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Determination of changes in the degree of salinity of the marine water environment by acoustic methods

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Given the pressing need to address the escalating water supply challenges in the coastal regions of southeastern and southern Ukraine, the expansion of methodologies for identifying zones of submarine groundwater discharge (SGD) within the Ukrainian shelf of the Azov-Black Sea basin stands as a paramount task for national marine hydrogeologists and geoecologists. Consequently, the advancement of novel comprehensive methodologies and technologies for locating additional freshwater reservoirs specifically, the segment of groundwater outflow into the Black Sea geo-ecosystem (GES), holds immense potential to broaden the horizons for water provisioning to the populace and other stakeholders (such as agricultural entities, industrial sectors, etc.) across the coastal areas of Ukraine.

The article presents theoretical findings on the feasibility of using acoustic methods to detect changes in salinity of the marine aquatic subsystem (MASUS) within geo-ecosystem (GES) of the sea basin, particularly in areas where freshwater discharge from geological aquifers or riverbed runoff is probable. To achieve this objective, we examine the unique characteristics of acoustic signal reflection as it propagates through the MASUS water environment, analyzing variations in sound speed corresponding to changes in salinity within the marine water environment. Theoretical calculations employ methods from statistical physics and quantum mechanics to investigate such phenomena.

The comprehensive theoretical insights outlined in this article enable us to propose a practical and cost-effective approach for identifying sources of submarine groundwater discharge. This method combines two acoustic techniques: measuring sound speed within the MASUS water environment and assessing the reflection coefficient of an acoustic signal from the interface between MASUS water and the geological environment of GSUS GES within the marine basin.

Key words: marine water environment, degree of salinity, acoustic methods, submarine groundwater discharge.

Introduction. The importance of water resource development for improving economic efficiency and social welfare does not usually receive due assessment, although all types of socio-economic activities are largely dependent on the supply and water quality. As the populations grow and economies develop, many countries face water shortages. Demand for water is skyrocketing, with 70—80 % of water required for irrigation, less than 20 % needed to meet industrial needs, and only 6 % to meet household needs. A comprehensive approach to freshwater use as a limited and vulnerable resource and the inclusion of sectoral plans and programs for water use in national socio-economic policies have the ut-

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most significance for further economic activity. The goal is to meet all countries' freshwater needs for their sustainable development.

The integrated exploitation of water resources is based on the concept of water as an integral part of the ecosystem, one of the types of natural resources; the nature of its use is determined by its quantity and quality. For these purposes, water resources should be conserved, taking into account the functioning of aquatic ecosystems and the renewability aspect, to meet the people's needs or to align people's activities with the supply. During the development and use of water resources, priority should be given to meeting basic needs and ensuring the preservation of ecosystems.

The need to solve the growing problems of water supply to the coastal areas of the southeastern and southern regions of Ukraine, to expand the range of methods for detecting zones of SGD on the Ukrainian shelf of the Azov-Black Sea basin is one of the most important tasks of domestic marine hydrogeologists and geoecologists. Therefore, the development of new integrated methods and technologies to search for additional freshwater resources, i.e. the part of groundwater runoff that is discharged in the Black Sea GES space, can significantly expand the prospects for water supply to the population and other consumers (farms, industrial facilities, etc.) in the coastal regions of Ukraine [Borisenko, 2001; Iemelianov, 2003; Moore, 2010; Ivanov et al., 2010; Rodellas et al., 2015; Moosdorf, Oehler, 2017; Fresh …, 2021; Le Menn, Nair, 2022; Makar, 2022].

The theoretical foundations of a new method for detecting places of submarine freshwater *discharge* by determining the change in salinity of SASS using a complex of hydroacoustic methods are presented.

Materials and Methods. Remote methods for studying the seabed using sonar systems of various types, built according to a coherent scheme and using correlation methods for processing echo signals, can significantly increase the information content of marine research works of various types. Parametric echo sounders and sonar systems consisting of an echo sounder-profiler and an interferometric side-scan sonar with a chirp sounding signal, using similar schemes, can significantly improve remote methods for classifying bottom sediments. At the same time, both the instruments themselves and methods for extracting hydrophysical and geological-morphological information from experimental data are being developed. In recent years, sonar systems have been actively developing, using probing signals with linear frequency modulation and coherent processing of echo signals. In this case, useful information is contained in both amplitude, frequency, and phase characteristics of echo signals.

Sound reflection coefficient from the boundary between the spaces occupied by SASS and SGSS of marine GES. Let us consider the reflection of an acoustic wave propagating in a weak solution of SASS electrolyte from the boundary between the spaces occupied by SASS and SGSS of a marine GES. Let the reflection of sound from the specified section of SASS-SGSS occur in the plane of $X0Z$.

