluent load per refinery is the sum of all the individual effluent stream loads given for each refinery. Since total loading may be directly related to the number of refineries reporting, loadings relative to throughput are also presented. In addition, to ensure accurate trend analyses, both total and relative loadings are presented for data that is limited to the subset of sites that reported in 2010, 2013 and 2016. If less than 10 sites reported for the given parameter in each of the 3 years, then the trend plots for repeat sites are considered statistically weak and not displayed. Industry level loading values for 2016 are displayed in Table 13 above;
- The average concentration per outfall across the industry is plotted. Refineries that have multiple outfall streams with measures for the same parameter will be included more than once in the plots as well as when computing industry averages;
- The number “n” stated is the number of outfalls included in each plot. The value in parentheses is the number of refineries included.

An analysis of the outliers was done in the past for the 2013 data but was not repeated for this report (Concawe, 2018).

Figure 39. Definition of box plot components



In general, taking 2016 as well as 2013 and 2010 data into account, reductions in relative load is observed for 12 of the analysed quality elements (TPH, ammonia, COD, BOD, TOC, TSS, BTEX, tPAHs, cadmium, lead and nickel), whereas three were kept at constant levels (TN, phenols and TP) and two increasing (mercury and vanadium).

The following sections (3.1.1 to 3.1.6) describes the discharge loading and concentration data for all parameters listed in **Table 13** in more detail.

3.1.1. TPH or Oil in Water (OiW)

As observed **Table 15**, the number of refineries reporting for Concawe water use/effluent surveys has varied between 61 and 125 throughout the years which partly is due to the fact that the number operational of refineries have decreased. The total TPH or OiW discharged in effluents has decreased significantly from 44,000 tonnes in 1969 to 257 tonnes in 2016. TPH or OiW discharge relative to refining capacity and throughput has also continued to reduce over the whole period covered by the surveys; in 2016, the relative discharge was 0.44 g TPH/tonne capacity and 0.50 g TPH/tonne throughput.

Table 15. TPH or Oil in Water (OiW) discharge load data from 1969 to 2016.

Year	Number of refineries reporting data	Total TPH or OiW[1] discharge load (tonne/year)	TPH or OiW discharge load (g/tonne capacity)	TPH or OiW discharge load (g/tonne throughput)
1969	73	44,000	127	n.a.
1974	101	30,700	44.8	n.a.
1978	109	12,000	15.9	22.5
1981	105	10,600	14.9	24.0
1984	85	5,090	8.39	12.1
1987	89	4,640	7.90	10.3
1990	95	3,340	5.86	6.54
1993	95	2,020	3.30	3.62
1997	105	1,170	1.74	1.86
2000	84	750	1.32	1.42
2005	96	1,050	1.44	1.57
2008	125	993	1.18	1.33
2010	98[2]	798	1.10	1.30
2013[3]	73	334 (354)	0.66 (0.70)	0.67 (0.71)
2016[3]	61 (65)	257 (262)	0.44 (0.45)	0.50 (0.51)

n.a. = not applicable

[1] OiW was the reporting metric until 2000 (including) for reporting hydrocarbon discharges, from 2005 it was replaced with TPH.

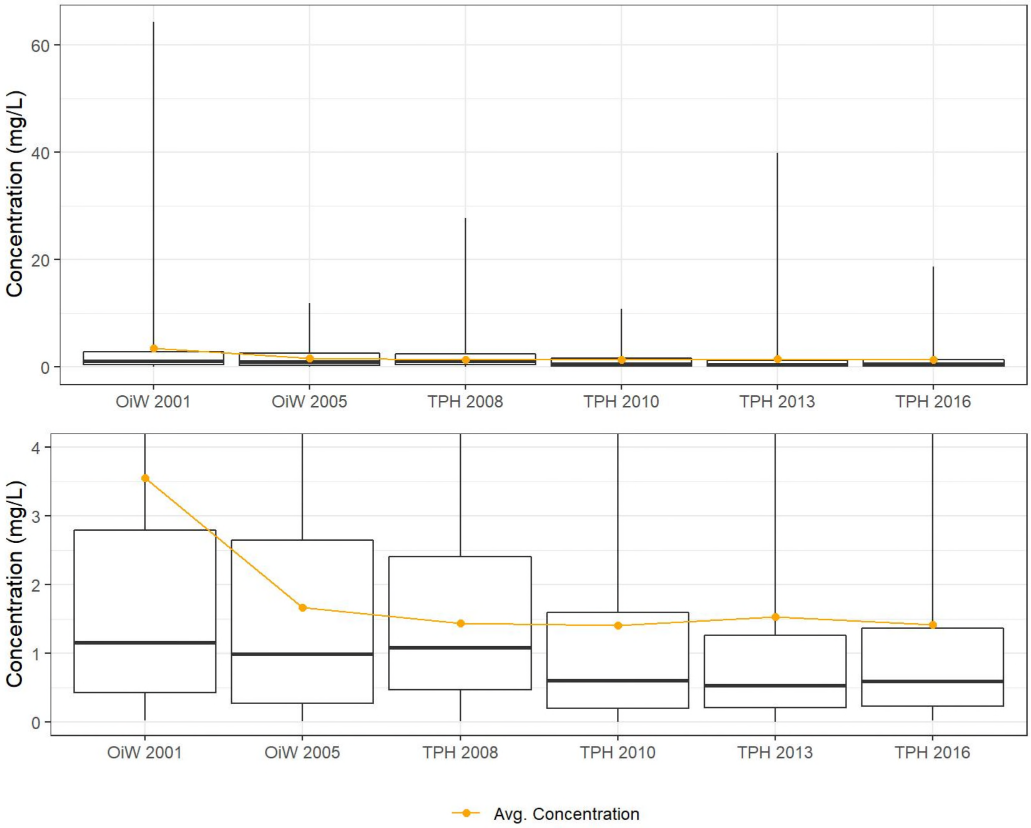
[2] Figures exclude the two installations that only reported data for water use.

[3] The figures reported considering transfer streams assuming the external facilities had a reduction efficiency of 95% (this is comparable with the reduction efficiency of treatment on site). The number in brackets show the number reported when transfer streams are not considered.

In 2016, five refineries measured concentrations of TPH in effluent streams that were subsequently transferred to an external facility for treatment. The final treatment efficiency at these external locations is unknown so exact loadings from these streams were not able to be determined. To stay consistent with previous reports, it was assumed that the reduction efficiency at the external facility was 95% (Concawe, 2012) which could potentially yield an additional 4.5 tonnes of estimated oil that were discharged. Since it is reasonable that the external facilities were comparable to refineries in their ability to treat oil in water, this assumption was checked with the 2013 dataset by applying the average concentration of oil in water across the industry (from not transferred streams) to the volume of effluent water that was transferred. This yielded that the external facilities had just under a 97% reduction efficiency (Concawe, 2018).

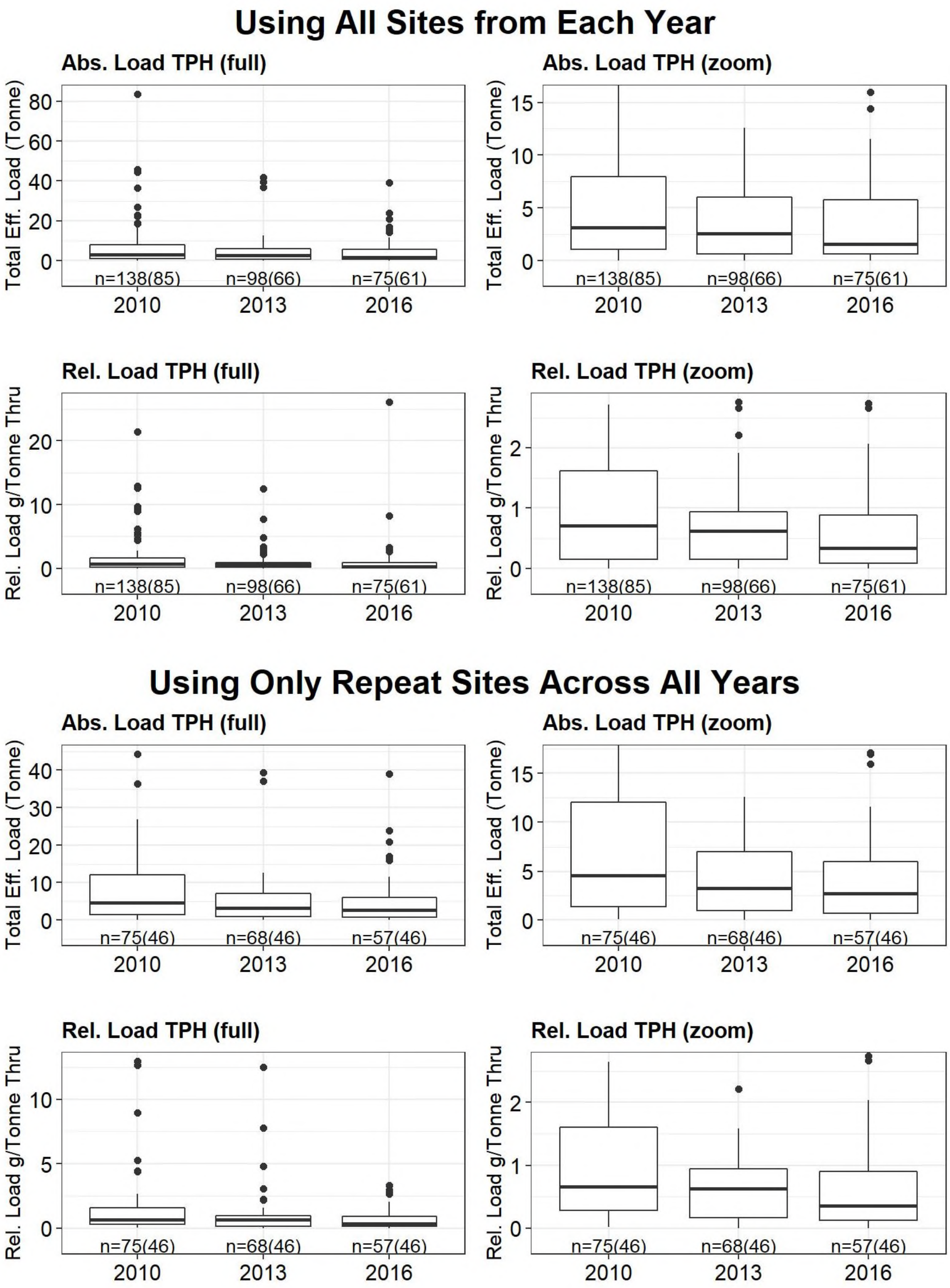
Figure 40 presents the historical trends of average annual TPH or OiW concentrations in refinery effluents from 2001 to 2016. Following a decrease from 2001 to 2005, the average concentrations have remained more or less constant. Similarly, the median concentrations and the dataset distributions (size of the boxes) have remained more or less constant from 2010, but with a decrease observed from 2008 to 2010. The maximum concentration values (top of the whiskers in the top graph of **Figure 40**) shows a variation from 2005, but with a clear decrease compared to 2001.

Figure 40. Historical Trend in Refinery Effluents for TPH. The bottom plot is a zoomed version of top plot.



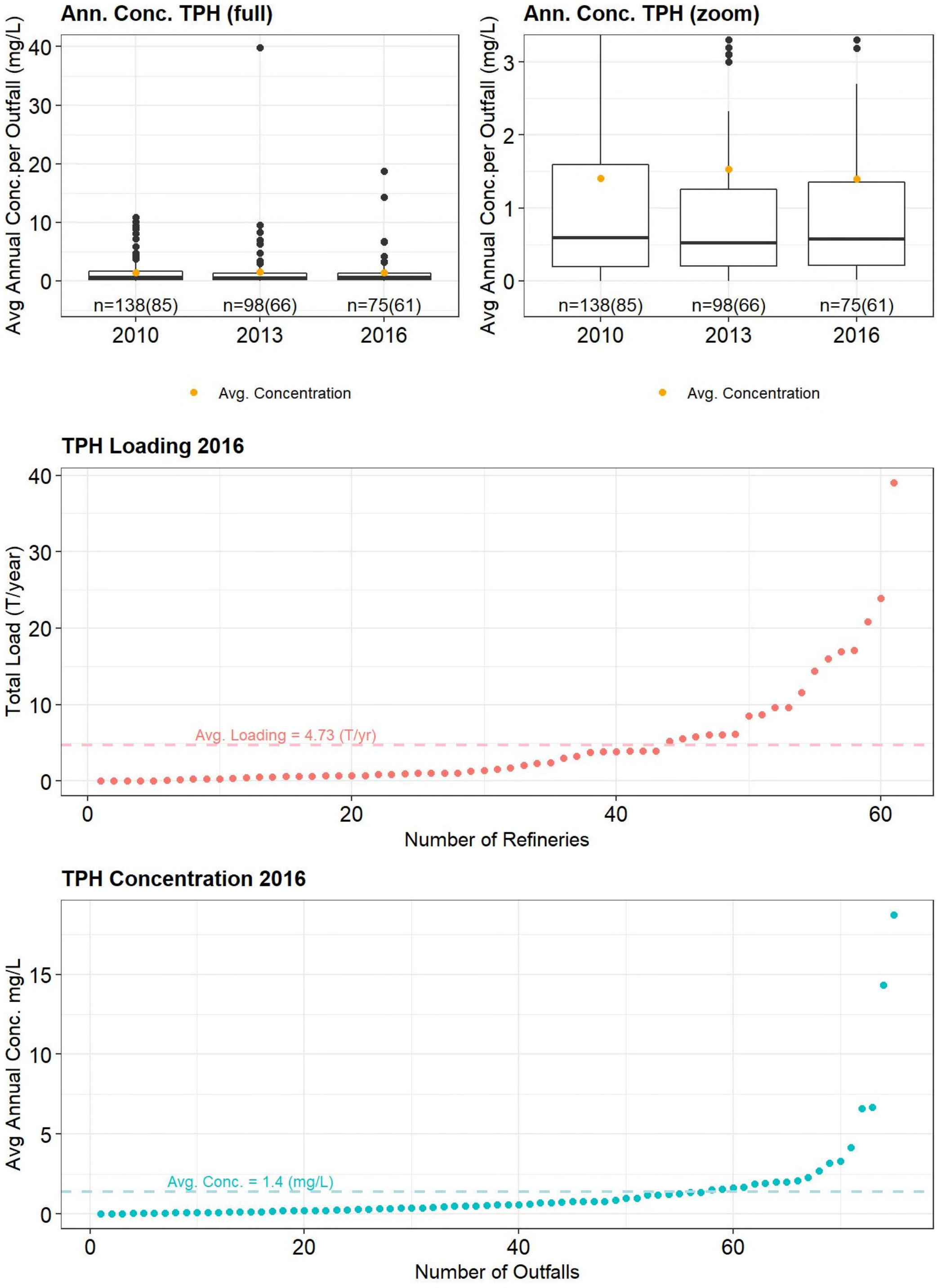
From the plots of TPH discharge loads for all recent survey datasets (2010-2016) (**Figure 41**), it is shown that the median loads have decreased both in absolute and relative terms. The decrease holds both when the full dataset is considered and when only the repeat sites (n= 46 sites) are considered. All three survey datasets contain high outliers in terms of TPH loads, which amount were not significantly different between the datasets.

Figure 41. 2010, 2013 and 2016 survey results for TPH total and relative discharge load.



For TPH discharge concentrations (**Figure 42**) it is shown that the median concentration, average concentration and the dataset distribution are similar in all the three survey datasets (2010-2016). The two bottom plots of **Figure 42** show that a clear majority of the sites (70 %) and outfalls (77 %) are below the average for TPH total load and average annual concentration, respectively.

Figure 42. 2010, 2013 and 2016 survey results for TPH concentrations (two upper plots) and TPH total load and average annual concentration s-curves for 2016 (two bottom plots).



3.1.2. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC),

Historic absolute and relative discharge loads from 2000-2016 for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC), are summarised in **Table 16**. For relative BOD discharge load, a large reduction is apparent from 2005 to 2010, with the relative load in 2010, 2013 and 2016 being similar. For COD, the main reduction in relative load is between 2010 and 2013, with 2013 and 2016 being similar. In addition to a large TOC reduction being apparent from 2005 to 2010, also a large reduction between 2013 and 2016 is apparent.

Table 16. 2016 and historical discharge loads of BOD, COD and TOC

Year	BOD	COD	TOC
	tonne/year (Number of refineries reporting[1])		
2000	3,129 (47)	19,002 (61)	3,094 (21)
2005	6,242 (84)	33,156 (90)	3,559 (45)
2010	3,450[2] (68) 75.9[3] (7)	31,765[2] (81) 380.7[3] (9)	2,680[2] (41) 195[3] (6)
2013	2,717[2] (57) 65.6[3] (4)	15,980[2] (64) 293[3] (8)	2,480[2] (37) 32.8[3] (6)
2016	2,397[2] (54) 3[3] (1)	16,151[2] (64) 995[3] (6)	1,473[2] (39) 56.7[3] (5)
	g/tonne throughput		
2000	10.4	50.9	17.9
2005	13.5	58.0	12.7
2010	6.3[2] 0.13[3]	57.7[2] 0.63[3]	4.9[2] 0.32[3]
2013	5.4[2] 0.13[3]	32[2] 0.59[3]	5.0[2] 0.07[3]
2016	4.7[2] 0.01[3]	31.6[2] 1.95[3]	2.9[2] 0.11[3]

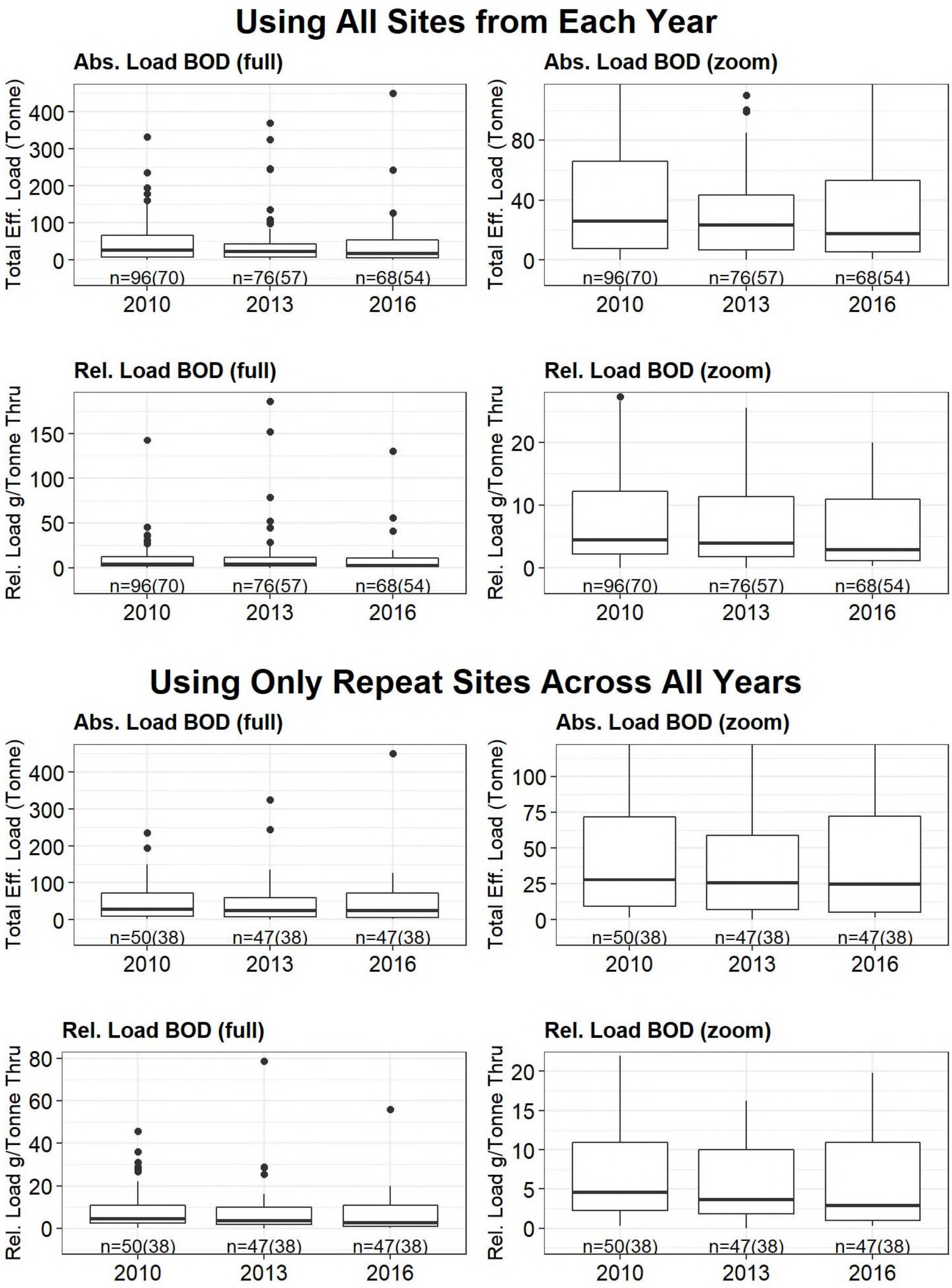
[1] Some refineries may have both a direct discharge as well as a transfer. These refineries would be included in both the direct discharge as well as transfer site count.

