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NUMERICAL SIMULATION OF THERMOHYDRODYNAMICS DURING HEATED WATER DISCHARGE INTO LAKE BALKHASH

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Abstract. This paper presents a numerical study of thermal pollution from a potential discharge of heated water from a nuclear power plant's cooling system into the coastal zone of Lake Balkhash. The aim of the study was to determine the dynamics of the formation and spatial propagation of the thermal footprint, as well as to assess its impact on the hydrodynamic characteristics of the water area. A two-dimensional computational fluid dynamic (CFD) model based on the Navier-Stokes and energy equations, supplemented by a k-ω SST turbulence model, was used for the simulation. The simulation was conducted using the geometry of a real coastline. The model was validated using a test jet injection problem, which demonstrated good agreement with experimental data. The experimental data were taken from the work of other authors. Modeling results showed that within the first hour after the discharge begins, a stable zone of thermal pollution, approximately 1.5 km^2 in area, forms, where water temperatures exceed background values by 0.5–1.0 K. The high-temperature plume gradually transforms into a diffuse heat spot, which persists in the coastal zone due to weak water exchange and recirculation. Velocity field analysis revealed zones of local circulation that facilitate long-term heat retention. The scientific novelty of the study lies in the use of computational fluid dynamics (CFD) to assess the thermohydrodynamics of discharge under conditions of limited water exchange in a large lake with the actual morphology of the shoreline of Lake Balkhash. The practical significance lies in the potential use of the developed method for predicting environmental risks and optimizing the cooling systems of nuclear and thermal power plants located near the lake.

Keywords: thermal pollution, CFD modeling, Lake Balkhash, heated waters, SST k–ω model, hydrodynamics, environmental safety

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БАЛҚАШ КӨЛІНЕ ЖЫЛЫ СУ АҒЫЗУ КЕЗІНДЕГІ ТЕРМОГИДРОДИНАМИКАНЫ САНДЫҚ МОДЕЛЬДЕУ

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Аннотация. Бұл мақалада атом электр станциясының салқындату жүйесінен Балқаш көлінің жағалау аймағына қыздырылған судың ықтимал ағызылуынан термиялық ластанудың сандық зерттеуі ұсынылған. Зерттеудің мақсаты жылулық іздің пайда болу динамикасын және кеңістіктік таралуын анықтау, сондай-ақ оның су айдынының гидродинамикалық сипаттамаларына әсерін бағалау болды. Модельдеу үшін Навье-Стокс және энергия теңдеулеріне негізделген екі өлшемді есептеу сұйықтық динамикасы (CFD) моделі қолданды, қосымша k-ω SST турбуленттілік моделімен толықтырылды. Модельдеу нақты жағалау сызығының геометриясын қолдана отырып жүргізілді. Модель эксперименттік деректермен жақсы сәйкестікті көрсеткен сынақ ағынды инжекция есебін қолдана отырып тексерілді. Ал эксперименттік деректер басқа авторлардың жұмыстарынан алынды. Модельдеу нәтижелері ағызылу басталғаннан кейінгі алғашқы сағат ішінде су температурасы фондық мәндерден 0.5–1.0 K асатын ауданы шамамен 1.5 км² болатын тұрақты термиялық ластану аймағы пайда болатынын көрсетті. Сондай-ақ жоғары температуралы шлейф біртіндеп су алмасуының және қайта айналымының әлсіздігіне байланысты жағалау аймағында сақталатын диффузиялық жылу нүктесіне айналады. Жылдамдық өрісін талдау ұзақ мерзімді жылуды сақтауға ықпал ететін жергілікті айналым аймақтарын анықтады. Зерттеудің ғылыми жаңалығы Балқаш көлінің жағалау сызығының нақты морфологиясымен бірге үлкен көлде шектеулі, ал су алмасу жағдайында ағынды сулардың термогидродинамикасын бағалау үшін есептеу сұйықтық динамикасын (CFD) пайдалануда жатыр. Тәжірибелік маңыздылығы көлдің жанында орналасқан атом және жылу электр станцияларының салқындату жүйелерін экологиялық тәуекелдерді болжау және оңтайландыру үшін әзірленген әдісті қолдану мүмкіндігінде жатыр.

Түйін сөздер: термиялық ластану, CFD модельдеу, Балқаш көлі, жылытылған сулар, SST k–ω моделі, гидродинамика, экологиялық қауіпсіздік

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ТЕРМОГИДРОДИНАМИКИ ПРИ СБРОСЕ ПОДОГРЕТЫХ ВОД В ОЗЕРО БАЛХАШ

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Аннотация. В данной работе представлено численное исследование теплового загрязнения от возможного сброса нагретой воды из системы охлаждения атомной электростанции в прибрежную зону озера Балхаш. Целью исследования являлось определение динамики формирования и пространственного распространения теплового следа, а также оценка его влияния на гидродинамические характеристики акватории. Для моделирования использовалась двумерная вычислительная гидродинамическая модель (CFD), основанная на уравнениях Навье-Стокса и энергии, дополненная k-ω SST-моделью турбулентности. Моделирование проводилось на основе геометрии реальной береговой линии. Валидация модели была проведена на тестовой задаче инжекции струи, которая показала хорошее согласие с экспериментальными данными. Экспериментальные данные были взяты с работ других авторов. Результаты моделирования показали, что в течение первого часа после начала сброса формируется устойчивая зона теплового загрязнения площадью около 1,5 км², где температура воды превышает фоновые значения на 0,5–1,0 K. Высокотемпературный шлейф постепенно трансформируется в диффузное тепловое пятно, сохраняющееся в прибрежной зоне благодаря слабому водообмену и рециркуляции. Анализ поля скорости выявил зоны локальной циркуляции, способствующие длительному сохранению тепла. Научная новизна исследования заключается в применении вычислительной гидродинамики (CFD) для оценки термогидродинамики сброса в условиях ограниченного водообмена в крупном озере с реальной морфологией береговой линии озера Балхаш. Практическая значимость заключается в возможности использования разработанного метода для прогнозирования экологических рисков и оптимизации систем охлаждения атомных и тепловых электростанций, расположенных вблизи озера.

Ключевые слова: тепловое загрязнение, CFD-моделирование, озеро Балхаш, подогретые воды, SST k–ω модель, гидродинамика, экологическая безопасность

Introduction. Growing energy production and the development of industrial complexes are increasing the pressure on aquatic ecosystems, especially in regions with limited water resources. Thermal pollution, caused by the discharge of heated water from power plants, remains one of the most significant anthropogenic impacts. Rising temperatures alter the thermal and hydrodynamic regimes of water bodies, affecting dissolved oxygen levels, biochemical processes, and ecosystem structure. In large lakes and reservoirs, localized heating can lead to an extension of the stratification period, increased evaporation, and redistribution of matter and energy flows. Quantifying these effects requires highly accurate models capable of reproducing the spatiotemporal dynamics of temperature fields, taking into account the actual shoreline geometry and hydrological features.

