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RIVM Report 2017-0116
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Colophon

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Synopsis

Wetted surface area of recreational craft

The wetted surface area of recreational craft is often treated with special paint that prevents growth of algae and other organisms. The active substances in this paint (antifouling) are also emitted into the water. The extent of this emission is among others determined by the treated surface area.

The RIVM has developed a method to calculate the wetted surface area of recreational craft based on boat length. This is essential to assess the environmental effects associated with these emissions. The final result of this study is a weighted average value for the wetted surface area of recreational craft in Dutch marinas, including separate values for salt water, transitional waters, and fresh surface water.

Paints sold with this purpose are known as biocides. The safety of biocides for both humans and the environment is assessed during the authorisation phase of biocidal products. The active substance in antifouling paint may also be toxic to organisms other than those on the ship's hull.

Keywords: recreational boats, pleasure craft, antifouling, wetted surface area, underwater area, hull, form coefficient, design ratios, biocide

Publiekssamenvatting

Het onderwateroppervlak van pleziervaartuigen

Het onderwateroppervlak van pleziervaartuigen wordt vaak met speciale verf behandeld die voorkomt dat er algen en andere organismen op gaan groeien. De werkzame stoffen in deze verf (antifouling) komen in het water terecht. Hoeveel dat is wordt mede bepaald door de grootte van het behandelde oppervlak.

Het RIVM heeft een methode ontwikkeld om het onderwateroppervlak van recreatievaartuigen te berekenen op basis van de bootlengte. Een goede schatting van de grootte van dit oppervlak is essentieel voor de milieubeoordeling. Het eindresultaat is een gewogen gemiddelde voor het onderwateroppervlak van recreatievaartuigen in Nederlandse jachthavens en een uitsplitsing daarvan naar zeewater, binnenwateren en overgangswateren.

Verven die verkocht worden met dit doel zijn biociden. Bij de toelating van biociden wordt de veiligheid van het product voor mens en milieu beoordeeld. De werkzame stof in de aangroeiwerende verf is mogelijk niet alleen giftig voor organismen die onder water aangroeien op de boot, maar ook voor de overige organismen in het water.

Kernwoorden: pleziervaartuigen, recreatievaart, antifouling, aangroeiwerende verf, nat oppervlak, onderwateroppervlak, romp, coëfficiënten, verhoudingen, biocide

Contents

Summary

The underwater area or wetted surface area of recreational craft is often treated with an antifouling coating. Paint applied on the ship's underwater hull contains (an) active substance(s) that help(s) to prevent fouling on ship hulls. In Europe, the Biocidal Product Regulation regulates market authorisation of these paints. As part of the market authorisation process, an environmental risk assessment is performed to ensure safe use of antifouling products. The assessment covers the life cycle stages of application of new paint, removal of old paint, and service life. The estimation of the environmental emission discerns between commercial ships and recreational ships, and between marine and fresh surface water environments. Harbour and marina environments are modelled in order to predict the concentrations of the active substance in e.g. surface water. One of the critical parameters determining the model outcome is the wetted surface area of the boats moored in marinas. This area equals the painted area of boats that is in direct contact with water and is directly proportional to the predicted environmental concentration.

This report focuses on the wetted surface area of recreational craft. The emission model uses a single, average value for this parameter by default. In 2012, a new default value was proposed in a Dutch study; this was nearly 2 times lower than the existing value. As both values were not well underpinned, it remained unclear which value was most realistic. This prompted us to derive a new scientifically valid and traceable default value.

We present a number of models and methods used to calculate the wetted surface area of motor boats, traditional sailing boats and sailing yachts. The final procedure returns the wetted surface area as a function of the overall length of the boat.

Data on the length class distribution of recreational craft in a sample of 40 marinas in the Netherlands were available. These data distinguished between motor boats, traditional sailing boats, and sailing yachts. Furthermore, the data were split into marine, transitional (brackish) and fresh (inland) water environments. With these data and the selected model, a weighted average value for the wetted surface area was calculated for each boat type and for the three environments. This was further aggregated to an overall value for recreational craft. The resulting value is proposed as a new default value for use in the environmental risk assessment, and is considered valid for the Netherlands.

In other European Member States, the length class distribution and relative share of various boat types in pleasure craft marinas is likely to be different. Using our methodology, the weighted average values for the wetted surface area for marinas in other Member States can be calculated.

1 Introduction

1.1 Authorisation of antifouling paints

Regulation (EU) No 528/2012 (EU, 2012), as amended, concerns the making available on the market and use of biocidal products. This legislation covers antifouling paints, meaning that a product authorisation is required before these types of paints can be placed on the EU market. The authorisation procedure includes an assessment of possible negative environmental effects. Emission scenarios have been developed for this purpose. In these scenarios, a (standard) environment is described that receives the active ingredient from a specific application of a biocidal product.

In the past, various emission scenarios for biocidal antifouling paints have been developed for different situations, environments and types of ships. A comprehensive overview is provided by Van de Plassche and Van der Aa (2004). The release of the active substance does not only occur when ships are in service, but also during construction, maintenance and repair, i.e. when actually coating, removing the old paint layer and recoating the hull of the ship with antifouling paint at shipyards, boatyards and marinas. Therefore, a number of scenarios have been developed not only for use during construction, maintenance and repair but also for ships moving in shipping lanes and open seas, and for ships at berth in commercial harbours and estuarine, coastal and freshwater marinas.

Deltares and the Vrije Universiteit Amsterdam developed the 'Marine antifoulant model to predict environmental concentrations' (MAMPEC) (Van Hattum et al., 2016). Using MAMPEC, environmental concentrations of active substances released from antifouling paints can be calculated for different default environments and situations. The model takes important factors into account including hydrodynamic exchange, expected emissions in relation to number and size of the boats, dimensions of the harbour and water, and substance characteristics affecting partitioning and degradation (or speciation in the case of metals) of active substance. Many of the emission scenarios developed take the MAMPEC model as a basis, providing default values for the MAMPEC model parameters (Van de Plassche and Van der Aa, 2004).

1.2 Wetted surface area as critical factor

Van der Meulen et al. (2012) performed a review of existing Dutch inland marinas and proposed representative settings for the environmental and emission definitions in MAMPEC to allow an exposure assessment for small freshwater marinas in the Netherlands. This was done in response to the finding, resulting from discussions with Dutch regulatory agencies for the approval of new antifouling paints, that the existing OECD-EU scenarios in MAMPEC were not representative of the exposure conditions in small inland freshwater marinas in the Netherlands.

One of the critical factors in the assessment is the underwater surface area (also indicated as wetted surface area WSA) of ships at berth. Van de Plassche and van der Aa (2004) provide an overview of reported WSA values for recreational boats at berth in freshwater marinas taken from different studies. Values for the average under water surface area vary from 5 m^2 to 30.7 m^2. These values result from surveys, expert estimates or different equations, rules of thumb, or on statistical analysis of hull forms used for calculating the WSA, in order to estimate the resistance of ships in the water in ship design. Most of these equations require the dimensions of the ship such as length, breadth (beam) and draught as input. More advance equations also require information on the hull form expressed by hull form coefficients. Detailed calculations can only be performed if information on average boat characteristics for the different types of boats (the length and corresponding width and depth) and the distribution of the number of boats within the length classes for each type of boat are available. This kind of information on the types of boats and dimensions is generally based on surveys, measurements or experience.

In the above-mentioned review, Van der Meulen et al. (2012) proposed a new value for the WSA of pleasure craft at berth in inland marinas. Together with the number of ships at berth and the leaching rate, this parameter determines the emission of the mass of active antifouling ingredient into the aquatic environment. The authors concluded that the typical yacht sizes for small inland marinas are considerably smaller than those defined in the OECD scenario (OECD, 2005), therefore they recalculate the WSA for this category. The proposed value was 17.8 m^2 for an average boat length of 8.9 m, which is considerably less than the value defined in the OECD scenario: 30.7 m^2 for an average boat length of 9.2 m. The fact that fairly similar boat lengths resulted in such a large difference in the WSA, raised the question of which value would be appropriate.

1.3 Aim of this report

From the above, it is clear that there is a need for a well-substantiated typical value for the WSA of ships for small inland freshwater marinas in the Netherlands. It is important to note that the size of recreational craft might differ from country to country, and may also depend on the type of water where the marina is situated. Variation may also be caused by differences in the share of different types of boats such as sailing yachts, motor yachts, and traditional craft. This leads to the need for a generic procedure to calculate the WSA of recreational boats for other countries as well as for estuarine and coastal marinas. The focus of this report is to provide data which will enable the calculation of the WSA for pleasure craft, and to provide a typical average value for recreational boats at freshwater marinas in the Netherlands.

2 Wetted surface area estimation

2.1 Introduction

A number of methods can be used to estimate the WSA of ships, including empirical formulas, measurement, computer aided design systems, or hull form design plans. Each of these methods (except for computer aided design systems) will be briefly explained in the following sections.

2.2 Empirical formulas

There are a number of empirical formulas for WSA calculation. These are mainly based on statistical relationships between various selected hull characteristics and the known WSA from ships' records or ship model experiments. The applicability domain of these formulas can be either very specific for a certain ship type, while others may be very general. Some equations are generally applicable with respect to the type of ship, though only applicable within certain constraints or ranges of hull dimension ratios or ranges of form coefficients. Many formulas are based on the displacement volume in combination with the length, draught[a] or beam of the ship. For estimating the wetted area, the length and the beam on the waterline should be used. The draught is the depth measured from the baseline to the load waterline, being the depth of the canoe hull excluding the skeg and keel.

The Holtrop-Mennen equation (Holtrop and Mennen, 1982) is one of the most recently developed formulas, and is applicable to a wide range of forms. This formula (Equation 1) is extensive with regards to data requirements. It requires the length, beam, draught as well as the block coefficient, midship coefficient, and water plane coefficient to calculate the WSA. A final term in this equation does not contribute in case of a hull without a bulbous bow. Since bulbous bows are rarely used on small recreational craft, this term is not included here.

Other formulas require less information and are often based on the displacement volume. Some formulas use specific coefficients that can be derived either from an equation or from a graph which, especially in the latter case, makes them more difficult to apply. In addition to the Holtrop-Mennen equation, some other well-known and popular formulas are provided below. An overview can be found in Molland et al. (2011).

Holtrop-Mennen (1982), Equation 1:

$$WSA = L \cdot (B + 2 \cdot T) \cdot \sqrt{C_\mathrm{M}} \cdot \left(0.453 + 0.4425 \cdot C_\mathrm{B} - 0.2862 \cdot C_\mathrm{M} - 0.003467 \cdot \frac{B}{T} + 0.3696 \cdot C_\mathrm{W}\right) \tag{1}$$

The Holtrop formula without the water plane area coefficient (Holtrop, 1977), Equation 2:

$$WSA = L \cdot (B + 2 \cdot T) \cdot \sqrt{C_\mathrm{M}} \cdot \left(0.530 + 0.632 \cdot C_\mathrm{B} - 0.360 \cdot (C_\mathrm{M} - 0.5) - 0.00135 \cdot \frac{L}{T}\right) \tag{2}$$

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[a] Usually understood to be the depth of water needed to float a ship, thus including appendages like the skeg and keel.

Taylor (1893), Equation 3

$$WSA = C_{\mathrm{S}} \cdot \sqrt{L \cdot \nabla} \tag{3}$$

C_{S} is the wetted surface coefficient and has to be read from a graph and depends on the B_{WL}/T-ratio and the midship area coefficient, see Annex I.

Froude, Equation 4:

$$WSA = \nabla^{2/3} \cdot \left(3.4 + \frac{L}{2 \cdot \nabla^{1/3}}\right) \tag{4}$$

Denny-Mumford (1), Equation 5:

$$WSA = L \cdot (1.7 \cdot T + B \cdot C_{\mathrm{B}}) \tag{5}$$

Denny-Mumford (2), Equation (6):
Replacing C_{B} by $\nabla/L \cdot B \cdot T$ the Denny-Mumford equation turns into

$$WSA = 1.7 \cdot L \cdot T + \frac{\nabla}{T} \tag{6}$$

Variations on the Denny-Mumford formula are listed below.

Muragin, Equation 7:

$$WSA = L \cdot (1.36 \cdot T + 1.13 \cdot B \cdot C_{\mathrm{B}}) \tag{7}$$

Kirk, Equation 8:

$$WSA = L \cdot (2 \cdot T + B \cdot C_{\mathrm{B}}) \tag{8}$$

Specifically for sailing yachts, the empirical relationship based on Delft series of hull forms can be used to estimate the wetted area of the canoe body (Molland et al., 2011 and Larsson and Eliasson, 2000), Equation 9:

$$WSA = \left(1.97 + 0.171 \cdot \frac{B_{\mathrm{WL}}}{T_{\mathrm{C}}}\right) \cdot \sqrt{\nabla_{\mathrm{C}} \cdot L_{\mathrm{WL}}} \cdot \left(\frac{0.65}{C_{\mathrm{M}}}\right)^{1/3} \tag{9}$$

In which:

WSA	wetted surface area (m^2).
$T = T_{\mathrm{C}}$	draught of the canoe body of the ship excluding fin, rudder or keel (m), also T_{C}.
$L = L_{\mathrm{WL}}$	length of the ship on the waterline (m).
$B = B_{\mathrm{WL}}$	beam of the ship on the waterline (m).
∇	displacement volume (m^3).
C_{M}	midship area coefficient of the underwater hull.
C_{B}	block coefficient of the underwater hull on the basis of length on the waterline.
C_{W}	water plane area coefficient based on length on the waterline.
C_{S}	wetted surface coefficient.

