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Mixing of brine waste in Puck Bay (the south Baltic Sea) in the light of in-situ measurements

by

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Abstract

In the north-eastern part of Poland, the underground gas stores are being constructed by diluting salt deposits. Brine, a by-product of the technology applied, is discharged into the coastal waters of the south Baltic Sea by a system of diffusers. To assess the intensity of brine mixing in the near-field of the discharge installation, a monitoring program was carried out. The results demonstrated that under the mildly dynamic conditions of Puck Bay, the discharge of brine (saturation 250 kg m^{-3}, discharge 300 m^3 h^{-1}) leads to salinity excess below 0.5 PSU. For parameters of a real brine discharge, the dilution coefficient estimated by formulas derived from analytical solutions, predictive models and laboratory experiments for stagnant water conditions, varied in the range of 123÷360. The dilution coefficient value estimated on the basis of measurements was 1.27÷3.72 times higher than its value obtained by the use of predictive models, while estimated by formulas obtained from laboratory experiments was in the range of 1.41÷2.26 of the dilution coefficient based on measurements.

Key words: brine discharge, in-situ measurements, Puck Bay, mixing process, salinity of water

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Introduction

The growing demands for gas storage capacity encouraged the Polish Gas and Oil Company to build underground gas stores in salt deposits located in the north-eastern part of Poland, in the area bordering on the Gulf of Gdańsk (South Baltic Sea). The construction site is located about 4 km away from the Baltic Sea coast. The drilling of boreholes and diluting of salt rock was proposed as a method of creating the chambers. The aim of the paper is to analyze the mixing processes due to a brine discharge into the marine environment in order to confirm the efficiency of the constructed installation. Assessment of brine mixing can be carried out using different approaches: laboratory and/or field experiments, analytical methods, modelling. The laboratory approach, the most common one (e.g. Abraham 1967; James et al. 1983; Roberts & Toms 1987, 1988; Roberts et al 1997; Cipollina et al. 2005; Shao & Law 2010; Bashitialshaaer et al. 2012), focuses on the analysis of a single jet shape as a function of selected parameters, such as initial velocity, angle of incidence, a density difference between effluent and ambient water. The majority of laboratory experiments was carried out for stagnant water (e.g. Zhang & Baddour 1998; Shao & Law 2010; Papakonstantis et al. 2011), however, a few experiments for non-stagnant conditions in the ambient environment were also described (e.g. Gungor & Roberts 2009; Roberts et al. 2011; Lai & Lee 2014). Field experiments are quite rare due to difficulties associated with their execution. In marine conditions, simultaneous registrations of all parameters of interest usually require a support of a vessel and divers. It should be emphasized that data measured in-situ always represent a unique, non-repeatable, situations. Despite all difficulties and limitations, field measurements are an invaluable source of information on all natural processes. Field measurements focus mainly on mixing processes in the far field of the installation (e.g. Marti et al. 2011).

Considerable interest in the mixing processes is related to the brine discharged from desalination plants. Brine produced in the desalination process is usually characterized by the salt concentration below 100 kg m^{-3}, whereas the present study deals with the discharged brine characterized by the concentration of salt reaching 250 kg m^{-3}. Due to environmental reasons, the discharge located in Puck Bay, the area protected by the Natura 2000 program, is limited to 300 m^3 h^{-1} to meet the restrictions imposed by local administration to reduce the salinity excess to 0.5 PSU in the near-field of the discharge installation.

Materials and methods

Study site

The Gulf of Gdańsk is situated in the south-eastern part of the Baltic Sea (Fig. 1a) in the area limited by the imaginary line between the Cape of Rozewie and the Cape of Taran (Fig. 1b). Puck Bay is a shallow, western sub-region of the Gulf of Gdańsk separated from the open sea by the Hel Peninsula. In the middle of the Hel Peninsula, there is a shallow sandbank (called Rybitwia Mielizna) stretching from the Rewa Cape to Kuźnica, which divides the Bay of Puck into two parts characterized by different circulation patterns: the eastern part, called the Outer Puck Bay (av. depth ~20.5 m), and the western part, called the Puck Lagoon (av. depth ~3 m). Currents in this non-tidal region are generated mainly by wind and the accompanying water level variations in time and space. In addition, the circulation in the Puck Lagoon is influenced by water exchange with the eastern part of the bay. The water circulation patterns were described by Nowacki (1993) on the basis of occasional field observations of currents. It is quite well documented that water circulation patterns in the Outer Puck Bay depend on the wind direction. The direction of surface currents usually follows the wind direction, although the opposite current direction can be observed in the south-eastern part of the Outer Puck Bay. The direction of bottom currents frequently follows the surface currents. However, the available field measurements of the currents are insufficient to present the flow patterns that are generated by spatially and temporarily varying wind conditions in the region. Wind statistics for coastal stations, Gdynia and Hel, show the prevalence of W-SW wind (i.e. Gdynia: SW – 18.7%, 4.2 m s^{-1}, W – 24.0%, 4.3 m s^{-1}; Hel: SW – 15.6%, 5.1 m s^{-1}, W – 22.4%, 5.5 m s^{-1}; Kwiecień 1990). The maximum measured current in Puck Bay in the vicinity of Rybitwia Mielizna, 0.37 m s^{-1} at the surface and 0.34 m s^{-1} at the bottom, was associated with the northern wind (Nowacki 1993).

Water salinity in the Puck Bay is determined by interactions between marine and fresh waters. In the Outer Puck Bay, salinity is closely related to the inflow of more saline water from the Gdańsk Basin through surface and bottom layers. In addition, the surface layer is modified by fresh water from the Vistula River discharging into the Gulf of Gdańsk