A number of studies have assessed the impacts of thermal pollution and developed numerical models describing the dynamics of thermal discharges. Råman Vinnå et al. (2017) showed that discharges of heated water from nuclear power plants into lakes cause a temperature increase of up to 3 °C and an extension of the stratification period, which significantly alters exchange processes and heat fluxes. Gaudard et al. (2018) noted that the use of rivers and lakes as heat-exchange reservoirs should be considered a form of anthropogenic impact that has long-term effects on hydrological and biological systems. Caissie (2006) emphasized the importance of understanding river thermal regimes, noting that deterministic models using energy-efficient approaches are crucial for predicting changes in water temperature due to anthropogenic impacts, including thermal pollution. These studies highlight the need for an integrated approach to modeling thermal processes in real water bodies, followed by an assessment of their environmental impacts.

Modern research employs a wide range of computational methods to describe the propagation of heated waters. Issakhov (2019) implemented a two-dimensional CFD model based on the Navier–Stokes and energy equations to analyze the formation of thermal pollution zones under the influence of power plant discharges. The model was successfully verified using field data, confirming its reliability in predicting the scale of thermal impact. Al-Suhaili (2006) developed a similar approach for river flows with a point heat source, taking into account unsteady transport and dissipation processes. Tang (2008) proposed a three-dimensional CFD model taking into account complex coastal geometry and turbulent effects, which allowed for obtaining a detailed structure of temperature and velocity fields in coastal areas. Thus, computational fluid dynamics provides the most accurate and spatially resolved description of the interaction of hydrodynamic and thermal processes.

Particular attention is paid to the influence of discharge parameters on the formation of temperature traces. Mahmood and Mohammad (2022) studied the propagation of a thermal plume along a section of the Tigris River using COMSOL Multiphysics. It was shown that reducing the discharge velocity from 1.6 to 0.5 m/s promotes more uniform mixing and reduces temperature anomalies. Kalinowska et al. (2012) obtained similar results for the Vistula River, where optimizing the discharge flow and direction minimized localized overheating zones.

In recent years, research aimed at an integrated description of thermohydrodynamic and ecological processes in aquatic ecosystems has gained significant momentum. Du et al. (2025) showed that the volume of thermal discharge has a stronger effect on the extent of the thermal footprint than the heating temperature, emphasizing the need for parametric optimization of cooling scenarios. Velázquez-Araque et al. (2025) demonstrated the versatility of CFD approaches by applying them to the analysis of microplastic dispersion using a multiphase turbulent model in ANSYS Fluent; the proposed approach was also applicable to thermal dispersion problems. Tarena et al. (2024) conducted a systematic review of the use of CFD in hydroecological studies and showed that the most widely used methods remain RANS and LES models implemented in the ANSYS Fluent and FLOW-3D software packages.

In a global context, Raptis et al. (2016) found that the world's largest rivers, including the Mississippi and Rhine, experience significant increases in water temperature due to energy discharges, with thermal energy dispersed tens of kilometers downstream. Miara et al. (2018) extended these findings by using 3D CFD modeling to analyze the impact of heat fluxes on energy system infrastructure and the sustainability of their operations. According to Råman Vinnå et al. (2017), in lake systems, up to 60% of excess heat is removed through spillways, while the remainder alters internal convective structures, increasing ecosystem sensitivity to anthropogenic impacts.

Modern CFD approaches enable highly accurate analysis of the spatial structure of temperature fields, assessment of mixing efficiency, and prediction of the impact of thermal emissions at the local and regional levels. In this context, numerical modeling of thermal pollution within Lake Balkhash—a large transboundary ecosystem in Central Asia characterized by a complex coastal configuration and high sensitivity to external influences—is of particular interest. Studying the propagation of heat flow processes arising from the potential construction of a nuclear power plant in the coastal zone allows for a quantitative assessment of the scale of thermal impact and the identification of critical zones of thermal regime change.

Materials and Methods. Geographical and hydrological characteristics of the study area

The study was conducted on the coastal section of Lake Balkhash, located near the village of Ulken on the southwestern shore of the reservoir (Figure 1). This area is considered a potential intake and discharge zone for cooling water during the operation of the nuclear power plant. Geographically, it is a closed part of the lake, partially separated from the main body of water by hydraulic structures (dams and bridges), which limits water exchange and creates a relatively isolated ecosystem.

The main geometric parameters of the study area are: length 7.6 km, average width 3.8 km, area 16.07 km², and shoreline perimeter approximately 22.6 km. According to the International Lakes Environment Committee (ILEC), Balkhash is a warm lake with pronounced seasonal variability in its thermal regime: surface temperatures range from 0°C in December to 28°C in July, with a long-term average of approximately 10°C in the western part and 9°C in the eastern part. Freezing occurs annually from November to March, with ice persisting for 10–15 days longer in the eastern part.

Using this coastal section of the lake as part of the nuclear power plant's cooling system could lead to a number of hydrodynamic and environmental consequences. Under conditions of limited water exchange, the heated jet stream can create persistent water temperature anomalies reaching 3–9°C relative to background values. Such temperature increases potentially alter vertical circulation and stratification processes, reduce dissolved oxygen concentrations, and may disrupt the natural thermal and biochemical balance of the ecosystem.

Figure 1. Top view of the study area of Lake Balkhash

Mathematical Model. To numerically describe the currents and temperature distribution in the studied reservoir, the equations for a non-stationary viscous incompressible fluid in the Navier-Stokes form with an added energy equation were used.

– continuity equation

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

– momentum equation

$$\frac{\partial u_i}{\partial t} + u_i \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \upsilon \frac{\partial^2 u_i}{\partial x_j^2} \tag{2}$$

– pollution transfer equation

$$\frac{\partial T}{\partial t} + u_j \frac{\partial \mathrm{T}}{\partial x_j} = \alpha \frac{\partial^2 T_i}{\partial x_j^2} \tag{3}$$

where u_i – are the components of the velocity vector, T is the temperature, υ is the molecular viscosity, α is the thermal conductivity coefficient, ρ is the density, p is the pressure.