[2] Figures for direct discharges from installations.

[3] Figures for additional loading due to discharges after transfer to and treatment by offsite WWTP, assuming 95% reduction efficiency (Concawe, 2012)

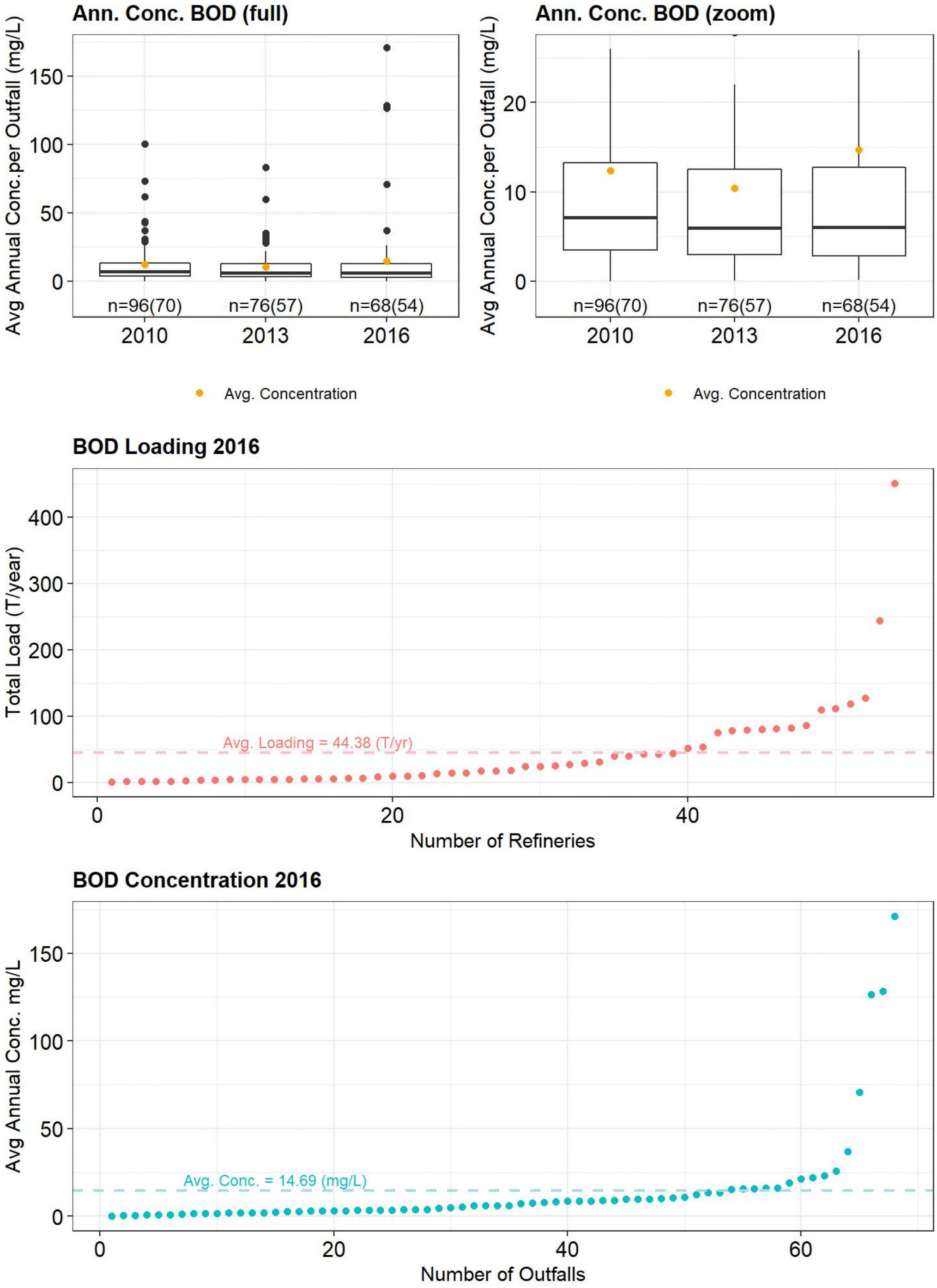
From the plots of BOD discharge loads (**Figure 43**), it is shown that the median BOD loads and the dataset distribution are similar in all recent survey datasets (2010-2016). These observation holds both when the full dataset is considered and when only the repeat sites are considered (n = 38 sites). All three survey datasets contain high outliers, however they were significantly less in 2016 compared to 2013 when considering the full dataset (3 vs. 6).

Figure 43. 2010, 2013 and 2016 survey results for BOD total and relative discharge load.



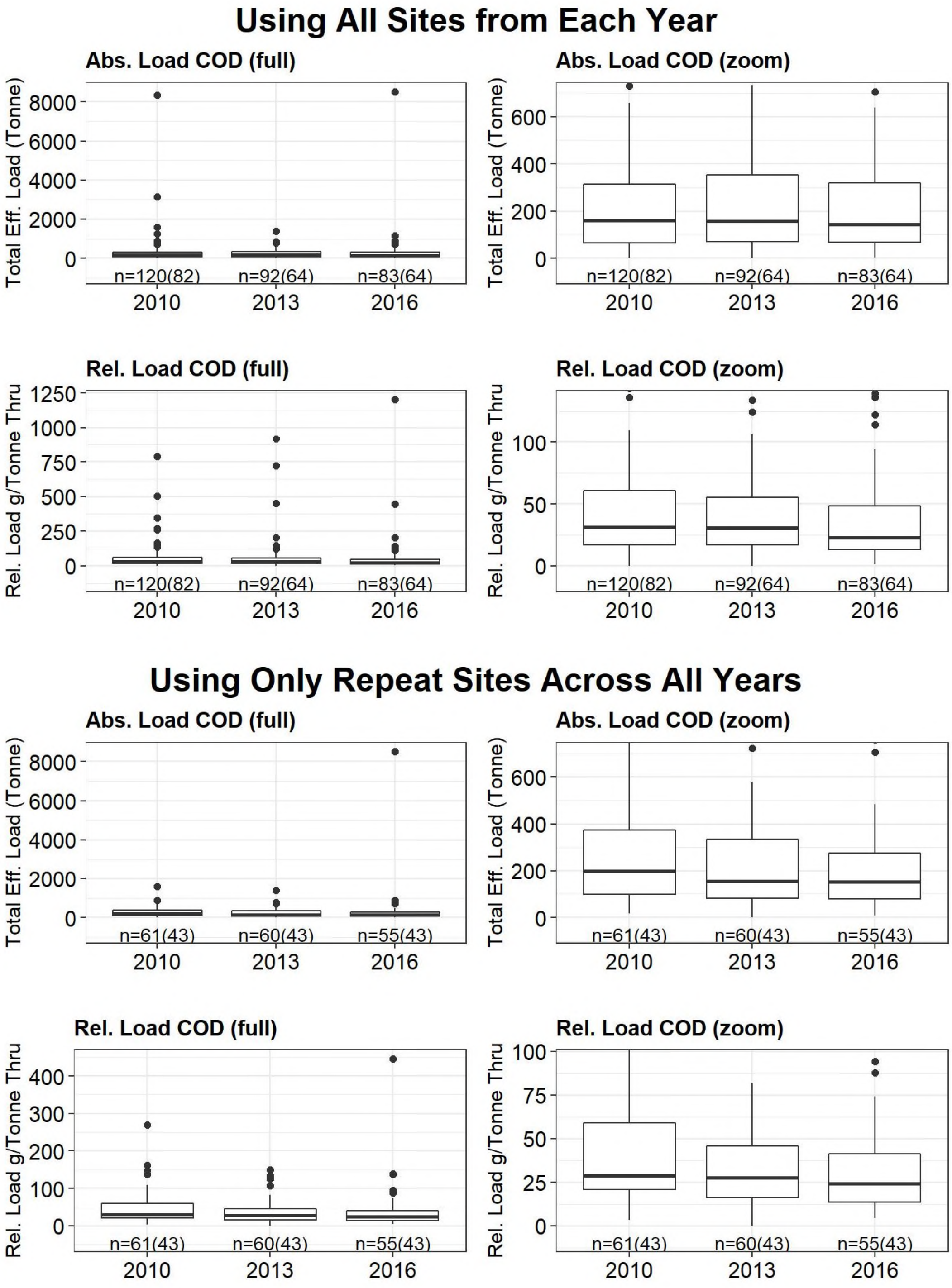
From plots of BOD discharge concentrations (**Figure 44**), it is shown that the median concentration, average concentration and the dataset distribution are similar in all recent survey datasets (2010-2016). The two bottom plots of **Figure 44** show that a clear majority of the sites (72 %) and outfalls (84 %) are below the average for BOD total load and average annual concentration, respectively.

Figure 44. 2010, 2013 and 2016 survey results for BOD concentrations (two upper plots) and BOD total load and average annual concentration s-curves for 2016 (two bottom plots).



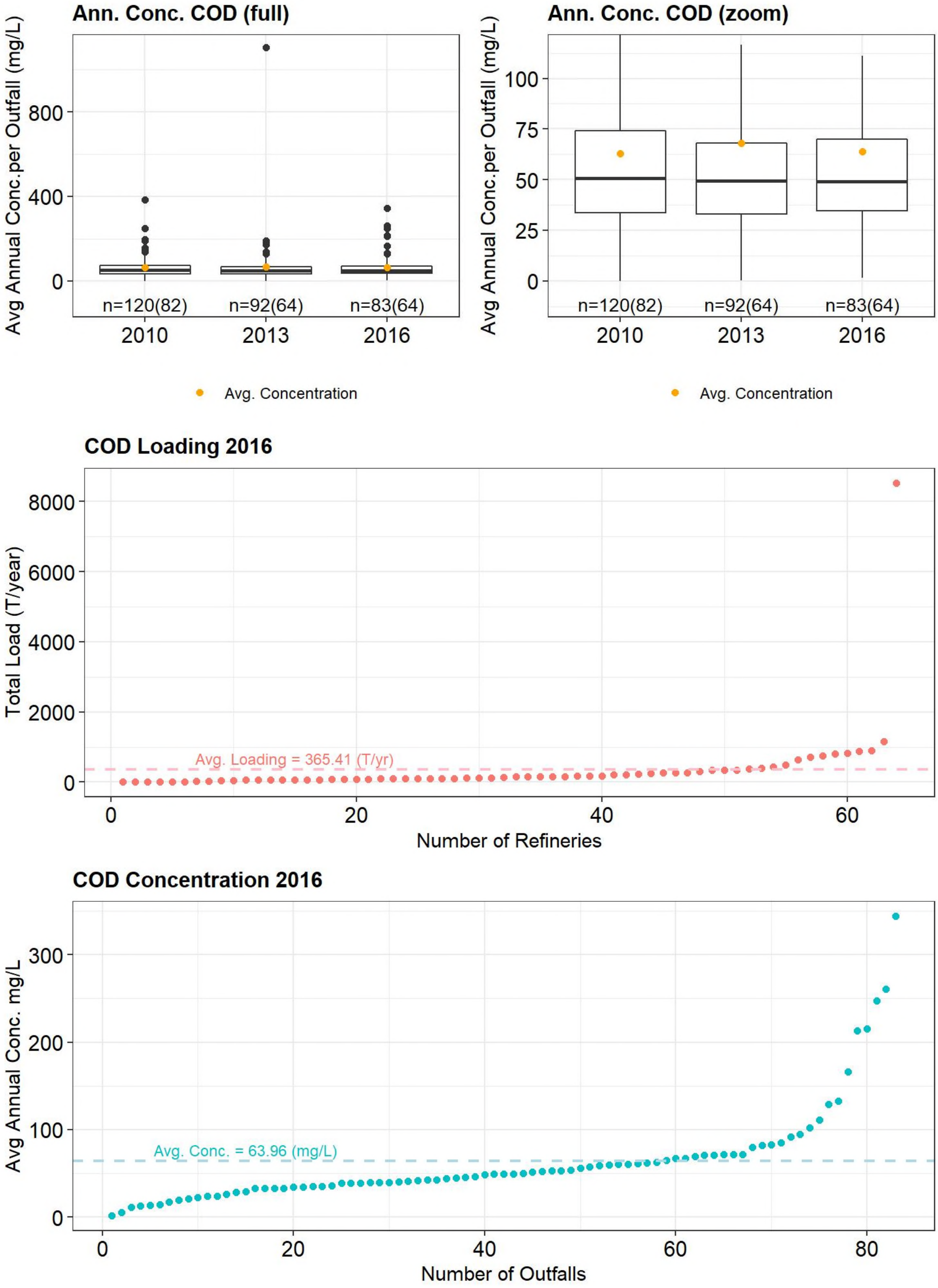
From the plots of COD discharge loads (**Figure 45**), it is shown that the median COD loads and the dataset distribution are similar in all recent survey datasets (2010-2016). These observation holds both when the full dataset is considered and when only the repeat sites are considered (n = 43 sites). All three survey datasets contain high outliers, which amount were not significantly different between the datasets.

Figure 45. 2010, 2013 and 2016 survey results for COD total and relative discharge load.



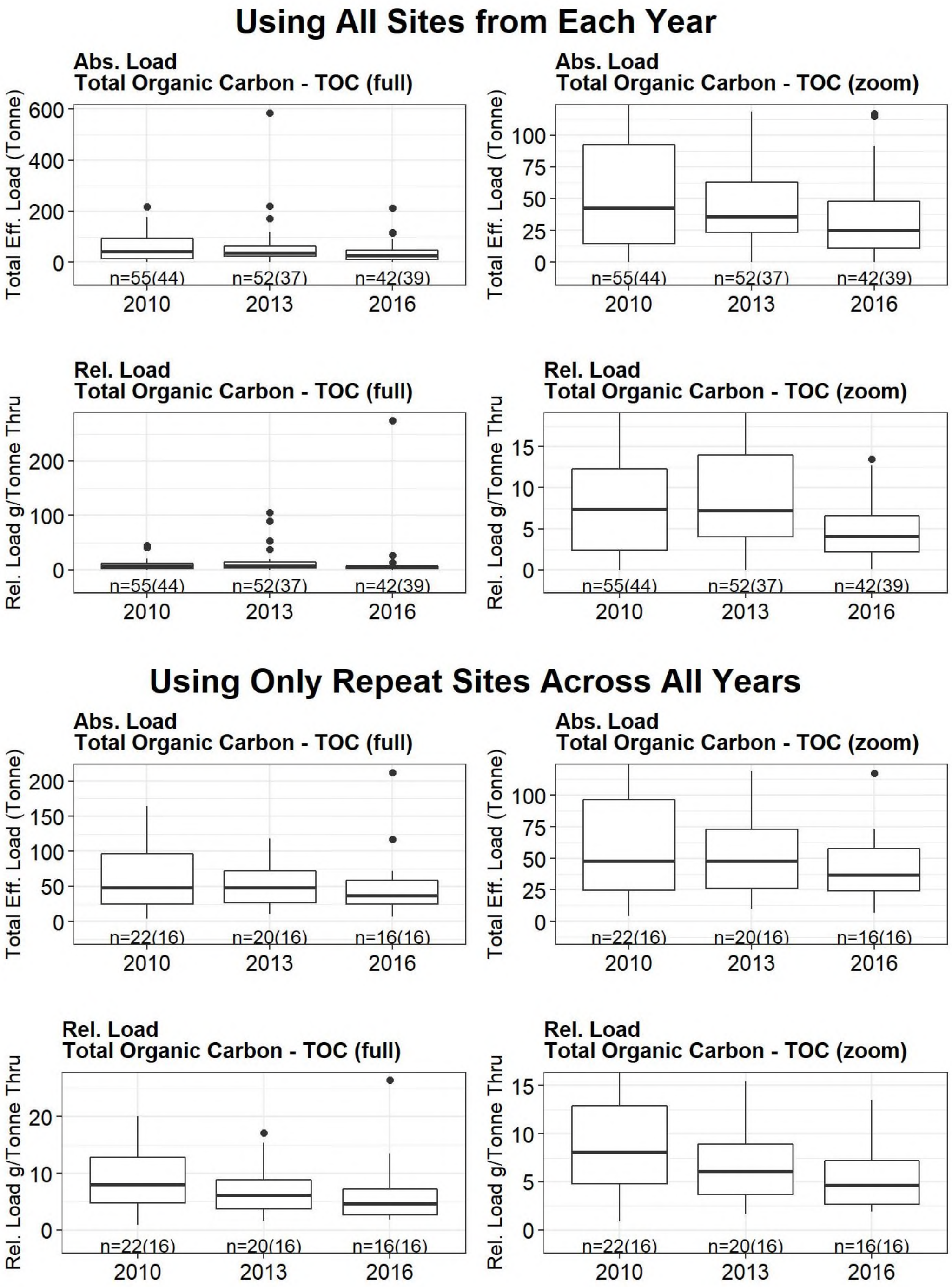
From the plots of COD discharge concentrations (**Figure 46**), it is shown that the median concentration, average concentration and the dataset distribution are similar in all the three survey datasets (2010-2016). The two bottom plots of **Figure 46** show that a clear majority of the sites (84 %) and outfalls (72 %) are below the average for COD total load and average annual concentration, respectively.

Figure 46. 2010, 2013 and 2016 survey results for COD concentrations (two upper plots) and COD total load and average annual concentration s-curves for 2016 (two bottom plots).



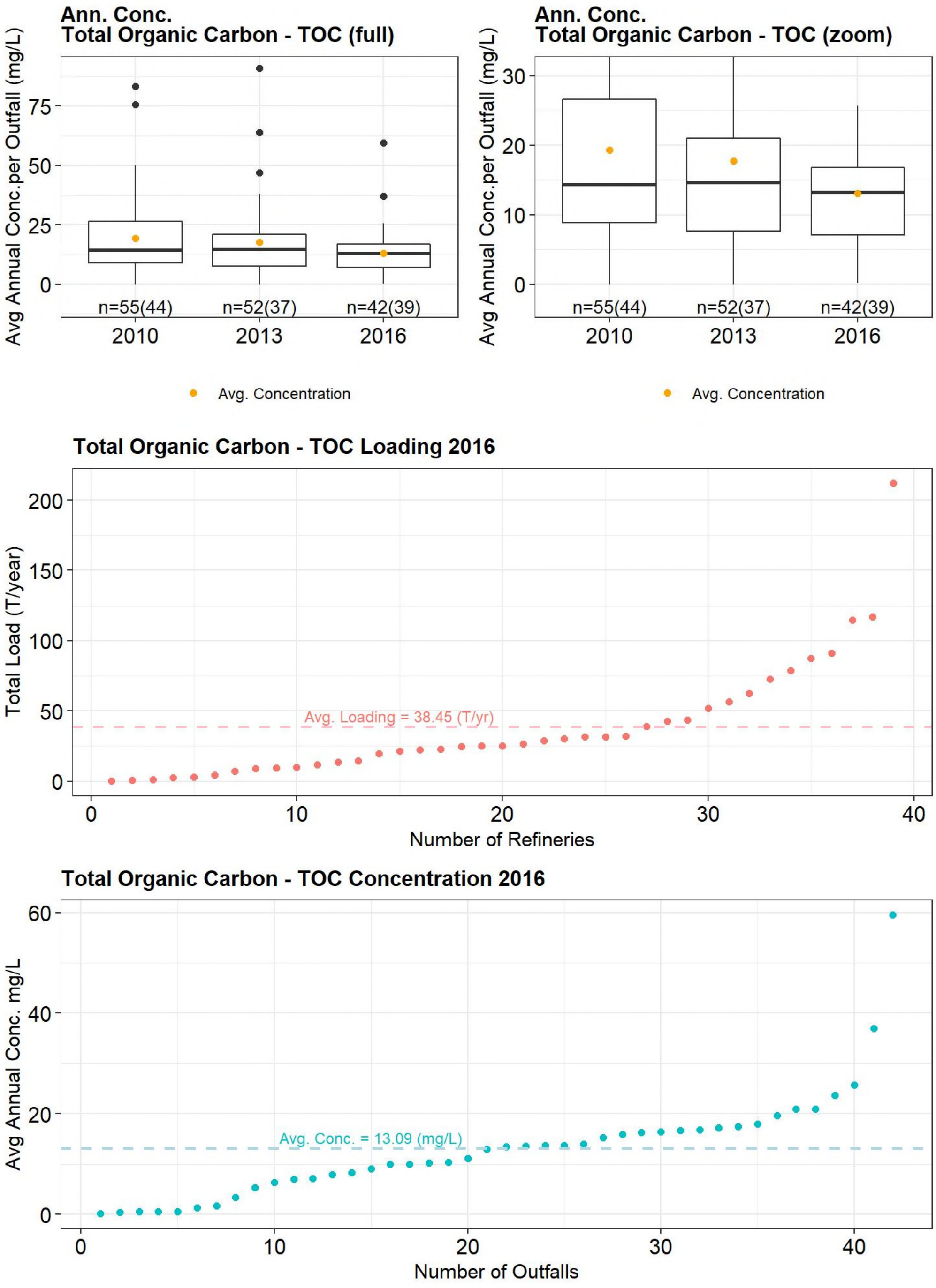
From the plots of TOC discharge loads (**Figure 47**), it is shown that the median TOC loads and dataset distribution have been decreasing from 2010 to 2013, and 2013 to 2016, respectively. These observations holds both when the full dataset is considered and when only the repeat sites are considered (n = 16 sites). All three survey datasets (2010-2016) contain a number of high outliers, which were not significantly different between the datasets.