For the incident and the reflected from the SGSS plane wave in SASS space in the case of harmonic oscillations, we have [Landau, Lifshits, 2001]:

$$\varphi_1 = \varphi_0 \exp\left\{-ik_1\left(x\sin(\theta_1) - z\cos(\theta_1)\right)\right\}\exp\{i\omega t\},$$
$$\varphi_1 = \varphi_0 k_\mathrm{r} \exp\left\{-ik_1\left(x\sin(\theta_1') + z\cos(\theta_1')\right)\right\}\exp\{i\omega t\}, \qquad (1)$$

where φ_0 is amplitude, k_1 — wave number for water ($k_1 = 2\pi/\lambda$), θ_1 — angle of incidence composed of the normal to the wave front and the axis z, θ'_1 — angle of reflection, k_r — coefficient of reflection. The total field φ in water consists of the incident and reflected waves:

$$\varphi_1 = \varphi_0\Big[\exp\left\{-ik_1\left(x\sin(\theta_1) - z\cos(\theta_1)\right)\right\} + k_\mathrm{r}\exp\left\{-ik_1\left(x\sin(\theta_1') + z\cos(\theta_1')\right)\right\}\Big]\exp\{i\omega t\}. \qquad (2)$$

In the following, we will omit the multiplier $\exp\{i\omega t\}$.

We will consider a layer of unconsolidated sediments composed of silt-type sediments as an SGSS. In this case, the shear modulus is practically zero; therefore, there are no transverse (shear) waves in it [Hampton, 1973].

Then, for a longitudinal wave propagating in the SGSS, we can write

$$\varphi_2 = \varphi_0 W \exp\left\{-ik_2\left(x\sin\left(\theta_2\right) - -z\cos\left(\theta_2\right)\right)\right\}, \quad (3)$$

where θ_2 is the angle of refraction, k_2 is the wave number for the wave propagating in SGSS, and W is the transparency coefficient for the longitudinal wave.

When crossing the interface between SASS and SGSS, the continuity of pressures must be observed, i.e., at z=0, the pressures are equal on both sides of the interface. Thus, at z=0 we have:

$$\varphi_1 \exp\left\{-2\pi ixf\frac{\sin\left(\theta_1\right)}{c_1}\right\} + +k_r\rho_1\left\{-2\pi ixf\frac{\sin\left(\theta_1'\right)}{c_1}\right\} - -W\rho_2\exp\left\{-2\pi ixf\frac{\sin\left(\theta_2\right)}{c_2}\right\} = 0, \quad (4)$$

where ρ_1 and ρ_2 — density of seawater (SASS) and soil (SGSS), respectively, f — linear frequency (f=ω/2π) acoustic wave, and c_1 and c_2 are the speed of sound in seawater and soil, respectively. It follows from equation (4) that [Isakovich, 1973]:

$$\frac{\sin\left(\theta_1\right)}{c_1} = \frac{\sin\left(\theta_1'\right)}{c_1} = \frac{\sin\left(\theta_2\right)}{c_2}. \quad (5)$$

The last expression shows that $\theta_1=\theta'_1$, i.e., that the angle of incidence is equal to the angle of reflection. In addition, it follows from formula (5) that

$$\frac{\sin\left(\theta_1\right)}{\sin\left(\theta_2\right)} = \frac{c_1}{c_2}. \quad (6)$$

In turn, from expression (4), we obtain the following relations

$$W=1+k_r. \quad (7)$$

Further, from the equality of normal velocities in both media at the interface, taking into account the relation $\theta_1=\theta'_1$, we have

$$\frac{\cos\left(\theta_1\right)}{c_1}\left(1-k_r\right) = \frac{\rho_1 W}{\rho_2 c_2}\cos\left(\theta_2\right). \quad (8)$$

Solving equation (8) in conjunction with (7), taking into account the relation (6), we find an expression for the reflection coefficient of the acoustic wave from the SGSS (actually, the bottom of the reservoir)

$$k_r = \frac{m\cos\left(\theta_1\right) - \sqrt{n^2 - \sin^2\left(\theta_1\right)}}{m\cos\left(\theta_2\right) - \sqrt{n^2 - \sin^2\left(\theta_2\right)}}, \quad (9)$$

where $m=\rho_2/\rho_1$ and $n=c_2/c_1$.

Reflection coefficient with loss adjustment. Formula (9) can also be applied in the case of reflection from an SGSS with losses, as well as considering the losses of an acoustic wave propagating in an electrolyte solution [Mackenzie, 1960]. Therefore, we consider the velocities c_1 and c_2 in formula (9) to be complex, i.e.

$$c_1^2 = c_{1,0}^2\left(1+i\eta_1\right),\ c_2^2 = c_{2,0}^2\left(1+i\eta_2\right), \quad (10)$$

where $c_{1,0}$ and $c_{2,0}$ is the material fraction of the sound velocity in SASS and SGSS, respectively, η_1 and η_2 are relevant loss factors.