After Reynolds averaging of the Navier–Stokes equations, additional terms describing the momentum transfer by turbulent fluctuations appear in the momentum equations. To close these terms, the Boussinesq hypothesis is used, linking these terms to the mean velocity gradients through the turbulent viscosity υ_t, calculated from the turbulence model equations. The effective viscosity $\upsilon_{eff} = \upsilon + \upsilon_t$ is used in the equations for averaged fields, ensuring the correct accounting for the influence of turbulent eddies. In the energy equation, turbulent heat transfer is accounted for through an additional diffusion term υ_t / Pr_t , analogous to the effect of turbulent viscosity in the momentum equation.

To describe turbulence, the SST k–ω (Shear Stress Transport) model was used, combining the advantages of the standard k–ε and k–ω models. It provides a stable and physically correct solution near rigid boundaries and in regions with weakly turbulent coastal currents.

The model is based on solving two transport equations—one for the kinetic energy of turbulence *k* and the specific rate of its dissipation ω:

$$\frac{\partial k}{\partial t} + \bar{u}_j \frac{\partial u_j k}{\partial x_j} = P_k - \beta^* k\omega + \frac{\partial}{\partial x_j}\left((\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_j}\right) \tag{4}$$

$$\frac{\partial \omega}{\partial t} + \bar{u}_j \frac{\partial u_j \omega}{\partial x_j} = \alpha \frac{\omega}{k} P_k - \beta\omega^2 + \frac{\partial}{\partial x_j}\left((\upsilon + \sigma_\omega \upsilon_t)\frac{\partial \omega}{\partial x_j}\right) + 2(1 - f_1)\frac{\sigma_{\omega 2}}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \tag{5}$$

where P_k – is the generation of turbulent energy caused by the velocity shift.

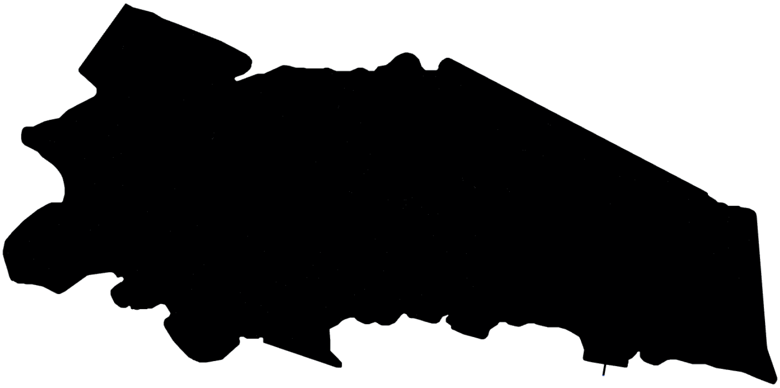
Boundary and Initial Conditions. At the jet outlet boundary, a constant velocity of 3.89 m/s and a temperature of 297 K are specified. The shoreline is treated as a stationary rigid wall with a no-slip condition ($u = 0$) and a zero temperature gradient along the normal. Symmetry conditions are used at the remaining boundaries.

The initial water temperature in the lake is assumed to be 291 K, and the initial flow velocity is 0 m/s. These values correspond to the state of a calm lake before the discharge begins. The same initial and boundary conditions were used for all simulations, ensuring a fair comparison of the scenarios.

Since the simulated domain is a closed coastal section of the lake with no distinct inlet or outlet, zero gradient conditions for all parameters were used at the outer boundaries. The propagation of the heated water occurred due to the inertia of the jet and turbulent mixing within the computational domain.

Computational Grid Construction and Independence Test. A digital copy of the coastline, created using satellite and cartographic data, was used to construct the geometry and grid (Figure 1). The computational domain was discretized using an unstructured triangular grid with localized densification in the jet outlet zone and in the warm flow dilution zone (Figure 2).

The overall cell size in the global part of the reservoir was 6–7 m, while densifications of 0.15–2.1 m were used near the jet source. The radius of the densification zone was 1400 m from the discharge center. Three grid variants with varying resolutions were created (Table 1). To verify the independence of the solution from grid size, identical physical models, boundary conditions, and time step (0.05 s) were used. The convergence criterion for all parameters was set at 10^{-6}.



(a)

(b)

(c)

Figure 2. Computational grid

Table 1. Parameters of computational grids for convergence studies

Mesh	Global size [m]	Maximum size in the clustering zone [m]	Minimal size in the clustering zone [m	Number of nodes	Number of cells
1	7 m	2.3 m	0.16 m	3 395 393	1 695 132
2	7 m	2.2 m	0.15 m	3 982 539	1 988 612
3	6 m	2.1 m	0.14 m	5 683 954	2 838 985

Figure 3 shows the average temperature distribution along the longitudinal profile for each mesh. As can be seen, when moving from the coarse mesh (mesh 1) to the more detailed meshes (mesh 2 and mesh 3), the shape of the temperature profile changes only slightly, indicating that mesh convergence has been achieved. The difference in maximum temperatures between meshes 2 and 3 does not exceed 1.5%, suggesting that mesh 3 is sufficient for subsequent calculations.

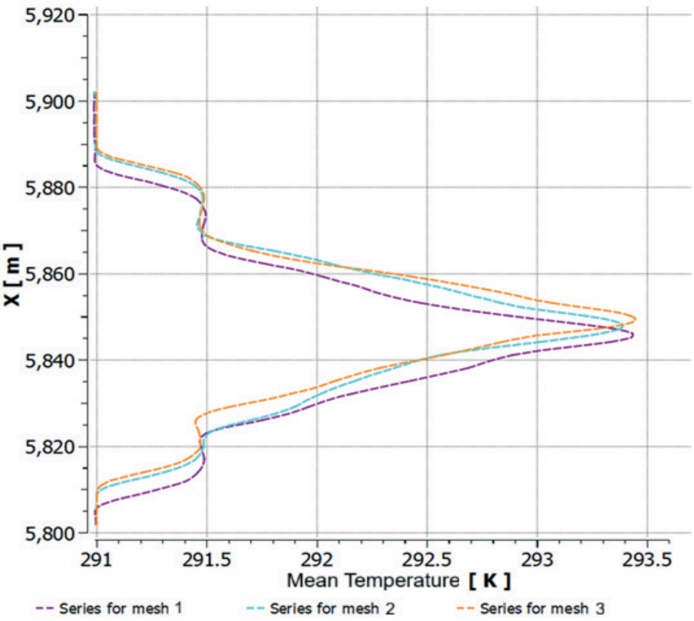


Figure 3. Distribution of average temperature along the x-axis for three variants of computational grids (mesh 1–3).