Figure 47. 2010, 2013 and 2016 survey results for TOC total and relative discharge load.



From the plots of TOC discharge concentrations it is shown that the median concentration (**Figure 48**), average concentration and the dataset distribution are overall decreasing from 2010 to 2013, and 2013 to 2016, respectively. The two bottom plots of **Figures 48** show that there is a fairly even distribution of sites and outfalls being above and below the average values for TOC total load and average annual concentration, respectively.

Figure 48. 2010, 2013 and 2016 survey results for TOC concentrations (two upper plots) and TOC total load and average annual concentration s-curves for 2016 (two bottom plots).



3.1.3. Ammonia, total nitrogen and phenols in refinery water discharges

Absolute and relative discharge loads from 1993-2013 for ammonia, total nitrogen and phenols are summarised in **Table 17**. Overall, there is a clear reduction in direct discharges of ammonia from 1993 to 2016, which is also reflected in the relative discharge data, with a major reduction happening from 2005 to 2010. For total nitrogen an overall reduction is less marked, however refinery intake waters often contain total nitrogen in the form of nitrate. For phenols, a large reduction in total and relative discharge is apparent from 1993 to 2013, with 2016 being similar to 2010 and 2013 reported values.

Table 17. 2016 and historical discharge loads of ammonia, total nitrogen and phenols

Year	Ammonia	Total Nitrogen	Phenols
	tonne/year (Number of refineries reporting[1])		
1993	5,202 (82)	n.a.	179 (77)
1997	3,210 (82)	n.a.	161 (73)
2000	1,715 (46)	1,884 (46)	61 (55)
2005	1,959 (64)	4,778 (80)	180 (84)
2010	454[2] (34) 22[3] (5)	2,308[2] (69) 55[3] (9)	32[2] (79) 5.2[3] (9)
2013	560 (19 TKN[4])	2,279[2] (56) 9.8[3] (6)	17[2] (59) 0.15[3] (6)
2016	330[2] (35) 16[3] (5)	1,856[2] (51) 18[3] (4)	29.6[2] (54) 0.6[3] (3)
	g/tonne throughput		
1993	10.4	n.a.	0.41
1997	8.0	n.a.	0.32
2000	5.7	7.4	0.16
2005	5.5	10.0	0.35
2010[5]	0.75[2] 0.04[3]	3.8[2] 0.09[3]	0.052[2] 0.009[3]
2013	1.12 (TKN[4])	4.6[2] 0.02[3]	0.034[2] 0.003[3]
2016	0.65[2] 0.03[3]	3.6[2] 0.03[3]	0.058[2] 0.001[3]

n.a. = not applicable

[1] Some refineries may have both a direct discharge as well as a transfer. These refineries would be included in both the direct discharge as well as transfer site count.

[2] Figures for direct discharges from installations.

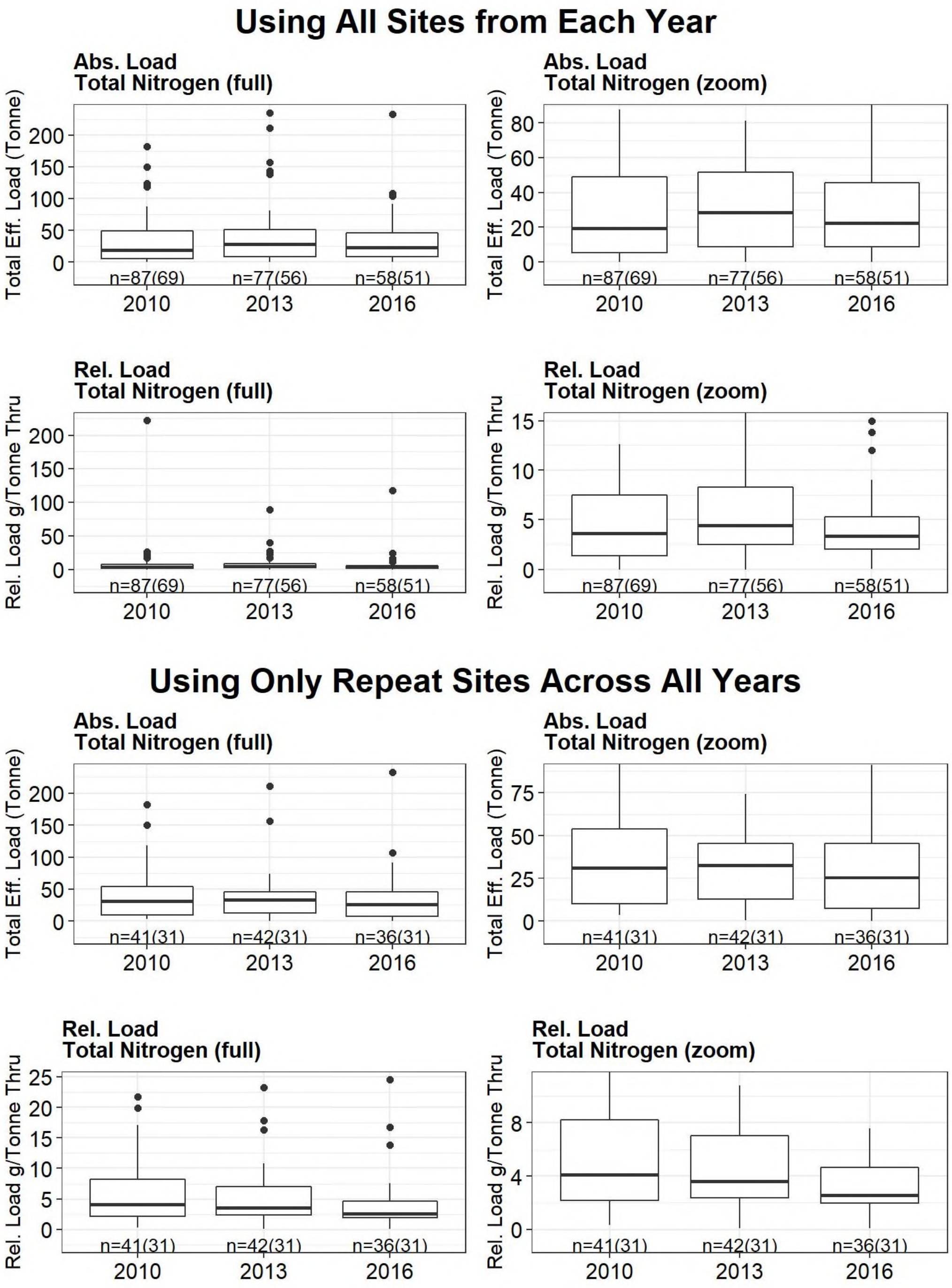
[3] Figures for additional loading due to discharges transferred to offsite WWTP, assuming 95% removal for all parameters (Concawe, 2012)

[4] Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen, ammonia (NH3), and ammonium (NH4+). To calculate Total Nitrogen (TN), the concentrations of nitrate-N and nitrite-N are determined and added to the total Kjeldahl nitrogen. TKN is reported instead of ammonia since the data returns for TKN were considerably higher in 2013 compared to ammonia (19 vs. 1 refineries reporting).

[5] 5 Error corrected compared to 2010 Survey Report (Concawe, 2012).

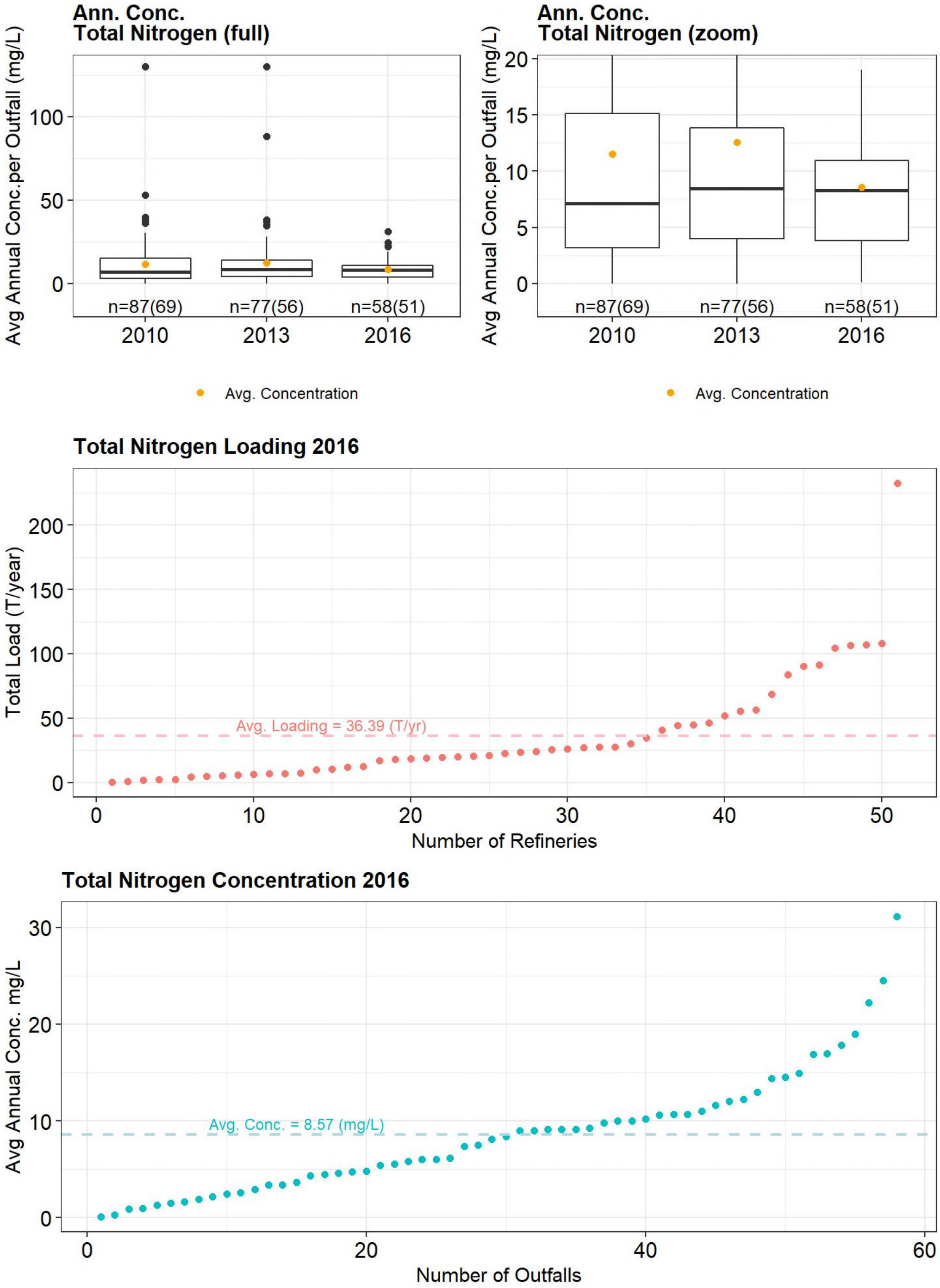
From the plots of total nitrogen discharge loads (**Figure 49**), it is shown that the median loads and the dataset distribution are similar in all recent survey datasets (2010-2016). However, when only the repeat sites are considered (n = 31 sites), both median loads and the dataset distribution have decreased from 2013 to 2016. All three survey datasets contain high outliers, however they were slightly less in 2016 compared with 2013 (3 vs. 5, looking on absolute loads).

Figure 49. 2010, 2013 and 2016 survey results for total nitrogen total and relative discharge load.



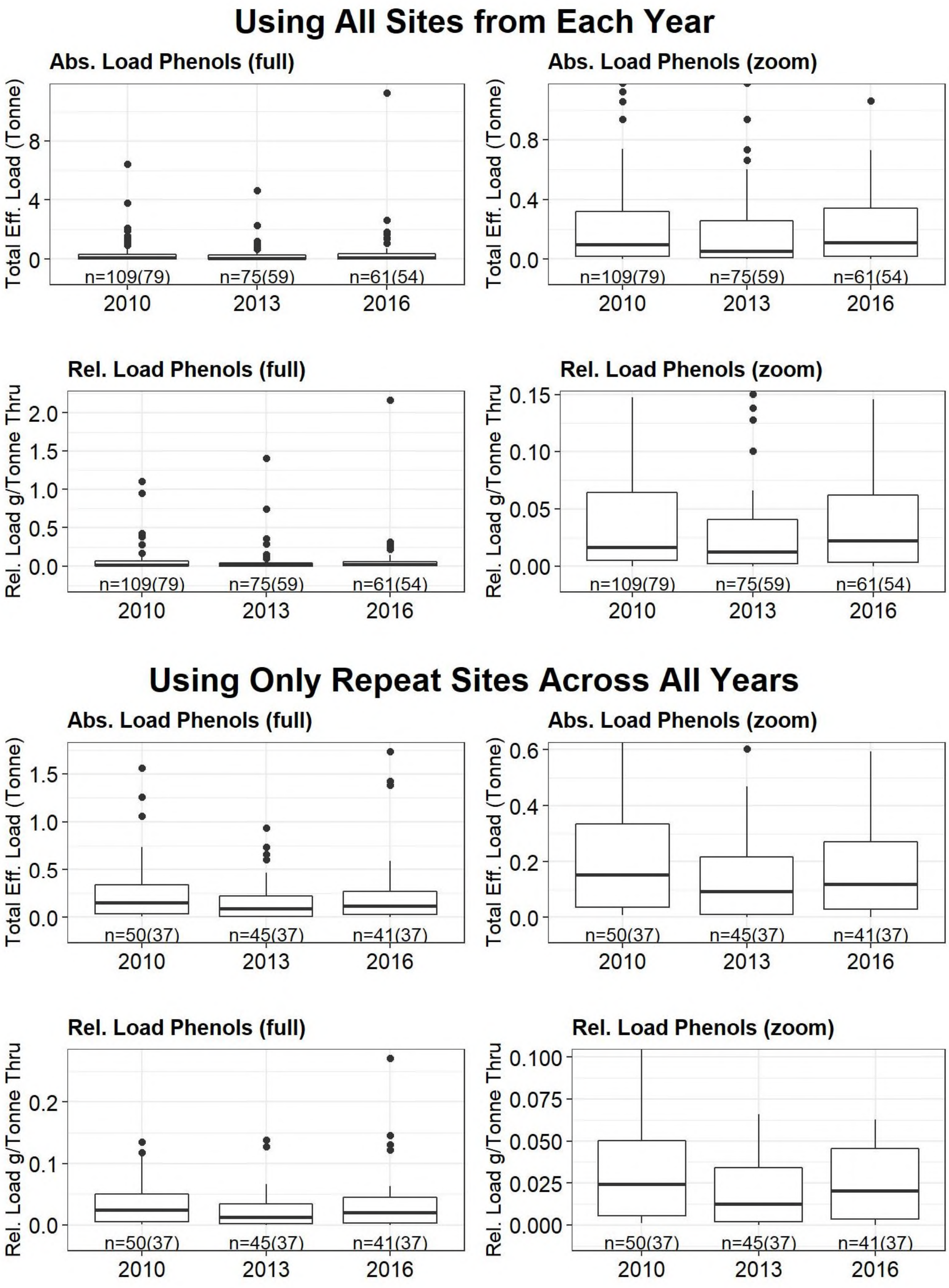
From the plots of total nitrogen discharge concentrations (**Figure 50**), it is shown that the median and average concentration are similar in all the three survey datasets (2010-2016), whereas the dataset distribution has been decreasing. The two bottom plots of **Figure 50** show that there is a fairly even distribution of sites and outfalls being above and below the average values for total nitrogen total load and average annual concentration, respectively.

Figure 50. 2010, 2013 and 2016 survey results for total nitrogen concentrations (two upper plots) and total nitrogen total load and average annual concentration s-curves for 2016 (two bottom plots).



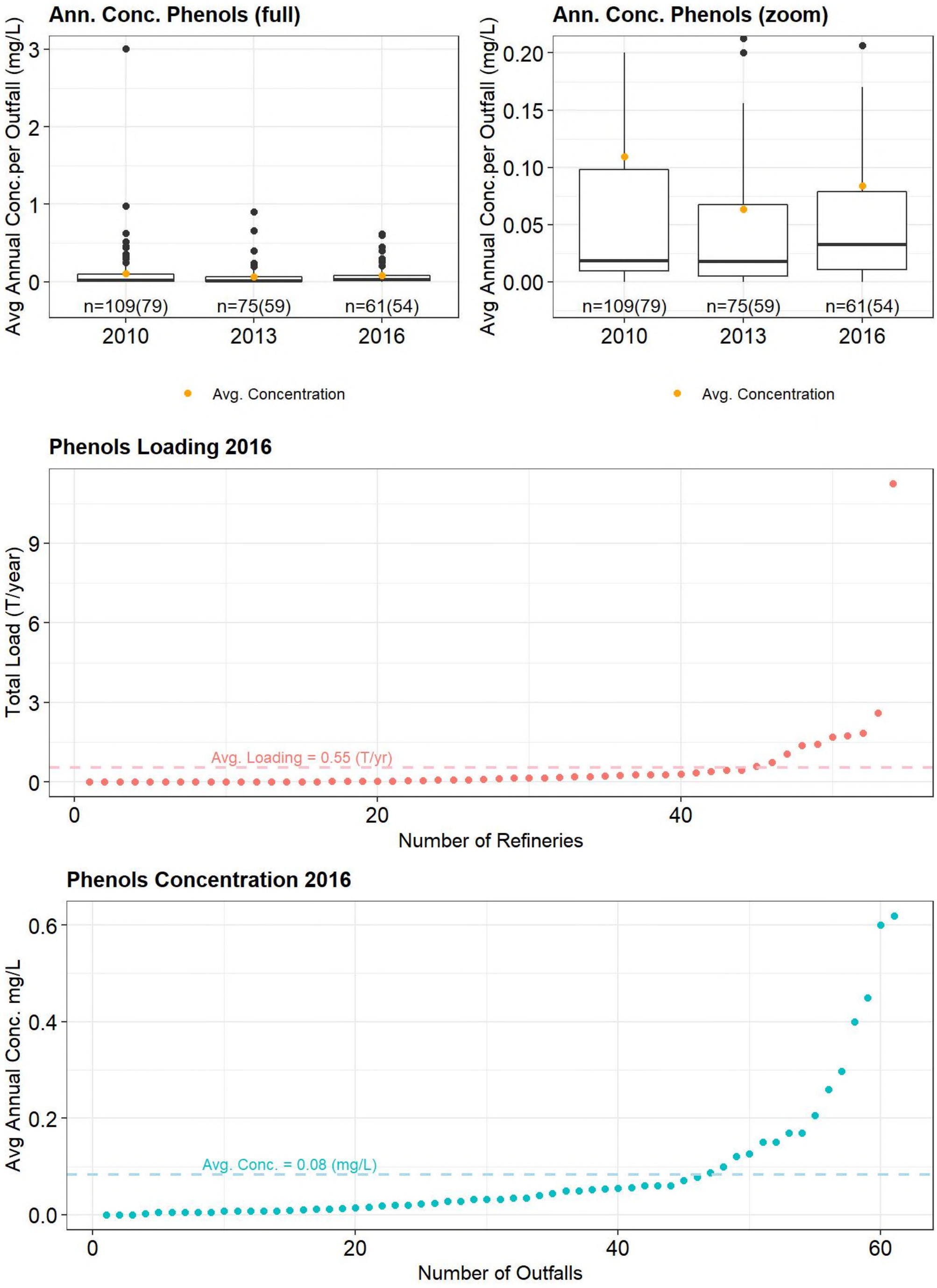
From the plots of phenols discharge loads (**Figure 51**), it is shown that the median loads and the dataset distribution have slightly increased in 2016 compared to 2013. These observations holds both when the full dataset is considered and when only the repeat sites are considered (n = 37 sites). All three survey datasets contain high outliers, which amount were not significantly different between the datasets but with a very high one (9.7 t/y or 2.3 g/tonne throughput) being introduced in 2016.