2.3 Measurements

To be able to fairly compare different sailing yacht types in any range of wind conditions and course types, hull shape characteristics such as length on the waterline while sailing, displacement volume, and WSA have to be known. For this purpose, a hull measurement is performed to create an offset (OFF) file describing the body plan of the hull together with appendages. This can be done, for instance, by using a hull measurement machine approved by the Offshore Racing Council (ORC, 2017). The recorded measurement data are included in certificates.

2.4 Hull design plans and reported data

The WSA and other hull characteristics can also be estimated from the lines plan of the hull for the three different views, i.e. the profile plan (side view), half breadth plan (shape of the hull from the top view) and the body plan (front to back view). A common and simple numerical method for estimating areas under a curve is Simpson's rule. By applying Simpson's rule, the WSA, the displacement volume, the water plane area, the hull section area and other parameters can be estimated as explained by Larsson and Eliasson (2000). In their report, lines plans are (mainly) applied to estimate the water plane area and the lateral area of the skeg (sternward extension at the centre line of the keel of boats) for traditional Dutch sailing boats.

Some boat designers report the WSA and other design parameters on their website or in brochures. This is usually only available for a few of their models, and the information provided is quite limited. Very unusually, Dudley Dix Yacht Design (2017) reports extensive data on their (sailing) boat designs on their website.

2.5 Discussion

Measured WSAs and areas derived from hull design plans are considered the most accurate. However, measured data are only available for sailing yachts taking part in sailing competitions. For sailing yachts, the measured WSAs from the ORC certificates and the WSAs reported by Dudley Dix Yacht Design (2017) are available to derive an average value.

Because the WSA is usually not measured for traditional craft and motor yachts, it has to be estimated using empirical formulae. This requires the dimensions, hull form coefficients and design ratios. This information is presented in Chapter 3. The data collected for sailing yachts is included in Annex II for completeness. Design plans are generally not readily available. In addition, it is a complex task to derive the WSA from hull plans, and it would take a large number of different types and sizes of boats to derive a representative figure. However, it is relatively easy to use hull plans to determine other characteristics such as hull form coefficients and typical ratios compared to the WSA. We only used hull plans in this study to complete essential missing data. For traditional boats, hull plans are, for instance, available from the archives of maritime museums. For sailing yachts and motor boats, lines plans are available at boat design studios or boat builders, but these are usually not publically available.

3 Ship hull shape parameters

3.1 Hull form coefficients

The form of the hull can be characterised by different coefficients. The most common coefficients needed to estimate the WSA from empirical relations are the block coefficient, midship area and water plane coefficient as listed in section 2.2.

The block coefficient C_B indicates how full-bodied the underwater volume of the ship is, and is calculated as the displacement volume divided by the circumscribed block:

$$C_{\mathrm{B}}=\frac{\nabla}{L\cdot B\cdot T}$$

The midship area coefficient C_M expresses how full-bodied the main arch (largest underwater section) of the ship is, and is calculated as the cross-sectional area at midship divided by the area of a rectangle of the same overall width and depth as the underwater section of the hull. The main arch is not necessarily located midship. The coefficient is calculated as:

$$C_{\mathrm{M}}=\frac{A_{\mathrm{M}}}{B\cdot T}$$

The prismatic coefficient C_P is the ratio of the displacement volume and the maximum section area multiplied by the waterline length:

$$C_{\mathrm{P}}=\frac{\nabla}{A_{\mathrm{M}}.L}$$

The prismatic coefficient can also be presented as the ratio of the block coefficient and the midship area coefficient:

$$C_{\mathrm{P}}=\frac{C_{\mathrm{B}}}{C_{\mathrm{M}}}$$

The water plane area coefficient (C_W) is the water plane area of a ship to a rectangle of the same length and width. The water plane coefficient expresses the fullness of the water plane:

$$C_{\mathrm{W}}=\frac{A_{\mathrm{W}}}{L\cdot B}$$

Finally, the lateral area coefficient is the actual area of the underwater lateral plane of the hull as a fraction of the rectangle of the same overall length and depth based on the waterline of the hull:

$$C_{\mathrm{LP}}=\frac{A_{\mathrm{LP}}}{L\cdot T}$$

In which:

A_{LP} area of underwater lateral plane (m^2).
A_M cross-sectional area at midship (m^2).
A_W water plane area (m^2).

3.2 Boat statistics

To calculate the WSA by applying empirical equations such as the Holtrop-Mennen equation, in addition to the hull form coefficients, the length on the waterline (L_{WL}), the beam on the waterline (B_{WL}) and the draught of the canoe body (T) should be known. As stated in the introduction, calculation of the average WSA for recreational craft can only be performed if, in addition to this information, statistics on (the average) boat dimensions are available, e.g., the distribution by type of boat such as motor boats and sailing boats (traditional craft and sailing yachts), and the distribution of the number of boats within the length classes.

From a survey conducted on recreational boats present in 40 Dutch inland marinas, the length, the average beam and draught is available for different length classes for six types of boats e.g., sailing yachts (open and cabin), motor yachts (open and cabin), traditional craft, and others (Waterrecreatie Advies, 2005). These data combined with the hull characteristics provide the basis for the calculation of the average WSA for recreational boats in the Netherlands.

Although not explicitly mentioned, it is assumed that the figures presented by Waterrecreatie Advies (2005) refer to the overall[b] length and overall beam[c] and the maximum draught. This is partly based on the fact that the beam and draught are based on information taken from yacht brokers' websites. These websites usually only provide overall dimensions. Furthermore, the data were generated by sending surveys to harbour masters who were asked to register the measurements of the boats at berth. There were no specific guidelines provided to measure the boats. Considering that it is much easier to estimate the length of a ship at berth compared to its beam and draught, it can be concluded that the average length of each length class is the most reliable measure. The reported beam and draught are considered as rough estimates; this is also indicated by Waterrecreatie Advies. Therefore, we decided to base the dimensions of each boat type on the reported overall length.

3.3 Design ratios

To be able to compare and characterise ships with different proportions a useful starting point in boat design is, besides the hull form coefficients, to use dimensionless numbers or ratios (Larsson and Eliasson, 2000, Miller and Kirkman, 1990, Henry and Miller, 1963). The following dimensionless numbers or ratios can be applied to derive the dimensions on the waterline and that of displacement volume of the hull, with the overall length of the hull as the only known parameter. A further explanation of the procedure is provided in the next section. Relevant parameters are:

B_{OA}	maximum breadth or beam or overall beam (m).
B_{WL}	beam on the waterline (m).
L_{OA}	overall hull length (m).
L_{WL}	hull length on the waterline (m).
∇	displacement volume (m^3)
T	draught of the canoe body of the ship, also T_C (m).

The ratio between the overall length (of the hull) and the length on the waterline is known as the overhang ratio, i.e. L_{OA}/L_{WL}.

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[b] Overall length means the length measured from bow to stern at deck level of the boat as opposed to waterline length, which means length measured from bow to stern at the water level. Length at the waterline for a boat is smaller than overall length.

[c] The beam is the maximum width of a ship.

The ’beaminess’ of a boat can be quantified by the length to beam ratio. This ratio increases with the length. Often the ratio of length overall and the maximum beam (L_{OA}/B_{OA}) is used. If the waterline length and the beam (L_{WL}/B_{WL}) are used, this produces different values. In this study, we used the ratio based on the hull waterline.

To be able to calculate the draught, either the load waterline length to canoe body draught ratio (L_{WL}/T) or the waterline beam to draught ratio (B_{WL}/T) can be used. As for the length-beam ratio, typical values were taken from literature or derived from actual data on ship dimensions.

Some of the equations use the displacement volume (∇) to calculate the WSA. Because the displacement volume is not provided in the statistics from the Waterrecreatie Advies report (2005), the displacement volume also needs to be estimated from the available data on typical ratios for the different types of boats. For this purpose, the length-displacement volume ratio is used which is a measure of the slenderness of the hull, expressed as:

$$LDR = \frac{L}{\nabla^{1/3}}$$

This number can be plotted against the length to beam ratio (L_{WL}/B_{WL}). The length to beam ratio is derived from its relation with the waterline length.

The relationships between design ratios and their typical values are either taken from the literature or are derived from real data on ship dimensions. Typical values of the above-mentioned ratios will be provided for each shipping type: motor yachts, traditional sailing ships, and sailing yachts.

3.4 Stepwise procedure for estimating the wetted surface area

The dimensions of the ship hull on the waterline are needed as input parameters for WSA calculations. From the boat statistics provided by Waterrecreatie Advies (2005), only the overall length of the hull is known, as noted in section 3.2. Therefore, we needed a procedure to estimate the dimensions on the waterline from the overall length of the ship. The first step was to calculate the length on the waterline by applying the overhang ratio; the ratio between the overall length and the length on the waterline (L_{OA}/L_{WL}). The next step was to determine the beam on the waterline from the waterline length to beam ratio (L_{wl}/B_{WL}). This ratio can be presented as a function of the waterline length. Finally, the draught of the hull had to be calculated; here we applied the commonly used beam to draught ratio. The displacement volume can be derived from the waterline length to displacement volume ratio, which increases with the waterline length to beam ratio. The linear relationship between these two ratios is used to calculate the displacement volume using the waterline length to beam ratio as input. Figure 1 shows a graphical representation of the procedure followed.

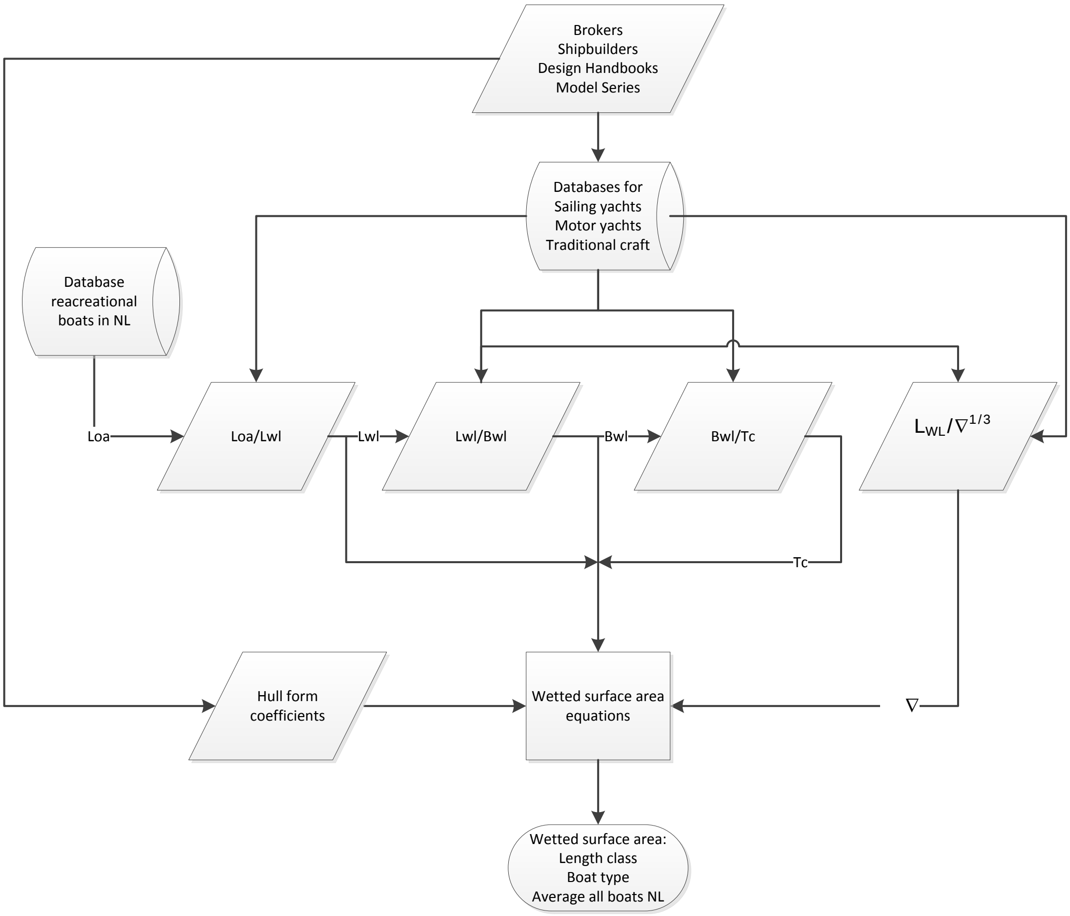

Figure 1. Overall data flow and overview of the procedure to determine the WSA from reported overall length of the hull.

The design ratios are based on actual hull dimension data from ships within each ship category and reported typical values from literature. The data came from public reports and handbooks or, if needed, additional information was collected from databases such as the ORC database, brokers' websites, and manufacturers' websites. The collected data on hull dimensions for the different types of boats is presented in Annex III and Annex IV. Finally, with the estimated hull dimensions on the waterline and the displacement volume of the canoe body, the WSA can be derived using the various equations listed (section 2.2) including the information collected on hull form coefficients.

3.5 Ship hull parameters for motor yachts

3.5.1 Hull form coefficients

Typical values for the block coefficient C_B are, amongst others, reported by Colombo (1908), Dewan (2015), Gaillarde et al. (2004) and Van Oossanen and Van Oossanen (2006). These are summarised in Table 1. Gaillarde et al. report a wide range of C_B values for motor yachts and state that block coefficients around 0.45 to 0.50 appear to be common. The values presented by Dewan are for frigates and are considered representative for large motor yachts. These values are in line with those reported by Gaillarde et al. The data presented by Gaillarde et al., shows no dependency between the block coefficient and the length.