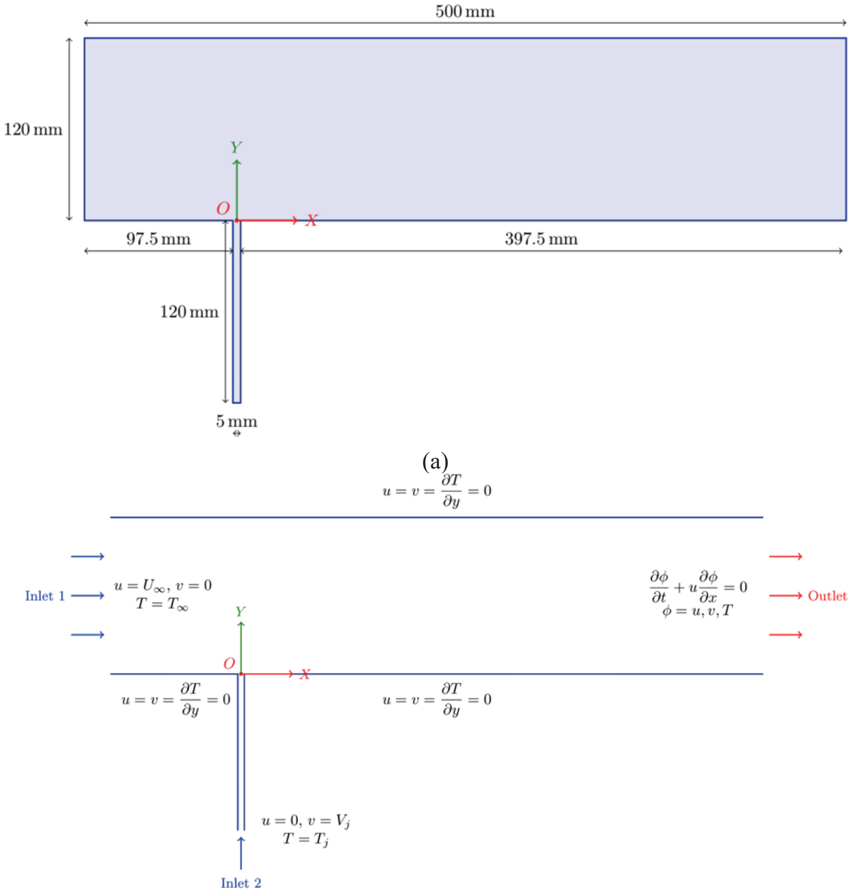
Numerical Implementation. For flow modeling, the equations for conservation of mass, momentum, and energy for a two-dimensional, steady, incompressible flow were used. The calculations were performed using the finite volume method, with the SIMPLE algorithm for coupling pressure and velocity. Temporal discretization was performed using an implicit first-order scheme. Convective terms were approximated by a second-order approximation using the upwind scheme, ensuring stability and accuracy of the solution while preserving sharp temperature gradients.

To speed up the computations, the problem was parallelized and run on 32 processors. The simulation time interval was 1 hour, and the results were saved every 10 minutes for analysis of the evolution of the temperature and velocity fields.

Model Validation. To verify the correctness of the mathematical model and numerical algorithm used, validation was performed using a benchmark problem: a heated jet injected into a horizontal closed channel. This configuration was chosen in accordance with the experimental studies of Chen and Hwang (1991) and the numerical analysis of Chang and Chen (1995), allowing the obtained results to be compared with reliable laboratory measurements.

Geometry and Problem Conditions

The computational domain (Figure 4a) consisted of a rectilinear channel 500 mm long and 120 mm high, with a single hot fluid injection point through a nozzle with a width of D = 5 mm, located 97.5 mm from the inlet. The nozzle center was taken as the origin, the X-axis was directed along the channel, and the Y-axis was directed vertically upward.



(a)

(b)

Figure 4 - Computational domain (a) and boundary conditions (b) of the test problem

The boundary conditions are shown in Figure 4b. The main flow temperature (Inlet 1) was T_∞ = 298 K (25 °C), and the temperature of the heated water entering through the nozzle (Inlet 2) was T_j = 354 K (81 °C). The main flow velocity was U_∞ = 2.005 m/s, and the jet injection velocity was V_j = 11.969 m/s.

No-slip conditions (u = v = 0) and adiabatic boundary conditions for temperature ($\partial T/\partial n = 0$) were used on the channel walls. Neumann-type boundary conditions were applied at the channel outlet, ensuring a free flow without reflections.

Comparison with Experiment. The numerical results (Figure 5) were compared with experimental data in five cross sections at distances X/D

= 2, 4, 6, 8, and 10 from the nozzle. To compare temperature profiles, the normalized value was used $Q = \frac{T - T_\infty}{T_j - T_\infty}$.

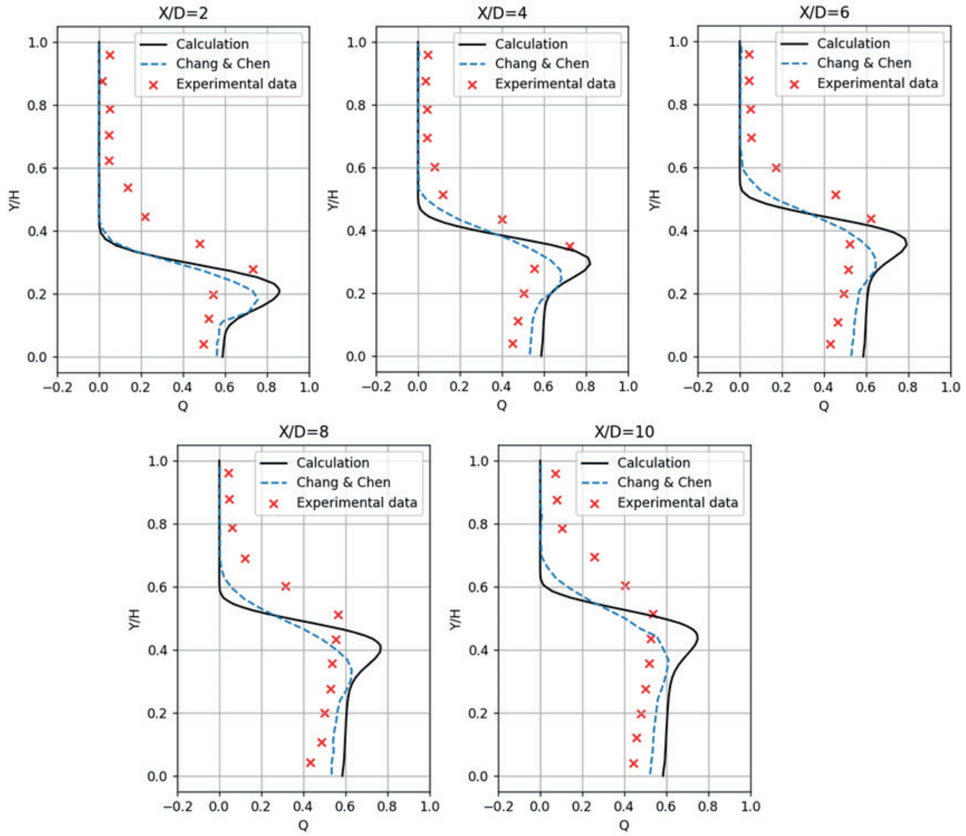


Figure 5 - Comparison of results with the experiment of Chen and Hwang (1991) [14] and the numerical analysis of Chang and Chen (1995) [15]