Then, after some rather cumbersome transformations, we obtain for the reflection coefficient $R=|k_r|^2$, taking into account the losses, the following expression

$$R = \frac{4X^2\left(m\cos\left(\theta_1\right) - X\right)^2 + n_0^4\varepsilon^2}{4X^2\left(m\cos\left(\theta_1\right) + X\right)^2 + n_0^4\varepsilon^2}, \quad (11)$$

where

$$X = \frac{1}{\sqrt{2}}\sqrt{n_0^2 - \sin^2\left(\theta_1\right) + \sqrt{\left(n_0^2 - \sin^2\left(\theta_1\right)\right)^2 + n_0^4\varepsilon^2}},$$

$$\varepsilon = \frac{\eta_1 - \eta_2}{1+\eta_1\eta_2}, \quad (12)$$

and

$$n_0 = \frac{c_{1,0}}{c_{2,0}}\sqrt{\frac{1+\eta_1\eta_2}{1+\eta_2^2}}. \quad (13)$$

Here are some of the experimental data. According to Hamilton et al. [1956], in the frequency range 23—35 kHz, sound velocity $c_{2,0}$ in SGSS is 1.480 to 1.730 meters per second; the attenuation coefficient of longitudinal waves η_2 is in the range of 0.63—0.3 dB/cm. Also, the sound velocity in a clay medium with a density of ρ_2=1.82 g/cm^3 is 1755 m/s.

The formula can determine the value of the sound velocity in SASS

$$c_{0,1} = \sqrt{\frac{k}{\rho_1}}, \qquad (14)$$

where k is the coefficient of volume elasticity and ρ_1 is SASS density. In marine conditions, under the influence of changes in temperature, salinity, and static pressure, the modulus of volume elasticity and density of SASS undergo significant changes, as a result of which the sound velocity can reach values ranging from 1440 to 1540 m/s. The dependence of the sound velocity on temperature, salinity, and static pressure was established experimentally. According to Del Grosso formula [1952]:

$$c_{1,0} = 1448.6 + 4.618t - 0.0523t^2 + 0.00023t^3 + \\ +1.25(S-35) - 0.011(S-35)t + \\ +0.0027\cdot 10^{-5}(S-35)t^4 - 2\cdot 10^{-7}(S-35)^4 \times \\ \times\left(1+0.577t-0.0072t^2\right) + 0.0175h, \qquad (15)$$

where $c_{1,0}$ is the sound velocity in m/s, t is the temperature in °C, h is the depth in meters, and S is salinity in ‰ (g/kg). The salinity of SASS is calculated from the ratio of electrical conductivity of the sample and standard solution according to the empirical formula:

$$S = \alpha_0 + K, \qquad (16)$$

where α_0=0.008 and K — relative electrical conductivity of seawater under standard conditions.

The average salinity of the World Ocean is 35 ‰. In the Dead Sea S~350 ‰ [Stepanov, 1983]. Sound absorption in a neutral liquid is related to the influence of viscosity and thermal conductivity since the process of sound propagation is not completely adiabatic. SASS is characterized by the presence of dissolved salts and various impurities. Experimental studies have shown that the sound absorption observed in SASS can be explained by the dissociation of boric acid molecules H_3BO_3 and magnesium sulfate $MgSO_4$, the relaxation frequencies of which are respectively [Francois, Garrison, 1982]:

$$f_1 = 0.78\sqrt{S/35}e^{t/26},\ f_2 = 42e^{t/17}. \qquad (17)$$

Both frequencies depend on the temperature t, but only the boric acid relaxation frequency depends on the salinity SASS S.

The generalized formula for calculating the attenuation coefficient, taking into account the attenuation in fresh water and the chemical relaxation mechanism, according to [Ainslie, McColm, 1998], is as follows:

$$\alpha = 0.106\frac{f_1 f^2}{f_1^2+f^2}e^{(\mathrm{pH}-8)/0.56} + \\ +0.52\left(1+\frac{t}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f_2^2+f^2}e^{-h/6000} + \\ +0.00049f^2e^{-(t/27+h/17000)}, \qquad (18)$$

where f — is the frequency of sound in kHz, and pH is the hydrogen index. SASS is a slightly alkaline medium; its hydrogen pH varies from 7.5 to 8.4. The attenuation value α in formula (18) is related to η_1 (10) as follows:

$$\eta_1 = \tan\left[2\arcsin\left(\frac{\alpha c_{1,0}}{20000\pi f}\right)\right]. \qquad (19)$$