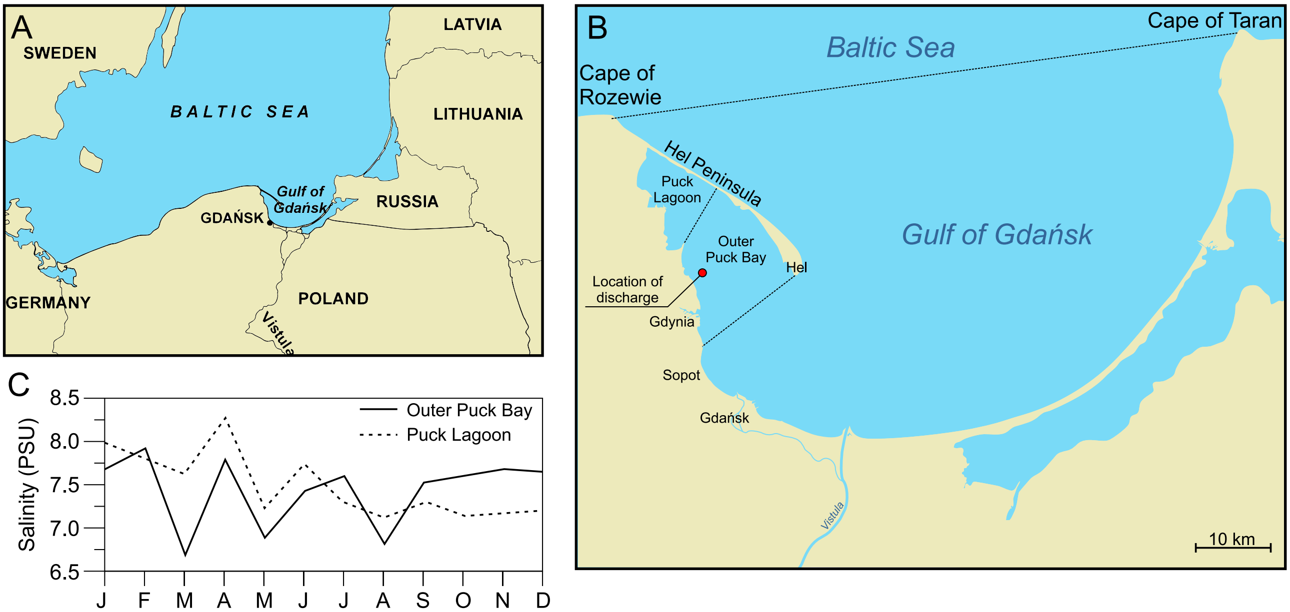

Figure 1

General view of the Gulf of Gdańsk (A), including the location of the discharge site (B) and the variability of the mean monthly salinity in the surface layer in the Outer Puck Bay and in the Puck Lagoon (based on data from the Institute of Meteorology and Water Management for 1965-1974, see Nowacki 1993) (C)

about 40 km away from the center of the brine discharge installation. In the Puck Lagoon, salinity depends mainly on the intensity of water exchange with the Outer Puck Bay. The influence of small rivers is limited to their outlets. Statistics indicate (Fig. 1c) that the mean monthly salinity in the Outer Puck Bay is significantly lower compared to the Puck Lagoon during periods of increased discharge from the Vistula River, i.e. early spring, because of snow melting. Long-term statistics (1951-1990) for the Vistula River show a mean annual discharge equal to 1080 $m^3 s^{-1}$, and the highest annual discharge equal to 3840 $m^3 s^{-1}$ (Fal et al. 1997).

Water density in the Puck Bay changes seasonally, like water temperature, with spatial modifications due to weather conditions (i.e. air pressure, wind) and bottom configuration in the analyzed region. Due to intensive mixing, stratification cannot develop in the Puck Lagoon and in the shallow parts of the Outer Puck Bay. In the eastern, deeper, part of the Outer Puck Bay, the density stratification can develop occasionally. In this context, the density stratification in the area of discharge was not taken into account.

The analysis of brine mixing in Puck Bay was carried for the constructed diffusing system located 2300 meters from the shore designed by the EMPORIUM design office. The discharge installation consists of 16 diffuser's blocks (Fig. 2), each with 3 nozzles distributed every 120^{o} of the circumference. The installation was constructed to discharge brine with the density (ρ_e) of 1160 kg m^{-3} (salinity 215 PSU), salt concentration of 250 kg m^{-3} at a rate of 300 $m^3 h^{-1}$. The installation covers a rectangular area of 180 × 180 m.

Field Experiments

The in-situ measurements were carried out from October 2010 to December 2012 to monitor mixing processes during the early functioning of the brine discharge installation. The monitoring program included three types of in-situ measurements: (1) continuous measurements of salinity, temperature, and water currents in two locations carried out by the use of autonomous Aanderaa Instruments rotor type current meters (A and B, Fig. 3); (2) CTD measurements taken by the InterOcean probe (conductivity, temperature, depth) in the near-field of the installation; (3) CTD measurements in the vicinity of a single block. Information on the quality and quantity of brine was made available by the owner of the installation, while wind conditions come from meteorological station in Gdynia (2010, 2011) or measurements carried out by the owner of the installation using an instrument located at a

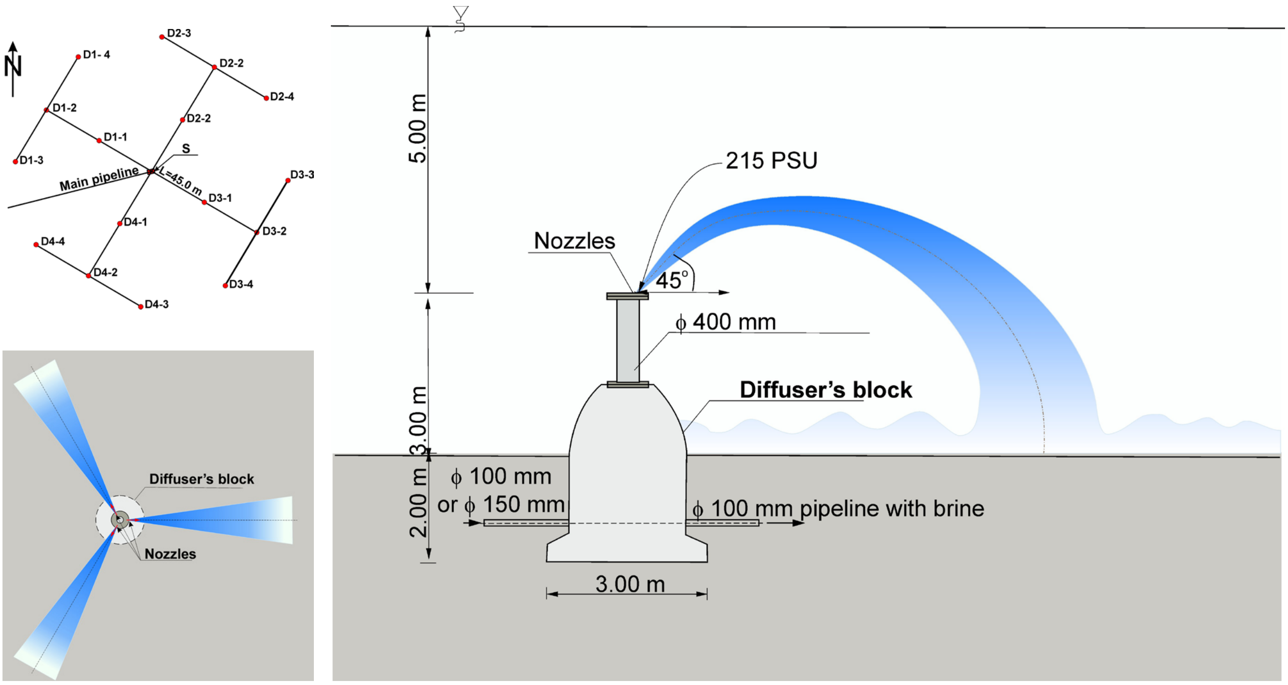

Figure 2

General view on: (a) the discharge system with 16 diffuser's blocks marked as D spaced every 45 m, (b) a single block, and (c) discharge from a single block through 3 nozzles, according to the project of EMPORIUM

fixed platform in the center of the brine discharge installation (location S, Fig. 2a).