A comparison of the profiles showed that the obtained calculated data were in good agreement with the experiment: maximum deviations in temperature values did not exceed 5–7%, and the jet profile shape and isotherm positions matched the measurements. The SST k–ω model accurately reproduced both thermal diffusion and the jet trajectory in the crossflow, demonstrating high accuracy near the symmetry axis and in the region of intense mixing.

Results and Discussion. Numerical modeling allowed us to study in detail the spatiotemporal dynamics of the formation and propagation of a thermal wake from a potential discharge of heated waters in the coastal zone of Lake Balkhash over the course of one hour. A combined analysis of temperature and velocity fields (Figures 6a–f, 7a–f) demonstrates the consistent evolution of the thermal plume and corresponding changes in the hydrodynamic structure of the flow.

At the initial stage of the process (t = 10 min), the formation of a compact, high-temperature jet is observed, caused by the discharge of water with a temperature of 297 K. The core of the jet, with a temperature above 296.4 K, has a distinct directional structure and extends over more than 500 meters from the source, reflecting the dominant influence of the discharge impulse in the first minutes of the flow.

Over time (t = 20–40 min), the structure of the thermal field changes significantly. The inertial phase gives way to a diffusion phase: the role of turbulent heat transfer and advection increases, leading to a gradual expansion of the elevated temperature zone. As a result, the temperature field equalizes and coastal waters are involved in the warming process.

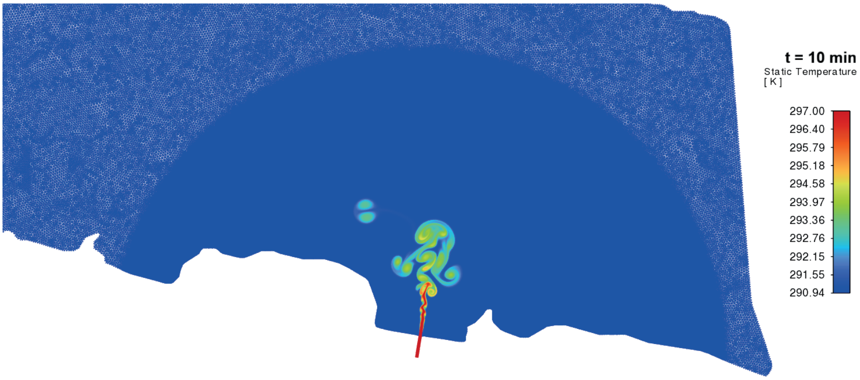
By the 50th minute of the simulation, the formation of the thermal plume enters a quasi-stationary phase. The temperature field stabilizes, as evidenced by the virtually identical temperature distributions at 50 and 60 minutes. By the 60th minute of the simulation, the warm jet loses its compactness, and the thermal plume covers a significant portion of the water area.

The calculated estimate shows that by the end of the 60-minute simulation interval, the area of water subject to noticeable thermal effects ($\Delta T \geq 0.5$ K) is approximately 1.5 km^2, which corresponds to approximately 14% of the area of the study area (10.5 km^2). The average water temperature within the calculated region increases to 291.25 K, reflecting an overall increase in thermal background even over the short period of the release.

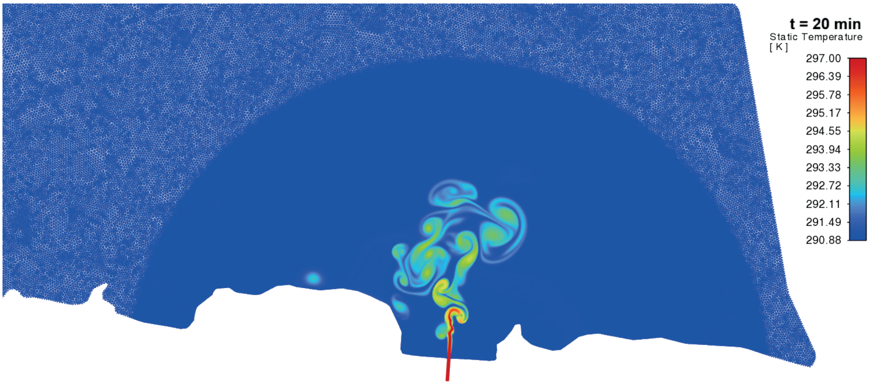
Flow Hydrodynamics. Analysis of the velocity field revealed that during the first 30 minutes of the simulation, the maximum velocity in the jet core gradually decreases – from 4.51 m/s (t = 10 min) to 4.15 m/s (t = 30 min). This is due to the development of turbulent mixing and the interaction of the jet with the surrounding waters. By the 40th minute, a localized increase in velocity to 5.03 m/s is recorded, likely due to flow reflection from the shoreline and the formation of localized vortex structures.

In the final stage (t = 50–60 min), the hydrodynamic structure stabilizes. The maximum velocity in the core decreases from 4.38 m/s to 4.32 m/s, reflecting the establishment of a balance between jet inertia and energy dissipation. The area with elevated velocities (≥ 2.5 m/s) forms a stable corridor aligned with the direction of the main thermal plume. In the peripheral areas of the water area, velocities do not exceed 0.5–1.0 m/s, creating conditions for local stagnation and heat accumulation.