Figure 51. 2010, 2013 and 2016 survey results for phenols total and relative discharge load.



From the plots of phenols discharge concentrations (**Figure 52**), it is shown that the average concentration and the dataset distribution are similar in all the three survey datasets (2010-2016), whereas an increase in the median concentration is observed for 2016. The two bottom plots of **Figure 52** show that a clear majority of the sites (81 %) and outfalls (75 %) are below the average for phenols total load and average annual concentration, respectively.

Figure 52. 2010, 2013 and 2016 survey results for phenols concentrations (two upper plots) and phenols total load and average annual concentration s-curves for 2016 (two bottom plots).



3.1.4. TSS and total phosphorous

Total and relative discharge data for TSS and total phosphorus in 2010 to 2016 are summarised in **Table 18**. For relative TSS discharge a large reduction is apparent from 2010 to 2013, and again from 2013 to 2016. For total phosphorus, the relative discharge in 2010 to 2016 were similar.

Table 18. 2016 and historical discharge loads of TSS and total phosphorus

Year	TSS	Total phosphorus
	tonne/year (Number of refineries reporting[1])	
2010	85,409[2] (74) 36.6[3] (6)	238[2] (72) 1.28[3] (9)
2013	12,491[2] (59) 30.6[3] (6)	171[2] (57) 0.25[3] (6)
2016	4,098[2] (62) 257[3] (5)	158[2] (52) 0.49[3] (5)
	g/tonne throughput	
2010	138[2] 0.06[3]	0.40[2] 0.002[3]
2013	25.0[2] 0.06[3]	0.34[2] 0.0005[3]
2016	8.0[2] 0.5[3]	0.31[2] 0.001[3]

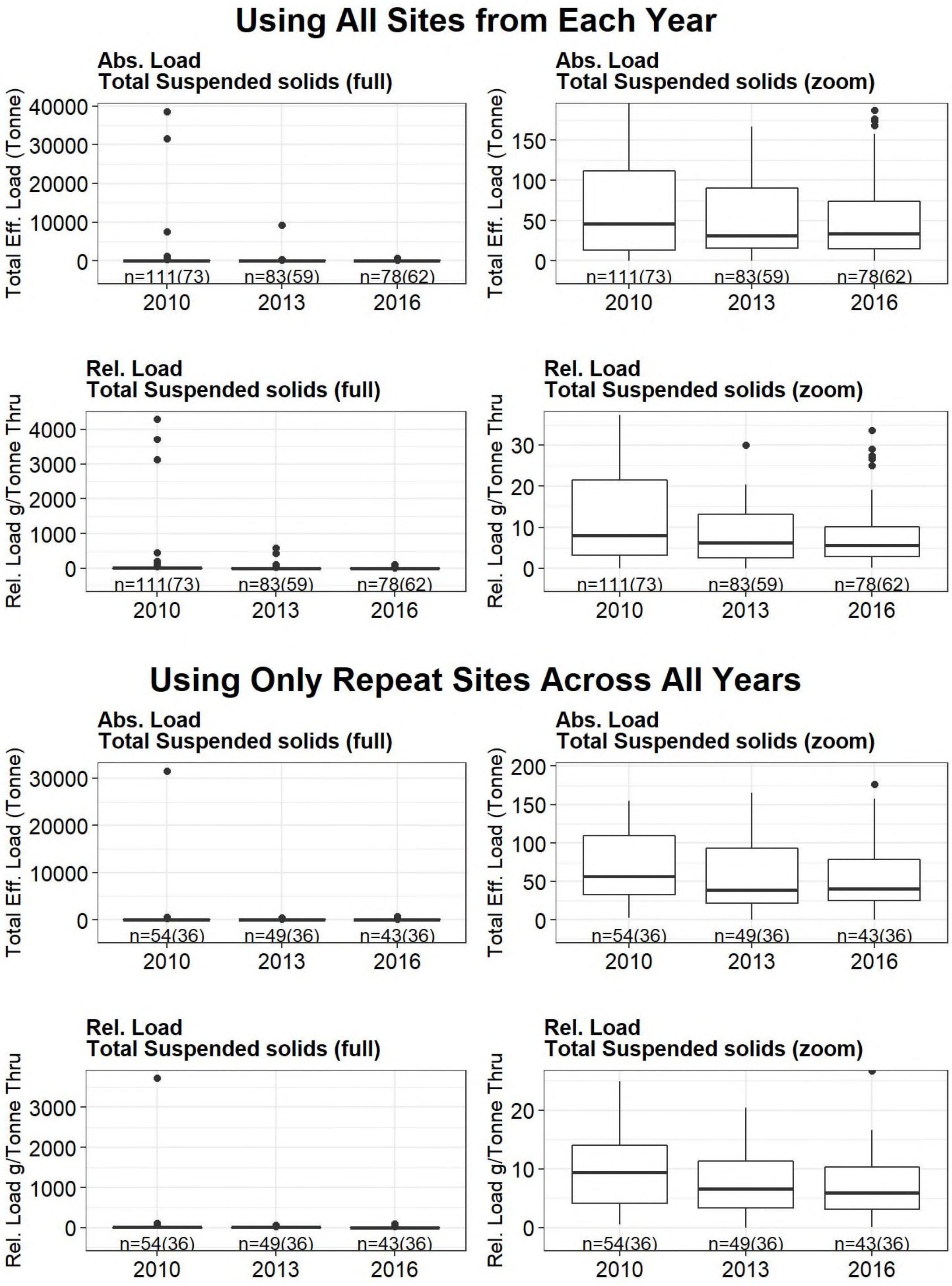
[1] Some refineries may have both a direct discharge as well as a transfer. These refineries would be included in both the direct discharge as well as transfer site count.

[2] Figures for direct discharges from installations

[3] Figures for additional loading due to discharges after transfer to and treatment by offsite WWTP, assuming 95% removal (Concawe, 2012)

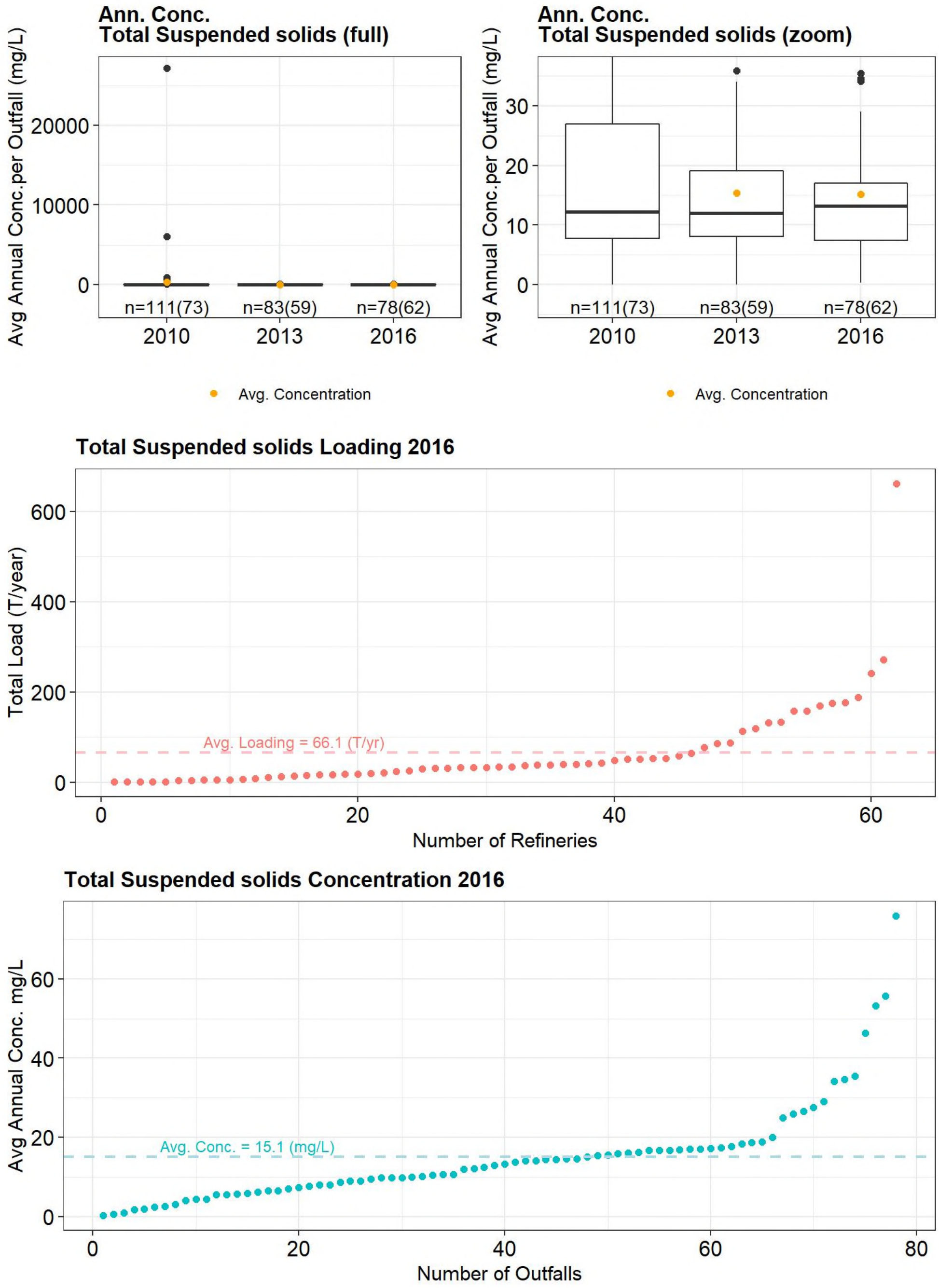
From the plots of TSS discharge loads (**Figure 53**), it is shown that the median loads are similar for 2013 and 2016, but are decreasing compared to 2010. The dataset distribution has decreased from 2010 to 2013, and 2013 to 2016, respectively. These observations holds both when the full dataset is considered and when only the repeat sites are considered (n = 36 sites). All three survey datasets contain high outliers, however they were significantly less in 2016 (and 2013) compared to 2010 when considering the full dataset (4 vs. 7, looking at relative loads).

Figure 53. 2010, 2013 and 2016 survey results for TSS total and relative discharge load.



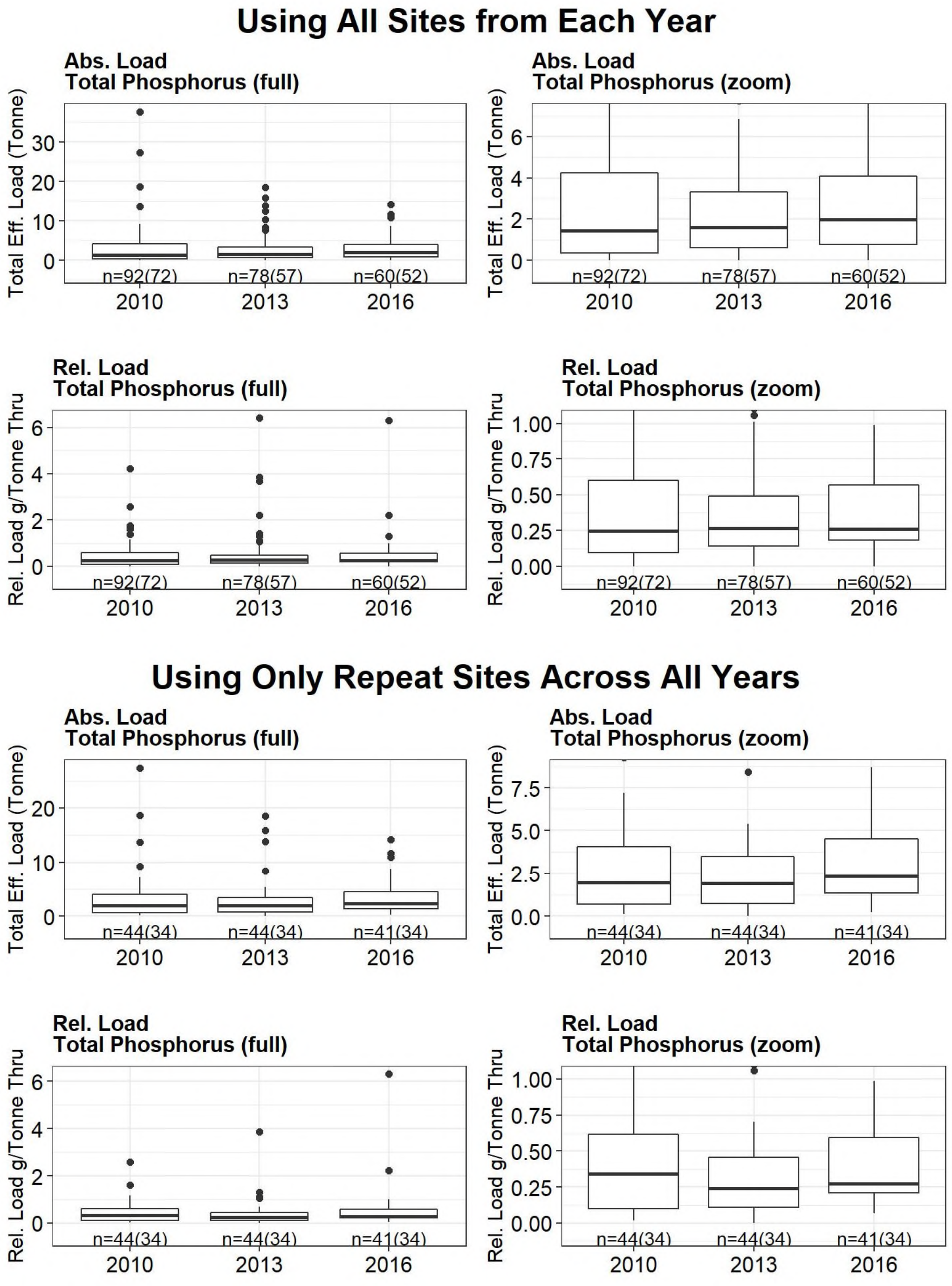
From the plots of TSS discharge concentrations (**Figure 54**), it is shown that the median concentration has slightly increased in 2016 compared to 2013, whereas the average concentration in 2013 and 2016 are similar with a clearly decrease in compared to 2010. The two bottom plots of **Figure 54** show that a clear majority of the sites (74 %) are below the average for TSS total load, and a majority of the outfalls (63 %) are below the average for TSS average annual concentration.

Figure 54. 2010, 2013 and 2016 survey results for TSS concentrations (two upper plots) and TSS total load and average concentration s-curves for 2016 (two bottom plots).



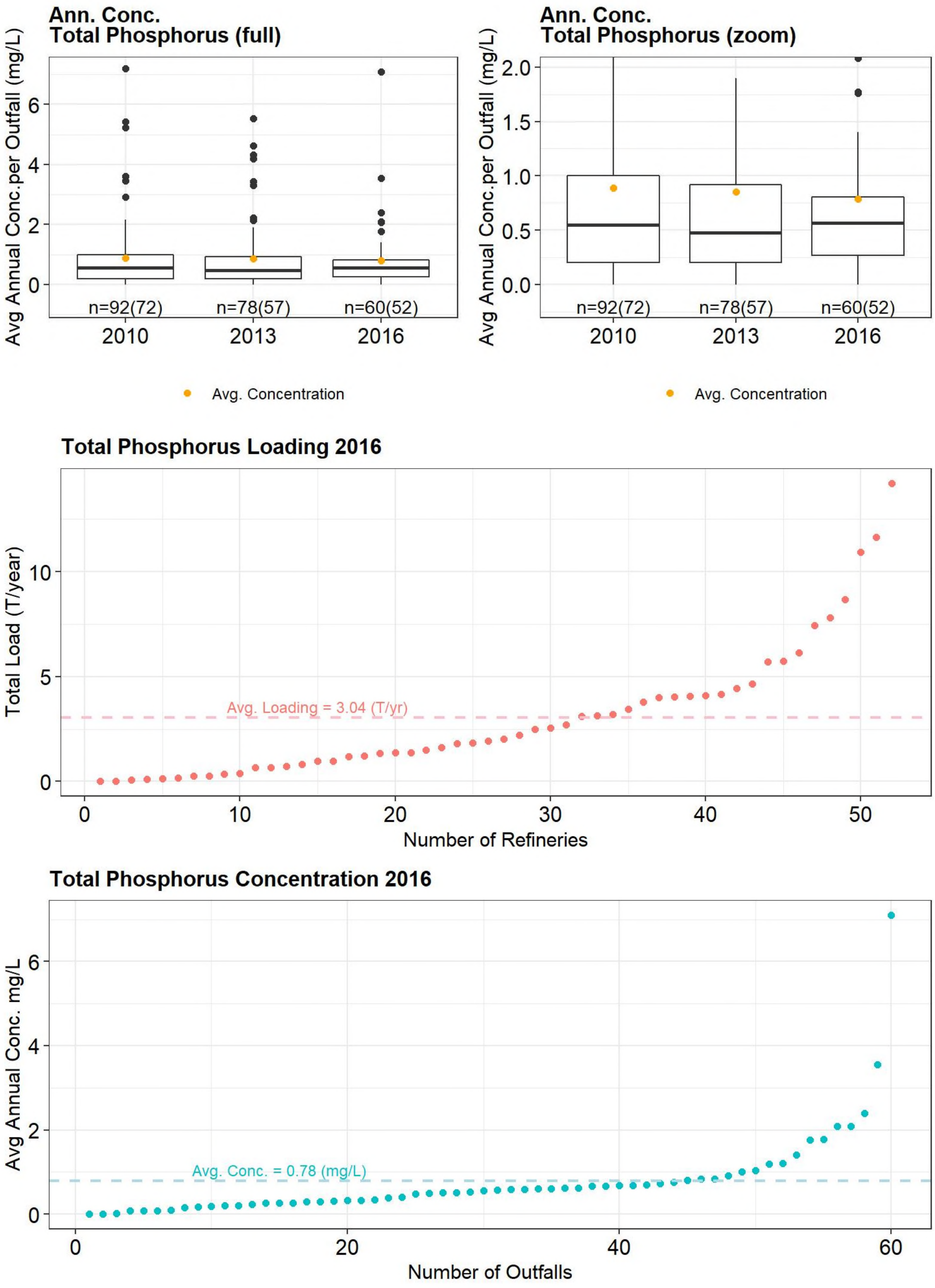
From the plots of total phosphorus discharge loads (**Figure 55**), it is shown that the median loads had slightly increased in 2016 compared to both 2013 and 2010. The dataset distribution had also increased from 2013 to 2016, but decreased from 2010 to 2016. The observations were different when only the repeat sites are considered (n = 34 sites), with the median loads and dataset distribution being constant. All three survey datasets contain high outliers, however they were significantly less in 2016 compared to 2013 when considering the full dataset (3 vs. 8, looking at absolute loads).

Figure 55. 2010, 2013 and 2016 survey results for total phosphorus total and relative discharge load.



From the plots of total phosphorus discharge concentrations (**Figure 56**), it is shown that the median concentration, average concentration and the dataset distribution of the datasets are similar in all the three survey datasets (2010-2016). The two bottom plots of **Figure 56** show that a majority of the sites (60 %) are below the average total phosphorus total load, and a clear majority of the outfalls (73 %) are below the average for total phosphorus average annual concentration.

Figure 56. 2010, 2013 and 2016 survey results for total phosphorus concentrations (two upper plots) and total phosphorus total load and average annual concentration s-curves for 2016 (two bottom plots).