Results. ***Detection of changes in salinity of SASS by measuring the reflection coefficient.*** Graph 1 shows the dependence of the sound velocity (15) on the degree of electrolysis K (‰) of SASS. Graphs 2 and 3 show the dependence of loss coefficient (19), which is included as an imaginary addition to the sound velocity c_1 (10), under different conditions, on K. Fig. 1 shows the dependence of the sound velocity (15) on the degree of electrolysis K (‰) of SASS. Fig. 2 and 3 show the dependence of loss coefficient (19), which is included as an imaginary addition to the sound velocity c_1 (10), under different conditions, on K. Fig. 4—8 show the dependence of reflection coefficient (11), expressed as a percentage, under different conditions (including different angles of incidence

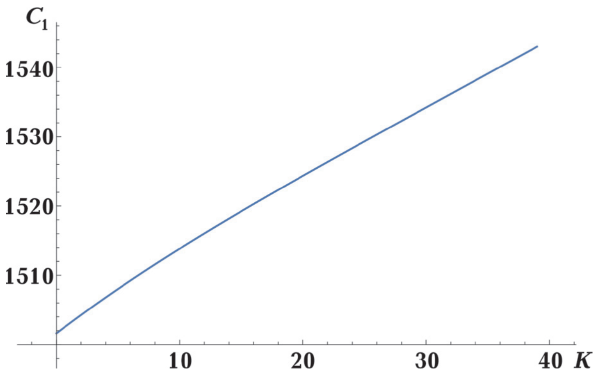

Fig. 1. The velocity of sound (15) at t=26 °C, h=100 m.

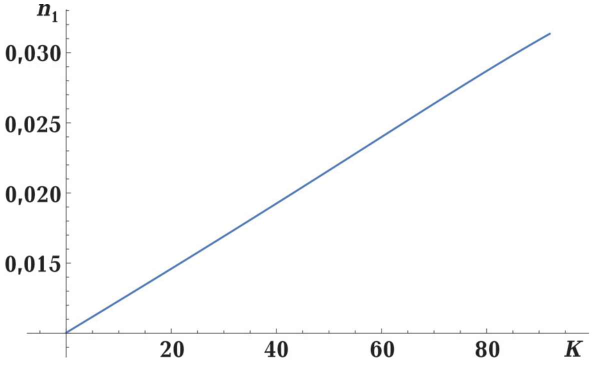

Fig. 2. Loss factor (19) at t=30 °C, f=1 MHz, pH=8, h=100 m.

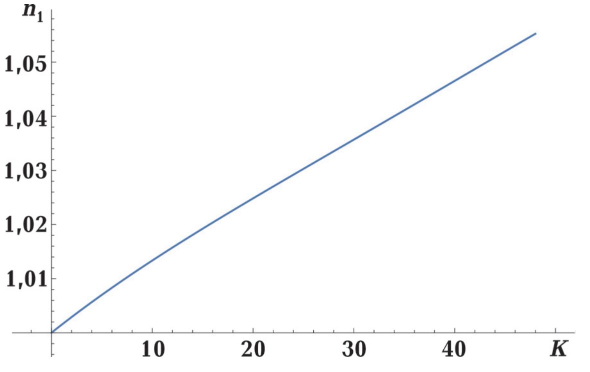

Fig. 3. Loss factor (19) at t=30 °C, f=10^8 Hz, pH=8, h=300 m.

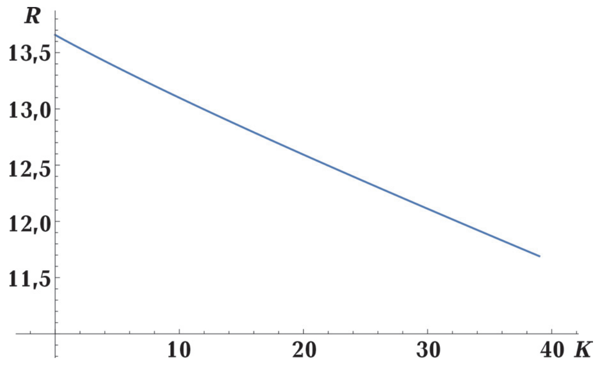

Fig. 4. Reflection coefficient R×100 % (11) at t=30 °C, f=30 kHz, pH=7.5, h=1000 m, θ_1=0 (normal drop), $c_{2,0}$=1755 m/s, η_2=0.3.