Van Oossanen and Van Oossanen (2006) report values for the midship coefficient C_M for four different model hull types, see Table 1. Values for the midship coefficients reported by Dewan are in line with this, but somewhat on the higher side. The values for C_M from Colombo tend to be on the lower side of the range, and are probably valid for a more specific type of motor boat.

Savitsky and Brown (1976) report extensive data covering the geometric characteristics of 118 models, based on published results of resistance tests carried out for seven methodical series of transom-stern craft (planing hulls). Except for one series (Series 62), which was a hard chine hull form, all other series were round bilge hulls. The minimum value and maximum value for the block coefficient are 0.35 and 0.64 respectively, with an average value of 0.45. The values for the midship coefficient are calculated from the reported block coefficient and the prismatic coefficient; values range from 0.55-0.87 with an average value of 0.67. For the water plane coefficient (C_W), values range from 0.73 up to 0.83 with an average of 0.77. The water plane coefficient for a hard chine hull fishing boat and a cruising tug (single chine hull) designed by Dix Yacht Design (2017) are 0.77 and 0.76 respectively. In addition to this information, the water plane area coefficient reported by Van Oossanen and Van Oossanen (2006) for the four model ships vary very little and are somewhat higher, see Table 1.

Table 1. Hull coefficients for motor yachts as reported in the literature C_B = block coefficient, C_M = midship area coefficient, C_W = water plane area coefficient.

Reference	**Hull coefficients**		
	C_B	C_M	C_W
Dewan (2015)	0.45-0.48	0.75-0.78	
Gaillarde et al. (2004)	0.22-0.59		
Colombo (1908)	0.35-0.55	0.60-0.75	
Van Oossanen and Van Oossanen (2006)	0.35-0.55	0.57;0.65; 0.83;0.74	0.87;0.84; 0.84;0.80
Savitsky and Brown (1976)	0.35-0.64	0.55-0.87	0.73-0.83
Dix Yacht Design (2017)	0.32;0.38	0.48;0.59	0.77;0.76

3.5.2 *Hull design ratios*

L_{OA} / L_{WL}

The overhang ratio is used to derive the length on the waterline. The ratio between the overall length and the length on the waterline (L_{OA}/L_{WL}) for the four model ships presented in Van Oossanen and Van Oossanen (2006) ranges from 1.10 to 1.16. In addition, design data for 57 motor boats and yachts were collected in the current study. The overhang ratio ranged from 1.02 to 1.3, with an average value of 1.12. The data for the 57 boats are presented in Annex III.

L_{WL} / B_{WL}

The waterline length to beam ratio (L_{WL}/B_{WL}) as a function of the waterline length is presented in Figure 3 in Van Oossanen and Van Oossanen (2006). These data were used to derive a logarithmic trend line, see Equation 10 and Figure 2.

$$\frac{L_{\mathrm{WL}}}{B_{\mathrm{WL}}} = 0.8827 \times \ln(L_{\mathrm{WL}}) + 0.7941 \tag{10}$$

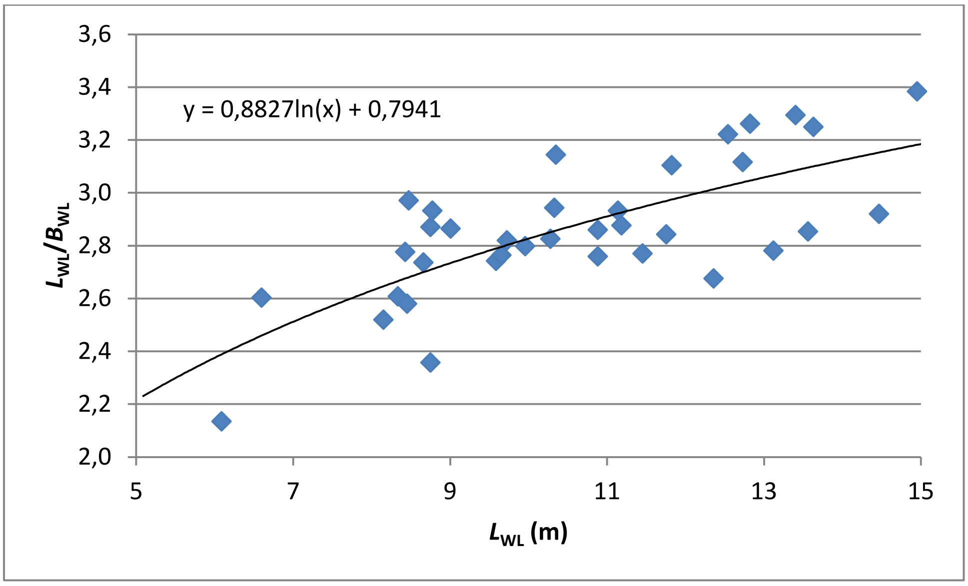

Figure 2. Waterline length to beam ratio as a function of the length on the waterline. Data from Van Oossanen and Van Oossanen (2006).

B_{WL} / T

Based on the design data of 27 motor boats in our database (Annex III), the values for the waterline beam to draught ratio (B_{WL}/T) vary from 1.5 to 8.4. These data include three extreme values (1.54; 7.51; 8.4) which if left out, would lead to an average value of the waterline beam to draught ratio of 3.7. When including the extremes, the average value becomes 3.9. Based on these data, there seems to be no clear trend in relation to the length. The data presented by Gaillarde et al. (2004) show values in the range of 1.8-6.5 with the length ranging from 20-120 m. The authors state that for super or mega-yachts, the beam to draught ratio is around three. Van Oossanen and Van Oossanen (2006) report values in the range of 4.0-6.0 for the designs included in their database (n=19). From the collected information on the different model series, the beam to draught ratio also appears to vary substantially, ranging from 1.7 to 9.8: most commonly, values lie between 3 and 4 (Savitsky and Brown, 1976). A value of 4.0 was chosen. This choice was also based on the range for mainly Dutch made boats provided by Van Oossanen and Van Oossanen (2006), that indicates a slightly higher value and narrower range of the B_{WL}/T –ratio compared to the data in our database.

$L_{WL} / \nabla^{1/3}$

The length to displacement volume ratio increases with the waterline length to beam ratio as shown in Figure 4 in Van Oossanen and Van Oossanen (2006). The data in the figure were used to derive the relationship presented in Equation (11 and Figure 3. The average value of the length to displacement volume ratio is 4.5, which according to Van Oossanen and Van Oossanen can be considered low.

$$\frac{L_{\mathrm{WL}}}{\nabla^{\frac{1}{3}}} = 2.12 \cdot \ln\frac{L_{\mathrm{WL}}}{B_{\mathrm{WL}}} + 2.24 \qquad (11)$$

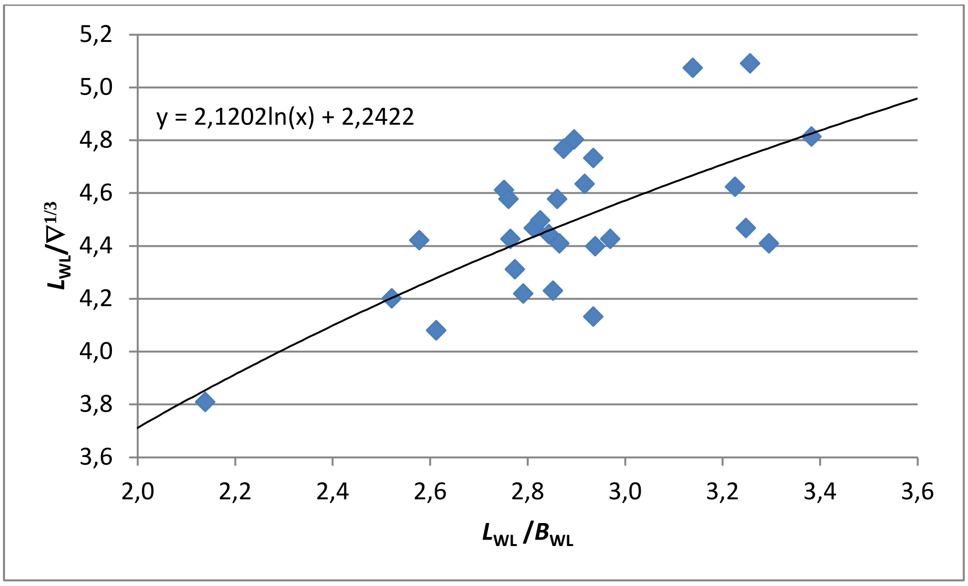

Figure 3. Length-displacement ratio as a function of length-beam ratio.

3.5.3 *Discussion, values selected*

The selected values for the design ratios and hull form coefficients are presented in Table 2. In addition to these data, Equation 10 and 11 are also needed to calculate the WSA. The reported values for the block coefficients C_B are reasonably comparable, and there seems to be little or no variation with length or the length to beam ratio. A value of 0.45 seems to be representative value based on the mid-range value of the range (0.35-0.55) presented by Van Oossanen and Van Oossanen (2006). Midship coefficients C_M range from 0.55-0.87, with a mid-range value of 0.71 based on data for a large number of model ship hulls presented in Savitsky and Brown (1976). For the water plane coefficient C_W a value of 0.77 seems typical based on the values provided by Savitsky and Brown. A somewhat higher value of 0.80 can be used based on more recent data on motor yacht characteristics provided by Van Oossanen and Van Oossanen (2006), and on the higher range values provided by Savitsky and Brown (1976). For the overhang ratio, we used an average value of 1.12. The beam on the waterline was estimated using Equation 10. The draught was calculated from the fixed beam to draught ratio using an average value of 4.0 for this ratio. The displacement volume was determined by applying Equation 11 A typical value for the length to displacement volume ratio is 4.5. Finally, the value for the wetted surface coefficient (C_S) was set at 2.8. Based on the typical values for C_M and B/T-ratio, the value for C_S can be read from Annex I.

Table 2. Summary of selected values for the design ratios and form coefficients for motor yachts.

Variable	**Value**
C_B	0.45
C_M	0.71
C_W	0.80
L_{OA}/L_{WL}	1.12
B_{WL}/T	4.0
$L_{WL}/\nabla^{1/3}$	4.5
C_S	2.8

3.5.4 *Lateral area of the rudder and skeg*

The WSA calculated from the selected relationships and dimensionless numbers refers to the canoe body only, thus excluding appendages such as the rudder and skeg. For motor boats, the rudder area can be determined as a fraction of the lateral area of the hull. Molland and Turnock (2007) indicate that this should be about 3-4% for semi-displacement and planing craft, based on the actual lateral area of the immersed hull. Van Oossanen and Van Oossanen (2006) indicate that the rudder area should be about 5% of the lateral hull area, probably referring to the actual immersed lateral area of the hull instead of $L_{WL} \cdot T$. In addition, Lewandowski (1993) refers to a recommended rudder area of 4% of the projected side area of the hull, which corresponds roughly with 3% of the more easily computed reference lateral area $L_{WL} \cdot T$[d], corresponding to a C_{LP} of 0.75. The average lateral plane area coefficient of the hull for six modern tug boats (Argyriadis, 1957) provides the same value of 0.75.

Another more convenient way to derive the rudder area is based on the relationship with the waterline length. Based on Figure 5.109 in Molland and Turnock (2007), this relationship can be expressed by Equation 12.

$$\text{Rudder area} = 7.00 \times 10^{-5} \cdot (L_{\mathrm{WL}})^3 - 2.20 \times 10^{-3} \cdot (L_{\mathrm{WL}})^2 + 5.23 \times 10^{-2} \cdot L_{\mathrm{WL}} - 0.1673 \qquad (12)$$

Alternatively, the rudder area can be related to the midship area A_M, which is calculated as $A_M = C_M \cdot B_{WL} \cdot T_C$. The rudder area should be at least 12% of A_M (Schneekluth and Bertram, 1998). The rudder area can thus be determined from the midship area, coefficient C_M:

Rudder area = $0.12 \cdot C_M \cdot B_{WL} \cdot T_C$.

The rudder areas derived by this method lie somewhere between the results obtained by the methods suggested by Lewandowski (1993) and Molland and Turnock (2007) and are therefore judged as a reasonable approximation.

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[d] Lewandowski refers to the transom draught to compute the reference lateral area. It is assumed that the transom draught equals the draught of the canoe body of the hull, which is probably only true for planing boats.

Besides the lateral area of the rudder, the lateral area of centre line skeg also contributes to the total wetted surface area. The lateral area of the skeg has been determined from the lines plans of the four model motor yacht hulls provided by Van Oossanen and Van Oossanen (2006). The results are presented in Table 3.

Table 3. Lateral area of centre line skeg of the model motor yachts presented by Van Oossanen and Van Oossanen (2006).

Hull type	**Lateral area skeg (m^2)**	**Draught, T**	**Percentage of reference lateral hull area (%)**	**Ratio to midship area**	**Percentage of water plane area (%)**
Hard chine	1.8	0.79	23	1.29	5.7
Hard chine, fast planing	0.5	0.75	7	0.32	1.6
Multi chine	2.0	0.51	39	1.27	6.3
Round chine	1.9	0.80	24	0.99	7

Following the approach suggested by Lewandowski, the lateral area of the skeg is expressed as a fraction of reference lateral area ($L_{WL} \cdot T$). All four designs have a length on the waterline of 10 meters; the values for the draught are presented in Table 3. For the fast planing hard chine hull, the value for the lateral area of the skeg is much smaller than for the other hull types. A value of about 20-30 percent of reference lateral area seems reasonable for the lateral area of the skeg. Similar to suggestions for the rudder area made by Schneekluth and Bertram (1998), the skeg area is related to the midship area A_M; results are presented in Table 3. A ratio of 1 (skeg area = midship area) seems to be a minimum for hull types other than hard chine fast planing hulls. There seems to be less variation when comparing the lateral skeg area to the water plane area. The calculated lateral area of the skeg based on the midship area and the reference lateral area of the hull provide similar results. The midship area is used as a representative value for the lateral skeg area.