3.1.5. BTEX and total PAH[14]

Historic absolute and relative discharge loads from 2010-2016 for BTEX and total PAHs are summarised in **Table 19**. For BTEX the total discharge has been reduced throughout all the survey years 2010-2016, while relative BTEX discharge appear relatively stable from 2010 to 2016. For total PAHs, a reduction for both total and relative discharge is apparent between 2010 and 2013, whereas they both appears relatively stable from 2013 to 2016.

Table 19. 2016, 2013, and 2010 discharge of BTEX and total PAHs

Year	BTEX	Total PAHs[1]
	kg/year (Number of refineries reporting[2])	
2010	11,300[3] (60) 3,260[4] (8)	107[3] (50) 2.2[4] (6)
2013	8,950[3] (43) 2,130[4] (6)	40[3] (19) 0.06 (4)
2016	6,604[3] (44) 317[4] (5)	39[3] (28) 2.0[4] (3)
	mg/tonne throughput	
2010	19[3] 5.4[4]	0.25[3] 1.1[4]
2013	18[3] 4.3[4]	0.08[3] 0.0001[4]
2016	13[3] 0.1[4]	0.08[3] 0.01[4]

n.a. = not applicable

[1] Total PAH values in this table include the total PAH value given by responders. When total PAH value was not provided, it was calculated as the sum of individual PAHs using 0 for non-detects. If all individual PAHs were reported as 0, then ½ of the LOQ for the highest LOQ value reported was used. Individual PAHs included Anthracene, Benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, Fluoranthene, and Indeno(1,2,3-cd)pyrene.

[2] Some refineries may have both a direct discharge as well as a transfer. These refineries would be included in both the direct discharge as well as transfer site counts.

[3] Figures for direct discharges from installations.

[4] Figures for additional loading due to discharges after transfer to and treatment by offsite WWTP, assuming 95% removal (Concawe, 2012)

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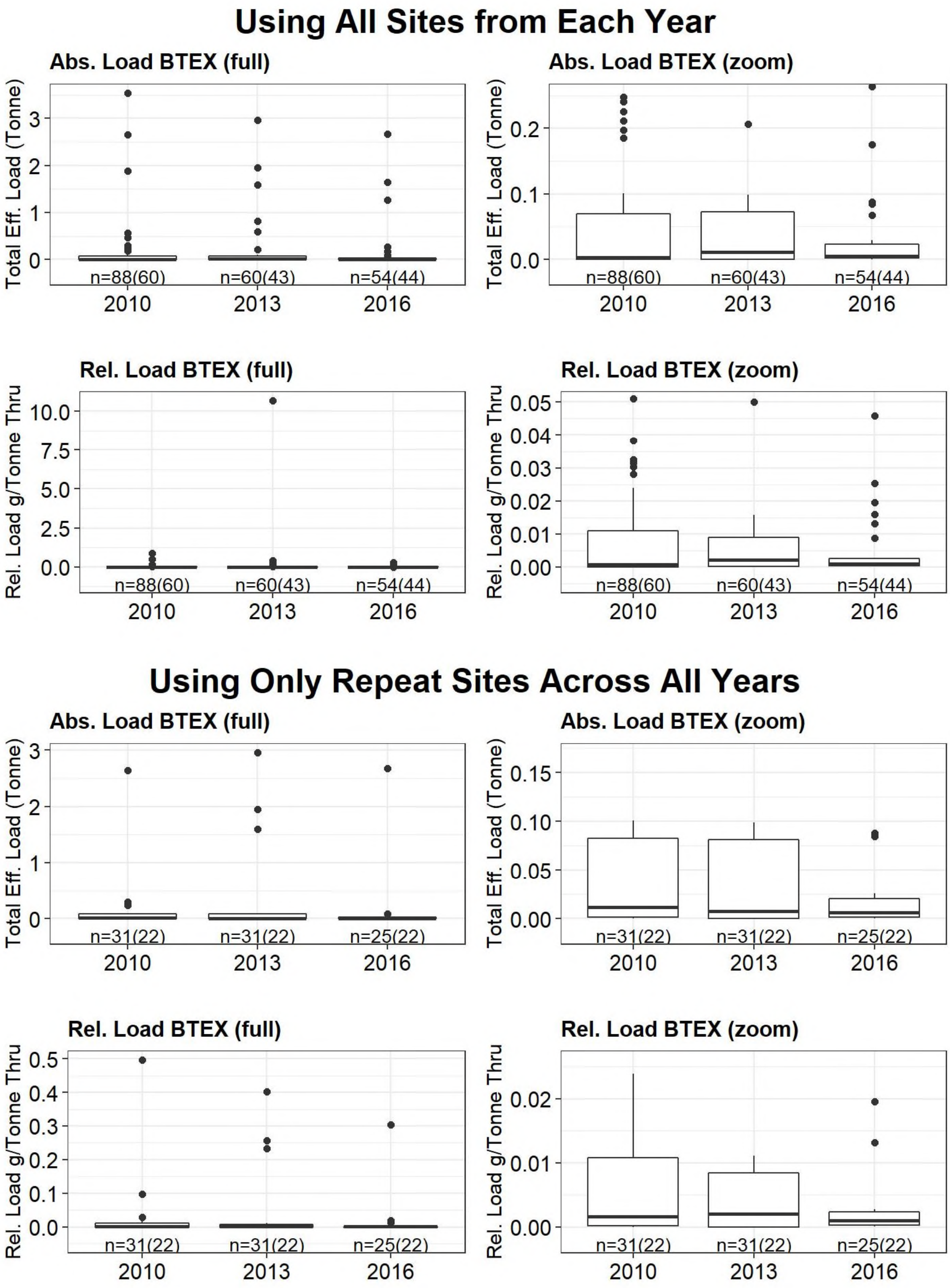
[14] Total PAH values in this table include the total PAH value given by responders. When total PAH value was not provided, it was calculated as the sum of individual PAHs using 0 for non-detects. If all individual PAHs were reported as 0, then ½ of the LOQ for the highest LOQ value reported was used. Individual PAHs included Anthracene, Benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, Fluoranthene, and Indeno(1,2,3-cd)pyrene.

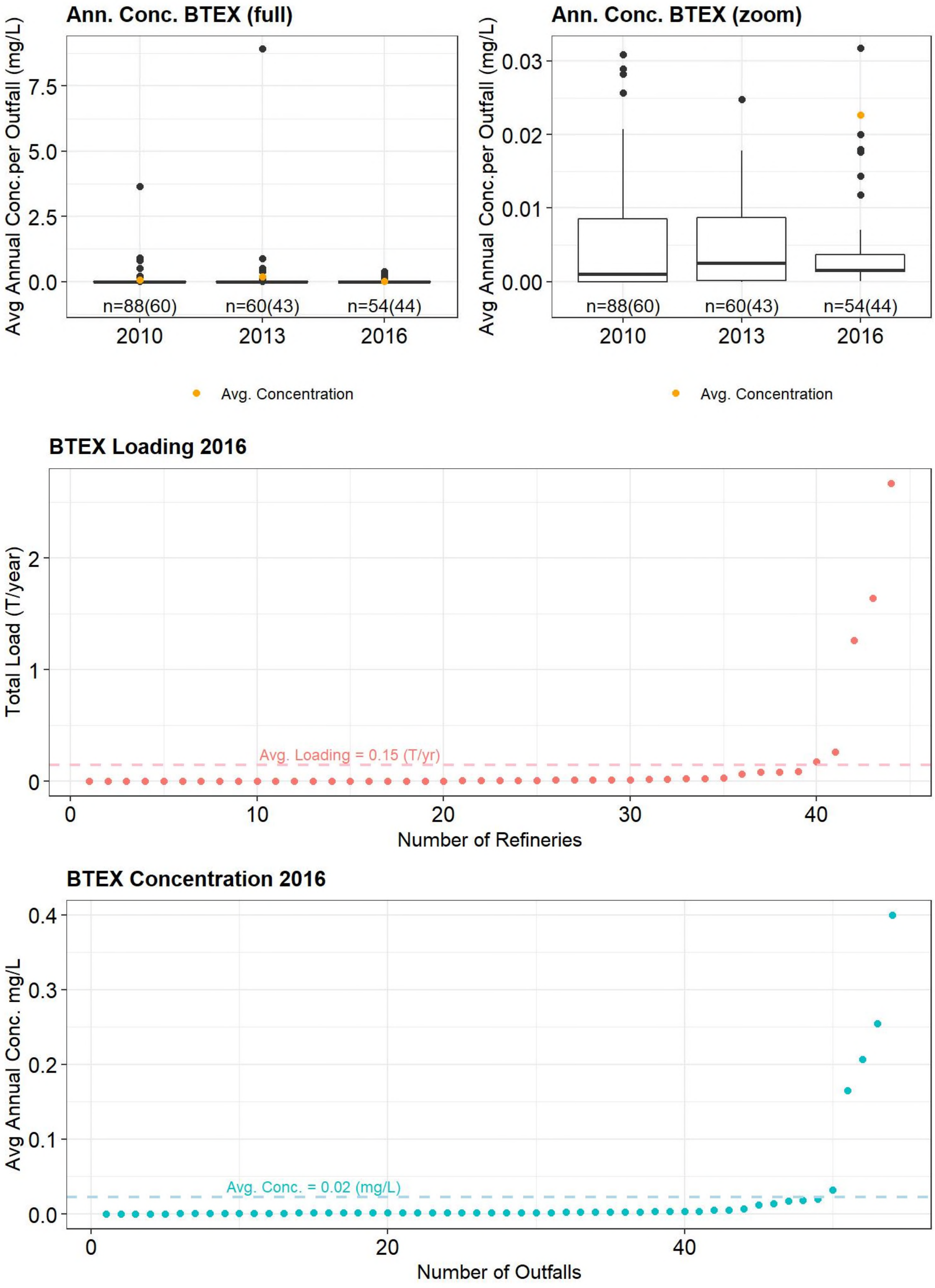
From the plots of BTEX discharge loads (**Figure 57**), it is shown that the median loads had slightly decreased in 2016 compared to 2013 only, whereas the dataset distribution had decreased in 2016 compared to both 2013 and 2010. These observations holds both when the full dataset is considered and when only the repeat sites are considered (n = 22 sites). All three survey datasets contain high outliers, which amount were not significantly different between the datasets.

Figure 57. 2010, 2013 and 2016 survey results for BTEX total and relative discharge load.



From the plots of BTEX discharge concentrations (**Figure 58**), it is shown that the median concentration are similar in all the three survey datasets (2010-2016), whereas the average concentration and dataset distribution has been clearly decreasing for 2016 compared to both 2010 and 2013. The two bottom plots of **Figure 58** show that a clear majority of the sites (89 %) and outfalls (91 %) are below the average for BTEX total load and average annual concentration, respectively.

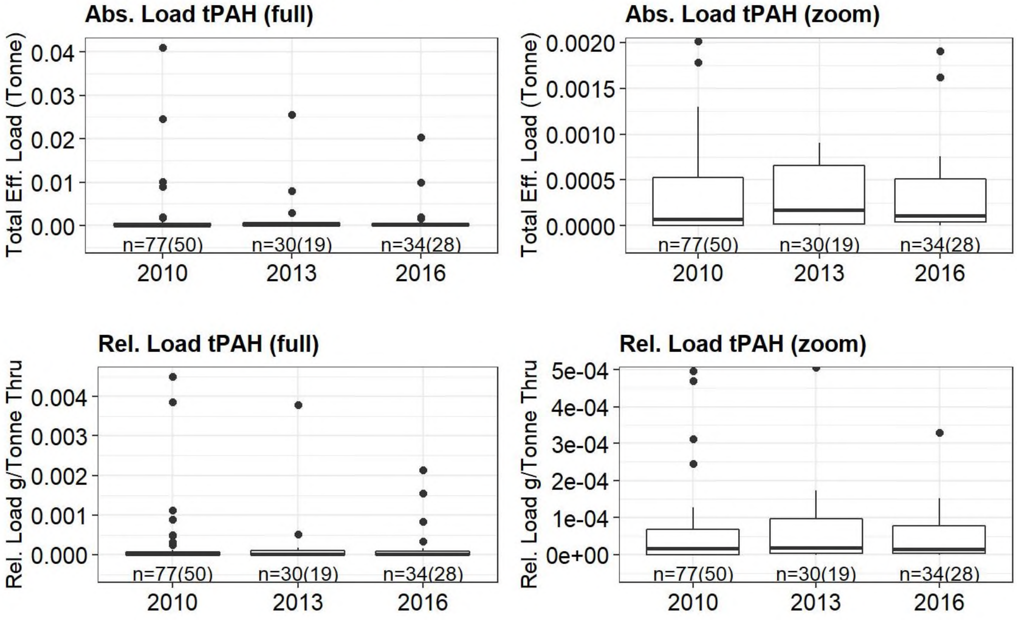
Figure 58. 2010, 2013 and 2016 survey results for BTEX concentrations (two upper plots) and BTEX total load and average annual concentration s-curves for 2016 (two bottom plots).



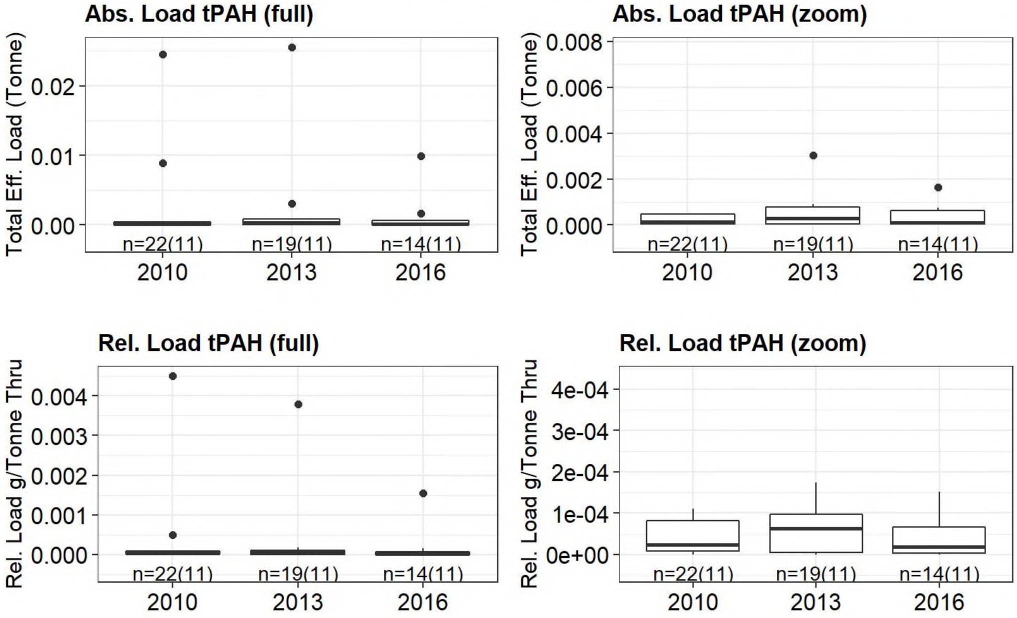
From the plots of total PAHs discharge loads (**Figure 59**), it is shown that the median loads dataset distribution had slightly decreased in 2016 compared to 2013, whereas it was similar in 2016 compared to 2010. These observations holds both when the full dataset is considered and when only the repeat sites are considered (n = 11 sites). All three survey datasets contain high outliers, however they were which amount were not significantly different between 2016 and 2013, but had decreased since 2010.

Figure 59. 2010, 2013 and 2016 survey results for total PAHs total and relative discharge load.

Using All Sites from Each Year

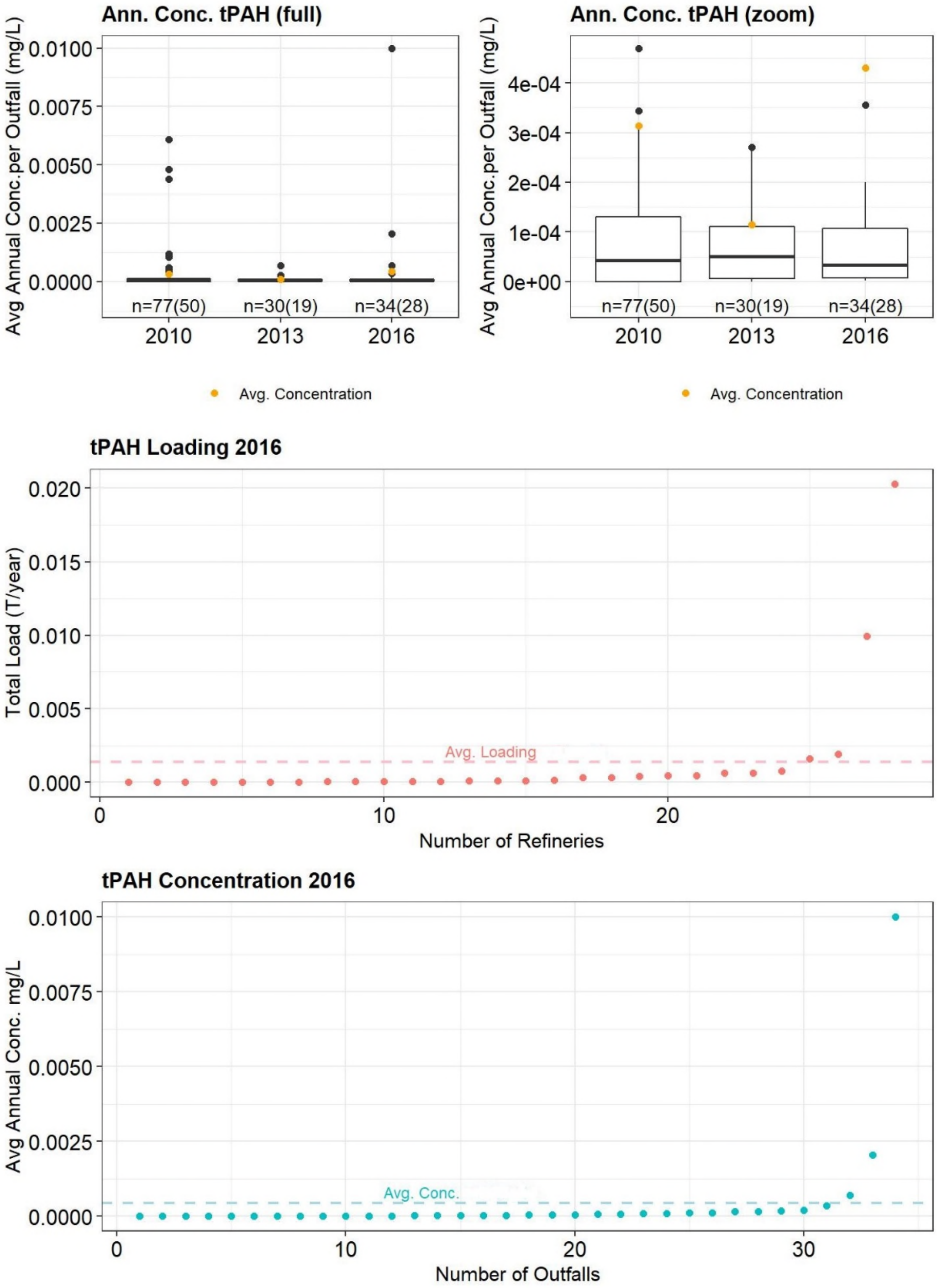


Using Only Repeat Sites Across All Years



From the plots of total PAHs discharge concentrations (**Figure 60**), it is shown that the median concentration and the distribution of the datasets are similar in all the three survey datasets (2010-2016), whereas the average concentration has increased from 2013 to 2016, to levels similar to 2010. The two bottom plots **Figure 60**, show that a clear majority of the sites (86 %) and outfalls (91 %) are below the average for total PAHs total load (0.003 tonnes/yr) and average annual concentration (0.00043 mg/L), respectively.

Figure 60. 2010, 2013 and 2016 survey results for total PAHs concentrations (two upper plots) and total PAHs total load and average annual concentration s-curves for 2016 (two bottom plots).



3.1.6. Heavy Metals

Total and relative discharge data for heavy metals (cadmium, lead, mercury, nickel, and vanadium – as per the REF BREF BAT Conclusions (2014/738/EU[15])) for 2010 to 2016 are summarised in **Table 20**. For cadmium, a reduction was apparent from 2010 to 2013 with a slight increase from 2013 to 2016, while the relative discharge appear relatively stable comparing all years. For lead, there was a large reduction from 2013 to 2016, both in total and relative terms. For mercury, an increase was observed from 2013 to 2016, both in total and relative terms. For nickel, big reductions were observed from both 2010 to 2013 and 2013 to 2016, although in relative terms only a big reduction from 2013 to 2016 was observed. For vanadium, a large increase was observed from 2013 to 2016, both in total and relative terms, returning it to levels comparable with 2010.