Results

Continuous measurements

Continuous measurements of environmental conditions in the ambient environment, including salinity, temperature, and water currents 1 meter above the bottom, were carried out in two locations, A and B (Fig. 3), situated on the eastern and western sides of the installation. Because of the technology applied for the construction of the underground stores, the amount, the concentration of salt and the density of brine increased gradually until the summer of 2012, when the maximum values were reached. During the first months, brine was discharged only for a few hours a day. The operating time was gradually extended until, starting from the summer of 2011, the discharge was carried out continuously, with short breaks for the maintenance of the installation. At the same time, the concentration of salt and the density of the effluent were gradually increasing, reaching the target density of 1160 kg m^{-3} and the concentration of salt of 250 kg m^{-3} in the summer of 2012. Three periods, 13 October – 26 November 2010; 12 July –26 August 2011; and 22 May – 9 August 2012, represent three stages of brine discharge (early, intermediate, target), characterized

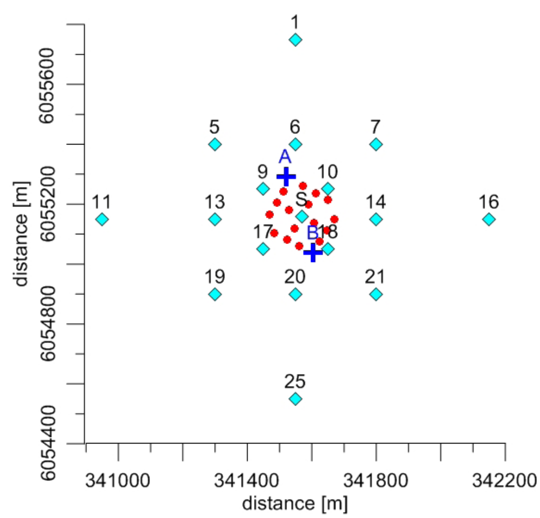

Figure 3

Location of the system of diffusers and in-situ measurements (dots – diffuser's blocks; squares – CTD measurement sites; crosses A, B – continuous measurement sites) in the WGS84 system of coordinates

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by different salt concentration in brine and density. Sample results for those measurements are presented in Fig. 4. All the results represent periods of relatively weak wind conditions, when wind velocity was generally lower than 6 m s^{-1}, and wind direction was varied. Water currents in the region are generated by wind. In such conditions, the measured flow velocity hardly ever exceeded 0.1 m s^{-1} (Fig. 4). It is characteristic that the predominant flow directions were to the north and to the south, which resulted from the local bathymetry and configuration of the coastline. It should be mentioned, however, that the measurements of currents conducted in the 1990s in similar locations, but under more severe wind conditions, showed velocities of up to 0.35 m s^{-1} (Jasińska 1996).

In the autumn of 2010 (the early stage), when brine was discharged for only a few hours a day, salt concentration in brine was relatively low (Fig. 4). At that time, the values of salinity in locations A and B were very similar, differing at most by 0.1 PSU. In the summer of 2011, the amount of brine increased to 250 m^3 h^{-1}, and the concentration of salt to 225 kg m^{-3}. During periods of weak dynamics, salinity differences between the two gauges did not exceed 0.25 PSU. In the summer of 2012, the discharged brine reached the maximum permissible parameters (total discharge – 300 m^3 h^{-1}, concentration of salt – 250 kg m^{-3}). Under such conditions, the maximum salinity differences between the two gauges occasionally reached 0.35 PSU.

CTD measurements in the near-field of the installation

The *in-situ* measurements of the spatial distribution of salinity in the near-field of the installation started in October 2010, at an early stage of its operation, and continued once a month until December 2012, when brine reached its maximum permissible parameters. In most cases, CTD measurements covered 17 verticals (Fig. 3). To illustrate the spreading of brine in the near-field, four examples representing the early (27.11.2010), intermediate (26.07.2011) and target (24.01.2012, 1.08.2012) stages of salt concentration in brine have been selected. Brine parameters, including the total rate of discharge and its division into arms, density, as well as wind conditions, measured on the selected dates are given in Table 1. In the analyzed period, the density of the effluent (ρ_e) increased from the initial value of 1055 kg m^{-3} to the maximum permissible level of 1160 kg m^{-3}. It should be pointed out that the discharge was not always equally distributed among the arms of the system, which may have influenced the local spreading of brine. All *in-situ* measurements were carried out under mild wind conditions, but characterized by varied wind directions.

The collected data make it possible to analyze the salinity distribution in selected verticals (Fig. 5), and the spatial distributions in selected layers (Fig. 6) or cross-sections (Fig. 7). It is important to note differences in salinity values, especially in the upper part of verticals, between the results from selected dates. Those values represent natural, or almost natural, salinity values in that region. The observed salinity variations in time are associated with the inflows of water from the Gulf of Gdańsk to Puck Bay.