3.6 Traditional ships (flat and round bottomed)

3.6.1 Hull form coefficients

The block coefficients for traditional flat bottom ships are calculated from the data from the certificates used for rating different types of traditional boats in sailboat racing. The data are available from the Dutch association '*Rond- en Platbodem Klassenorganisatie*' (2016). Values for the block coefficient (based on the waterline) vary from 0.60 to 0.70 with an average value of 0.64 based on the data of 17 ships from 12 different types (Annex IV). There were no certificates available for very bulky ships like the *tjalk*, *praam* and *poon*. The block coefficient for a *tjalk* for instance is 0.80 (Jorissen, 1986). Block coefficients reported by Moeyes and Kooijman (1975) are on the lower side of the range of values based on the certificate data. A notebook of the Universita degli studi di Trieste by Prof. Zotti (Zotti, 2000) mentions a typical value of 0.66 for the block coefficient C_B of traditional ships. The collected data is summarised in

Table 4.

Typical midship sections and corresponding midship coefficients are provided by Ventura (2017), see Figure 4. Based on the hull plans provided by Moeyes and Kooijman (1975) some of which are shown in Figure 5, many traditional ships have a hull form corresponding with midship coefficient values in the range of 0.80-0.98 when comparing them to the forms presented in Figure 4.

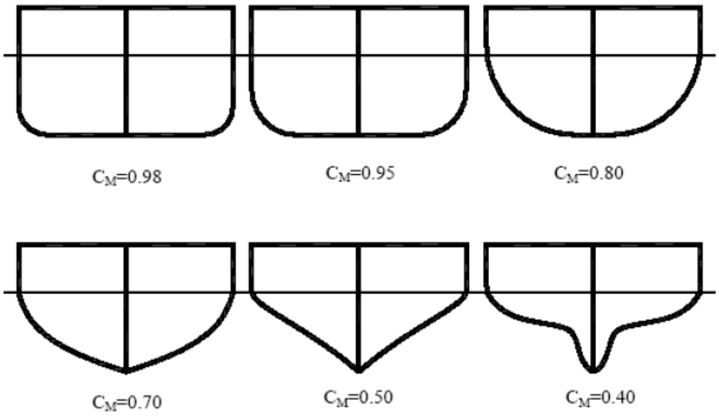

Figure 4. Typical midship sections and corresponding C_M value (Ventura, 2017).

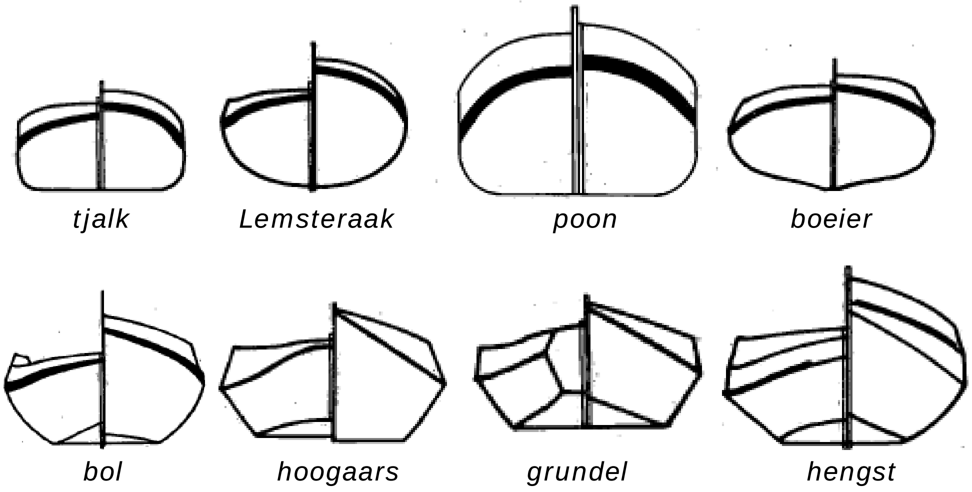

Figure 5. Hull plans for traditional craft from Moeyes and Kooijman (1975).

Table 4. Hull form coefficients for traditional craft.

Reference	**Hull coefficients** C_B	C_M
Zotti (2000)	0.66	
Rond- en Platbodem Klassenorganisatie (2016)	0.60-0.70	
Moeyes and Kooijman (1975)	0.48-0.60	0.83*
Cotteleer (2016)		> 0.90
Ventura (2017) & Moeyes and Kooijman (1975)		0.80-0.98
Jorissen (1986)	0.80	

*Calculated from the average block coefficient and prismatic coefficient (0.58-0.72) for flat bottom ships in Table I of Moeyes and Kooijman (1975).

Water plane area coefficients of some Dutch traditional craft are presented in Table 5. The water plane coefficient for the *tjalk* is from Jorissen (1986). The other values were derived from lines plans and by applying Simpson's rule for estimating the surface area under a curve. The average of these values (0.83) is taken as a typical value for Dutch traditional craft.

Table 5. Water plane area coefficients for traditional craft from hull lines drawing.

Ship type	**Hull coefficient, C_W**
tjalk	0.94
visaak	0.83
boeier	0.81/0.81/0-87
schokker	0.78
Lemsteraak	0.76/0.75

3.6.2 *Hull design ratios*

L_{OA} / L_{WL}

The overhang ratio for traditional craft is based on the certificates of the 17 traditional craft considered (Annex IV). The average value is 1.3. Overhang ratios vary from 1.12 up to a value of 1.52.

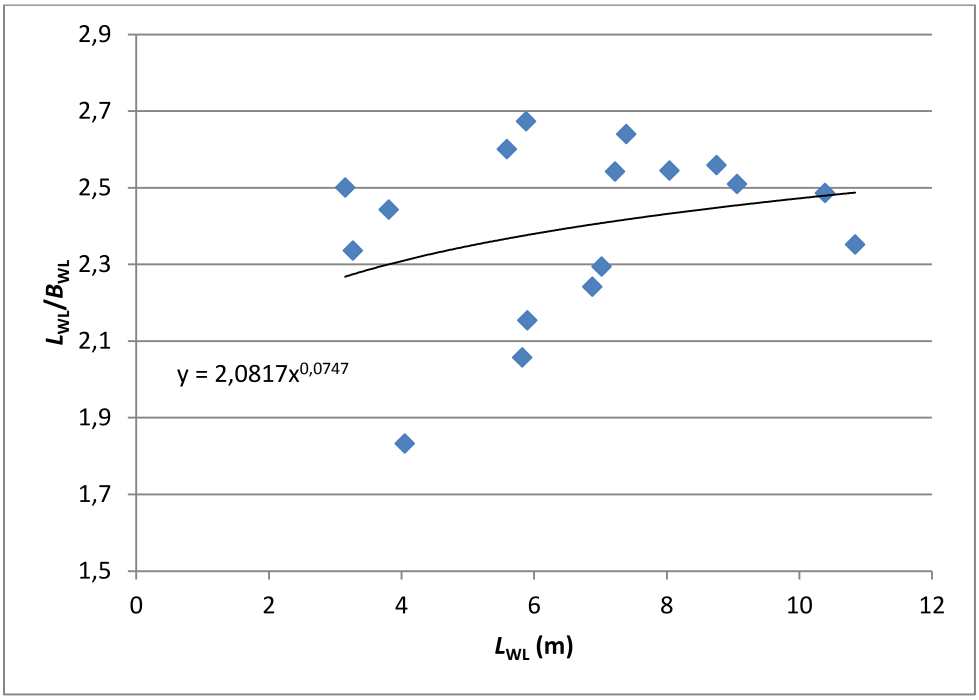

Figure 6. Waterline length to beam ratio as a function of the length on the waterline for Dutch traditional ships.

L_{WL} / B_{WL}

The waterline length to beam ratios (L_{WL}/B_{WL}) as a function of the waterline length presented in Figure 6, are also based on the data taken from the certificates of 17 Dutch traditional ships (Annex IV). There appears to be no clear trend or relationship with the length on the waterline, although it tends to be somewhat lower with smaller lengths. The average value of the waterline length to beam ratio for the 17 ships considered is 2.4. Moeyes and Kooijman (1975) provide a range from 2.2–4.5 for the waterline length to beam ratios. Although there is no clear trend, a power function was fitted to the data, resulting in Equation 13.

$$\frac{L_{WL}}{B_{WL}} = 2.08 \cdot L_{WL}{}^{0.075} \tag{13}$$

B_{WL} / T

The beam to draught ratio (B_{WL}/T) for the traditional craft in the database varies from 4.7-10.1, with an average value of 7.1. Moeyes and Kooijman give a range of 4.5-6.5, from which the upper range value was chosen for the calculations in order to exclude the effect of the extremes on the average to some extent.

L_{WL} / $\nabla^{1/3}$

The slenderness or length to displacement volume ratios show little variation, ranging from 3.6 up to 5.3 with an average value of 4.0 based on the data of 17 traditional craft (Annex IV). The length to displacement volume ratio increases with the length to beam ratio as shown in Figure 7. A linear relationship was derived from the data excluding two outliers see

Annex IV, resulting in Equation 14. This equation is used to calculate the displacement volume in order to finally determine the WSA.

$$\frac{L_{\mathrm{WL}}}{\nabla^{\frac{1}{3}}} = 0.40 \cdot \frac{L_{\mathrm{WL}}}{B_{\mathrm{WL}}} + 2.91 \qquad (14)$$

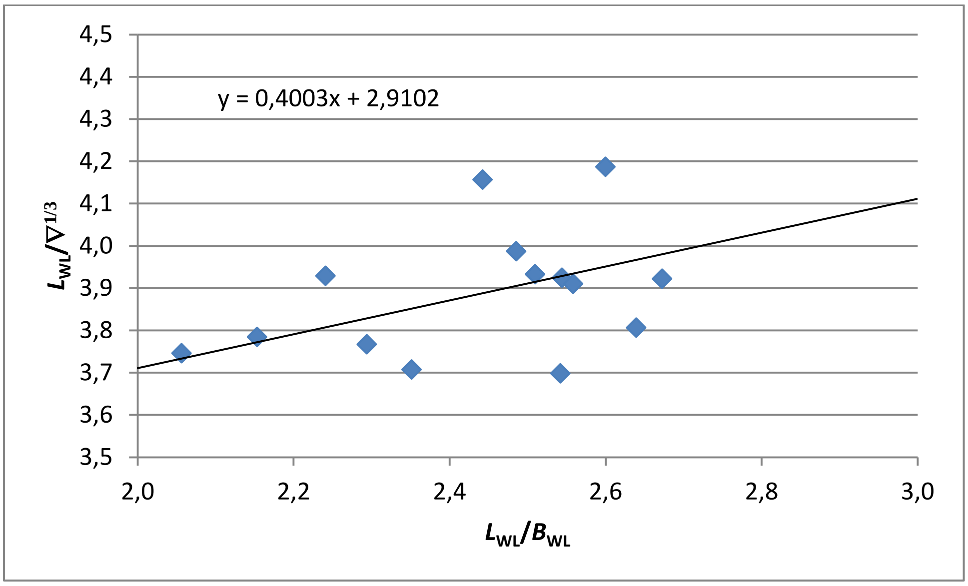

Figure 7. Length to displacement volume ratio as a function of length to beam ratio for traditional craft.

3.6.3 *Selected values for hull form coefficients and hull design ratios*

The selected values for the hull form coefficients and design ratios are presented in Table 6. For the block coefficient, a value of 0.65 seems appropriate and for the midship area coefficient, a value of 0.89 (midrange[e] value of range 0.80-0.98). For the water plane area coefficient, the average of the values presented in Table 5 (0.83) is taken as a typical value for Dutch traditional craft. The typical value for the length to displacement volume ratio and the waterline length to beam ratio are presented in Table 6 for completeness. In order to estimate the WSA, Equation (13) and (14) were used instead of the fixed values. Furthermore, we used the average value of 1.3 for the overhang ratio. Finally, it is difficult to read the value for C_S from the contour plot in Annex I, based on the typical values for C_M and B/T-ratio. The value for the wetted surface coefficient (C_S) was set at 2.84.

[e] The midrange value is calculated as the arithmetic mean of the lowest and highest value of a range or a data set. We use the midrange value when a data set is too small to calculate a well based average value.

Table 6. Summary of the selected values for traditional craft.

Variable	Value
C_B	0.65
C_M	0.89
C_W	0.83
L_{OA}/L_{WL}	1.3
L_{WL}/B_{WL}	2.4
B_{WL}/T	6.5
$L_{WL}/\nabla^{1/3}$	4.0
C_S	2.84

3.6.4 *Lateral area of the rudder, skeg and 'loefbijter'*

As for motor yachts, the WSA calculated from the selected relationships and dimensionless numbers refers to the canoe body only, thus excluding appendages such as the rudder, centre line skeg, front skeg ('*loefbijter*' in Dutch) and leeboards. Traditional craft are commonly equipped with a centre line skeg and *loefbijter,* and these contribute significantly to the total WSA. Therefore, the rudder area has to be determined as well as the area of the skeg and *loefbijter*. Leeboards are assumed not to be treated with antifouling paint as they are infrequently submerged into the water.

Rudder

Rudder area as a fraction of the sail area

For sailing ships, the rudder (planform) area is usually estimated as a fraction of the effective sail area down-wind. The sail area can be estimated from the sail area-displacement ratio, which equates to $\sqrt{SA}/\nabla^{1/3}$.

In which:
SA sail area in m^2.
∇ displacement volume in m^3.