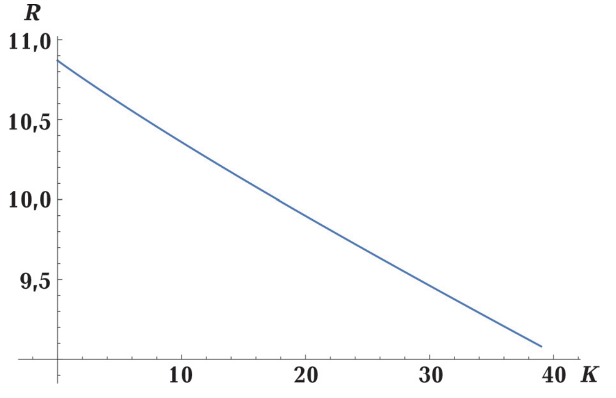

Fig. 5. Reflection coefficient R×100 % (11) at t=30 °C, f=30 kHz, pH=7.5, h=1000 m, θ_1=0 (normal drop), $c_{2,0}$=1600 m/s, η_2=0.3.

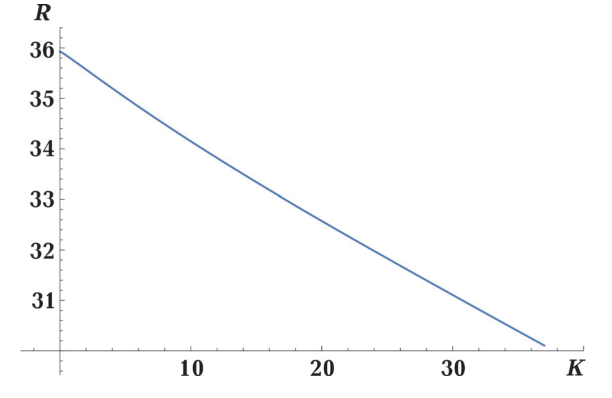

Fig. 6. Reflection coefficient R×100 % (11) at t=30 °C, f=30 kHz, pH=7.5, h=100 m, θ_1=60°, $c_{2,0}$=1755 m/s, η_2=0.3.

θ_1), on the degree of K electrolysis of SASS. Fig. 9—11 show the dependence of the function $r(\theta)=R(\theta)/R(0)$ on the K electrolysis of SASS at different angles of incidence θ. In all graphs, $\rho_1=1+S\cdot10^{-3}$ (g/cm^3).

Detection of changes in salinity of SASS by measuring the velocity of sound in it. Suppose that we measured the velocity of sound in SASS at t=10 °C, h=100 m, depending on the distance r from the conditional initial coordinate r=0, and found that in the interval 40—60 m, the sound speed drops by a certain amount in a jump, and then the speed value returns to the initial value. This indicates that

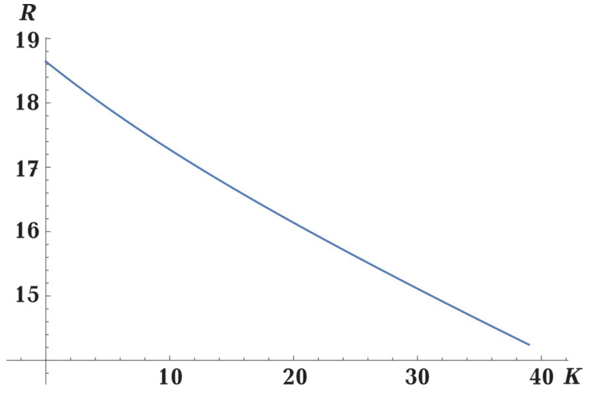

Fig. 7. Reflection coefficient R×100 % (11) at t=30 °C, f=30 kHz, pH=7.5, h=500 m, θ_1=60°, $c_{2,0}$=1600 m/s, η^2=0.3.

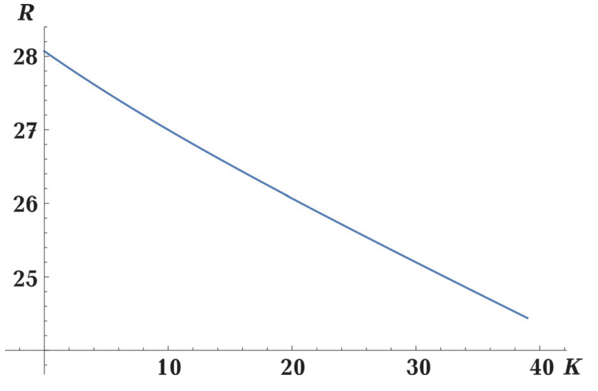

Fig. 8. Reflection coefficient R×100 % (11) at t=30 °C, f=30 kHz, pH=7.5, h=100 m, θ_1=45°, $c_{2,0}$=1755 m/s, η_2=0.6.