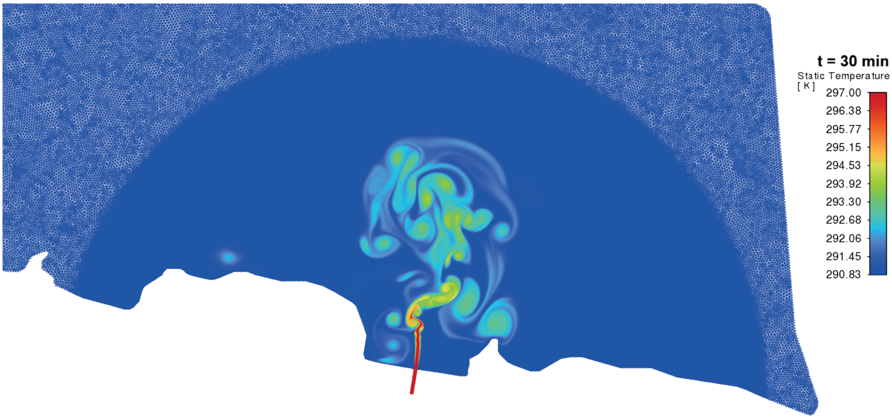
Thus, the results of the full hourly modeling demonstrate that, with a weak background current and complex coastal geometry, the discharge of heated waters forms a vast and stable zone of thermal pollution. Within the first hour, the system reaches a quasi-steady state, in which thermal impact becomes a constant environmental factor. The observed structure of the temperature and velocity fields indicates the potential for long-term changes in the local thermal regime, including disruption of seasonal stratification, a decrease in dissolved oxygen concentration, and the transformation of aquatic biocenoses.


t = 10 min
Static Temperature
[K]
297.00
296.40
295.79
295.18
294.58
293.97
293.36
292.76
292.15
291.55
290.94

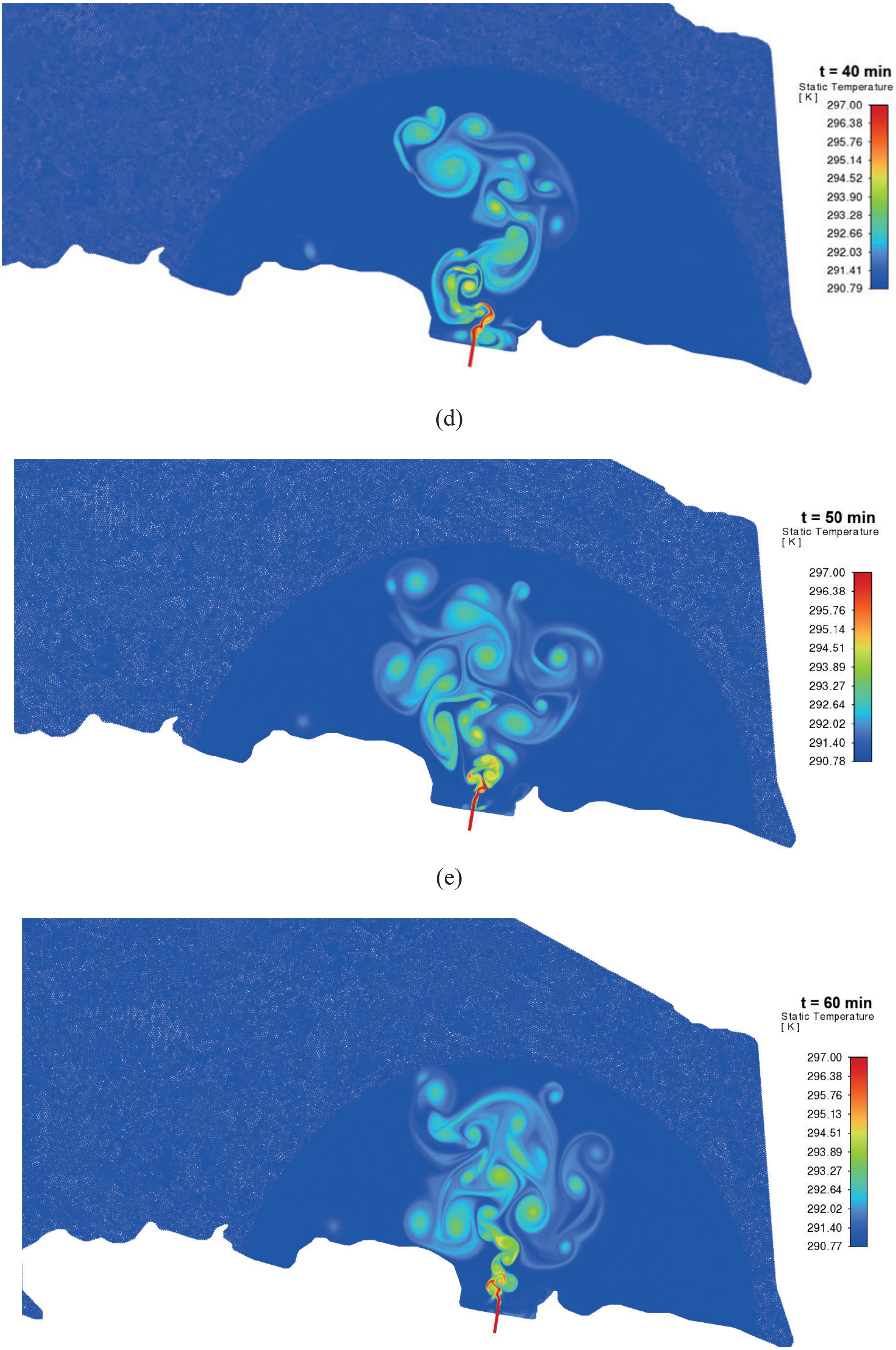
(a)


t = 20 min
Static Temperature
[K]
297.00
296.39
295.78
295.17
294.55
293.94
293.33
292.72
292.11
291.49
290.88

(b)


t = 30 min
Static Temperature
[K]
297.00
296.38
295.77
295.15
294.53
293.92
293.30
292.68
292.06
291.45
290.83

(c)

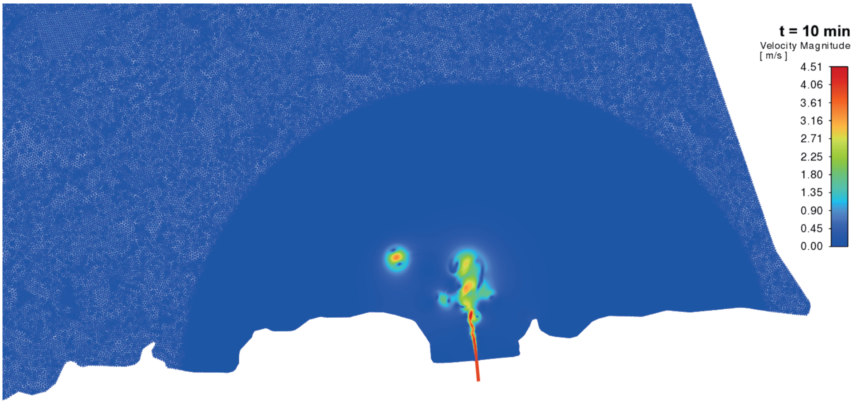


(d)