For flat-bottomed craft, Moeyes and Kooijman (1975) provide values for this ratio in the range of 2.5-3.5. In the current study, we used a sail area-displacement ratio with a value of 3.2 based on statistics for the boats tested by Moeyes and Kooijman. Based on Larsson and Eliasson (2000), the average value of rudder area to sail area on modern cruiser/racers is 1.4%, with an upper limit of 2%.

Rudder area as a fraction of the lateral area

Molland and Turnock (2007) indicate the rudder area as fraction of the lateral area for sailing yachts, being 7-11%. In this case, the lateral area should include the area of appendages such as the keel and skeg

From some arbitrarily chosen drawings in Moeyes and Kooijman, e.g. Figures 3 and 7, the rudder area was estimated and related to the reference lateral area (L_{WL} x T) of the hull under the waterline.

$A_{\text{rudder}}/A_{\text{LP,ref}}$

Boeier	$0.6 / (7.8 \cdot 0.52) = 15\%$
Lemsteraak	$1.5 / (14.2 \cdot 1.03) = 10\%$

In which:

A_{rudder}	rudder area (m^2).
$A_{\text{LP,ref}}$	reference lateral area of the hull under the water line (m^2).

The upper value of the range provided by Molland and Turnock (2007) is reasonably in line with the results obtained for the *boeier* and *Lemsteraak*. When including the lateral area of the skeg and *loefbijter*, for many traditional craft the lateral area coefficient is probably 0.95 or even higher. As a best guess, 12.5% of the reference lateral area is used for the calculation of the rudder planform or lateral area.

The results for the calculated rudder area based on the estimated sail area and the reference lateral area are quite similar, although in general, the method based on the sail area results in about 25% higher values. The sail area is calculated from the sail area to displacement ratio, applying an average value of 1.4% for the rudder area, based on Larsson and Eliasson (2000). The values based on the estimated sail area were used..

Lateral area of skeg and 'loefbijter'

No information or general rules were found to be able to determine the lateral area of skeg and *loefbijter*.

The lateral area coefficient, C_{LP} of the hull of a *Lemsteraak* is about 0.65, estimated from a hull plan. The lateral area of the skeg including the *loefbijter* is about 71% of the lateral area of the hull under the waterline ($A_{\text{LP,skeg}}/A_{\text{LP,hull}} = 3.2/4.5 = 0.71$).

Taking the reference lateral area of the hull ($L_{\text{WL}} \cdot T_{\text{C}}$) as a basis, the fraction of the lateral area of the skeg including the *loefbijter* is about 0.46:

$A_{\text{LP,skeg}} / (L_{\text{WL}} \cdot T_{\text{C}}) = 3.2/6.9 = 0.46.$

The reference lateral plane area of the hull for the *Lemsteraak* is 6.9 m:

$L_{\text{WL}} \cdot T_{\text{C}} = 9.33 * 0.74 = 6.9\ m^2.$

In which:

$A_{\text{LP,skeg}}$	lateral area of skeg+*loefbijter*.
$A_{\text{LP,hull}}$	lateral area of the hull under the water line.
$L_{\text{WL}} \cdot T_{\text{C}}$	reference lateral area of the hull.

The lateral area coefficient of the hull of a *schokker* determined from the lines plan of the ship is 0.79. The lateral area of the centre line skeg and *loefbijter* were also estimated from the lines plan. The lateral area of the skeg including the *loefbijter* was about 46% percent of the lateral area of the hull under the waterline ($A_{\text{LP,skeg}}/A_{\text{LP,hull}} = 0.46$). Taking the reference lateral area of the hull as a basis, $A_{\text{LP,skeg}}/(L_{\text{WL}} \cdot T_{\text{C}}) = 0.37$.

A value of 40% of the reference lateral area ($L_{WL} \cdot T_C$) was used to estimate the lateral area of the centre line skeg and *loefbijter* for traditional craft.

4 Calculated wetted surface areas of recreational boats

4.1 Sailing yachts

In this section, we present the data and methodology for sailing yachts. The methodology differs from that applied to motor yachts and traditional craft; instead of calculating the WSA using hull form coefficients and design ratios, measured WSAs are used. For the sake of completeness, the collected information on form coefficients and design ratios for sailing yachts is presented in Annex II.

The 'Offshore Racing Council' (ORC) rating system calculates corrected racing times for sailing yachts in order to rate different boat types fairly against each other in any range of wind conditions and course types. The rating system is based on specific measured boat characteristics. The measurement data are registered on the ORC certificates which contain, amongst others, the length on the waterline while sailing, the displacement volume, and the WSA of the hull. A hull measurement is performed to create an offset (OFF) file describing the body plan of the hull together with appendages, by using an ORC-approved hull measurement machine or any available measurement instrument. The certificates are stored in the ORC database available at http://www.orc.org/index.asp.

For the different length classes presented by Waterrecreatie Advies (2005), the WSA was determined based on the measured values recorded on the ORC certificates. For each length class, six different brands and types of sailing yachts were randomly selected from the ORC database, covering the whole range (two each on the lower and upper side of the range of the length class, and two in the middle). For each length class the average WSA was calculated based on these six values. It is important to note that the measured WSA of the hull according to ORC includes appendages like rudder and keel. Other appendages are measured separately and are not included on the ORC certificates. Table 7 shows the resulting average WSA per length class and the weighted average WSA over all boats based on the share of each length class in the total number of sailing yachts. The data for each length class are presented in Annex V.

In addition to the ORC certificate information, Dudley Dix yacht design provides the WSA for 39 of its models. These were grouped in the aggregated length classes and per class, the average WSA area was calculated. There is no information for ships in the length class above 20 meters. The calculated values are comparable with those based on the ORC certificates. The values based on Dudley Dix are less than 5% lower, except for the length class 15-20 meter, where Dudley Dix outcomes are higher. This indicates that the values obtained through the ORC certificates are likely to be representative.

Table 7. Wetted surface area (m^2) for sailing yachts based on reported measured values from ORC certificates and the data from Dudley Dix design (2017).

Length class	Average length*	Share	Wetted area	
			ORC	Dudley Dix
(m)	(m)	(%)	(m^2)	(m^2)
4-6	4.5	8.3	8.1	7.8
6-10	6.7	71.0	16.9	16.1
10-15	9.5	20.3	33.9	32.9
15-20	13.4	0.4	59.2	67.7
> 20	-	-	91.0	-
Overall		100%	19.8	18.9

* Length on the waterline calculated from the reported average overall length (Waterrecreatie Advies, 2005) and the overhang ratio. The data on the share of boats per length class is from Waterrecreatie Advies.

4.2 Motor yachts and traditional craft

The first step in calculating the WSA is the estimation of the hull dimensions and the displacement volume for each length class. This was done by applying the selected hull design ratios and derived equations described in sections 3.5 and 3.6 following the procedure described in section 3.4, starting from the overall length of the ship hull. The estimated dimensions and the displacement volume are presented in Table 8 and Table 9.

Table 8. Calculated hull dimensions and displacement volume for motor yachts.

	Dimensions (m)				Volume	Share
	Overall	Waterline			(m^3)	(%)
Length class (m)	Length	Length	Beam	Draught		
4-6	5.4	4.8	2.2	0.6	0.9	13.9
6-10	8.4	7.5	2.9	0.7	3.4	64.9
10-15	12.3	11.0	3.8	0.9	10.7	19.8
15-20	17.8	15.9	4.9	1.2	32.3	1.2
> 20	25.3	22.6	6.4	1.6	92.5	0.3
Average boat	8.9	8.0	3.0	0.76	4.1	
Mean		8.0	3.0	0.76	5.1	

Table 9. Estimated hull dimensions and displacement volume for traditional craft.

	Dimensions (m)				Volume	Share
	Overall	Waterline			(m^3)	(%)
Length class (m)	Length	Length	Beam	Draught		
4-6	5.7	4.4	1.9	0.29	1.3	7.7
6-10	8.9	6.9	2.9	0.44	5.1	54.5
10-15	12.0	9.2	3.7	0.58	12.1	34.7
15-20	19.0	14.6	5.7	0.88	48.7	3.1
> 20	-	-	-	-	-	-
Average boat	10.0	7.7	3.2	0.5	7.2	
Mean		7.7	3.2	0.5	8.6	

From the information provided in Table 8 and Table 9, and the selected hull form coefficients, the WSA for motor yachts and traditional craft was calculated using the Holtrop-equations and the formulas provided by Taylor, Froude and the different Denny-Mumford equations (section 2.2). The resulting WSAs are presented in Table 10 andTable 11. The total WSA includes the rudder and skeg area for motor yachts and the rudder, skeg and *'loefbijter'* area for traditional craft.

Table 10 andTable 11 contain the WSA results per length class. Furthermore, results are presented for the average sized boat as well as the weighted average for each method. The weighted average values were calculated for each type of boat using the share of the number of boats in each length class in the total number of boats, taken from the marina survey for the Netherlands published by Waterrecreatie Advies (2005).

The WSAs per length class, based on the different formulas are comparable. Somewhat lower values are obtained by the calculations based on displacement volume. As discussed in Chapter 2, the results obtained by the Holtrop-Mennen equation that include the water plane area, are considered to provide the best estimate.

The difference between the WSA based on the (weighted) average boat dimensions and the weighted average of the WSA from each length class, is probably related to the non-linear characteristics of the applied equations used for the WSA estimation. The values based on the weighted average of the wetted surface per length class are considered to be more realistic, as these better reflect the summed areas of all individual boats (the 'true' WSA value), while the other values are based on the average-sized boat as input.

Table 10. Calculated wetted surface area for motor yachts (m^2), including the rudder and skeg area.

	Formulas based on hull form coefficients					**Formulas based on displacement**		
Length class (m)	Holtrop-Mennen	Holtrop	Denny-Mumford 1	Muragin	Kirk	Taylor	Froude	Denny-Mumford 2
4-6	11.8	11.7	11.3	11.0	12.1	10.4	10.2	9.9
6-10	23.7	23.5	22.7	22.1	24.3	21.5	20.8	20.4
10-15	43.9	43.6	42.0	40.9	45.1	41.1	39.3	38.7
15-20	81.5	80.7	78.0	75.9	83.8	78.4	74.8	73.7
> 20	148.7	146.8	142.1	138.3	152.9	147.0	139.6	138.0
Average boat	26.0	25.7	24.8	24.1	26.6	23.7	22.8	22.4
Weighted average	27.1	26.9	25.9	25.2	27.8	24.9	24.0	23.5

Table 11. Calculated wetted surface area for traditional craft (m^2), including the rudder, skeg and loefbijter area.

	Formulas based on hull form coefficients					**Formulas based on displacement**		
Length class (m)	Holtrop-Mennen	Holtrop	Denny-Mumford 1	Muragin	Kirk	Taylor	Froude	Denny-Mumford 2
4-6	9.3	9.4	9.0	9.3	9.4	8.8	8.5	9.0
6-10	21.9	22.2	21.2	21.8	22.1	20.5	19.9	20.9
10-15	38.5	38.9	37.2	38.3	38.8	36.6	35.6	37.6
15-20	93.9	94.8	90.9	93.6	94.7	92.0	89.4	95.8
> 20	-	-	-	-	-	-	-	-
Average boat	27.5	27.8	26.6	27.4	27.7	25.9	25.2	26.5
Weighted average	28.9	29.2	28.0	28.8	29.2	27.4	26.6	28.1

4.3 Overall results

4.3.1 *Freshwater, brackish water and saltwater combined*

The average WSA for recreational boats at berth in the Netherlands is based on the share of the total number of boats for each boat type (sailing yachts, motor yachts and traditional sailing boats) and the calculated weighted average WSA for each type of boat. Results are presented in Table 12. The total number of boats in the Netherlands for the three types as estimated by Waterrecreatie Advies (2005) is also presented (last column).

Table 12. Wetted surface area and number of ships per type of recreational craft and overall values.

Type of ship	Wetted area, weighted average (m^2)	Total number of ships in survey (2005)	Total number of ships in NL (2005)
Motor yachts	27.1	2625	67478
Sailing yachts	19.8	3449	88614
Traditional craft	28.9	156	4046
Overall	23.1	6230	160138

The overall weighted mean WSA value of 23.1 m^2 corresponds to a weighted mean overall boat length (L_{OA}) of 8.9 m.

4.3.2 *Freshwater, brackish water and saltwater separated*

On our request, the original dataset on pleasure craft length distribution for the 40 Dutch marinas (Waterrecreatie Advies, 2005) was divided into marinas located in three water types by Waterrecreatie Advies (Waterrecreatie Advies, 2017). The resulting data are presented in Annex VI (Table A.VI.1-3). Three marinas are located in salt water (sea): Jachthaven De Leeuwenbrug (Harlingen), Marina IJmuiden (IJmuiden) and Marina Den Oever (Den Oever). Three marinas are located in transitional or brackish water: WSV Haringvliet (Hellevoetsluis), Jachthaven Oostwatering (Veere) and WSV Yerseke (Yerseke). The 34 remaining marinas are considered freshwater or inland marinas.

The same WSA calculations which led to the results in Table 12 can be applied to this split data set. This results in average, weighted values for the WSA of pleasure craft in marinas in the three different water types. The results are presented in Annex VI (Table A.VI.4) and summarised in Table 13. This split of data and recalculation of the WSA answers the question whether, based on the data sample available, a difference in boat size can be observed between e.g. boats moored in saltwater marinas compared to boats moored in freshwater marinas.

Table 13. Wetted surface area (m^2) per boat type and per marina type and mean weighted WSA values (m^2) per marina type. Data based on Waterrecreatie Advies, 2017.