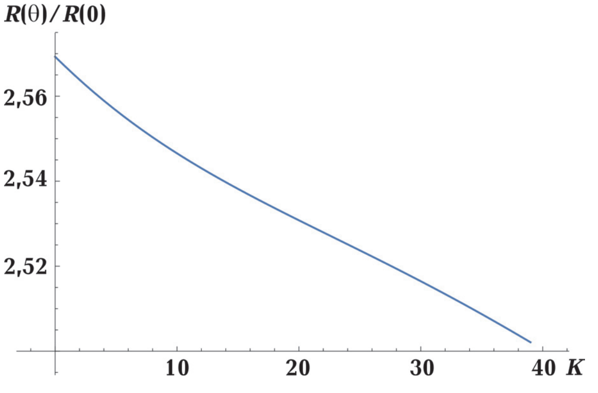

Fig. 9. Graph of the function $r(\theta)$ at t=30 °C, f=27 kHz, pH=7, h=100 m, $\theta=\pi/3$.

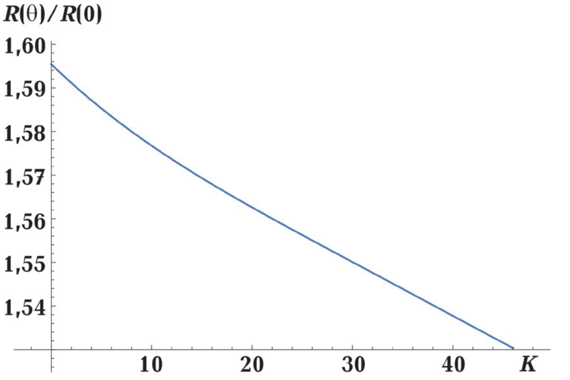

Fig. 10. Graph of the function $r(\theta)$ at t=30 °C, f=27 kHz, pH=7, h=100 m, $\theta_1=\pi/4$.

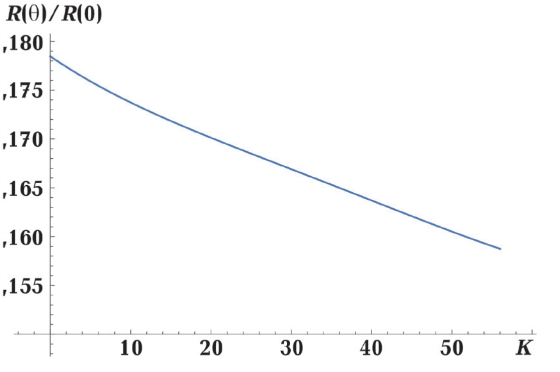

Fig. 11. Graph of the function $r(\theta)$ at t=30 °C, f=27 kHz, pH=8, h=100 m, $\theta=\pi/6$; f=30 kHz, pH=7.5, h=500 m, θ_1=60°, $c_{2,0}$=1600 m/s, η_2=0.3.

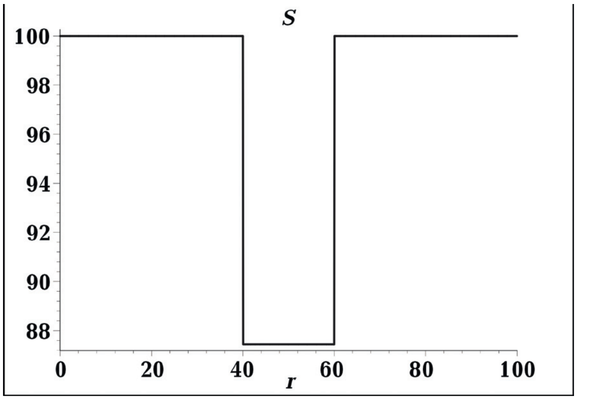

Fig. 12. Graph of changes in the relative salinity S expressed as a percentage of salinity in r=0, at t=10 °C, h=100 m, depending on the distance r, in the case when sound velocity in the interval 40—60 m has decreased by 10 m/s.

in such interval, the salinity of SASS may be decreasing, i.e., its desalination is taking place. Figs. 12—14 show the dependence of the relative salinity S expressed as a percentage (salinity at the point r=0 is assumed to be 100 %) on the distance r (m) in three cases.

The velocity of sound in SASS was calculated using the formula (15).

All three graphs show a significant change in sound velocity with corresponding changes in salinity.