Table 20. 2016, 2013, and 2010 discharge of heavy metals

Year	Cadmium	Lead	Mercury	Nickel	Vanadium
	kg/year (Number of refineries reporting[1])				
2010	740[2] (69) 12[3] (7)	3,014[2] (71) 48[3] (7)	170[2] (65) 5[3] (9)	7,960[2] (68) 221[3] (9)	7,197[2] (36) 115[3] (4)
2013	542[2] (72) 87[3] (5)	2,463[2] (71) 278[3] (6)	161[2] (72) 1.1[3] (5)	5,685[2] (72) 481[3] (5)	2,020[2] (72) 4.5[3] (1)
2016	618[2] (48) 0.09[3] (3)	1,123[2] (47) 10[3] (3)	386[2] (45) 0.05[3] (3)	2,870[2] (47) 1.3[3] (3)	8,670[2] (27) 0.2[3] (3)
	mg/tonne throughput				
2010	1.2[2] 0.04[3]	5.0[2] 0.05[3]	0.28[2] 0.002[3]	13.2[2] 0.36[3]	11.9[2] 0.72[3]
2013	1.1[2] 0.007[3]	4.9[2] 0.03[3]	0.32[2] 0.0001[3]	11.4[2] 0.05[3]	4.04[2] 0.0004[3]
2016	1.2[2] 0.0002[3]	2.2[2] 0.02[3]	0.76[2] 0.003[3]	5.6[2] 0.002[3]	15.9[2] 0.0005[3]

[1] Some refineries may have both a direct discharge as well as a transfer. These refineries would be included in both the direct discharge as well as transfer site count

[2] Figures for direct discharges from installations.

[3] Figures for additional loading due to discharges after transfer to and treatment by offsite WWTP, assuming 95% removal (Concawe, 2012)

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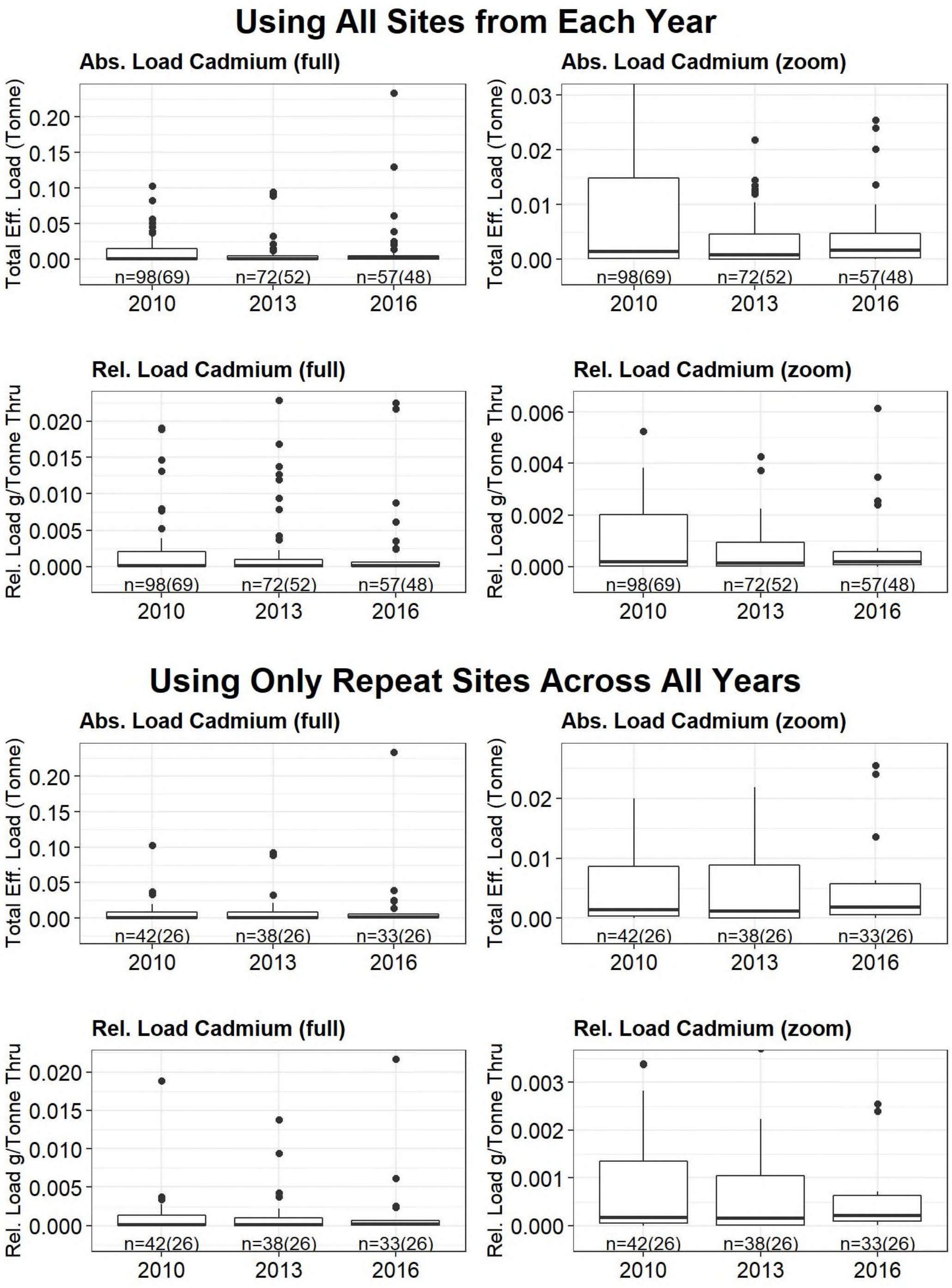
[15] 2014/738/EU: Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas.

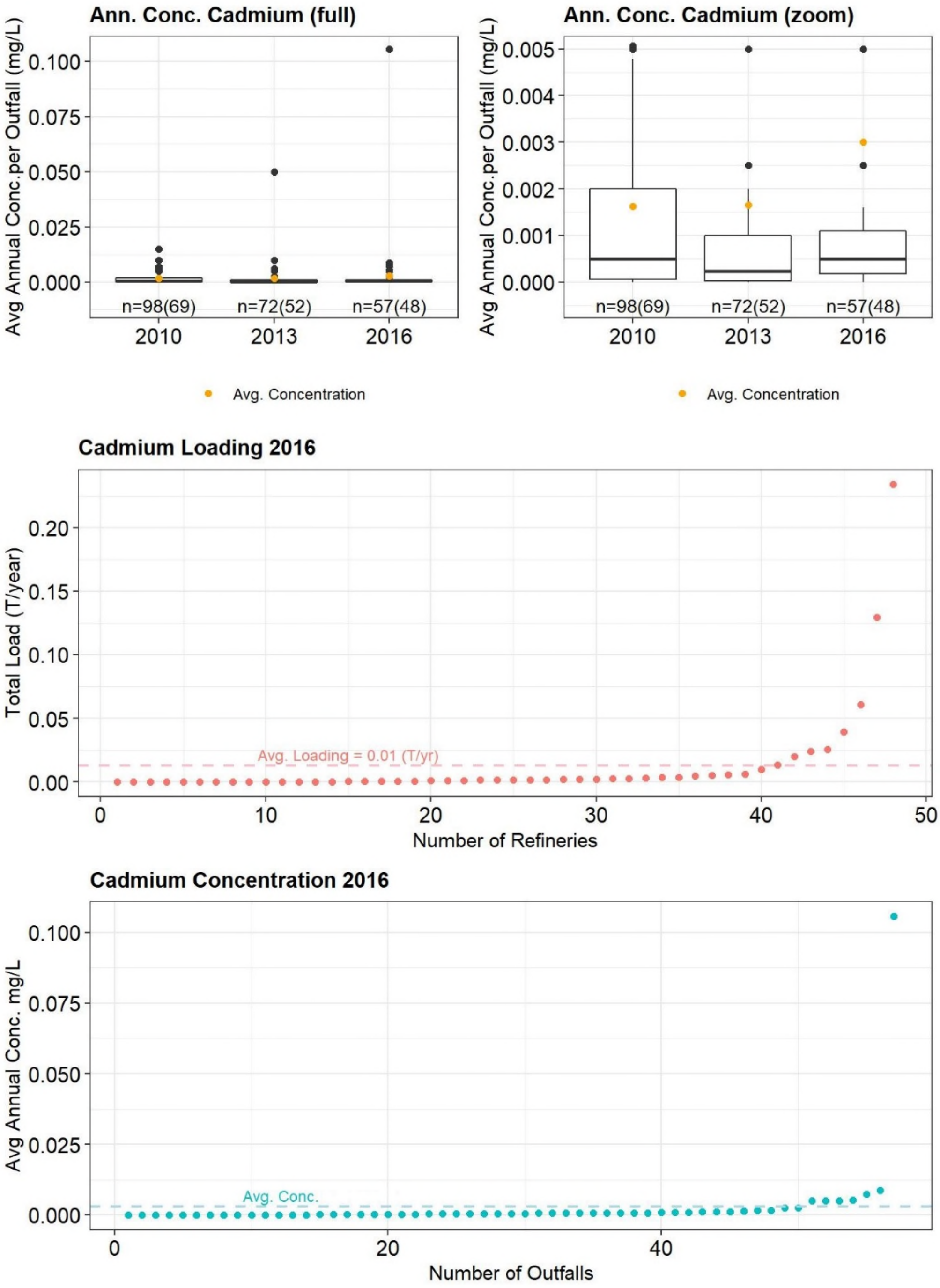
From the plots of cadmium discharge loads (**Figure 61**), it is shown that the median load, is similar in all the three survey datasets (2010-2016), whereas the dataset distribution is overall decreased. When only the repeat sites are considered (n = 26 sites), the observations regarding the median concentration and dataset distribution are the same as when all sites are included. All three survey datasets contain high outliers which amount did not significantly differ between the datasets.

Figure 61. 2010, 2013 and 2016 survey results for cadmium total and relative discharge load.



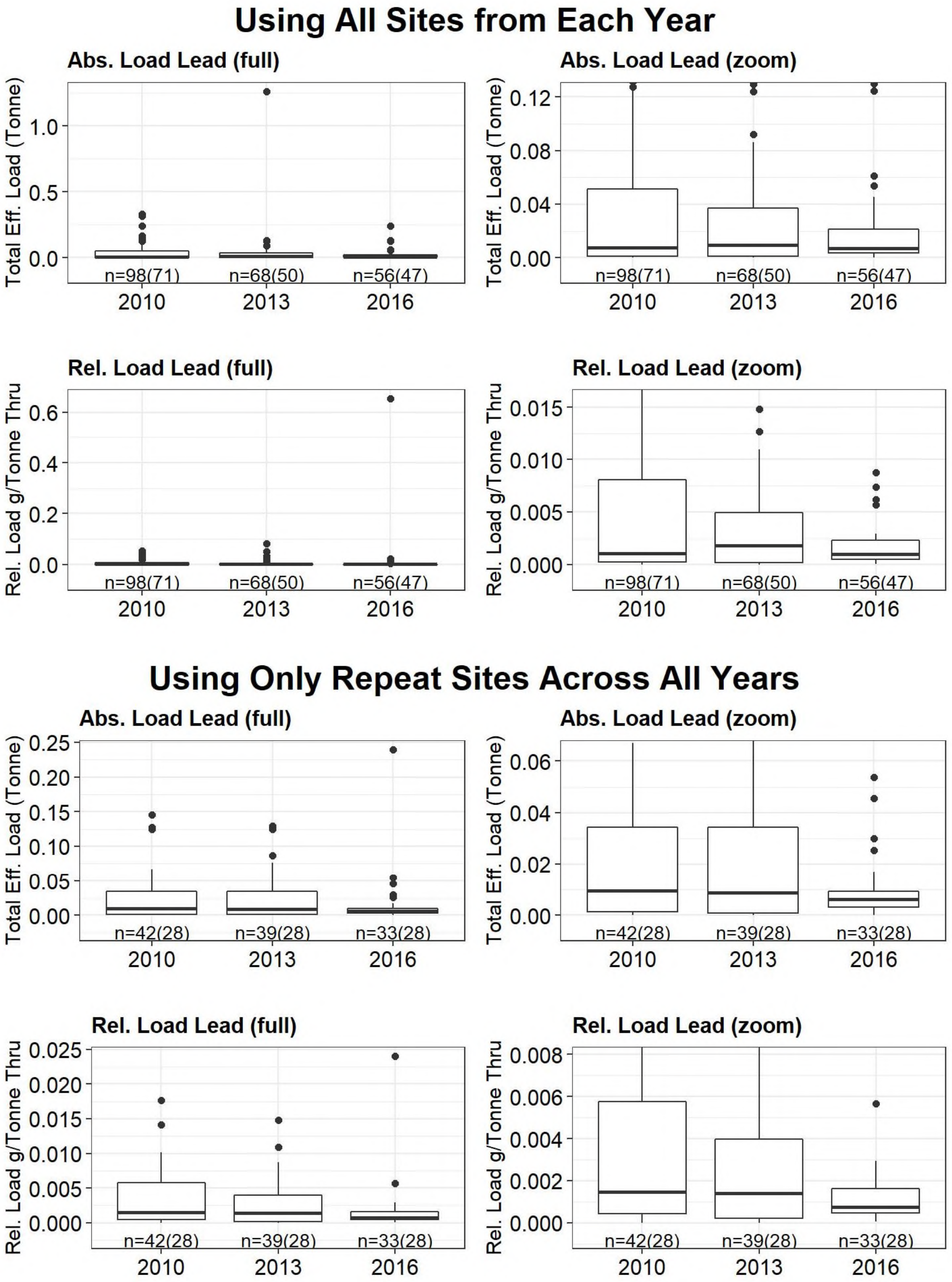
From the plots of cadmium discharge concentrations (**Figure 62**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the average concentration had slightly increased for 2016 driven by the presence of one outlier. The dataset distribution had clearly decreased for 2016 and 2013 compared to 2010. The two bottom plots of **Figure 62** show that a clear majority of the sites (83 %) and outfalls (88 %) are below the average for cadmium total load and average annual concentration (0.003 mg/L), respectively.

Figure 62. 2010, 2013 and 2016 survey results for cadmium concentrations (two upper plots) and cadmium total load and average annual concentration s-curves for 2016 (two bottom plots).



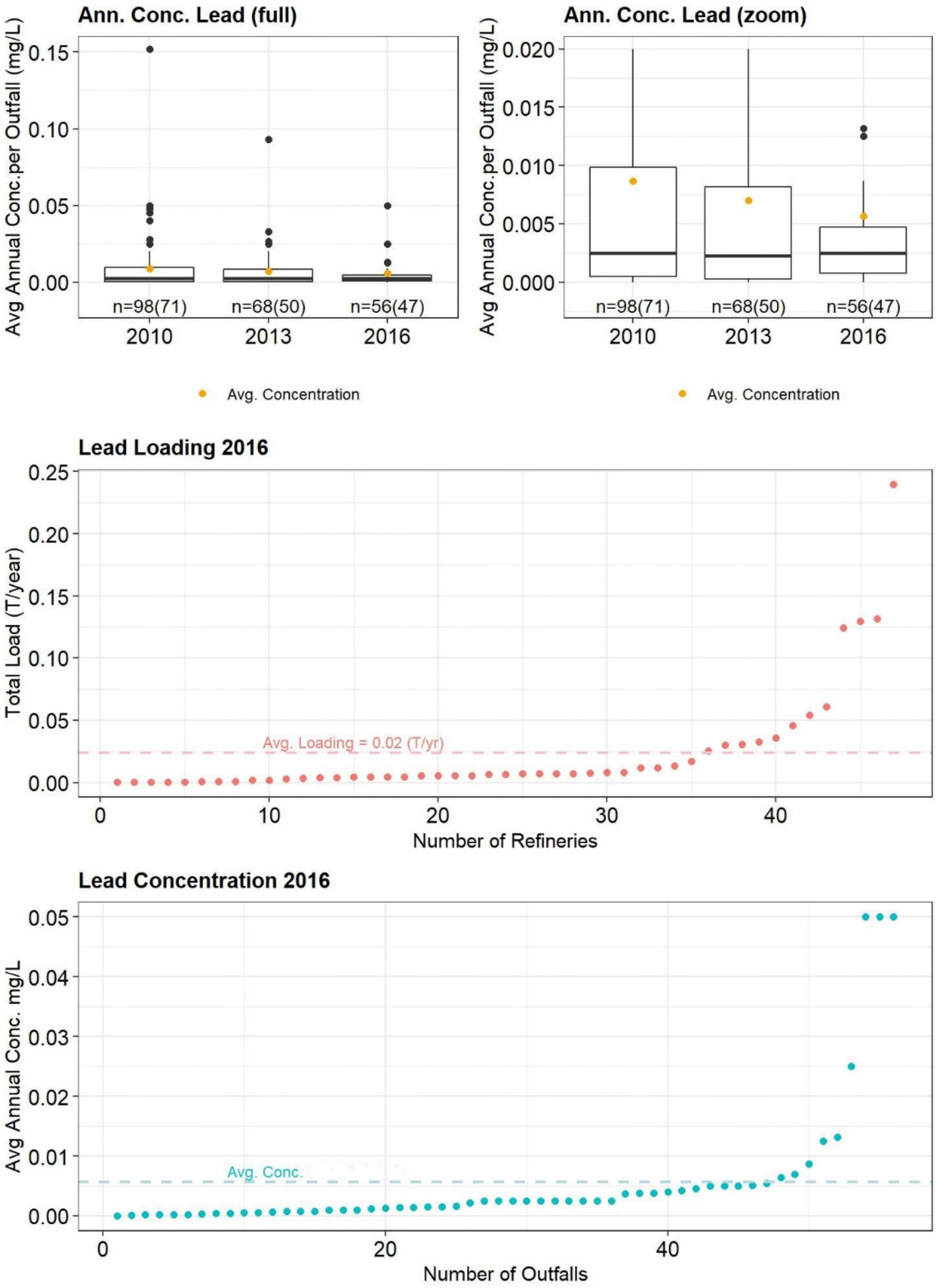
From the plots of lead discharge loads (**Figure 63**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the dataset distribution has decreased from 2013 to 2016, and 2010 to 2013, respectively. When only the repeat sites are considered (n = 28 sites), the median concentration is slightly lower for 2016 compared to 2013 and 2010, whereas the dataset distribution is clearly lower. All three survey datasets contain high outliers which amount did not significantly differ between the datasets.

Figure 63. 2010, 2013 and 2016 survey results for lead total and relative discharge load.