Marina type **Boat type**	**Saltwater**	**Transitional water**	**Freshwater**
Motor yachts	33.8	23.0	27.2
Sailing yachts	27.3	19.8	18.5
Traditional craft	35.9	26.8	27.6
Overall (weighted)	28.9	21.0	22.7

Further data are presented in Table 14, which gives the overall boat length per water type as well as the relative share of motor yachts and sailing yachts (sailing yachts plus traditional craft) per water type.

Table 14. Mean boat length per marina type and proportion of motor boats and sailing yachts (sum of sailing yachts and traditional craft) per marina type. Data based on Waterrecreatie Advies, 2017.

Marina type	**mean boat length (m)**	**% motor yachts**	**% sailing yachts**
Salt water	10.6	21	79
Transitional water	9.1	35	65
Freshwater	8.7	46	54
Overall (weighted)	8.9	42	58

5 Discussion and conclusion

Ship hull designs can vary significantly, but design parameters lie within certain constraints for different types of boats. For most of the parameters of the formulas used to calculate the WSA average or typical values were used. Many equations are available for calculating the WSA. The highest values result from the most recently derived equations (Holtrop and Mennen 1982; Holtrop 1977). The results from the two equations are similar. The equations based on the displacement volume tend to be on the low side of the estimates. Several well-known equations were used for a quantitative comparison. However, a statistical analysis and comparison with real, known data falls outside the scope of this study. The equation derived by Holtrop and Mennen (1982) is the most recent, has a wide applicability domain, and was therefore considered to provide the best estimate.

The equations used in this report only estimate the underwater area of the hull, excluding appendages such as the rudder and skeg (canoe body). The rudder and skeg contribute significantly to the area treated with antifouling paint and therefore they also have to be assessed. Our methodology also included the calculation of these areas.

Alternatively, for sailing yachts, measured data for the WSA is available, for example on the ORC certificates and from a yacht designer. These data show that within a length class, the WSA can vary by up to a factor of two. Although measured data are used, this approach is still an approximation based on a random selection of yachts from the ORC database. In the current study, we assumed that the selected sailing yachts are a representative sample of those present in Dutch marinas. Furthermore, there may be a tendency to an overrepresentation of racing yachts in the ORC-database. On the other hand, all kinds of sailing yachts of various designs, types and construction can partake in races. As the Dix Design information, which includes various designs of sailing yachts such as traditional yachts, racers and charters, provides quite similar results, we concluded that the sample of the ORC based surface areas is representative.

Based on collected information on ship lengths for different types of pleasure craft in the Netherlands, an average WSA for a recreational boat was estimated from typical ship hull form coefficients and design ratios. The methodology for calculating the WSA only requires the overall length of the ship hull as input variable and is applicable to three different types of boats: motor boats, sailing yachts and traditional (sailing) craft. Based on the average length per length class and the share of the number of boats within each length class in the total number of boats for the three types of boats, the overall weighted average WSA was calculated. The calculated value for the overall weighted average WSA is 23.1 m^2. As this is based on the length class distribution for different boat types in the Netherlands, this value can be used in the risk assessment for the national authorisation of antifouling products for recreational craft.

This proposed value is representative for the Netherlands and covers ships at berth in marine as well as inland (freshwater) harbours. Until recently, only one figure was used for the WSA covering both marine and freshwater harbours. A difference in boat size can be observed, with the largest boats moored in saltwater marinas and boats moored in transitional waters, in general, being larger than those in freshwater marinas. Furthermore, the share of sailing yachts in the total number of boats is largest for saltwater and the smallest for freshwater. Therefore, in addition to deriving a single calculated average WSA for recreational craft, we estimated average values for the WSA of pleasure craft in marinas in three different water types: freshwater, marine water and transitional water. Although the average length of craft in marinas in transitional waters is higher compared to boats in freshwater marinas, the average WSA for freshwater is higher. This is due to the fact that the share of motor boats and the WSA of motor boats in freshwater are higher than those in transitional waters.

The methodology described in this report is also applicable to length class distribution data of pleasure craft from other EU member states. We propose that the four resulting values: the overall WSA of 23.1 m^2, and the values of 28.9, 21.0 and 22.7 m^2 for pleasure craft in saltwater, transitional water and freshwater marinas respectively, are used in discussions at EU level, in order to derive EU-harmonised values for the WSA of recreational craft.

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Abbreviations

BPR	Biocidal Products Regulation
EU	European Union
LDR	length/displacement ratio
IMS	International Measurement System
MAMPEC	Marine antifoulant model to predict environmental concentrations
MARIN	Marine Research Institute Netherlands
OECD	Organisation for Economic Co-operation and Development
OFF	offset - file describing the body plan of the hull together with appendages
ORC	Offshore Racing Congress
RIVM	National Institute for Public Health and the Environment

Annex I – Contours of wetted surface coefficient

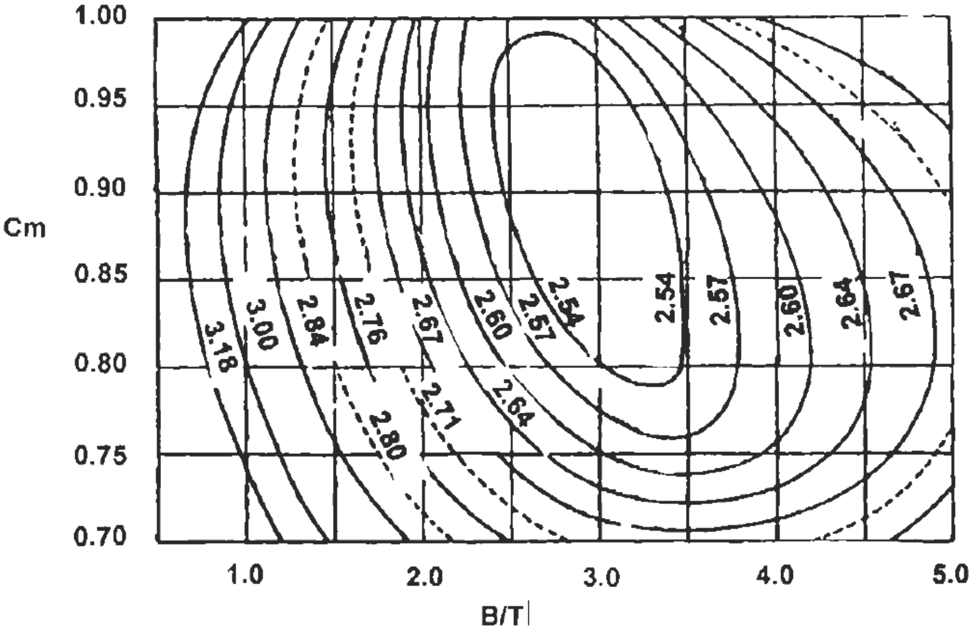

Figure A.I.1. Contours of wetted surface coefficient (C_S) vs midship area coefficient (C_M) and beam to draught ratio (B/T).

Annex II - Sailing yachts hull form coefficients and design ratios

Hull form coefficients

Gerritsma et al. (1981) report values for the block coefficient (C_B) in the range of 0.35-0.38 and midship coefficient (C_M) values in the range of 0.64-0.66. Van Oossanen and Van Oossanen (2006) mention typical values for the block coefficient for sailing yachts ranging from 0.35-0.50.

For an example sailing yacht design from Larsson and Eliasson (2000), a midship coefficient (C_M) of 0.75 and a prismatic coefficient (C_P) of 0.56 have been reported. From these two coefficients, the block coefficient can be calculated resulting in a value of 0.42. Furthermore, Larsson and Eliasson report typical C_P values ranging from 0.49-0.62. Using a midrange value of 0.385 (0.35-0.42) for C_B, this results in an estimated value for C_M of 0.69.

To calculate $C_{M,}$ the same procedure was followed with data provided by Moeyes and Kooijman (1975) resulting in a value of 0.65, see Table A.II.1.

Table A.II.1. Hull coefficients for sailing yachts.

Reference	**Hull coefficient**			
	C_B	C_M	C_P	C_W
Dewan (2015)	0.15-0.20	0.30-0.35		
Gerritsma (1981)*	0.35-0.38	0.64-0.66		
Larsson and Eliasson (2000)	0.35-0.42	0.75 (0.69*)	0.49-0.62	0.71
Moeyes and Kooijman (1975)	0.31-0.41	0.65**	0.52-0.58	
Van Oossanen and Van Oossanen (2006)	0.35-0.50			
Brewer (2017)			0.52-0.57	0.65-0.68
Dudley Dix Yacht Design (2017)	0.31-0.46	0.60-0.81	0.51-0.62	0.64-0.70

*Calculated from the midrange block coefficient and prismatic coefficient (0.49-0.62) from Larsson and Eliasson (2000).

**Calculated from the midrange block coefficient and prismatic coefficient (0.52-0.58) for modern keel yachts in Table I of Moeyes and Kooijman (1975).

The block coefficient for sailing yachts can be estimated from the ORC-certificates reporting the overall dimensions and the displacement. For 21 yachts with a length of approximately 9 metres, the overall length, maximum beam, draught and displacements were used to calculate the block coefficient. The draught on the certificates is the total depth of the hull including the length of the keel. This resulted in low values ranging from 0.07 up to 0.16 with an average value of 0.11. The values are in the low range of the data provided by Dewan (2015), see Table A.II.1. As previously stated, the hull dimensions on the waterline should be used to calculate the hull form coefficients, especially when calculating the WSA of the hull. Considering the relatively low values, the data provided by Dewan are probably based on the overall dimensions of the ship including the draught of the keel.

Detailed design characteristics for sailboats are provided by Dudley Dix Yacht Design (2017). The values for the block coefficients of 39 boat designs lie in the range of 0.31-0.46 with an average value of 0.40. The prismatic coefficient varies from 0.51 up to 0.62 with an average value of 0.55. This is in line with the data provided by Larsson and Eliasson (2000), reporting typical values ranging from 0.49-0.62 and typical values mentioned by Brewer (2017), ranging from 0.52-0.57.The calculated midship area coefficient for these 39 designs by Dix Design ranges from 0.60-0.81 with an average of 0.73.

The average value for the water plane area coefficient or the coefficient of fineness for the 39 Dudley Dix yacht designs is 0.67, values ranging from 0.64 up to 0.70. According to Brewer, typical values for sailing boats lie in the range of 0.65-0.68. From the data on the example design in Larsson and Eliasson, a water plane area coefficient of 0.71 can be calculated (A_{WP}= 22.61 m^2; L_{WL} = 10.02 m and B_{WL} = 3.17 m).

The lateral plane area coefficient is needed for dimensioning the rudder and keel/skeg. For sailing yachts, the coefficient can be estimated based on the relationship derived by Paris (Miller and Kirkman, 1990, Henry and Miller, 1963) using the prismatic coefficient. Typical values and ranges for the prismatic coefficient are provided in Table A.II.1. The selected midship coefficient (0.73) and block coefficient (0.41) in this study result in a prismatic coefficient (0.56), outside the range of the presented graph. Therefore, based on the modified Paris-curve a C_{LP} of 0.8 was chosen as an upper limit for the canoe body. It is important to note that C_{LP} can also be based on the hull including the keel. C_{LP} for the canoe body is typically higher. A typical value for a fin-keel boat is 0.47, based on the total lateral area excluding the rudder and fin/skeg (Henry and Miller, 1963).

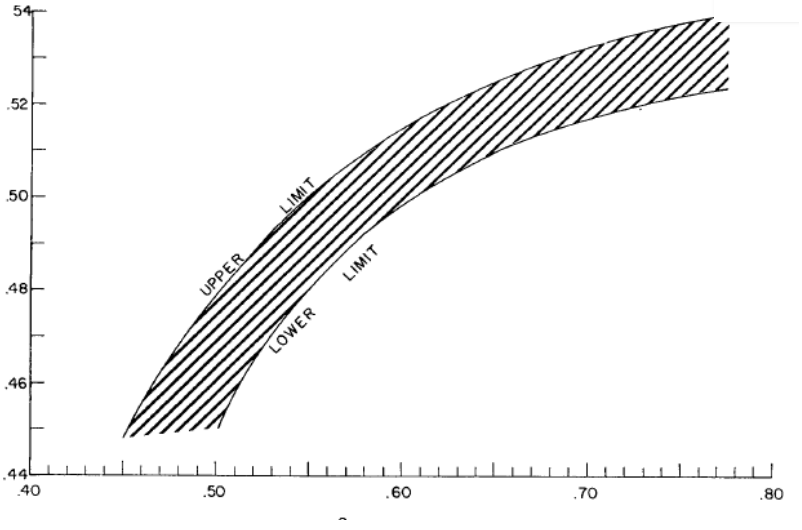

Figure A.II.1: Prismatic coefficient versus lateral plane coefficient.

Discussion, selected values for hull form coefficients

From the data reported on the ORC-certificates, it can be concluded that the values reported by Dewan (2015) are probably based on the overall dimensions of the ship rather than on the waterline dimensions of the hull or the canoe body. C_B lies in the range of 0.31-0.50 with a midrange value of 0.41. Considering C_M, values range from 0.60-0.81, this results in a midrange value of 0.73. For C_W a typical value of 0.67 seems most appropriate (see Table A.II.2).

Hull dimensions

L_{OA}/L_{WL}

To calculate the length on the waterline from the overall length, a simple approach is to use the overhang ratio. Miller and Kirkman (1990) provide figures based on IMS (International Measurement System) measurement data of forty-six cruising and racing yachts. The data show a reduction in the overhang ratio comparing ships built in the 1980s to ships built in the 1950s. For 1980s' sailing ships, the ratio ranges from 1.08 to 1.37, with 1.23 as an average. For their example sailing yacht, Larsson and Eliasson (Larsson and Eliasson, 2000) use an overhang ratio of 1.20. In a later edition of their book, they use a ratio of 1.08 (Larsson et al., 2014).