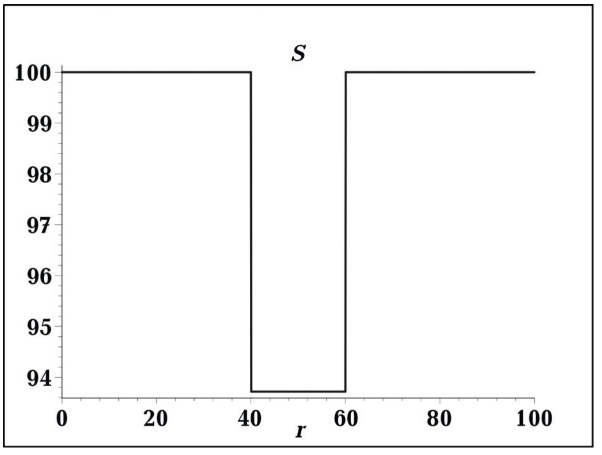

Fig. 13. Graph of changes in the relative salinity S expressed as a percentage of salinity in r=0, at t=10 °C, h=100 m, depending on the distance r, in the case when sound velocity in the interval 40—60 m has decreased by 5 m/s.

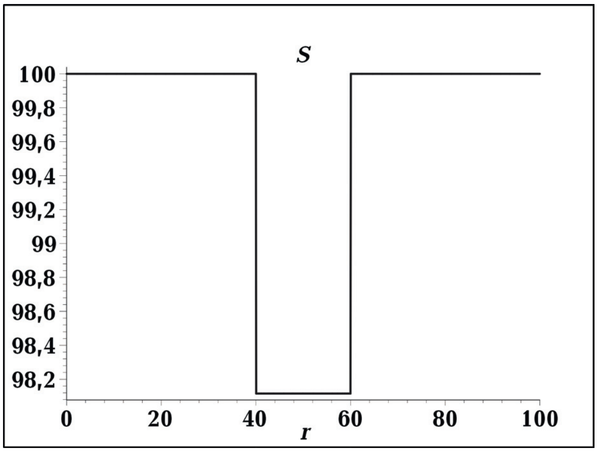

Fig. 14. Graph of changes in the relative salinity S expressed as a percentage of salinity in r=0, at t=10 °C, h=100 m, depending on the distance r, in the case when sound velocity in the interval 40—60 m has decreased by 1.5 m/s.

Conclusions. The dependence of the reflection coefficient of an acoustic signal propagating in SASS (seawater) on the boundary with SGSS (seabed soil) in the plane wave approximation, without taking into account the occurrence of shear waves in the layer of SGSS (unconsolidated sediments), is investigated basis on empirical formulas for velocity and attenuation of sound in SASS. The graphs above demonstrate a certain dependence of the sound reflection coefficient on the degree of electrolysis (salinity) of SASS under various external conditions and angles of incidence. We calculated the reflection coefficient from an SGSS with losses. Thus, we also took into account the effect of sound attenuation in the ground on the possibility determining changes in the degree of salinity of sea water using acoustic methods.

We also analyzed the magnitude of chan-ge in the sound velocity in SASS with corresponding changes in salinity and found a significant direct correlation between these values.

The presented theoretical data enable us to propose a practical method for finding the sites of freshwater discharge in SASS by determining the change in salinity of the water environment of an aquatic subsystem of the Ocean geoecosystem using acoustic methods, namely, by way of measuring the sound velocity in SASS and the reflection coefficient of acoustic signal from the denser SGSS of marine geoecosystem.

Given the importance and urgency of the search for fresh water, an attempt was made to reduce the costs of solving this problem, to theoretically prove the possibility of determining a «weak» signal against the background of other received signals. It appears this has been successful, and thus, it proves the feasibility of continuing such research and objectively verifying the obtained results in natural conditions.

References

Ainslie, M.A., & McColm, J.G. (1998). A simplified formula for viscous and chemical absorption in sea water. *The Journal of the Acoustical Society of America, 103*(3), 1671—1672. https://doi.org/10.1121/1.421258.

Borisenko, L.S. (2001). Hydrogeological Conditions of Submarine Groundwater Discharge in the Crimea. *Water Resources, 28*, 15—21. https://doi.org/10.1023/A:1018820628197.

Del Grosso, V.A. (1952). *The Velocity of Sound on Sea Water of Zero Depth*. Naval Research Laboratory Report, N 4002.

Francois, R.E., & Garrison, G.R. (1982). Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. *The Journal of the Acoustical Society of America, 72*, 1879—1890. https://doi.org/10.1121/1.388673.

Fresh Water under the Sea of Azov. (2021). Retrieved from https://www.eurasiareview.com/12052021-russia-to-drillfor-fresh-water-under-azov-sea-not-to-help-crimea-but-to-back-its-claims-analysisIemelianov, V.A. (2003). *Fundamentals of marine geoecology. Theoretical and methodological aspects*. Kyiv: Naukova Dumka, 300 p. (in Russian).