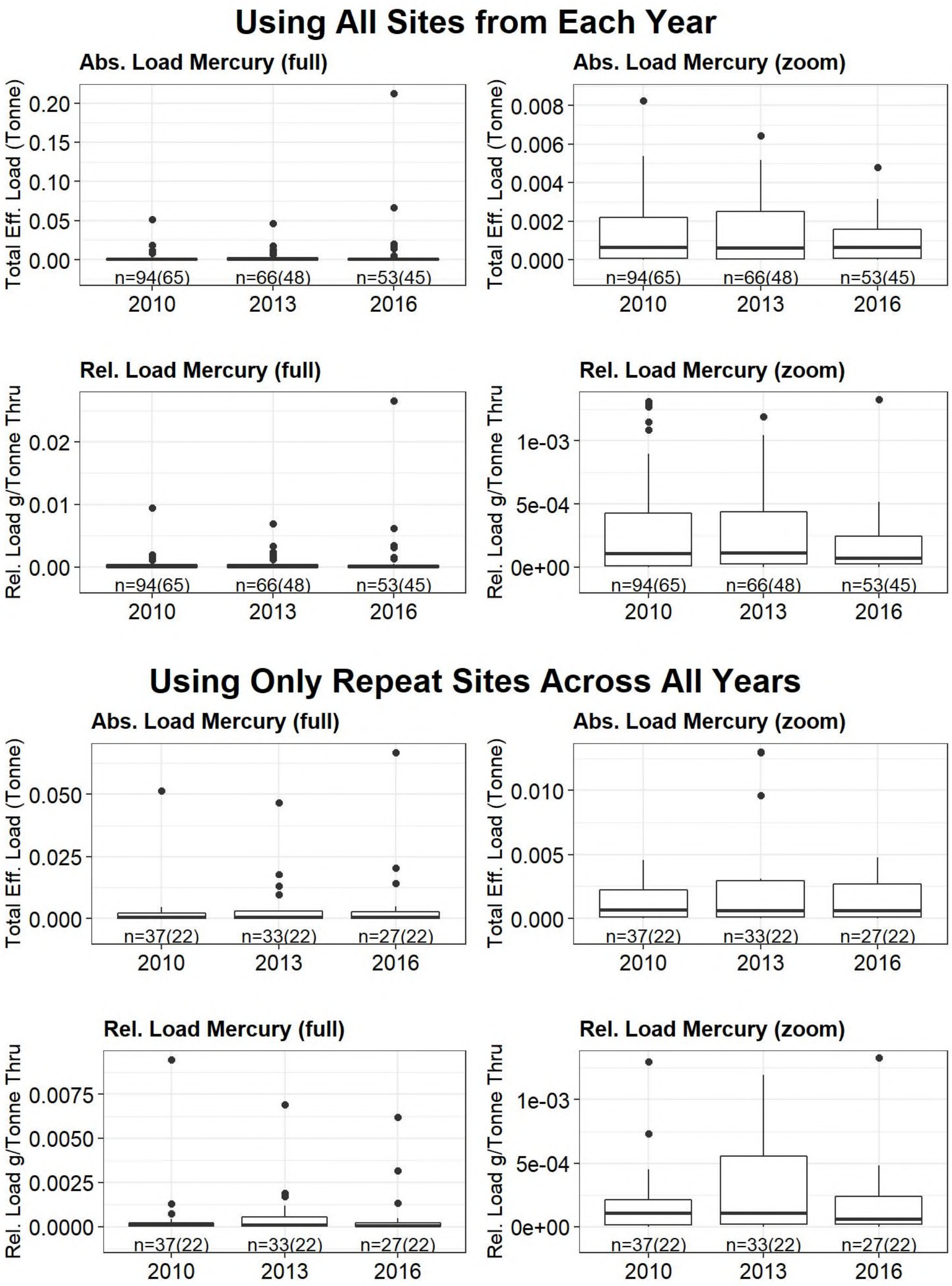
From the plots of lead discharge concentrations (**Figure 64**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the average concentration has been slightly decreasing throughout the survey years and the dataset distribution clearly decreased for 2016 compared to both 2013 and 2010. The two bottom plots of **Figure 64** show that a clear majority of the sites (77 %) and outfalls (84 %) are below the average for lead load and annual concentration (0.006 mg/L), respectively.

Figure 64. 2010, 2013 and 2016 survey results for lead concentrations (two upper plots) and lead total load and average annual concentration s-curves for 2016 (two bottom plots).



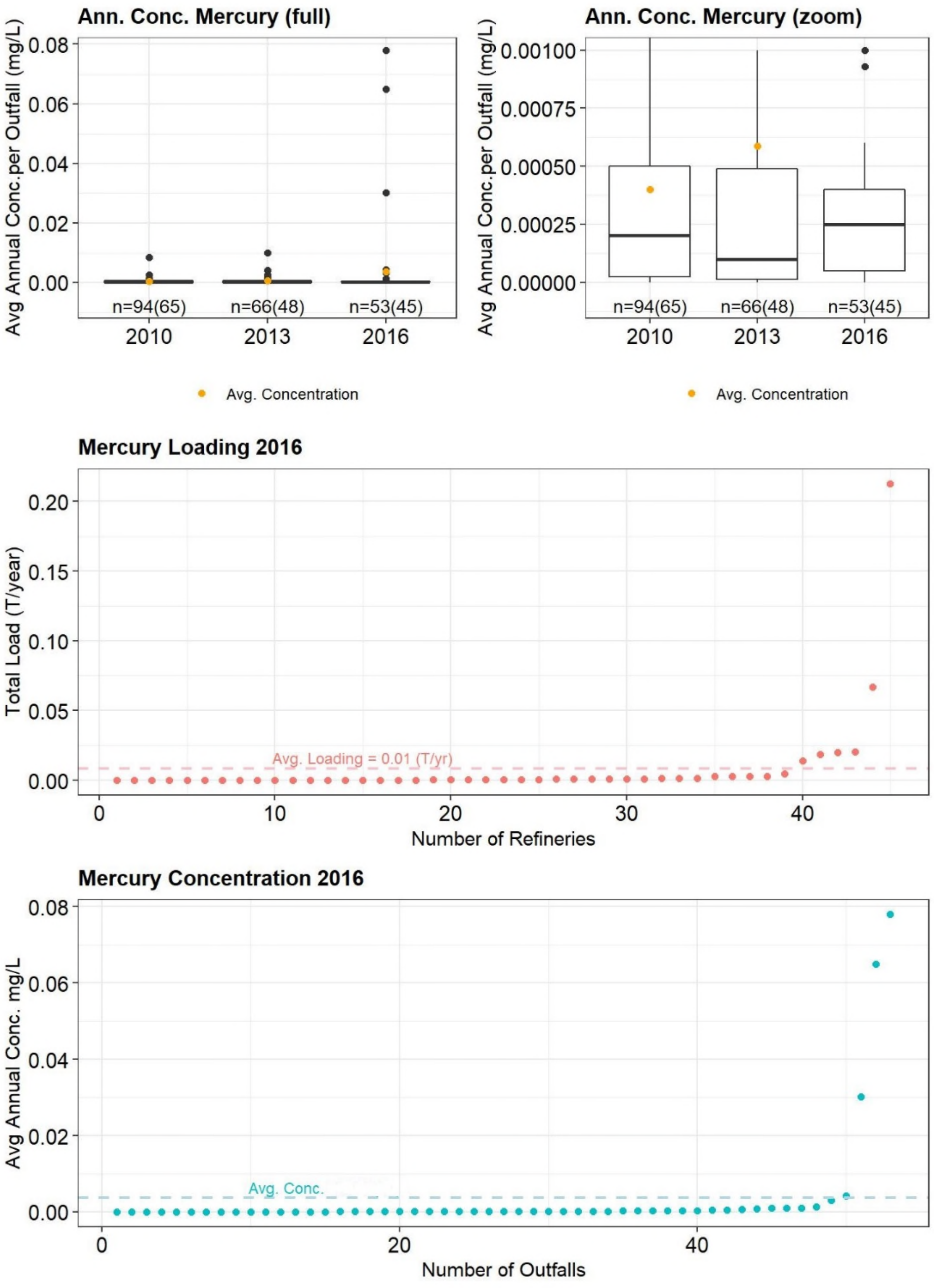
From the plots of mercury discharge loads (**Figure 65**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the dataset distribution was lower in 2016, compared to previous surveys. When only the repeat sites are considered (n = 22 sites), the median concentration trend was the same as when including all sites, whereas the dataset distribution looked slightly different with it clearly being higher in 2013. All three survey datasets contain high outliers which amount did not significantly differ between the datasets, however the highest 2016 outlier (using all sites data) was considerably larger than those of previous years.

Figure 65. 2010, 2013 and 2016 survey results for mercury total and relative discharge load.



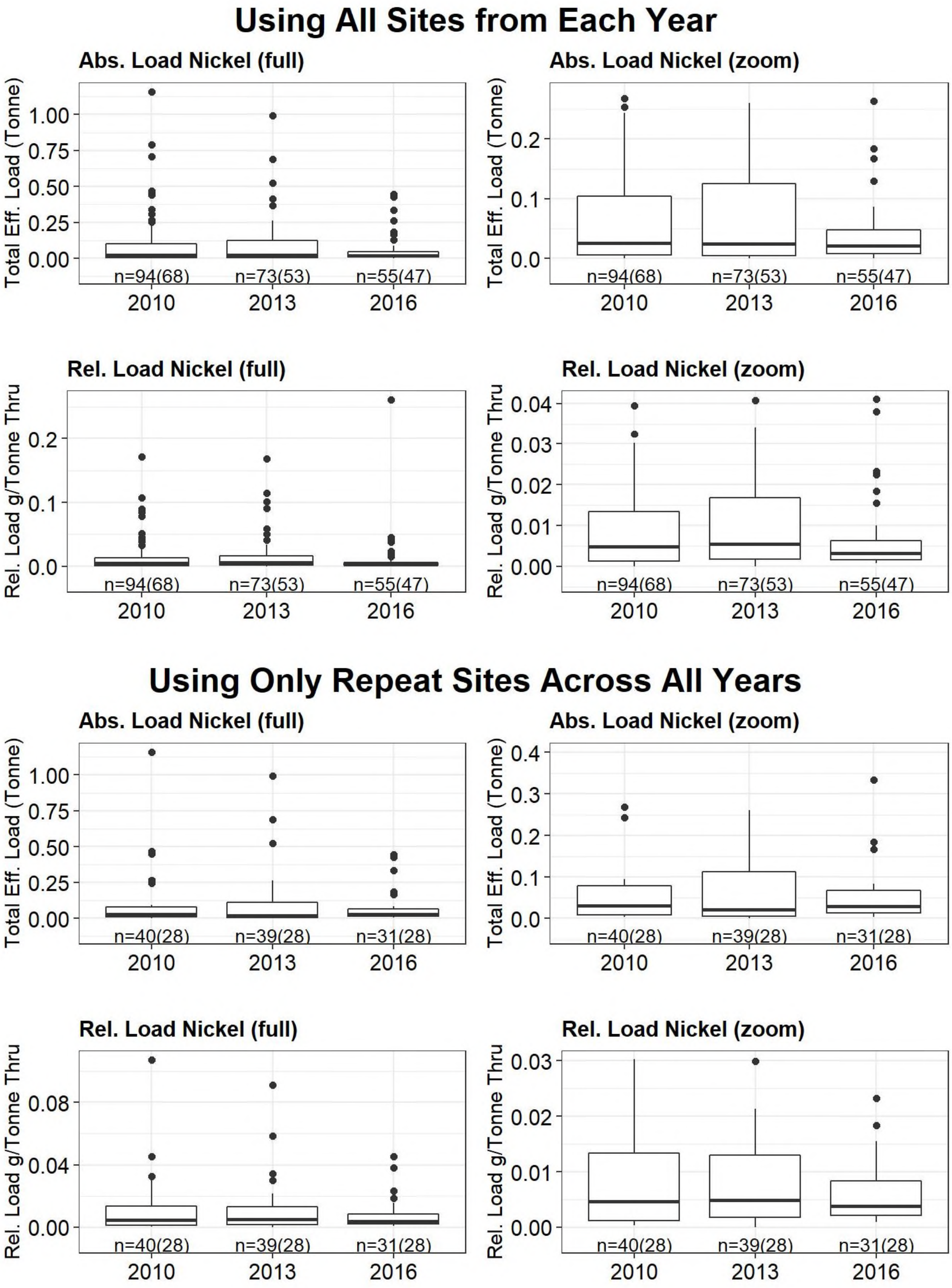
From the plots of mercury discharge concentrations (**Figure 66**), it is shown that the median concentration is varying for the three survey datasets (2010-2016) with 2016 being higher than 2013, whereas the average concentration has increased from 2010 to 2013 and 2013 to 2016, respectively. The average concentration increase in 2016 is driven by the presence of three outliers. The dataset distribution have decreased for 2016 compared to 2013 and 2010. The two bottom plots of **Figure 66** show that a clear majority of the sites (87 %) and outfalls (94 %) are below the average for mercury load and annual concentration (0.004 mg/L), respectively.

Figure 66. 2010, 2013 and 2016 survey results for mercury concentrations (two upper plots) and mercury total load and average annual concentration s-curves for 2016 (two bottom plots).



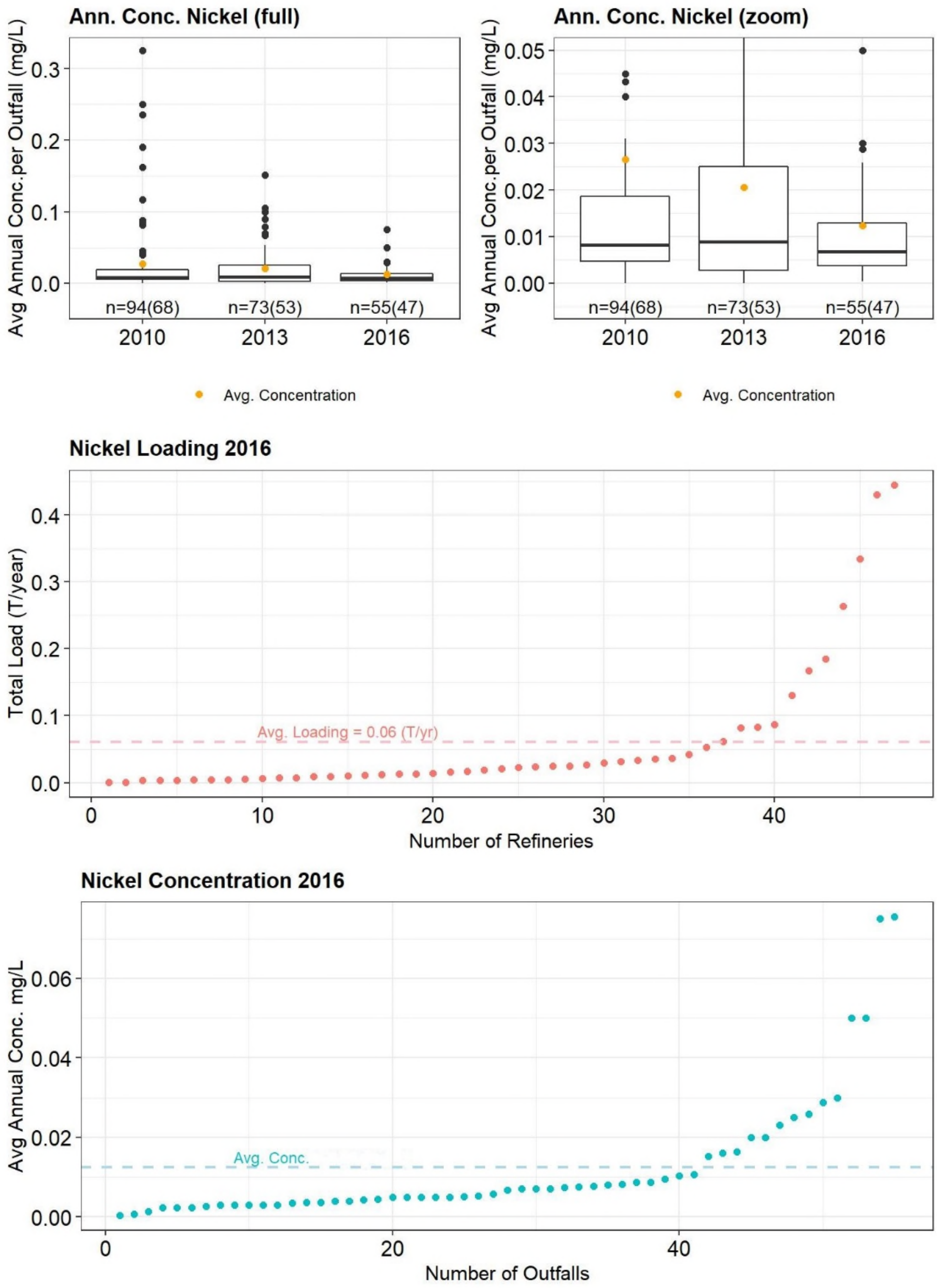
From the plots of nickel discharge loads (**Figure 67**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the dataset distribution was lower in 2016, compared to previous surveys. When only the repeat sites are considered (n = 28 sites), the median concentration trend was the same as when including all sites, whereas the dataset distribution looked slightly different with it clearly being higher in 2013. All three survey datasets contain high outliers which amount did not significantly differ between the datasets.

Figure 67. 2010, 2013 and 2016 survey results for nickel total and relative discharge load.



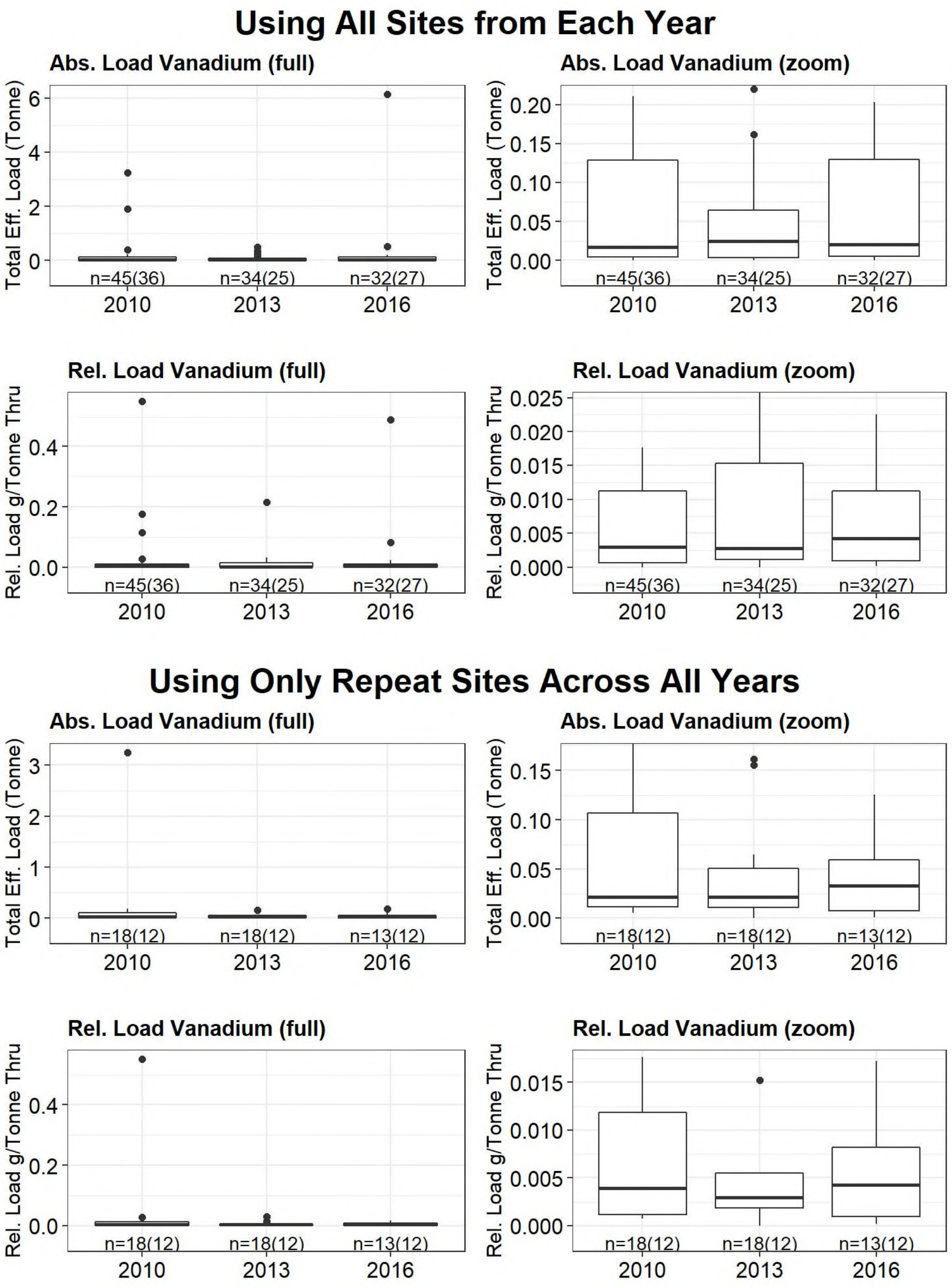
From the plots of nickel discharge concentrations (**Figure 68**), it is shown that the median concentration is similar in all the three survey datasets (2010-2016), whereas the average concentration has been decreasing throughout the survey years, and the dataset distribution clearly decreasing for 2016 compared to both 2013 and 2010. The two bottom plots of **Figure 68** show that a clear majority of the sites (77 %) and outfalls (75 %) are below the average for nickel load and annual concentration (0.012 mg/L), respectively.

Figure 68. 2010, 2013 and 2016 survey results for nickel concentrations (two upper plots) and mercury total load and annual average concentration s-curves for 2016 (two bottom plots).