The most pronounced influence of brine discharge on the salinity distribution can be expected in the lower part of verticals located at the center and in the closest vicinity of the installation (locations S, 9, 10, 17, 18 – Fig. 3). In the presented cases, a full range of vertical profiles can be seen (Fig. 5), from a well-mixed one (27.10.2010) to a well-pronounced halocline (24.01.2011). In calm weather,

Table 1

Parameters of brine discharged during selected in-situ measurements

date	Q (m^3 h^{-1})					ρ_e (kg m^{-3})	d (m)	wind direction (deg)	wind velocity (m s^{-1})
	arm1	arm 2	arm 3	arm 4	total				
27.10.2010	0.0	0.0	76.8	57.8	**135.3**	1055	0.008	225	2*
26.07.2011	75.5	55.9	0.0	61.5	**192.9**	1135	0.009	315	4*
24.01.2012	74.9	74.5	74.7	75.8	**299.9**	1164	0.009	315	2*
1.08.2012	74.0	67.0	78.0	76.0	**295.0**	1160	0.009	120	3.5**

(*) – measured in Gdynia station; (**) – measured at a center of installation (location S)

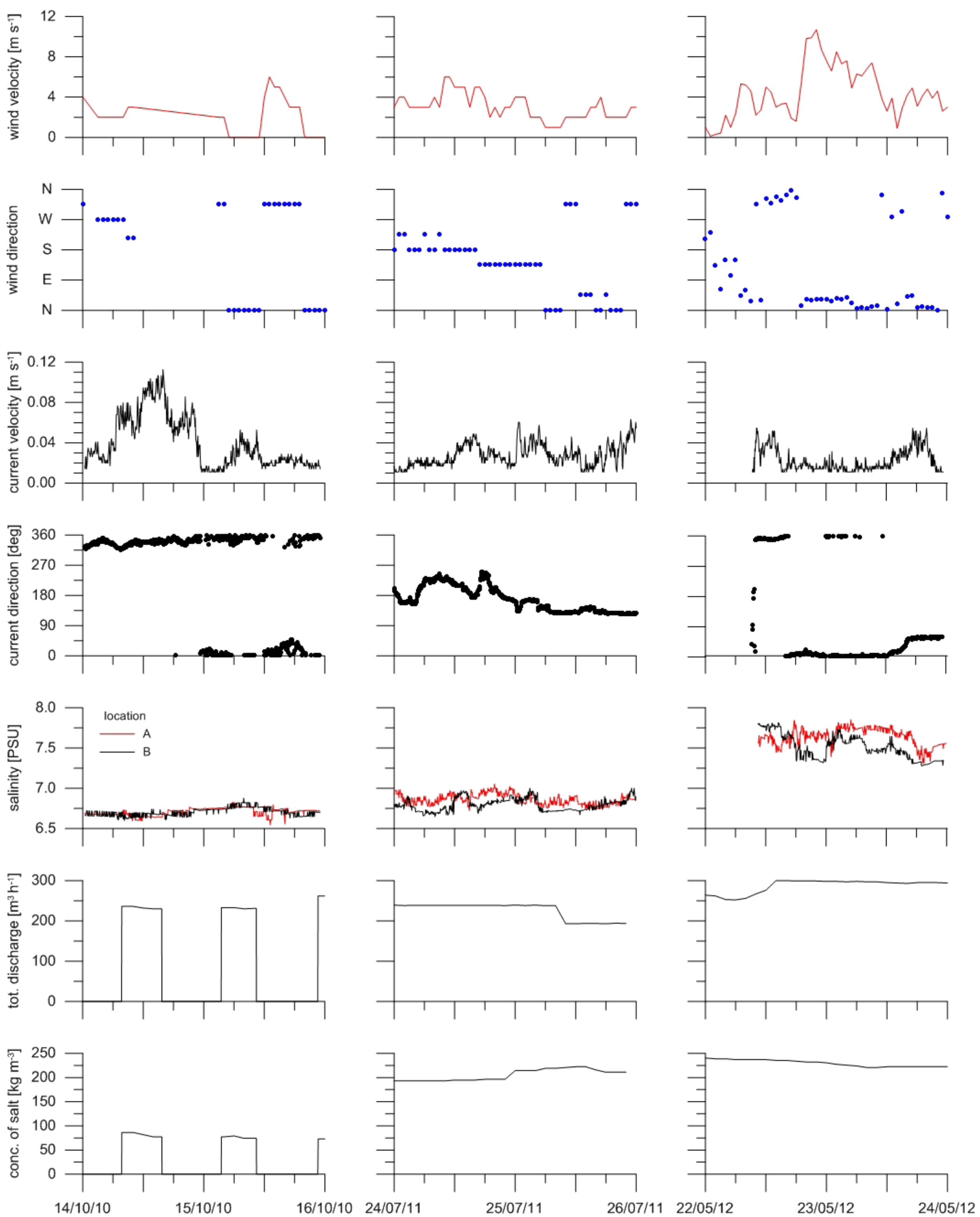

Figure 4

Changes in wind conditions (2010, 2011 – Gdynia station; 2012 – location S), water currents in location A, salinity in locations A and B, total discharge and concentration of salt in brine during three periods: early stage (2010), intermediate stage (2011), target stage (2012); sample results of measurements

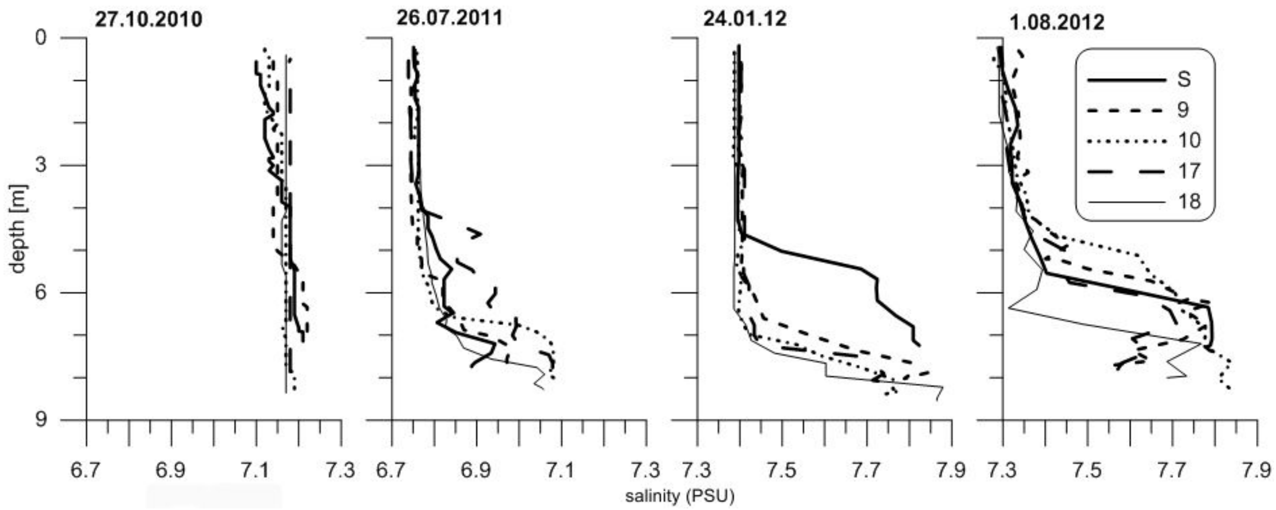

Figure 5

Salinity distribution in verticals S, 9, 10, 17 and 18 on four selected dates: 27.10.2010, 4.05.2011, 26.07.2011, 1.08.2012