L_{WL}/B_{WL}

The next step is to determine the waterline beam. To do this, the graphical representation of the relation between the waterline length and the waterline length to beam ratio, as presented by Miller and Kirkman (1990), is used (see Figure A.II.2).

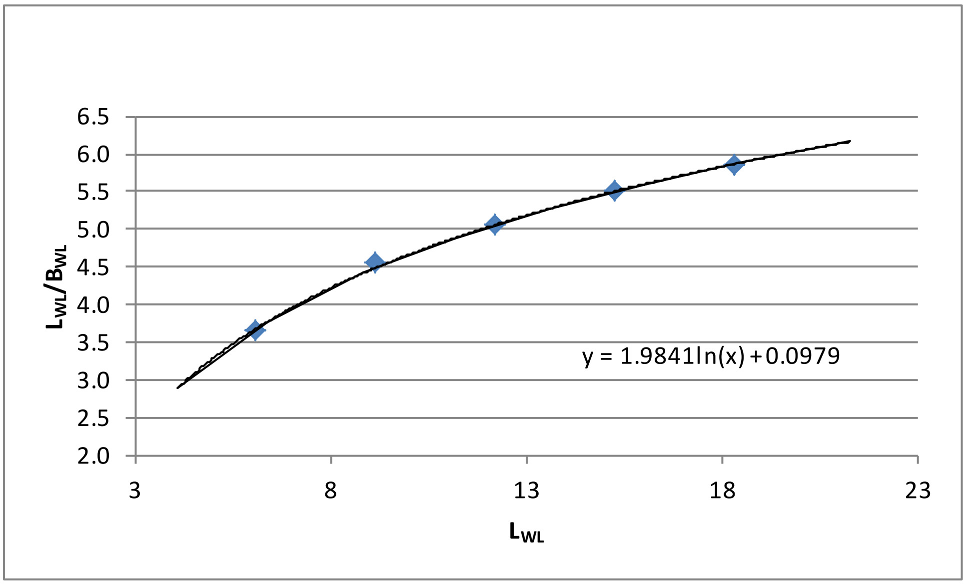

Figure A.II.2: Waterline length to beam ratios versus waterline length.

From Figure A.II.2, a logarithmic trend line is determined as presented in Equation 15.

$$\frac{L_{\mathrm{WL}}}{B_{\mathrm{WL}}} = 1.9841 \cdot \ln(L_{\mathrm{WL}}) + 0.0979 \tag{15}$$

This equation and the overhang ratio allow deriving the length and beam on the waterline from the reported overall length.

B_{WL}/T

Miller and Kirkman (1990) report typical values for the load waterline length to canoe body draught ratio (L_{WL}/T). Alternatively, the waterline beam to (total) draught ratio (B_{WL}/T) can be used to determine the draught of the canoe body. Typical values vary depending on the type of hull. The average value of L_{WL}/T is 18 (minimum 12 and maximum 27). Values are somewhat larger for modern yachts, with median values between 21 and 23. Modern hulls are thus shallower. The ratio increases slightly with length, but the dependence is not strong. For a model yacht, the ratio is about 30 (Larsson et al., 2014), which is much higher compared to the model described in their earlier edition, with a value of 18 (Larsson and Eliasson, 2000). For the (B_{WL}/T) ratio, some typical values are 6.5 (Moeyes, 1972) and 5.6 (Larsson and Eliasson, 2000).

Table A.II.2. Summary of selected values for the WSA calculation for sailing yachts.

Variable	**Value**
C_B	0.41
C_M	0.73
$\underline{C}_P$	0.55
$C_{LP,c}$	0.80
$C_{LP,T}$	0.47
C_W	0.67
L_{OA}/L_{WL}	1.23
B_{WL}/T	6.0
$L_{WL}/\nabla^{1/3}$	4.9
$SA/\nabla^{2/3}$	17

$L_{WL}/\nabla^{1/3}$

A slenderness or length/displacement ratio (LDR) larger than 5.2 is difficult to obtain for standard yachts due to structural problems, according to Larsson and Eliasson (Larsson and Eliasson, 2000) who refer to a linear relationship of the length/displacement ratio with the length. The LDR increases as $(\text{length})^{2/9}$. Equation 16 is derived from the graphical relationship shown in Figure A.II.3. For cruising yachts, Van Oossanen and Van Oossanen (2006) provide a range for the value of LDR from 4.5 to 6.5. The average value based on the data from the ORC-certificates is 4.9, ranging from 4.0-6.3. The LDR seems to increase with length, although there is quite some variation within each length class. Additionally, LDRs seem to be lower than those predicted by Equation 16, derived from Larsson and Eliasson (2000). The LDRs from the ORC-certificates are probably more representative for light cruising and auxiliary sailing yachts following the classification presented by Brewer (2017). The average value from the ORC-certificates of 4.9 is used to estimate the displacement volume, which then will be used for the calculation of the WSA instead of using Equation 16.

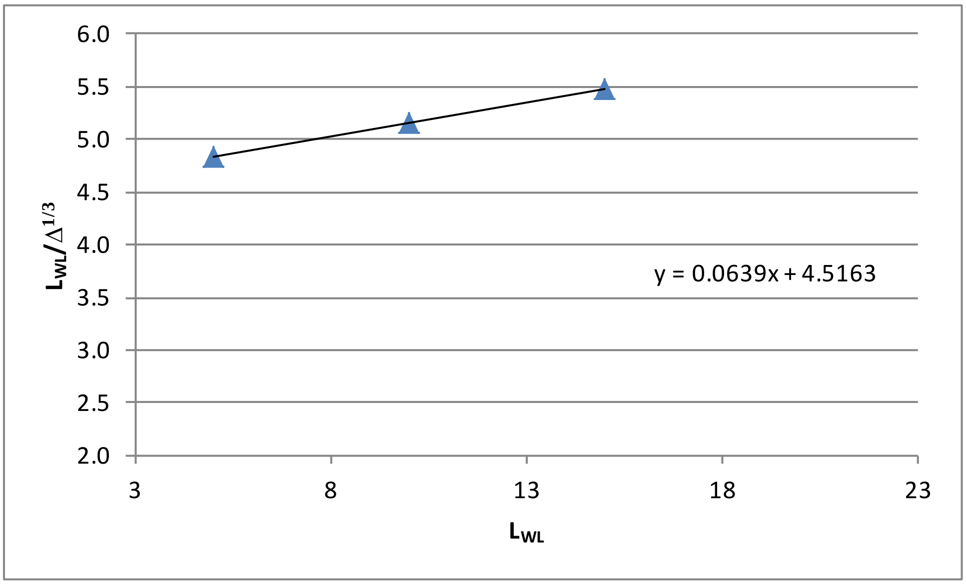

Figure A.II.3: Waterline length to beam ratios.

$$\frac{L_{\mathrm{WL}}}{\nabla^{\frac{1}{3}}} = 0.064 \cdot L_{\mathrm{WL}} + 4.52 \qquad (16)$$

With the above information, the WSA of the canoe body can be determined by applying the various empirical relations provided in section 2.2.

The total WSA that is coated with antifouling paint also includes the rudder area and the keel area. This can be as much as 20% of the WSA of the canoe body. For sailing yachts, the lateral area of the keel and rudder very much depend on the sail area.

The sail area is usually determined from the sail area to displacement ratio $SA/\nabla^{2/3}$. The average value for "52 Designs" and for IMS-values for unique boats is approximately 19, according to Miller and Kirkman (1990). Brewer (2017) states that typical values for racing dinghies, inshore racers and ocean racing yachts are in the range of 18-20. Overall values might range from 15 for motor sailers, to about 20 for racing yachts. Very high *SA*/*D* ratios with a value of 20+ are typical for ultra-light racers and class racers, with possible values of 40-50 (Sponberg, 2011). To compare these values with those presented as $\sqrt{SA}/\nabla^{1/3}$ such as by Moeyes and Kooijman (1975), the square root of the values should be used, meaning a value of 20 represents a value of 4.47 for the alternative expression. Moeyes and Kooijman (1975) provide a range of 3.5-4.5 for keel yachts, that equals a range of 12-20 expressed as $SA/\nabla^{2/3}$. A value of 17 was chosen, which is typical for coastal cruisers and racing yachts.

An average value of rudder area to sail area on modern cruiser/racers is 1.4% with an upper limit of 2% (Larsson and Eliasson, 2000). Molland and Turnock (2007) indicate the rudder area as a fraction of the actual immersed lateral area for sailing yachts, being 7-11%. The actual immersed lateral area of a hull can be derived from the lateral plane coefficient C_{LP}. The lateral area should include the area of the keel, which according to Larsson and Eliasson is approximately 3.5% of the sail area, and the spread is approximately 0.75%. Henry and Miller (1963) suggest that the fin and keel area should be approximately 8% of the sail area.

Annex III - Hull characteristics for motor yachts

Boat	L_{OA} (m)	L_{WL} (m)	B_{OA} (m)	B_{WL} (m)	T (m)	**Weight (kg)**	L_{OA} / L_{WL}	L_{WL} / B_{WL}	$L_{WL} / \nabla^{1/3}$	B_{WL} / T
Riverfox 390	3.84	3.45	1.58	1.35	0.18	0.2	1.11	2.55	6.5	7.51
Capri 21	5.98	5.23	2.41	2.29	0.43	-	1.14	2.28	-	5.30
PowerBoat CRAB 620	6.20	5.87	2.33	2.10	0.25	1.4	1.06	2.80	5.2	8.40
Antaris 630 Lounge 2	6.30	5.35	2.35	1.93	0.55	1.3	1.18	2.77	4.9	3.51
Antaris 680	6.72	6.55	2.45	2.10	0.72	1.8	1.03	3.12	5.4	2.92
Behance Tide	7.36	6.75	2.30	2.20	0.46	1.6	1.09	3.07	5.8	4.78
25′ Coastal Cruiser	7.83	7.49	2.84	2.49	0.83	4.7	1.05	3.01	4.5	2.99
PowerBoat CRAB 800	8.00	7.40	2.50	2.20	0.57		1.08	3.36	-	3.86
Linssen Grand Sturdy 25.9	8.20	6.85	3.00	-	0.95	6.0	1.20	-	3.8	-
Aquadraat 800	8.30	7.30	3.05	-	0.85	2.4	1.14	-	5.5	-
Antaris MK825	8.37	7.00	2.97	2.65	0.60	2.6	1.20	2.64	5.1	4.42
Joe Speight Design 27 ft	8.38	7.09	2.59	2.36	0.94	3.5	1.18	3.00	4.7	2.51
De Antonio D28	8.40	7.00	2.95	-	0.50	2.7	1.20	-	5.0	-
Abalone 28	8.50	7.97	2.65	2.55	0.87	7.1	1.07	3.13	4.1	2.93
Wyboat vlet 9000	9.00	7.93	3.30	-	0.90	6.7	1.13	-	4.2	-
Viking Viki 285 Pilot	9.20	7.70	3.31	2.88	0.90	-	1.19	2.67	-	3.20
Barkas 930	9.30	8.20	3.00	-	0.70	7.0	1.13	-	4.3	-
Bully 960	9.60	8.40	3.45	-	0.90	7.0	1.14	-	4.4	-
Gillissen-vlet 970	9.70	8.23	3.25	-	0.90	9.0	1.18	-	4.0	-
Pedro Levanto 32	9.70	8.83	3.50	-	1.00	8.0	1.10	-	4.4	-
Heechvlet 980	9.80	8.35	3.65	-	0.90	8.5	1.17	-	4.1	-
Noordkaper NK31MOC	10.00	9.40	3.40	2.95	-	8.0	1.06	3.19	4.7	-
Linssen Grand Sturdy 60.33	10.35	8.83	3.40	-	1.00	8.3	1.17	-	4.4	-
Yellow Cedar 34	10.36	10.16	2.92	2.67	0.91	-	1.02	3.81	0.0	2.92

Boat	L_{OA} (m)	L_{WL} (m)	B_{OA} (m)	B_{WL} (m)	T (m)	**Weight (kg)**	L_{OA}/L_{WL}	L_{WL}/B_{WL}	$L_{WL}/\nabla^{1/3}$	B_{WL}/T
WJH 1080	10.40	9.60	3.50	-	1.05	10.0	1.08	-	4.5	-
Motor yacht 34 aft	10.60	8.15	3.42	2.95	0.62	5.5	1.30	2.76	4.6	4.76
Boarnscruiser 1100 Elegance	10.86	10.57	3.60	-	1.08	11.5	1.03	-	4.7	-
Brandma Vlet 1100 AK	11.60	9.62	3.95	-	1.05	11.5	1.21	-	4.3	-
Aquanaut 1150	11.65	10.52	3.90	-	1.00	10.5	1.11	-	4.8	-
Virtess 420 Coupé	11.95	10.41	4.21	3.78	0.77	14.5	1.15	2.75	4.3	4.91
Gruno 38 Classic	12.00	10.90	4.10	-	1.00	13.5	1.10	-	4.6	-
Aquanaut Drifter 1200 CS	12.10	10.94	4.10	-	1.05	12.5	1.11	-	4.7	-
Vikiing Viki 405 fly	12.50	10.18	4.00	3.25	1.07	12.3	1.23	3.13	4.4	3.04
Pikmeer 12.5 Royal	12.90	11.50	4.00	-	1.20	12.5	1.12	-	5.0	-
Freedom	13.00	11.20	4.20	3.61	1.20	15.8	1.16	3.10	4.5	3.01
Keizer 42	13.42	11.26	3.99	-	0.00	0.0	1.19	-	0.0	-
Super Lauwersmeer Discovery 45 AC	13.67	12.75	4.36	-	1.15	17.0	1.07	-	5.0	-
Linssen Grand Sturdy 60.43	13.90	11.80	4.35	-	1.25	18.0	1.18	-	4.5	-
Linssen Grand Sturdy 45.9	14.45	12.40	4.40	-	1.27	21.0	1.17	-	4.5	-
Abalone 48	14.50	13.60	4.18	4.08	0.72	-	1.07	3.33	-	5.67
Silverton 453	14.51	12.68	5.32	5.17	1.53	19.0	1.14	2.45	4.8	3.37
SL Evolve 48 OC	14.60	12.85	4.50	-	1.20	22.0	1.14	-	4.6	-
Cayman 50fly	15.60	12.70	4.40	3.90	0.80	7.0	1.23	3.26	6.6	4.88
Kanaalkotter	16.00	14.30	4.75	-	1.40	38.0	1.12	-	4.3	-
t Wije/Vripack Brandaris Q52	16.00	14.50	4.50	3.90	1.02	-	1.10	3.72	-	3.82
Flevolution 1610	16.10	14.22	4.88	-	1.50	38.0	1.13	-	4.2	-
NoLimit 16.4 FB	16.40	14.35	5.26	-	1.35	22.0	1.14	-	5.1	-
PBB Convertible 59	18.40	16.40	5.70	-	1.85	58.0	1.12	-	4.2	-
Integrety	18.98	16.67	5.07	-	1.50	37.5	1.14	-	5.0	-