Hamilton, E.L., Shumway, G., Menard, H.W., & Shipec, C.J. (1956). Acoustic and Other Physical Properties of Shallow-Water Sediments off San Diego. *The Journal of the Acoustical Society of America, 28*(1). https://doi.org/10.1121/1.1908210.

Hampton, L. (Ed.). (1973). *Physics of sound in marine sediments*. Proc. of a symposium conducted by the Ocean Science and Technology, 569 p.

Isakovich, M.A. (1973). *General Acoustics*. Moscow: Nauka, 502 p. (in Russian).

Ivanov, V.A., Prusov, A.V., & Chepyzhenko, A.I. (2010). A submarine groundwater discharge in the region of the cape Aya (Crimea). *Reports of the National Academy of Sciences of Ukraine*, (2), 103—109. https://www.libr.dp.ua/text/dan_2010_2_18.pdf (in Russian).

Landau, L.D., & Lifshits, E.M. (2001). *Theoretical physics: textbook (in 10 vol.). Hydrodynamics. Vol. VI*. Moscow: Fizmatlit, 736 p. (in Russian).

Le Menn, M., & Nair, R. (2022). Review of acoustical and optical techniques to measure absolute salinity of seawater. *Frontiers in Marine Science*, (9). https://doi.org/10.3389/fmars.2022. 1031824.

Mackenzie, K.V. (1960). Reflection of Sound from coastal Bottoms. *The Journal of the Acoustical Society of America, 32*(2), 221—231. https://doi.org/10.1121/1.1908019.

Makar, A. (2022). Simplified Method of Determination of the Sound Speed in Water on the Basis of Temperature Measurements and Salinity Prediction for Shallow Water Bathymetry. *Remote Sensing, 14*, 636. https://doi.org/10.3390/rs14030636.

Moore, W.S. (2010). The effect of submarine groundwater discharge on the ocean. *Annual Review of Marine Science*, (2), 59—88. https://doi.org/10.1146/annurev-marine-120308-081019.

Moosdorf, N., & Oehler, T. (2017). Societal use of fresh submarine groundwater discharge: An overlooked water resource. *Earth-Science Reviews, 171*, 338—348. https://doi.org/10.1016/j.earscirev.2017.06.006.

Rodellas, V., Garcia-Orellana, J., Masqué, P., Feldman, M., & Weinstein, Y. (2015). Submarine groundwater discharge as a major source of nutrients to the Mediterranean Sea. *Proceedings of the National Academy of Sciences, 112*, 3926—3930. https://doi.org/10.1073/pnas.1419049112.

Stepanov, V.N. (1983). *Oceanosphere*. Moscow: Mysl, 270 p. (in Russian).

Визначення зміни ступеня солоності морського водного середовища акустичними методами

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У зв'язку з необхідністю розв'язання зростаючих проблем водозабезпечення приморських районів південно-східних і південних областей України розширення комплексу методів виявлення зон субмаринного розвантаження прісних вод на українському шельфі Азово-Чорноморського басейну є одним з найважливіших завдань вітчизняних морських гідрогеологів та геоекологів. Отже, розробка нових комплексних методів і технологій пошуку додаткових прісноводних ресурсів, тобто тієї частини підземного стоку, що розвантажується в просторі геоекосистеми (ГЕС) Чорного моря, дає можливість значно розширити перспективи водозабезпечення населення та інших споживачів (аграріїв, промисловців тощо) приморських районів України.

У статті наведено результати теоретичних досліджень щодо визначення за допомогою акустичних методів зміни солоності водного середовища шквальної субсистеми (МАСУС) ГЕС морського басейну в місцях імовірного розвантаження прісних вод з геологічних водоносних горизонтів або підруслового стоку річок. Для досягнення цієї мети розглянуто особливості відбиття акустичного сигналу, що поширюється в просторі водного середовища МАСУС, від її межі з геологічною субсистемою (ГСУС) ГЕС морського басейну, проаналізовано ступінь зміни швидкості поширення звуку залежно від солоності за її відомої зміни у морському водному середовищі. При відповідних теоретичних розрахунках залучаються методи статистичної фізики і квантової механіки.

На підставі наведених у статті теоретичних даних запропоновано практичний та більш дешевий метод порівняно з іншими методами виявлення джерел субмаринного розвантаження прісних вод. Основою методу є комбінація акустичних методів: методу вимірювання швидкості поширення звуку у водному середовищі МАСУС та методу вимірювання коефіцієнта відбиття акустичного сигналу від граничної поверхні між просторами, зайнятими, з одного боку, водним середовищем МАСУС, а з іншого — геологічним середовищем ГСУС ГЕС морського басейну.

Ключові слова: морське водне середовище, ступінь солоності, акустичні методи, субмаринне розвантаження прісних вод.