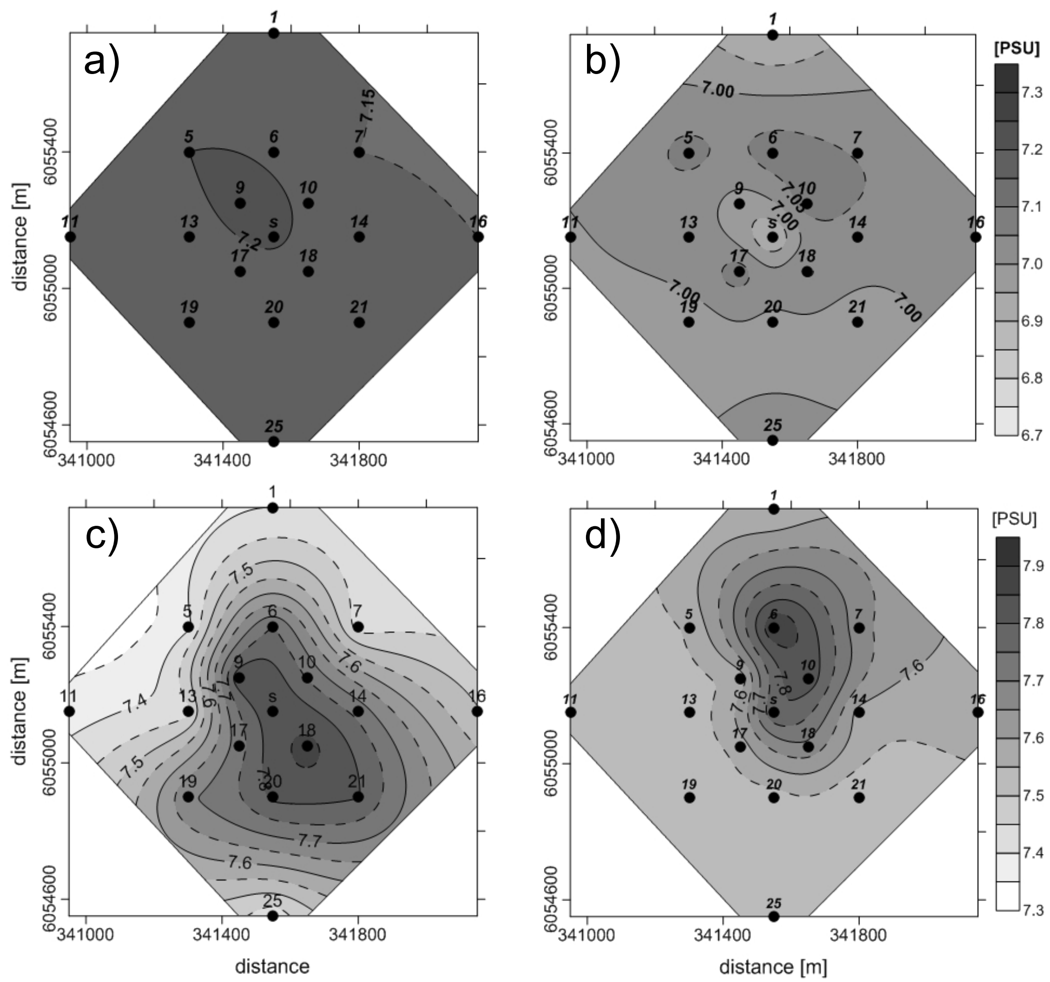

Figure 6

Spatial distribution of salinity in the bottom layer on: a - 27.10.2010, b - 26.07.2011, c - 24.01.2012 and d - 1.08.2012