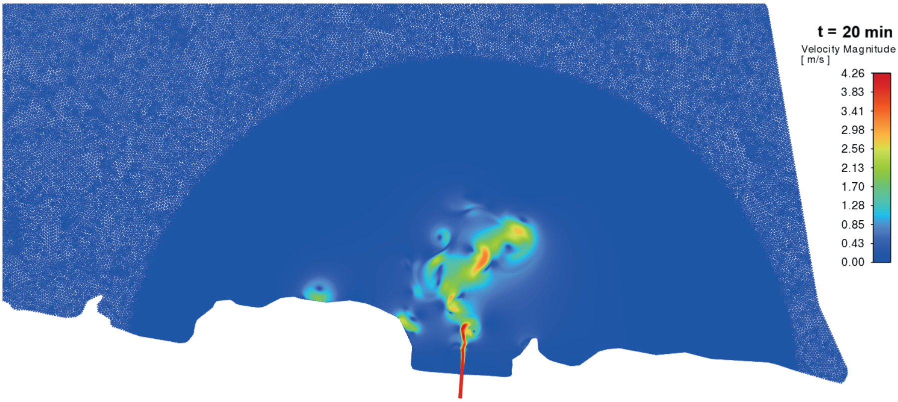
(e)

(f)

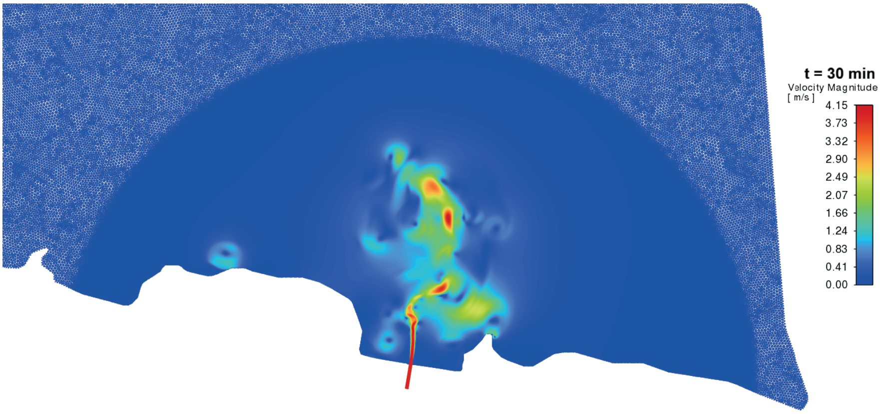
Figure 6. Evolution of the temperature field (K) in the coastal zone of Lake Balkhash during the simulation of the discharge of heated water: (a) t = 10 min, (b) t = 20 min, (c) t = 30 min, (d) t = 40 min, (e) t = 50 min (f), t = 60 min.


t = 10 min
Velocity Magnitude
[m/s]
4.51
4.06
3.61
3.16
2.71
2.25
1.80
1.35
0.90
0.45
0.00

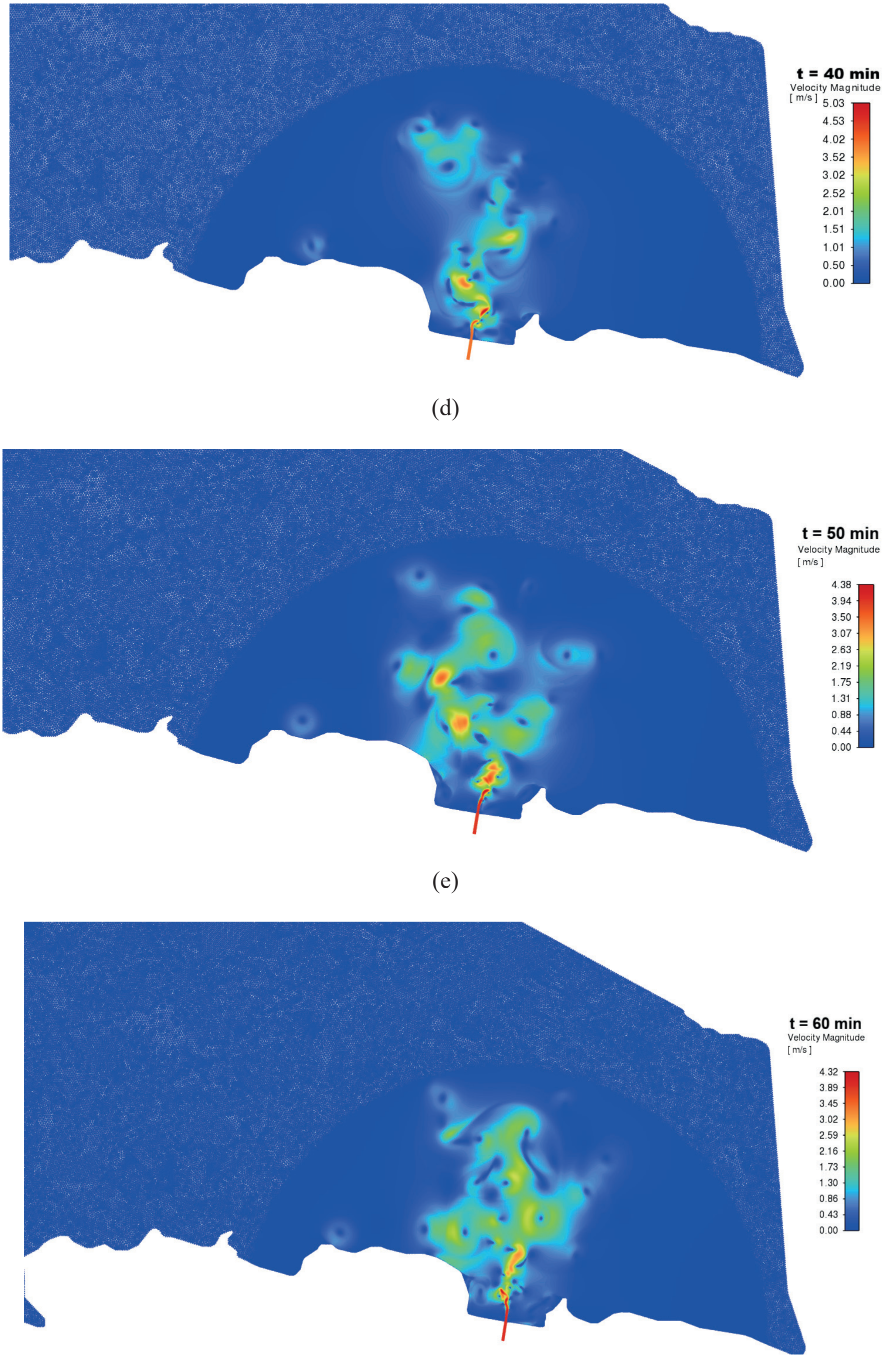
(a)


t = 20 min
Velocity Magnitude
[m/s]
4.26
3.83
3.41
2.98
2.56
2.13
1.70
1.28
0.85
0.43
0.00

(b)


t = 30 min
Velocity Magnitude
[m/s]
4.15
3.73
3.32
2.90
2.49
2.07
1.66
1.24
0.83
0.41
0.00

(c)



(d)

(e)

(f)

Figure 7. Velocity field (m/s) in the coastal zone of Lake Balkhash at different time stages of the simulation.

