Determination of the Territorial Sea Baseline – Measurement Aspect

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Abstract. Determining the course of the territorial sea baseline (TSB) of the coastal state is the basis for establishing its maritime boundaries, thus becoming indirect part of maritime policy of the state. Besides the following aspects: legal and methodological as described in the conventions, acts, standards and regulations, equally important is the issue of measurement methodology with respect to the boundaries of the territorial sea. The publication discussed accuracy requirements of the TSB measurement implementation, the relationship of sea level with a choice of the method of its determination, and discussed the implementation of such a measurement on a selected example. As the test reservoir was used the 400-meter stretch of the public beach in Gdynia. During the measurements they used the GNSS geodetic receiver operating in real time based on the geodetic network - VRSnet.pl. Additionally, a comparison was made of the applied method with analogous measurements of the TSB performed in 1999.

1. Introduction
Mathematical determination of the course of the TSB is a necessary condition for the establishment of an external boundary of the territorial sea, which is the state border. Since upon its determination depends primarily defining the extent of the sovereign rights of each country [1-2]. In the case of Poland, the problem of determining the course of the TSB can be seen in the following aspects: legal and measuring.

In the legal sense, the current boundaries of Polish sea areas are established by the national legislation set out in [3]. Taking into consideration only the dates of the documents cited in the above Act (1957-1995) and the variability of the hydrological conditions of the basin of the Baltic Sea, it can be concluded that the Polish state today doesn’t have any current set of geographic data setting the course of the maritime boundaries of the state. The cited thesis was confirmed in the publication [2], where we read: “... despite the passing years, the territorial sea is still the geodetic and cartographic fallow”. So far, only about 200 of the 430 boundaries of the world's maritime zones were delimited, which is less than half of all of them [4]. Other boundaries are defined improperly in terms of: technical, methodological and political aspects [5].

In terms of measuring, the document regulating the conduct of hydrographic surveys, including determining the TSB, is the IHO S-44 standard [6]. This document doesn’t define, however, the direct method for determining the course of the TSB, and doesn’t assign the minimum accuracy requirements for this type of measurements.
For many years the problem of determining the course of the Polish TSB could have also be considered in terms of competence, where till the end of November 2015 they didn’t solve all aspects of the division of tasks between: the maritime administration (maritime offices), the Hydrographic Office of the Polish Navy (HOPN) and the Head Office of Geodesy and Cartography (GUGiK) [3]. That resulted in a lack of coordinated action in this regard, spectacularly exemplified with the report of the Supreme Chamber of Control [7]. The report found out about: “…not working out mechanisms and instruments for evaluation of achieving the objectives set out in the Act of 23 March 2003 on establishing a multiannual programme for coastal protection, relating mainly to ensuring the stability of the coastline (as compared to the status in 2000)”.

The most important problem impacting directly the course of the sea boundary is the acceptance by the coastal states of different vertical datums (the so-called “chart datum” or “zero of the map”). The use of not uniform height datums and their time-space change may result in: the displacement of the coastline, and at the same time the change in the position of the state border, the need to draw up new bathymetric and hydrographic maps, and the existence of conflicts between countries (with different vertical datums). Therefore, for navigational safety, the majority of national hydrographic offices and the International Hydrographic Organization (IHO) adopt as the chart datum the Lowest Astronomical Tide (LAT) [8].

2. Change of the sea level in the context of the TSB measurements

The method of determining the TSB depends on the shape of the coast. If the coastline is varied, the state can designate normal and straight baselines in the case of various coastal landforms. These rules have been strictly defined in [8-14]. Determining the course of the TSB comes down to measuring geodetic coordinates (points) of the lowest water level in terms of the mean sea level (MSL) adopted in a given country.

According to the expertise of the Institute of Meteorology and Water Management (IMGW), May 1994, on the: “Lowest sea level along the Polish coast” it is stated that this level for Poland is: -1.6 m. Adoption in Poland the level of -1.6 m (observed in 1967) equally across the whole coast seems to be disputable, according to the authors, due to the high variability of the lowest level on the coast of Poland, but it won’t be discussed in this publication.

Before determining the TSB, it is necessary to acquire historical data recorded at a water the gauges located around the coast of the state. In Poland, the relevant state institutions (branches of IMGW) gather information from gauging stations, such as: zero ordinates of water gauges, extreme water levels etc. They allow determining the minimum water level along the coast (ever recorded), which is necessary to determine the course of the TSB. For the purposes of this publication the authors obtained the information from the maritime branch of IMGW in Gdynia. These included data for 12 gauging stations (Figure 1) [15].