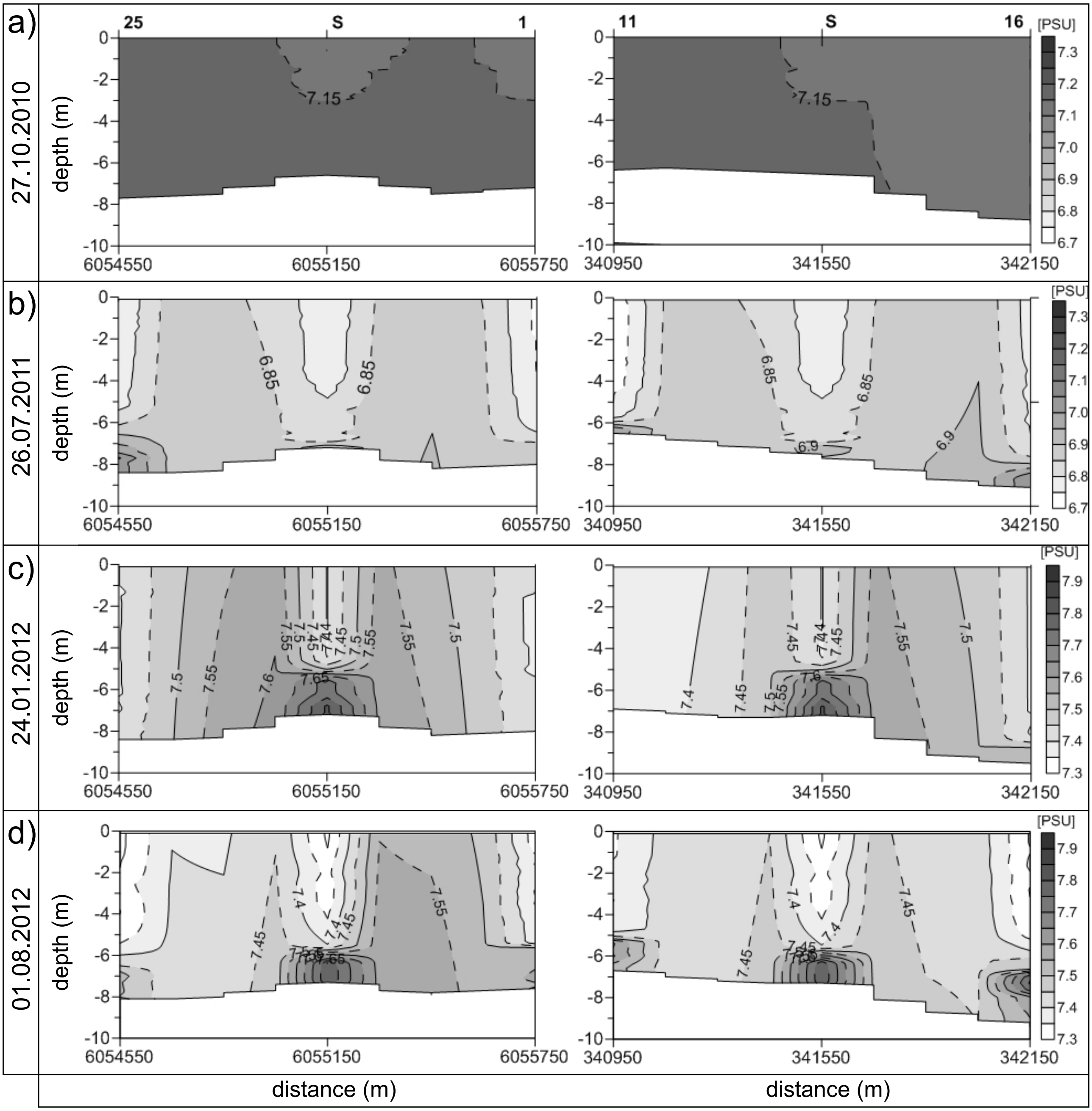

Figure 7

Salinity distribution in vertical cross-sections 25-1 and 11-16 on: a - 27.10.2010, b - 26.07.2011, c - 24.01.2012 and d - 1.08.2012

the highest salinity value can be expected in location S; such a situation was observed on 24 January 2012. On 26 July 2011 and 1 August 2012, the highest values of salinity in the lower part of verticals were observed in some locations in the close vicinity of the installation. This salinity pattern may have been caused by water currents and a non-uniform distribution of discharge among arms.

On the selected dates, salinity distributions in the bottom layer (Fig. 6) and in two perpendicular cross-sections (Fig. 7) present four different situations. In the first case – on 27 October 2010 – the amount and the concentration of salt in brine were low, leading to small variation in salinity values at the bottom (7.14-7.24 PSU, Fig. 6a). However, owing to water currents, a “plume” of higher salinity was shifted in the north-western direction. The asymmetry of water salinity is quite well seen in vertical cross-sections (Fig. 7a). Similar distributions on 26 July 2011 (Figs 6b, 7b) present a rather unusual situation when salinity at the center of the installation was lower than in the surrounding area. In that case, the salinity differences at the bottom ranged from 6.88 to 7.28 PSU, while the minimum value in the water column did not exceed 6.7 PSU.

On 24 January 2012, a "plume" of increased salinity at the bottom (7.35-7.90 PSU) was located quite symmetrically in relation to the center of the installation (Fig. 6c). This observation is confirmed by salinity distributions in two perpendicular cross-sections (Fig. 7c). On 1 August 2012, a clear, elongated "plume" of increased salinity at the bottom (7.50-7.95 PSU, Fig. 6d) moved northward from the center of the installation. It is very characteristic that the salinity "plume" is limited to 1-1.5 meters in thickness and a few hundred meters in the horizontal plane (Fig. 7d).

The above examples make it sufficiently clear that measurements in a single vertical at the center of the installation do not provide adequate information on brine spreading in the surrounding environment. A full analysis must be based on measurements conducted in a number of verticals. The above results show the effect of water currents on the shape of the high-salinity "plume", and demonstrate the close relationship between brine parameters and excess salinity patterns. The detailed analysis of salinity changes in Puck Bay in the period of October 2010 – December 2012 has shown (Robakiewicz 2014) that salinity excess hardly ever reached a value of 0.5 PSU.

Measurements in the vicinity of a single head

Numerous laboratory experiments (e.g. Abraham 1967; James et al. 1983; Roberts & Toms 1987, 1988; Roberts et al. 1997; Cipollina 2005; Shao & Law 2010; Bashitialshaaer et al. 2012) and some theoretical investigations (e.g. Oliver et al. 2013b) have been carried out to describe characteristic dimensions of a single jet (Fig. 8) and to assess the dilution of discharged brine in the ambient environment. The aim of the *in-situ* measurements taken on 26 August 2011 in the vicinity of a single diffuser's block was to register the behavior of a single jet under natural conditions, and to compare it with estimates based on laboratory experiments and theoretical investigations. From the engineering point of view, the coordinates of the trajectory maximum (X_Y, Y), the location of the impact/edge point (X_i/Xe) and the dilution coefficient are of greatest interest.

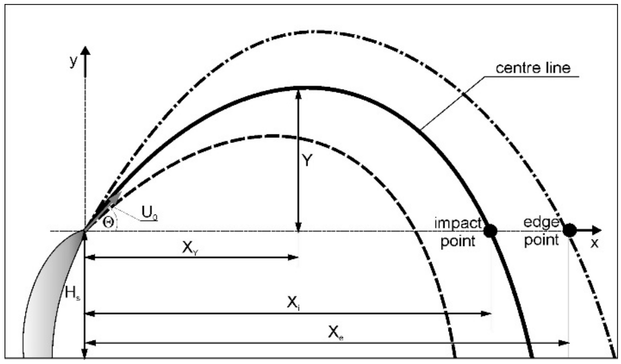

Figure 8
Schematic diagram of an idealized discharge configuration, where d – diameter of source, U_0 – initial velocity, Θ_0 – angle of incidence, X_Y, Y – coordinates of the maximum of the center line, X_i – coordinate of the impact point, X_e – coordinate of the edge point, H_s – source height above the boundary

In most cases, laboratory experiments were carried out for stagnant water (e.g. Roberts & Toms 1987, 1988; Roberts et al. 1997, Bashitialshaaer et al. 2012), whereas calm weather lasting more than a few hours is very unusual for the Puck Bay region. During the *in-situ* measurements, wind velocity measured at the Gdynia station was 1-2 m s^{-1} (Fig. 9). At the same time, the water flow velocity in location B at a depth of 1 meter above the bottom was 0.02-

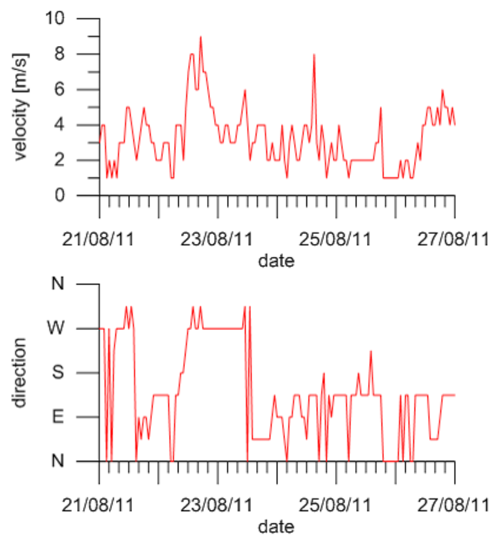

Figure 9
Wind conditions preceding in-situ measurements executed on 26 August 2011, as measured at the Gdynia station

0.06 m s-1 (Fig. 10), and the flow was directed to the north.