Conclusion. This numerical study provided the first detailed analysis of the spatiotemporal dynamics of heated water propagation during a potential discharge from the cooling system of a nuclear power plant in the coastal zone of Lake Balkhash. The use of a two-dimensional model based on the Navier–Stokes equations, supplemented by an energy equation and the SST k–ω turbulence model, provided a reliable description of thermohydrodynamic processes under complex coastal conditions and weak background currents.

Validation of the model on a test problem of jet injection demonstrated high agreement with experimental data, confirming the validity of the chosen approach for modeling local heat exchange processes in reservoirs. A grid-independence test demonstrated the stability of the solutions for cell sizes exceeding 2.7 million, ensuring the reliability of the obtained results. Modeling results showed that within the first 60 minutes of the discharge, a distinct thermal pollution zone of approximately 1.5 km² is formed, with water temperatures exceeding background values by 0.5–1.0 K. The high-temperature jet emanating from the source gradually transforms into a diffuse thermal spot, which persists in the coastal zone due to weak water exchange and recirculation. Analysis of the velocity field revealed the presence of localized circulation zones and stagnant areas that facilitate long-term heat retention.

These results indicate that the discharge of heated waters, even at moderate temperatures, can cause significant changes in the thermal and hydrodynamic regime of the water area. Under conditions of limited water exchange and complex shoreline morphology, such impacts can lead to long-term changes in the stratification structure, oxygen balance, and biological processes. Thus, the performed modeling confirms the effectiveness of computational fluid dynamics (CFD) methods for analyzing thermal pollution of aquatic ecosystems and can serve as a basis for subsequent assessment of environmental safety and optimization of the parameters of cooling systems of nuclear and thermal power plants located near lake areas.

References

Al-Suhaili R.H., Nasir M.J. (2006) Two-dimensional numerical model for thermal pollution of single source in river. J Eng, 12(1). — P. 25–35. DOI: 10.31026/j.eng.2006.01.03 (in English).

Caissie D. (2006) The thermal regime of rivers: a review. Freshwater Biol, 51. — P. 1389–1406. DOI: 10.1111/j.1365-2427.2006.01597x (in English).

Chang Y.R., Chen K.S. (1995) Prediction of opposing turbulent line jets discharged laterally into a confined crossflow. *Int J Heat Mass Transfer, 38(17). — P. 3069–3082. DOI: 10.1016/0017-9310(94)00390 (in English).

Chen K.S., Hwang J.Y. (1991) Experimental study on the mixing of one- and dual-line heated jets with a cold crossflow in a confined channel. AIAA J, 29(3). — P. 353–360. DOI: 10.2514/3.10619 (in English).

Du T., Dugdale S.J., Johnson M. F. (2026) A scenario-based, generalised model of the thermal impacts of cooling water discharge from thermoelectric power plants: thermopeaking and spatio-temporal interactions. Water Res, 288(Part A), 124529. DOI: 10.1016/j.watres.2025.124529 (in English).

Gaudard A., Weber C., Alexander T.J., Hunziker S., Schmid M. (2018) Impacts of using lakes and rivers for extraction and disposal of heat. WIREs Water, 5, e1295. DOI: 10.1002/wat2.1295 (in English).

Issakhov A., Zhandaulet Y. (2019) Numerical simulation of thermal pollution zones' formations in the water environment from the activities of the power plant. Eng Appl Comput Fluid Mech, 13(1). — P. 279–299. DOI: 10.1080/19942060.2019.1584126 (in English).

Kalinowska M.B., Rowiński P.M., Kubrak J., et al. (2012) Scenarios of the spread of a waste heat discharge in a river – Vistula River case study. Acta Geophys, 60. — P. 214–231. DOI: 10.2478/s11600-011-0045-x (in English).

Mahumood N.S., Mohammad T.A. (2022) Assessment of thermal pollution at selected stretch of Tigris River in Baghdad by field observations and numerical simulations. J Eng, 28(9). — P. 18–34. DOI: 10.31026/j.eng.2022.09.02 (in English).

Miara A., Vörösmarty C.J., Macknick J.E., Tidwell V.C., Fekete B., Corsi F., Newmark R. (2018) Thermal pollution impacts on rivers and power supply in the Mississippi River watershed. Environ Res Lett, 13(3), 034033. DOI: 10.1088/1748-9326/aaac85 (in English).

Råman Vinnå L., Wüest A., Bouffard D. (2017) Physical effects of thermal pollution in lakes. Water Resour Res, 53. — P. 3968–3987. DOI: 10.1002/2016WR019686 (in English).

Raptis C.E., van Vliet M. T. H., Pfister S. (2016) Global thermal pollution of rivers from thermoelectric power plants. Environ Res Lett, 11(10), 104011. DOI: 10.1088/1748-9326/11/10/104011 (in English).

Tang H.S., Paik J., Sotiropoulos F., Khangaonkar T. (2008) Three-dimensional numerical modeling of initial mixing of thermal discharges at real-life configurations. J Hydraul Eng, 134(9). — P. 1210–1224. DOI: 10.1061/(ASCE)0733-9429(2008)134:9 (1210) (in English).

Tarena F., Nyqvist D., Katopodis C., Comoglio C. (2024) Computational fluid dynamics in fishway research: a systematic review on upstream fish passage solutions. J Ecohydraulics, 10(1). — P. 107–126. DOI: 10.1080/24705357.2024.2363772 (in English).

Velazquez-Araque L., Flor J., Méndez A., Cárdenas-Calle M. (2025) Modeling microplastic dispersion in the Salado Estuary using computational fluid dynamics. Fluids, 10(5), 118. DOI: 10.3390/fluids10050118 (in English).

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