Boat	L_{OA} (m)	L_{WL} (m)	B_{OA} (m)	B_{WL} (m)	T (m)	Weight (kg)	L_{OA} / L_{WL}	L_{WL} / B_{WL}	$L_{WL} / \nabla^{1/3}$	B_{WL} / T
Motor Yacht 18.8	18.98	17.03	5.50	4.16	2.70	64.3	1.15	4.10	4.2	1.54
PB 1980 Motorcutter	19.40	16.85	5.60	-	1.70	64.3	1.15	-	4.2	-
PB 66 Bonker	19.90	18.15	5.60	5.30	1.78	76.0	1.10	3.42	4.3	2.98
Shottel XL 12	20.50	19.65	4.90	4.70	1.50	56.0	1.04	4.18	5.1	3.13
Sundsvall 78	24.44	22.39	7.80	-	1.80	85.0	1.09	-	5.1	-
Marlow Voyager 76 LR	25.17	23.17	6.31	5.13	1.52	52.2	1.09	4.52	6.2	3.38
Vripack 138 explorer	42.06	37.49	9.14	8.84	2.74	480.8	1.12	4.24	4.8	3.22
Vripack 141	42.99	38.79	9.52	8.20	2.50	-	1.11	4.73	-	3.28

Annex IV - Hull characteristics for traditional craft from *Rond- en Platbodem Klassenorganisatie* (2016)

Name	**Type**	$D_{calc.}$	L_{OA}	L_{WL}	B_{WL}	$D1$	$D2$	C_B	L_{OA} / L_{WL}	L_{WL} / B_{WL}	B_{WL} / T	$L_{WL} / \nabla^{1/3}$
Ouwe Reus	*schouw (cabin)*	2.38	8.03	5.59	2.15	0.35	0.29	0.62	1.44	2.60	6.72	4.19
Meeuw	*schouw*	0.77	5.65	3.81	1.56	0.22	0.21	0.60	1.48	2.44	7.26	4.16
Kadots	*Friesche schouw (open)*	0.23	4.67	3.27	1.40	-	0.16	0.63	1.43	**2.34**	8.75	**5.34**
Fram	*schokker*	0.30	4.80	3.15	1.26	0.14	0.11	0.60	1.52	**2.50**	10.08	**4.71**
Geertruid	*hoogaars*	25.00	14.80	10.84	4.61	0.87	0.80	0.60	1.37	2.35	5.52	3.71
Windroos	*Lemsterhoogaars*	17.70	14.10	10.39	4.18	0.77	0.60	0.59	1.36	2.49	6.10	3.99
Cambria	*Staverse jol*	6.47	7.83	7.02	3.06	0.46	0.40	0.70	1.12	2.29	7.12	3.77
De Goede Hoop	*Staverse jol*	3.75	6.77	5.82	2.83	0.35	0.30	0.70	1.16	2.06	8.71	3.75
Sylnocht	*boeier*	3.37	7.16	5.88	2.20	0.40	0.39	0.66	1.22	2.67	5.57	3.92
Contanter	*boeier*	5.37	8.04	6.88	3.07	0.42	0.35	0.66	1.17	2.24	7.97	3.93
Wytske	*Fries jacht*	3.79	7.07	5.90	2.74	0.39	0.32	0.66	1.20	2.15	7.72	3.78
Triton	*tjotter*	1.45	5.04	4.05	2.21	0.26	0.23	0.66	1.24	1.83	9.02	3.58
Zwarte Zwaan	*Lemsteraak*	11.21	10.28	8.75	3.42	0.60	0.51	0.67	1.17	2.56	6.16	3.91
Elckerlyc	*Lemsteraak*	12.23	10.75	9.06	3.61	0.57	0.53	0.68	1.19	2.51	6.56	3.93
Schuimer	*schokker*	7.32	9.83	7.39	2.80	0.63	0.54	0.60	1.33	2.64	4.79	3.81
De Bruine Os	*schokker*	8.60	10.74	8.04	3.16	0.60	0.51	0.61	1.34	2.54	5.69	3.92
De kleine Johannes	*zeeschouw*	7.44	9.12	7.22	2.84	0.67	0.54	0.60	1.26	2.54	4.69	3.70

$D_{calc.}$: Calculated displacement volume = ∇
$D1$: Draught at bow
$D2$: Draught at stern
T: $T = (D1+D2)/2$
C_B: Calculated block coefficient $D_{calc.}/[(D1+D2)/2*L_{WL}*B_{WL}]$
Values in **bold** are considered as outliers left out of Figure 6 and Equation (14

Annex V - Hull characteristics from OCR certificates for sailing yachts

Table A.V.1 shows the WSA based on ORC certificates for various sailing yacht types. Data are grouped in five length classes that correspond with the length classes in Waterrecreatie Advies (2005). This study presents numbers of recreational craft per length class in a sample of 40 Dutch marinas. In that data set, boats were categorised into sailing boats, traditional boats, and motorboats. In Table A.V.1, the average boat length and WSA for each length class are presented at the bottom of each class in **bold**.

Table A.V.1. Hull characteristics and wetted surface area for sailing yachts from ORC certificates.

Overall length (m)	**Maximum breadth (m)**	**Draught (m)**	**Displacement (kg)**	**Wetted surface area (m^2)**	**Type / Class**
class 4-6 m					
5.2	2.33	0.94	685	7.2	Leisure 17
5.4	1.95	1.36	361	5.8	Flaar 18
5.5	2.07	1.07	1.400	10.3	Beneteau first 18
5.8	2.49	1.32	750	8.0	Elan 19
6.0	2.40	1.06	1.266	8.9	Triss Magnum
6.0	2.29	1.56	830	8.3	Idea 19
5.65				**8.1**	
class 6-10 m					
6.7	2.37	1.36	1.603	11.3	Ocean 22
7.4	2.30	1.25	2.130	12.0	Hallberg Rassy 24
8.2	2.71	1.33	3.350	15.6	Macwester 27
9.1	3.00	1.72	3.437	17.9	Kolibri 900
9.5	3.02	1.77	4.700	22.0	Bavaria 31
9.6	3.34	1.75	5.052	22.5	Dufour 32
8.4				**16.9**	

Overall length (m)	Maximum breadth (m)	Draught (m)	Displacement (kg)	Wetted surface area (m^2)	Type / Class
class 10-15 m					
10.5	3.55	2.23	5.989	19.5	Hanse 350 R
10.5	3.60	1.90	5.783	25.6	Bavaria 34
12.0	3.98	2.03	9.501	32.2	Dufour 41
12.2	3.98	2.09	10.324	32.3	Standfast 40
14.3	4.31	2.12	13.860	42.4	Northwind 47
15.3	4.39	2.12	17.752	51.7	Bestevaer 49
12.4				**33.9**	
class 15-20 m					
14.9	4.10	1.54	18.930	41.8	Bestwind 50
15.2	4.90	2.10	12.737	47.5	Beneteau cyclades
17.5	5.01	2.31	20.740	58.7	Northwind 58
18.0	4.16	2.54	29.805	62.8	Classic Yawl
18.8	5.16	2.60	33.128	74.8	Hallberg Rassy 62
19.7	4.95	2.91	32.835	69.8	Swan 65 Sketch
17.3				**59.2**	
class > 20 m					
20.1	4.95	2.35	32.300	72.2	Truly Classic 65
22.2	5.85	2.87	53.902	99.8	Oyster 72
22.3	5.07	3.02	37.408	79.7	Retro Classic
23.3	5.76	2.92	40.615	90.0	Swan 75
24.0	5.89	3.88	36.525	91.2	Nauta 78
27.4	6.28	5.18	45.050	112.9	Besozzi 90
23.2				**91.0**	

Annex VI. Length class distribution of Dutch recreational craft – split data of 2005 survey

Table A.VI.1. Length class distribution of pleasure craft in Dutch salt water marinas (n=3) (Waterrecreatie Advies, 2017).

	Sailing yachts		**Traditional craft**		**Motor yachts**	
Length class (m)	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**
until 4						
4.01 - 6					5.0	17
6.01 - 10	9.0	193	9.1	2	9.2	51
10.01 - 15	11.8	243	11.4	13	12.3	50
15.01 - 20	16.5	12	17.0	1	17.7	5
> 20						
Total	10.7	448	11.5	16	10.2	123

Table A.VI.2. Length class distribution of pleasure craft in Dutch marinas in transitional water (n=3) (Waterrecreatie Advies, 2017).

	Sailing yachts		**Traditional craft**		**Motor yachts**	
Length class (m)	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**
until 4					4.0	3
4.01 - 6	5.3	4			5.4	73
6.01 - 10	9.2	322	9.2	7	8.6	110
10.01 - 15	12.0	70	14.0	1	13.1	28
15.01 - 20						
> 20						
Total	9.7	396	9.8	8	8.1	214

Table A.VI.3. Length class distribution of pleasure craft in Dutch freshwater marinas (n=34) (Waterrecreatie Advies, 2017).

	Sailing yachts		**Traditional craft**		**Motor yachts**	
Length class (m)	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**	**mean length (m)**	**nr. of boats**
until 4	4.0	1			4.0	7
4.01 - 6	5.6	281	5.6	12	5.5	267
6.01 - 10	8.0	1.933	8.9	76	8.4	1.537
10.01 - 15	11.7	384	11.9	40	12.3	441
15.01 - 20	16.5	6	19.5	4	17.9	28
> 20					25.6	8
Total	8.3	2.605	9.8	132	9.0	2.288

Table A.VI.4. Values per length class for: boat mid-length, relative share, total number of boats and calculated mean WSA. Also provided are total values for number or boats per boat type per water type and the mean, weighted WSA per boat type per water type. Results are based on data presented in Table A.VI.1 to A.VI.3.

Saltwater, sample size 3: marinas

open motor boats and cabin motor boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6	5.0	14	17	10.4
6-10	9.2	41	51	27.2
10-15	12.3	41	50	43.8
15-20	17.7	4	5	80.6
> 20				
total		100	123	
weighted mean				33.8

open sailing boats and cabin yachts

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6				
6-10	9.0	43	193	16.9
10-15	11.8	54	243	33.9
15-20	16.5	2.7	12	59.2
> 20				
total		100	448	
weighted mean				27.3

traditional sailing boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6				
6-10	9.1	13	2	22.6
10-15	11.4	81	13	34.9
15-20	17.0	6	1	75.5
> 20				
total		100	16	
weighted mean				35.9

Transitional waters, sample size: 3 marinas

open motor boats and cabin motor boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
≤ 4	4.0	1.4	3	7.5
4-6	5.4	34	73	11.8
6-10	8.6	51	110	24.5
10-15	13.1	13	28	48.3
15-20				
total		100	214	
weighted mean				23.0

open sailing boats and cabin yachts

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6	5.3	1	4	8.1
6-10	9.2	81	322	16.9
10-15	12.0	18	70	33.9
15-20				59.2
> 20				
total		100	396	
weighted mean				19.8

traditional sailing boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6				
6-10	9.2	88	7	23.2
10-15	14.0	13	1	51.9
15-20				
> 20				
total		100	8	
weighted mean				26.8

Freshwater, sample size: 34 marinas

open motor boats and cabin motor boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
≤ 4	4.0	0.3	7	7.5
4-6	5.5	112	267	12.0
6-10	8.4	67	1537	23.6
10-15	12.3	19	441	43.6
15-20	17.9	1.2	28	82.1
> 20	25.6	0.3	8	151.7
total		100	2288	
weighted mean				27.2

open sailing boats and cabin yachts

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
≤ 4	4.0	0.04	1	5.0
4-6	5.6	11	281	8.1
6-10	8.0	74	1933	16.9
10-15	11.7	15	384	33.9
15-20	16.5	0.2	6	59.2
total		100	2605	
weighted mean				18.5

traditional sailing boats

length class (m)	mid length (m)	relative share (%)	nr. boats	WSA (m^2)
4-6	5.6	9.1	12	8.9
6-10	8.9	58	76	21.5
10-15	11.9	30	40	38.0
15-20	19.5	3.0	4	98.3
total		100	132	
weighted mean				27.6

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