The detailed CTD measurements, covering 71 locations in an area of 17 × 17 meters (Fig. 11) were carried out in the vicinity of the D1-1 block equipped with nozzles of 0.009 m in diameter. The position of each CTD vertical was registered by a DGPS gauge. On 26 August 2011, salt concentration in brine 237 kg m^{-3} was discharged through the D1 arm at a rate of 61.1-61.4 m^3 h^{-1}, which means that the initial velocity at the nozzle was 22.20-22.45 m s^{-1}.

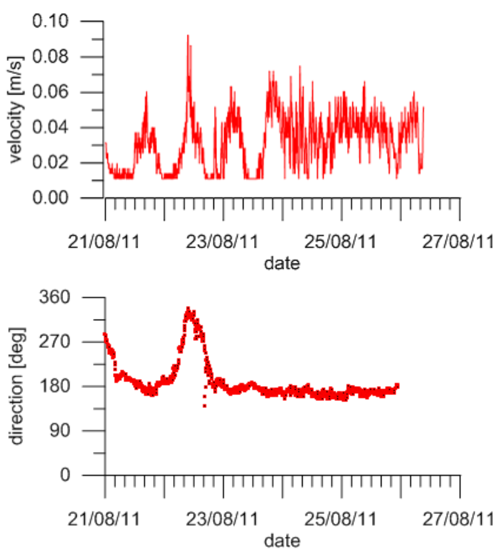

Figure 10

Water flow velocity and direction at a depth of 1m above the bottom in location B in the period of 21-26 August 2011

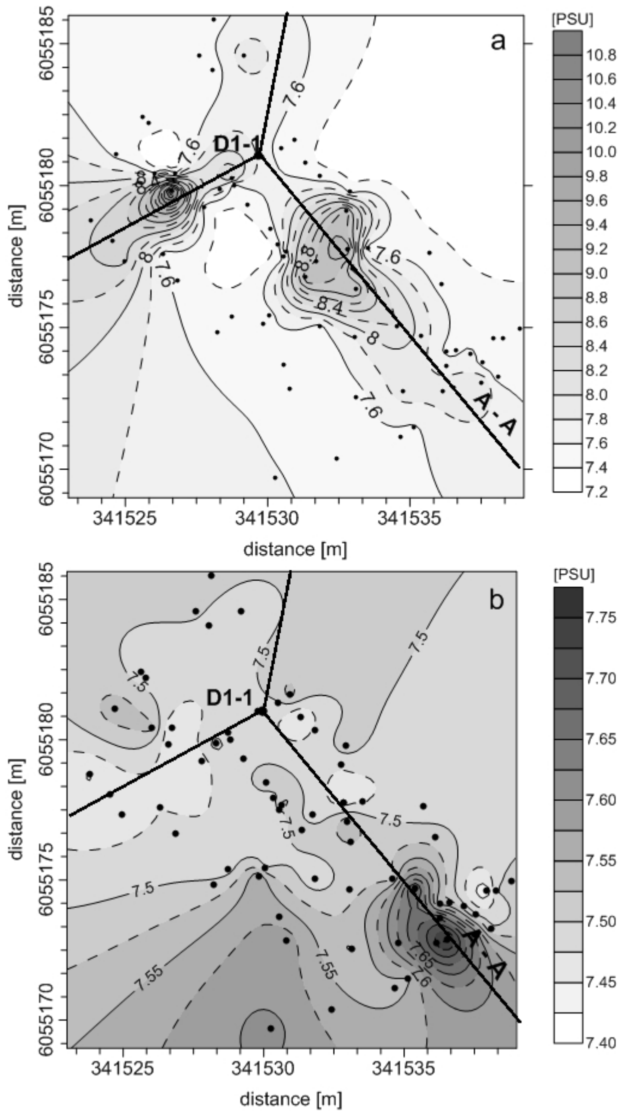

Figure 11

Spatial distribution of salinity: a – maximum salinity values in verticals, b – salinity at the bottom; dots – measurement locations

The spatial distribution of the maximum salinity values in verticals (Fig. 11a) shows three directions of salinity increase tracing the jets ejected from the D1-1 head. The spatial distribution of salinity in the bottom layer (Fig. 11b), obtained with the same data, clearly shows the area of increased salinity where a single jet reaches the bottom. The two above-mentioned distributions were used to select verticals for the presentation of the A-A vertical cross-section through a single jet.

The salinity distribution in Fig. 12 represents the A-A cross-section along the estimated axis of a single jet starting about 2 meters from the diffuser's block; measurements closer to the block do not coincide with the jet axis (Fig. 11). The trajectory of a single jet determined by measurements can be compared with characteristic dimensions predicted on the basis of laboratory experiments and derived in a pre-investment study using the JET3D model (Robakiewicz & Robakiewicz 2008). It should be mentioned that the discharge conditions assumed in that study were quite different from those encountered at the time of in-situ measurements. The major difference (Table 2) can be seen in the exit flow velocity, which was smaller during the in-situ measurements as a result of an increased nozzle diameter by 0.001m. In addition, a gentle water movement was registered under natural conditions.

The measured jet of brine was characterized by F_r ~190, whereas most of the previous laboratory

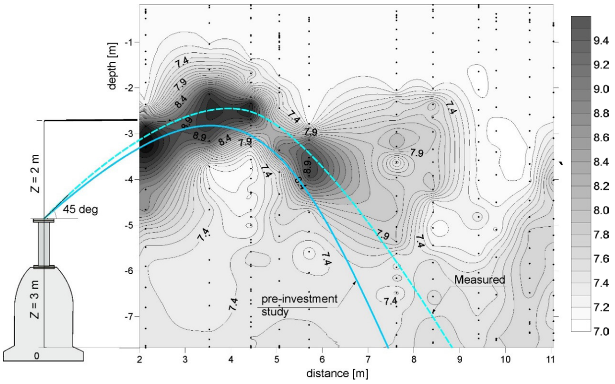

Figure 12

Salinity distribution in the A-A vertical cross-section based on in-situ measurements (dots) with the theoretical shape of a single jet estimated in the pre-investment study (solid line) and the center line location based on measurements (dashed line)

Table 2

Comparison of brine discharge conditions assumed in the pre-investment study and actual brine discharge conditions

Parameter	Assumed	Actual
nozzle diameter d (m)	0.008	0.009
exit flow velocity U_0 (m s^{-1})	30	22.2÷22.45
density of effluent ρ_e (kg m^{-3})	1160	1160
density of ambient water ρ_a (kg m^{-3})	1005	1005
densimetric Froude number F_r (-)	273	190-192
angle of incidence Θ (deg)	45	45
velocity in reservoir v (m s^{-1})	0	0.02 ÷ 0.06

$F_r = \frac{U_0}{\sqrt{gd\frac{|\rho_e-\rho_a|}{\rho_a}}}$; g - acceleration due to gravity

investigations were performed for jets characterized by F_r<100. Recent laboratory experiments of Bashitialshaaer et al. (2012), conducted under a wide range of conditions (F_r=21÷567), have shown substantial differences between characteristic dimensions of a jet in the cases of F_r<100 and F_r>100.