![Figure 1. Absolutely minimal water levels ever recorded for Polish gauging stations in years: 1945-2015. The vertical datum based on Kronstadt 86.](image-url)
The zero ordinate of each water gauge is referenced to sea level in Kronstadt in Russia. In Poland it amounts to 508 cm, with the exception of Darłowo (507.3 cm). Comparing the lowest and the current water level (e.g. from the weather service of IMGW-PIB) it can be determined at what depth (at the time of survey) the measurement of TSB points must be carried out. This depth is the difference between the current and the lowest water level. Figure 2 shows the difference between the level of Kronstadt and the lowest observed water level in Poland, registered on 12 water gauges [15].

![Figure 2. The difference between the level of Kronstadt and the lowest observed water level in Poland, registered on 12 water gauges.](image)

If we assume that the TSB is determined locally for the area in Gdynia, it is actually 93 cm below the MSL by the Kronstadt 86 (HKron86) vertical datum.

Baltic states don’t apply common geodetic reference system for the observation of sea levels. In order to harmonize vertical datums for the charts of the Baltic Sea, a working group Chart Datum WG was appointed. The main task of this group is to investigate the possibilities of using the European Vertical Reference System (EVRS), as the main alternative to the height datums on nautical charts of the Baltic Sea. Most of the Baltic countries use Kronstadt and Amsterdam vertical datums (the difference between them is 8 cm) to determine the sea level. In Poland there is still valid the height datums based on the Kronstadt system (BHS), but the registration of sea levels is linked to the system of Amsterdam (NAP) [16].

### 3. Determination of the TSB with the application of hydrographic methods

Creating nautical charts of inland waters, as well as determining the course of the TSB is related, in significant part, with measuring the depth of the water column, along with the assigned geographic coordinates. Such measurements are usually made using hydroacoustic systems, along with precise positioning system.

Contemporarily presented methodology of classical hydrographic measurements (bathymetry) assumes the realization of measurements using a manned vessel. A classic measurement (using a single beam echo sounder) consists in leading a hydrographic vessel along the so-called measurement profiles (Figure 3 left) - which are equidistant segments with respect to each other (or every few or a dozen meters), and those segments are perpendicular to the coastline (in accordance with the greatest gradient of the depth). Due to the immersion of small hydrographic vessels (approx. 0.5 m and more) and placing on their bow echo sounder transducer, the measurements at depths below 1 m are practically not performed. Because it can result in damage to the measuring equipment, however, it gives rise to large areas (in the near shore area), for which no measurement data were obtained (Figure 3 right).
Figure 3. Hydroacoustic measurement profiles (left) and the zone lacking due to the depth of measurement data (right) according to [17].

As a result, it can be obtained a bathymetric map of the reservoir, where contour lines for shallow depths are equidistant. This is the result of a linear interpolation between the coastline (0 m depth) and the measurements carried out to 1 m contour line (isobath).

4. Determination of the TSB with the application of geodetic methods

4.1. Measurements in 1999

An alternative method of measurement is the geodetic method that consists in determining the course of the TSB using a GNSS geodetic receiver. In 2000 the Polish Naval Academy (PNA) completed the research project titled: „Modernization of the infrastructure necessary for determining the boundaries of the territorial sea of the Republic of Poland”. Within the project's frameworks the course of the TSB was determined with the application of this method [18]. The project was managed by Prof. Kołaczyński. To complete the task, a set of measuring equipment was applied, consisting of two dual frequency receivers Leica SR 9500. Determination of the TSB and the coastline was carried out in two stages:

In stage I they set the coastline by measuring the coordinates on the border of the surf zone and the beach. The coordinates were determined with an interval of not more than 100 m. If the stretch of the coast was straight, then the interval was close to the previously assumed value. If the stretch of the coast showed irregularities, then the interval between the measurement points was small enough to adequately detect changes in the shape of the coastline. In stage II they determined measurement profiles perpendicular to the coastline. The length of the profiles was a function of the water depth and the MSL. Before the start of measurement sessions, they read the sea level with a water gauge located in the port of Władysławowo. Because a TSB was placed at a depth of 0.9 m below the MSL, the size read from a water gauge allowed to determine a given day depth at which the TSB was located. After determining in the measurement area the position corresponding to the current depth of the TSB, they determined the length of the measurement profiles - the distance from the coastline to the TSB was increased by an average of 10-meter stretch toward the mainland. For such a profile they determined coordinates of the points at the interval of 5 m (Figure 4). This allowed the unambiguously identify points of the TSB at designated measurement profiles.
Figure 4. Example of a cross-section of the area (height) along the measurement profile [18].

An example of the coastline and measurement profiles measured in the vicinity of the port of Władysławowo in 1999 is presented in Figure 5.

Figure 5. Measurement points along the course of the coastline with marked measurement profiles in the vicinity of the port of Władysławowo by [18].