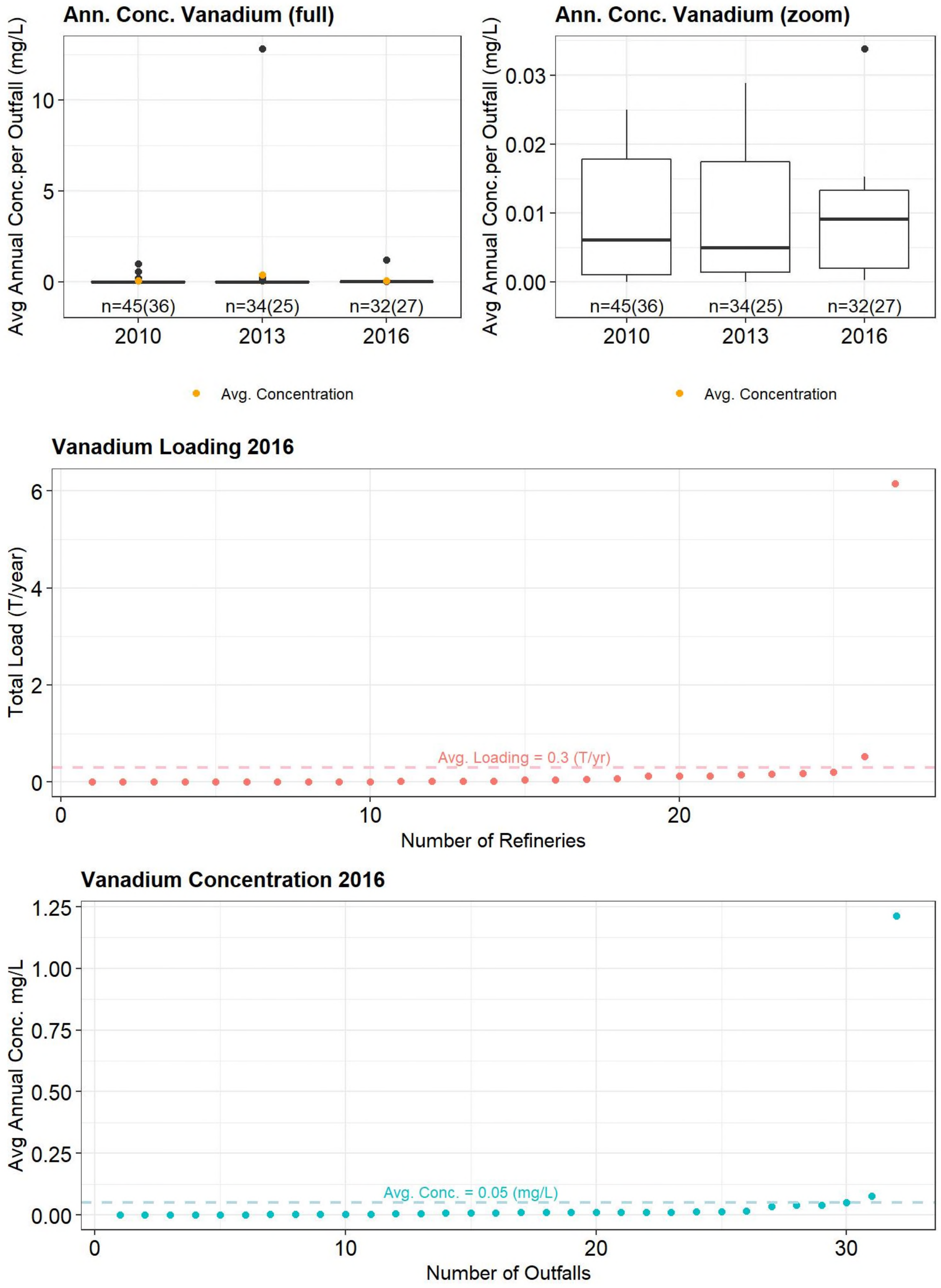
From the plots of vanadium discharge loads (**Figure 69**), it is shown that the median concentrations is similar in all the three survey datasets (2010-2016), whereas the dataset distribution was varying. When only the repeat sites are considered (n = 12 sites), the median concentration trend was the same as when including all sites, whereas the dataset distribution looked slightly different with it being slightly lower in 2013. All three survey datasets contain high outliers which amount did not significantly differ between the datasets.

Figure 69. 2010, 2013 and 2016 survey results for vanadium total and relative discharge load.



From plots of vanadium discharge concentrations (**Figure 70**), it is shown that the median concentration had slightly increased in 2016 compared to both 2013 and 2010, whereas the average concentration and dataset distribution had slightly decreased. The two bottom plots of **Figure 70** show that a clear majority of the sites (93 %) and outfalls (91 %) are below the average for vanadium load and annual concentration, respectively.

Figure 70. 2010, 2013 and 2016 survey results for vanadium concentrations (two upper plots) and mercury total load and annual average concentration s-curves for 2016 (two bottom plots).



4. CONCLUSIONS

This report provides a summary of data gathered by Concawe in a survey of refinery effluent quality and water use, which was completed for the 2016 reporting year. A total of 72 responses, of 98 potential respondents (73% response rate), were collected from refineries that represent a wide geographic scope and range of refinery types/complexities. The 2016 survey design had improved Quality Assurance and Quality Control (QA/QC) and data integrity compared to previous surveys.

4.1. WATER INTAKES, USES, DISCHARGES AND CONSUMPTION

All 72 refineries were included in the 2016 record of water intake, showing a total of 2.9 billion m^3 of water being withdrawn in 2016 (vs 3.5 billion m^3 for 78 refineries included in the 2013 survey analysis). Out of the total water withdrawn, 80% represented by once-through cooling water, which was primarily salt/brackish surface water (97%). The water withdrawn excluding once-through cooling water and pass-through waters (non-harvested rainwater) was 475 million m^3, out of which 352 million m^3 was fresh water (average 4.8 million m^3 per refinery). Out of the captured total rainwater volume (35 million m^3), most went directly to discharge and only 3.1 % was harvested for a subsequent use.

By way of comparison, the 2013 survey (78 refineries) and 2010 survey (98 refineries) indicated a total freshwater intake of 371 million m^3 and 419 million m^3, respectively, for purposes other than once-through cooling. However, comparison with 2010 and 2013 data could reflect the different population of refineries reported under the surveys, or differences in the way that the 2016 survey definition (volumes defined as the sum of intakes vs. volumes defined as the sum water uses in 2013 and 2010). Presenting the numbers relative to throughput decreases this bias, and it shows that 2010 and 2016 are comparable (690-693 m^3/kilotonne), whereas there was a higher freshwater intake reported in 2013 (742 m^3/kilotonne).

Of the total intake used for site purposes, most was used for recirculating cooling purpose (44%), followed by use in demineralised water production and/or steam/boiler (25%), and use in flue gas scrubbers (7 %). Water losses by use type was reported to be dominated by losses in recirculating cooling use (76 %), followed by steam/boiler use (10%) and demineralised water production (7%).

The 2016 discharge quantity data recorded 2,693 million m^3 of total aqueous effluents, and 5.3 m^3/tonne relative to total throughput. Considering only treated effluents the corresponding numbers were 330 million m^3 and 0.65 m^3/tonne, respectively. 2016 data showed comparable levels with 2013 data when it comes to total aqueous effluent volumes, while these comparisons with 2010, 2008 and 2005 data was difficult given the way 2005-2010 data was reported. Excluding once-through cooling showed a reduction in 2016 compared to 2013, and even further so compared to 2005. The relative total effluents volume were shown to have increased whereas the relative treated effluents decreased when comparing 2016 and 2013 (5.3 m^3/tonne vs. 4.7 m m^3/tonne for relative total effluents, and 0.65 m^3/tonne vs. 0.90 m^3/tonne for relative treated effluents, respectively). In contrast to total aqueous effluent volumes, treated effluent volume data for 2016 could be compared with 2005-2010 data and this showed a steady decrease.

With regard to process effluents, over 90% of the reporting refineries in 2016 applied three-stage biological waste water treatment, or transferred their process water effluent to an external facility applying three-stage biological waste water treatment. Assuming that the refineries which reported using three-stage biological waste water treatment on their process water in 2010 and 2013 continued to do so in 2016, the total percentage of refineries utilising three-stage biological waste water treatment on their process water is over 97%. This clearly illustrates that the vast majority of the reporting refineries utilise the provisions of the Best Available Techniques (BAT) Reference document (BREF) for the Refining of Mineral Oil and Gas (REF BREF)[16] and its BAT Conclusions (2014/738/EU[17]) for treatment of effluents. When biological treatment was done, the activated sludge process was reported to be the most used (76% of treated volume), followed by trickling filter (14% treated volume).

Using the IPIECA definition for freshwater consumption (indicator E6; IPIECA, API and IOGP, 2015), refineries consumed 246 million m^3 of fresh water in 2016 with an average of 3.4 million m^3 per year. When comparing the freshwater consumption with the freshwater intake (excluding once-through cooling) it was shown that country groups having a high freshwater consumption within the facility also had a high freshwater intake. The relative freshwater consumption was rather consistent across refineries with an average across individual refineries of 525 m^3 per kilotonne of throughput (or 399 m^3 per kilotonne when excluding potential outliers). Furthermore, it was indicated that relative freshwater consumption (within the facility) varied up to five-fold by country group and generally increased with increasing refinery complexity, respectively. Although a general increase of relative freshwater consumption with increased complexity was observed, it is not linear which suggested that more parameters than refinery complexity should to be taken into account when assessing relative freshwater consumption.

The freshwater consumption in 2016 was lower compared to 2013 (271 million m^3) and 2010 (282 million m^3) in 2010. The average relative freshwater consumption was lower in 2016 at 482 m^3/kilotonne compared to 2013 (598 m^3/kilotonne), but slightly higher compared to 2010 (467 m^3/kilotonne). In order to further remove the bias of different populations of refineries reporting under the different survey years, the freshwater consumption were compared utilising only sites reporting in all three surveys. The analysis (48 sites) showed that the total freshwater consumption was similar in 2016 and 2010 (168-177 million m^3), whereas it was higher in 2013 (213 million m^3). Total freshwater consumption showed the same pattern. The reason for the difference in 2013 was not evident, although it may be due to the way of collecting the data on intakes and uses in the different surveys. In previous surveys, the presence of non-harvest rainwater at a refinery often caused issues related to the calculation of total freshwater consumption since many refineries would include the volume of rainfall in their reported mixed effluent volumes, but not account for that rainfall on their intake volumes. As a result, it was difficult to remove the unharvested rainfall portion when computing the freshwater consumption.

4.2. WATER COSTS

From the high-level information collected on costs associated with refinery water use, it can be observed that the relative intake costs exceeded relative discharge costs independent of the country croup. Compared to 2013 not all regions exhibit the same trend, whereas in 2016 it was true for all. Also, relative treatment costs exceeded relative discharge costs independent of the country croup, whereas different country groups showed different patterns in comparing relative treatment costs and relative intake costs. E.g. in the Baltic region, Central Europe, and UK and Ireland the relative intake cost was >3 times higher than the treatment costs, whereas in Iberia, Germany, and Mediterranean region the treatment costs were clearly higher than the intakes.

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[16] Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas; European Commission Joint Research Centre, 2015.
https://eippcb.jrc.ec.europa.eu/reference/BREF/REF_BREF_2015.pdf

[17] 2014/738/EU: Commission Implementing Decision of 9 October 2014 establishing best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions, for the refining of mineral oil and gas.

4.3. EFFLUENT QUALITY

With regard to effluent quality, taking 2010-2016 survey data into account, reductions in relative load was observed for 12 of the analysed quality elements, whereas three were kept at constant levels and two have increased, as follows:

- Decreased relative loads (12):
    - Total Petroleum Hydrocarbons (TPH), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), ammonia, Total Suspended Solids (TSS), BTEX (Benzene, Toluene, Ethylbenzene and Xylene), total Polycyclic Aromatic Hydrocarbons (tPAHs), cadmium, lead and nickel;
- Constant (3):
    - Total nitrogen, phenols and total phosphorus;
- Increased relative loads:
    - Mercury and vanadium.

A clear majority of the sites (≥ 70 %) and outfalls (≥ 72 %) are below the average of total load and average annual concentration with regard to TPH, BOD, COD, phenols, BTEX, tPAHs, cadmium, lead, mercury, nickel and vanadium. For TSS, a clear majority of the sites (74 %) are below the average total load, and a majority of the outfalls (63 %) are below the average for average annual concentration. For total phosphorus a majority of the sites (60 %) are below the average total load, and a clear majority of the outfalls (73 %) are below the average for average annual concentration. For TOC and total nitrogen there is a fairly even distribution of sites and outfalls being above and below the average values for total loads and annual average concentration, respectively.

The results of 2016 are consistent with the long-term trend towards reduced discharge loads of oil (reported as Oil in Water (OiW) or TPH). Moreover, the total and relative TPH load are lower compared to the 2013 and 2010 survey years; being at 262 tonnes and 0.51 g/tonne throughput, respectively, for 2016. The decrease was confirmed by looking at the median relative TPH load for only the 46 refineries that reported under all surveys form 2010 to 2016.

BOD, COD, and TOC data from 2000-2016 indicated an overall decrease in relative discharge loads. Comparing the most recent datasets (2010-2016) showed that median BOD and COD loads and dataset distributions were similar, whereas the median TOC load and dataset distribution have been decreasing from 2010 to 2013, and 2013 to 2016, respectively.

Relative discharge loads of ammonia have clearly decreased from 1993 to 2016, with a major reduction happening from 2005 to 2010. For total nitrogen an overall reduction is less marked, however refinery intake waters will often contain significant total nitrogen in the form of nitrate. Comparing the most recent datasets showed that the total nitrogen median loads and the dataset distribution are similar. However, when only the repeat sites are considered (n = 31 sites), both median loads and the dataset distribution have decreased from 2013 to 2016.

For phenols, a large reduction in relative load is apparent from 1993 to 2016, with 2016 being similar to 2010 and 2013. Comparing the most recent datasets showed that the median loads and the dataset distribution have slightly increased in 2016 compared to 2013.

For TSS, a large reduction was apparent from 2010 to 2013, and again from 2013 to 2016. The median loads are similar for 2013 and 2016, but lower compared to 2010. The dataset distribution has decreased from 2010 to 2013, and from 2013 to 2016, respectively.

For total phosphorus, the relative loads in 2010 to 2016 are similar. The median loads had slightly increased in 2016 compared to both 2013 and 2010. The dataset distribution had also increased from 2013 to 2016, but decreased from 2010 to 2016. The observations were different when only the repeat sites are considered (n = 34 sites), with the median loads and dataset distribution being constant.

For BTEX, the relative loads have slightly decreased from 2010 to 2013, and from 2013 to 2016, respectively. The median loads had slightly decreased in 2016 compared to 2013 only, whereas the dataset distribution had decreased in 2016 compared to both 2013 and 2010.

For tPAHs, relative loads have been reduced from 2010 to 2013, but appear relatively stable from 2013 to 2016. The median loads dataset distribution had slightly decreased in 2016 compared to 2013, whereas it was similar in 2016 compared to 2010

Regarding heavy metals, water quality data for the ones listed in the REF BREF BAT Conclusions were analysed. For cadmium, there was a large reduction of the relative discharge load throughout all the survey years 2010-2016. For lead and nickel, a large reduction of total discharge load from 2013 to 2016. For mercury and vanadium, on the other hand, an increase in relative loads was observed. Median loads for all heavy metals are similar in the 2010-2016 datasets, whereas the dataset distribution has decreased for cadmium, lead, nickel and mercury in 2016 compared to 2013 but increased for vanadium.

5. GLOSSARY

BAT	Best Available Techniques
BOD	Biochemical Oxygen Demand
BREF	BAT Reference Document
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CAPEX	Capital Expenditure
CDP	Carbon Disclosure Project
COD	Chemical Oxygen Demand
E-PRTR	The European Pollutant Release and Transfer Register
EU	European Union
EU-28	Abbreviation of European Union (EU) which consists a group of 28 countries
GRI	Global Reporting Initiative
IPIECA	The Global Oil and Gas Industry Association for Advancing Environmental and Social Performance
LOQ	Limit of Quantification
OiW	Oil in Water
PAH	Polycyclic Aromatic Hydrocarbon
REF BREF	BREF for the Refining of Mineral Oil and Gas
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorous
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
QA/QC	Quality Assurance and Quality Control
WSWMG	(Concawe) Water, Soil & Waste Management Group
WWTP	Waste Water Treatment Plant

6. ACKNOWLEDGEMENTS

The project team would like to acknowledge the support received from refineries in assembling the effluent quality and water use data, and in particular the refinery focal points.

We would also like to acknowledge the contribution of the member company experts for their detailed review and critique of the report.

Finally, we would like to acknowledge the contribution of the former WSWMG Science Executive, Mike Spence, for the work involved in developing and launching the 2016 Concawe water use and effluent quality survey.

7. REFERENCES

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2. Concawe (2018), 2013 survey of effluent quality and water use at European refineries. Report No. 12/18. Brussels: Concawe

3. Global oil and gas industry association for environmental and social issues (IPIECA), American Petroleum Institute (API), and International Association of Oil & Gas Producers (IOGP) (2015), Oil and gas industry guidance on voluntary sustainability reporting, 3rd Edition, London: International Association of Oil & Gas Producers

APPENDIX 1 GEOGRAPHIC EXTENT OF COUNTRY GROUPINGS AND SUMMARY OF RESPONSES PER COUNTRY GROUP AND REFINERY COMPLEXITY

Figure A1-1. Geographic Extent of Country Groupings

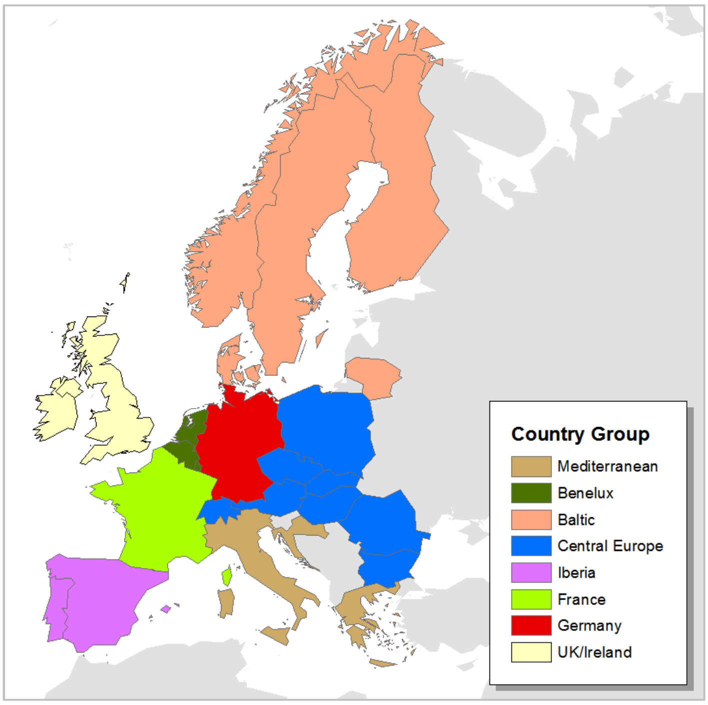

Table A1-1. Summary of responses collected by country group in 2013 and 2016

Country Group Name (countries included in country group)	Number of Responses in 2013	Total Throughput 2013 (kilotonne/year)	Number of Responses in 2016	Total Throughput 2016 (kilotonne/year)
Baltic (Denmark, Finland, Lithuania, Norway and Sweden)	9	49,612	10	56,884
Benelux (Belgium and Netherlands)	8	74,410	9	85,565
Central Europe (Austria, Czech Republic, Hungary, Poland, Slovakia, Switzerland and Romania)	13	61,291	12	55,459
France	8	50,541	8	68,485
Germany	12	81,665	9	77,581
Iberia (Portugal and Spain)	11	84,089	9	79,208
Mediterranean (Croatia, Greece and Italy)	12	55,770	11	58,193
UK and Ireland	5	42,473	4	29,076
TOTAL	**78**	**499,851**	**72**	**510,450**

Table A1-2. Summary of collected responses by site complexity groupings in 2013 and 2016. Complexity groups were derived for each site using their Nelson Complexity index from 2013.

Complexity Group[1]	Number of Responses in 2013	Total Throughput 2013 (kilotonne/year)	Number of Responses in 2016	Total Throughput 2016 (kilotonne/year)
Class 1	8	20,284	7	19,721
Class 2	9	40,951	11	74,533
Class 3	23	181,500	23	194,819
Class 4	18	114,693	12	81,749
Class 5	18	136,475	13	121,895
Not Available	2	5,947	6	17,733
TOTAL	**78**	**499,851**	**72**	**510,450**

[1] Complexity groups were derived for each site using their Nelson Complexity index from 2013 (Oil & Gas Journal, December 2, 2013). Complexity groups are categorized using these complexity indexes for analyses: Class 1 <4; Class 2 4-6; Class 3 6-8; Class 4 8-10; Class 5 >10

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ISBN 978-2-87567-121-9