Formulas derived from laboratory experiments for F_r<100 (Cipollina, 2005; Bashitialshaaer et al. 2012) and from theoretical investigations (Oliver et al. 2013) were used to estimate the characteristic dimensions of a single jet. It appears that the results obtained by those formulas slightly underestimate the horizontal distances to the jet centerline maximum (X_y) and to the edge point (X_e), as well as the vertical distance to the trajectory centerline maximum (Y) (Fig. 13) in comparison with the *in-situ* observations. At the same time, the JET3D model overestimates the X_e value. The characteristic dimensions derived from the experiments for F_r>100, using the formulas, are much smaller than the measured values (Fig. 13). The main reason of the underestimation can be associated with non-stagnant water conditions in natural conditions, which move the brine away from its source.

One of the main purposes of the discharge installation was to improve the mixing of brine with the ambient environment. To assess the effectiveness of mixing processes, the dilution coefficient is commonly used. It can be estimated as:

$$S = \frac{C_0}{C_{Mc}}$$

where C_0 – jet concentration at the source; C_{Mc} – the maximum concentration for the impact point.

On the basis of measurements taken in Puck Bay, the dilution coefficient was estimated at S = 458. Numerous formulas based on laboratory experiments have been proposed to estimate this coefficient, yielding a wide range of values (203-323; Table 3), underestimating the dilution observed during the experiment. Similarly, the dilution coefficient estimated by the predictive models (123-360), and using analytical solution (182), are below the observed dilution. This result is compatible with the estimated characteristic dimensions of a single jet. It indicates that the use of formulas derived for stagnant conditions will, in the majority of discharges into the natural water bodies, lead to underestimation of the dilution coefficient because stagnant conditions hardly ever occur in natural conditions.

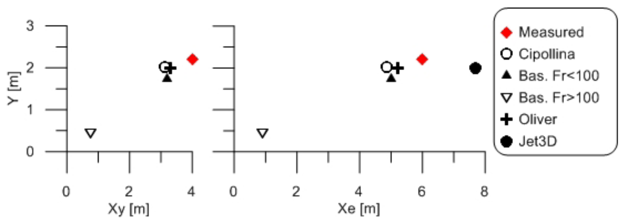

Figure 13

Comparison of the characteristic dimensions of a single jet estimated on the basis of measurements, relations derived from laboratory experiments (Cipollina 2005, Bashitialshaaer et al. 2012), theoretical investigations (Oliver 2013a) and the predictive model JET3D (Robakiewicz & Robakiewicz 2008)

Table3

Values of the return/impact point dilution coefficient *S* estimated by relations based on laboratory experiments, modelling approaches and analytical solution for discharge with a 45° angle of incidence and stagnant water conditions, compared with estimates based on in-situ measurements (H_s – source height above the boundary, *d* – source diameter, F_r – densimetric Froude number)

	$H_s/(F_r d)$	Dilution coefficient
Laboratory experiments		
Nemlioglu & Roberts (2006)	Not stated, boundary interaction	323
Shao & Law (2010)	0.05-0.47	239
Papakonstantis et al. (2011)	0.37-1.39	295±26,6
Lai & Lee (2012)	0.24-0.92	203
Analytical solution		
Kikkert et al. (2007)	No boundary	182
Predictive models		
VisJet (Lai 2010)	No boundary	148
CorJet (Jirka 2008)	No boundary	123
JET3D[1] (Robakiewicz & Robakiewicz 2008)	1.37	360
Measurements	1.75	458

[1] - condition as assumed in the pre-investment study

Shao and Law (2010) noted the potential influence of the bottom boundary on the dilution coefficient. They found that the minimum source height, necessary to avoid the influence of boundary interaction at the return point, should satisfy the relation $H_s/(F_r d) > 0.74$ (H_s – source height above the bottom). As shown in Table 3, the laboratory experiments were carried out under various conditions, with and without boundary interaction. High dilution observed in natural conditions can be associated with the negligible influence of the bottom boundary.

Concluding remarks

The *in-situ* measurements carried out in 2010-2012 in the vicinity of the brine discharge installation were conducted in different spatial and temporal scales and under a wide range of meteorological conditions. The continuous and CTD measurements during three stages of the increasing salt concentration in brine made it possible to analyze the mixing processes in the near-field of the installation. It was shown that excess salinity patterns depend on the discharge characteristic (its amount and concentration of salt) as well as on hydrodynamic conditions in the receiving reservoir. The spreading of brine was measured under gentle wind conditions when mixing was weak. Under such conditions, the excess salinity pattern was usually asymmetric with regard to the center of the installation because of bottom currents. A symmetric salinity pattern may be expected under windless conditions lasting sufficiently long to reduce the flow velocity to zero. However, in the case of the Puck Bay region, such conditions are extremely rare.

Measurements of a single jet behavior in the marine environment are quite unique. So far the jet configuration has been investigated by analytical approaches and laboratory experiments. Most of them dealt with jets characterized by low values of the densimetric Froude number (F_r<100) discharged into stagnant water. Measurements taken in 2011 in Puck Bay represent a situation when water velocity was 0.02-0.06 m s^{-1} and the jet was characterized by the densimetric Froude number F_r=190. The results of field measurements were compared with estimates done using the formulas derived from laboratory experiments and analytical investigations in terms of characteristic dimensions of a single jet and the dilution coefficient. It was found that the estimated characteristic dimensions of a single jet discharged into stagnant water were underestimated compared to the those observed during the field experiment. The estimates of the dilution coefficient done using the formulas derived from laboratory experiments, predictive models and analytical solutions for stagnant water conditions vary in a wide range of values (123÷360). These differences can be attributed to the influence of the bottom boundary represented by the $H_s/(F_r d)$ coefficient and the densimetric Froude number. The dilution coefficient evaluated based on the in-situ measurements is 1.2÷3.7 times higher than the value obtained using the predictive formulas for stagnant water conditions.

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