4.2. Measurements in 2016

Measurements carried out in Poland 17 years ago should be considered as pioneer ones in terms of both the methods of measurement and the data analysis. Their essence has been preserved in the measurements carried out in 2016, but technological advances in the field of GNSS enabled its both technical and measurement modification. The main elements which enabled its modernization were [19-22]:

1. In Poland in 1999 there was no possibility of using GNSS geodetic networks operating in real time providing the ability to use the staking out points function in real time for precise measurement performed on parallel profiles.
2. Measurements in 1999 were realized in the post processing. The network solution was unavailable then. In the research carried out in 2016 they used, in real time, the geodetic network GNSS VRSnet.pl.
3. Measurements in 1999 were based on the only then available GPS system. In the research performed in 2016 they used the multi-constellation receiver, which used satellites from three GNSS systems simultaneously (GPS/GLONASS/BeiDou).
4. The accuracy of calculating the orthometric height in 1999 was related to the accuracy of the GPS system, as well as the accuracy of the applied quasigeoid model. In the measurements performed in 2016 they used the quasigeoid model developed in 2011.

5. The accuracy of calculating the horizontal positions increased from 5 cm (RMS) in 1999 to 1 cm (RMS) in 2016.

After the analysis it was decided that the measurement implementation would be performed at the most typical reservoir, namely the public beach in Gdynia. The study was carried out in the area of sections: A1, A2, A3 and A4 (Figure 6).

![Figure 6](image_url)

**Figure 6.** The system of measurement and control profiles in determining the TSB on the public beach in Gdynia.

The measurements were carried out on 23.06.2016 in the hours: 08:30-18:00. 280 measurements points were performed on 40 profiles.

![Image](image_url)

**Figure 7.** Staking out a point of a measurement profile (left). Staking out the last point of a profile - a point of the TSB (right).
The term of measurements and hydrometeorological conditions play an important role, hence the measurements were carried out during the sea level 0, in calm weather. Before the measurements they set the current sea level using a website that allowed hourly updating. Figure 8 presents the sea level changes at the date of measurements. For the sea level amounting to 494 cm, the TSB was on the day of measurements at -79 cm below the temporary sea level.

![Chart of the sea level variability observed on the water gauge in Gdynia on the day of measurements, according to weather service of IMGW-PIB.](image)

**Figure 8.** Chart of the sea level variability observed on the water gauge in Gdynia on the day of measurements, according to weather service of IMGW-PIB.

4.3. Course of the TSB – measurement results

Obtained measurement data were developed in the Trimble Business Center software. When elaborating the study results was used: The Gauss-Krüger projection [23], the plane rectangular coordinate system 2000 [24], the height system Kronstadt 86 [25] and the quasigeoid model PL-geoid-2011, [19].

The use of measurements performed in real time along with staking out points allowed to obtain the even coverage of the reservoir with measurement points. Figure 9 presents an isometric illustration, using the Google Earth platform.

![Isometric projection of measurement points, together with a marked (in red) course of the TSB and the shore.](image)

**Figure 9.** Isometric projection of measurement points, together with a marked (in red) course of the TSB and the shore.

Next, the obtained measurement data made it possible to create a digital terrain model (DTM) based on triangle mesh (Figure 10).
The last stage was to develop a bathymetric map of the reservoir, together with an indication of the course of the TSB. The study was made in ArcGIS.

Figure 11. Bathymetric map of the reservoir on the public beach in Gdynia, together with a marked (in red) course of the TSB

The presented measurement results proved the ability to precisely determine the course of the TSB with the application of the method of direct GNSS geodetic measurements. The measurements showed considerable variability of the TSB, even for such a short stretch of the shore. It is particularly noteworthy to highlight a certain topographical feature associated with the appearance of successive "shallow areas" that appear even in a single profile. It can be presumed that the aforementioned local increases in the bottom surface are subject to periodic change. Hence it can be concluded that the reliability of measurement data of a TSB can be subject to quite rapid obsolescence. In the present context it should be noted that a coastal state - such as Poland - can in a relatively non-complex way influence the shape of the TSB of the country by filling with the material (sand) acquired, for example, from dredging of approach channels to ports, which is the primary (statutory) task of the maritime offices [15].
5. Conclusions
Summing up the current limitations of classical measurement methods in hydrography in the context of determining the TSB it should be stated that hydrographic vessels, due to the immersion, don’t perform in reality the bathymetric measurements at depths below 1 m. Common in hydrography bathymetric mapping (of ultra-shallow reservoirs with no real measurement data) is performed on the basis of the erroneous assumption of a linear decrease in depth in the area of the smallest depths (0÷1 m).

The publication discusses the implementation of determining the TSB on the example of a 400-meter stretch of the public beach in Gdynia. During the measurements they used the multi-constellation geodetic receiver Trimble R10 GNSS operating in real time based on the geodetic network - VRSNet.pl. Hence it has been shown that the GNSS geodetic networks, due to the real time measurement and the possibility of staking out points can be successfully used in such studies.

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