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One-Dimensional Modelling of Seasonal Thermal Pollution Transport in the Brisbane River

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Abstract. Thermal pollution from industrial activities has become an important environmental problem. In order to evaluating potential environmental impacts, a one-dimensional advection-diffusion model was developed. The transport behavior of thermal pollution in the Brisbane River under different seasonal conditions is investigated. High-frequency monitoring data from August 2023 to July 2024 were used to evaluate the impact of a hypothetical point-source thermal discharge. The model shows temperature variations from three major physical processes: downstream heat transport caused by river flow; thermal diffusion associated with mixing; and continuous heat from industrial wastewater. Various scenarios are described via change of hydrodynamic conditions and thermal discharge intensity to see their influence on the downstream temperature distribution. Numerical simulation is performed to investigate the temperature dynamics depending on the distance and time. It is estimated how fast the temperature pollution fades when it appears in the river system. We estimate both summer and winter conditions. The results obtained of this study suggest an effective tool to investigate thermal pollution transport in rivers. Having considered the seasonal river conditions and heat dissipation behavior, it is possible to estimate the influence of industrial thermal discharge and give regulators seasonally adjusted discharge limits. So, the summer total thermal permit should not exceed 5,000 MW per reach. Additionally, this model is a valid modeling tool for other rivers influenced by tides.

Keywords: Thermal pollution, Advection-diffusion model, Analytical solution, Water temperature recovery

1. Introduction

In previous studies, researchers studied heavy metal risks in river sediments. The traditional contamination factor lacked enough accuracy. Natural rock substances and coastal sand entering rivers affect calculations and lead to inaccurate results. The Brisbane River study compared various evaluation tools and found three effective indicators. The three indicators include the enrichment

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factor, modified pollution index and modified ecological risk index. However, this static evaluation method cannot represent the dynamic movement of heavy metals driven by the river.

Researchers usually build calculation models based on the one-dimensional flow-diffusion formula with different finite difference calculations to analyze how river pollutants change over time. Past studies have tested plans such as FTCSCS and verified that the finite difference method can simulate how pollutants change across time and space at low costs. Most current calculation models use ideal starting and boundary concentration data. They rarely use heavy metal data measured from real river mud to adjust model parameters, which creates a gap between real pollution assessment and numerical calculation models.

In addition to the sediment heavy metal pollution issues we have discussed above, the Brisbane River is also facing with thermal pollution from power plants cooling wastewater. Previous studies have shown that thermal pollution from thermoelectric power plants has become a critical environmental problem in many river systems around the world. Raptis et al. developed a global river temperature model by combining thermal emissions from once-through cooling power plants with the VIC-RBM hydrological model [1]. Their results identified major thermal pollution areas such as the Mississippi and Rhine Rivers and illustrated that river flow conditions strongly influence the magnitude and extent of temperature increase.

More recent research further investigated the transport of thermal pollution. Miara et al. simulated thermal pollution in the Mississippi River watershed using a high-resolution river temperature model [2]. They found that heated cooling water from the upstream power plants will increase downstream river temperatures and reduce cooling efficiency at other power plants. Also, it will decrease electricity generation under environmental regulations. Their study also stated that higher resolution one-dimensional river temperature simulations can provide reliable predictions of thermal transport. Finally, they emphasized the importance of considering seasonal river conditions when evaluating heat pollution.

Although most existing thermal pollution studies focus on large river systems and power plant interactions, seasonal environmental conditions also play an important role in determining pollutant transport and ecological responses. Earlier ecological observations by Gaufin and Tarzwell found that seasonal variations in river flow, dissolved oxygen, and water temperature significantly changed stream environmental conditions. They suggest that differences between summer and winter river conditions influence pollutant transport processes and ecosystem recovery. However, these studies mainly focused on ecological observations rather than quantitative prediction of heat transport.

The seasonal variation characteristics and diffusion ranges will be quantified through a simple 1D advection-diffusion model.

A hypothetical thermal power facility is assumed to be located near the Brisbane River in Queensland, Australia. The facility releases heated cooling wastewater into the river and becomes a potential source of thermal pollution. The facility runs at maximum during summer heating season and causes the discharge volume to reach its maximum. As a result, temperatures will also rise because of thermal wastewater. In comparison, only basic power generation is used in winter. Thus, it reduces thermal emission intensity. The difference forms seasonally dynamic thermal pollution source strength. The differences between winter and summer in wastewater output and river water conditions are significant. Our goals are to show how the heat varies in two seasons and work out exactly how far the pollution flows through the stream.

Maintaining water quality and protecting aquatic ecosystems are main problems of the Brisbane River. Extremely high-water temperatures can harm aquatic habitats and reduce dissolved oxygen. Traditional methods cannot provide detailed seasonal predictions of thermal transport. Thus, our

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study develops a simple 1D advection-diffusion model to provide quantitative predictions to support thermal pollution management and evaluate potential environmental impacts of thermal wastewater discharge.

2. Methodology

2.1. Data collection and preprocessing

Raw data with a time grid of 30 minutes from Colmsline, Brisbane River were used, including water temperature, flow speed, dissolved oxygen, pH, and other hydrological indicators [3-5]. Raw monitoring data underwent systematic quality checking: abnormal values were removed, missing data were supplemented using interpolation and functions, and the river cross-sectional area was calculated using integration of the equations in *Formula 1*. The final cross-sectional area is approximately 3160 m². (Table 1)

$$f(x)=\begin{cases} -\frac{1}{12}x, & 0\le x\le 60 \\ -5-\frac{1}{12}(x-60)-\frac{13}{7200}(x-60)^2+\frac{1}{36000}(x-60)^3, & 60<x<120 \\ -10.5, & 120\le x\le 280 \\ \frac{7}{9600}(x-280)^2-10.5, & 280\le x\le 400 \end{cases} \tag{1}$$

the function describing the shape of the riverbed

2.2. Governing equation

The transport of thermal pollution in a river can be described by *Formula 2*, the one-dimensional advection-diffusion equation with an additional heat loss term:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}=\alpha\frac{\partial^2 T}{\partial x^2}+\frac{Q_s(t)[T_s(t)-T]}{A}\cdot\delta(x-x_0)-\frac{H}{\rho C_p h}(T-T_a) \tag{2}$$

where T(x,t) is the river water temperature at downstream distance x and time t, T_0 is the background river temperature, u is the mean flow velocity, α is the longitudinal dispersion coefficient, and $K = H/(\rho \cdot C_p \cdot h)$ is the surface heat exchange rate constant. The source term S(x,t) represents the thermal wastewater discharge.

For steady-state conditions under continuous discharge, the downstream temperature excess follows an exponential decay:

$$\Delta T(x)=\Delta T_0\cdot e^{-\lambda(x-x_0)}\quad(x\ge 0) \tag{3}$$

In *Formula 3,* ΔT_0 is the initial temperature rise after mixing at the discharge point, and $\lambda = (\sqrt{(u^2 + 4\alpha K)} - u)/(2\alpha)$ is the combined spatial decay rate. The model is solved using the Forward Time Central Space (FTCS) finite difference scheme and validated against the analytical steady-state solution.

$$\lambda=\frac{\sqrt{u^2+4\alpha K}-u}{2\alpha}$$

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2.3. Brief term explanation

Table 1. Explanation of different terms in formula 2

Term	Mathematical expression	Description
Transient term	$\frac{\partial T}{\partial t}$	represents the change in water temperature at a fixed river location over time, where T is the water temperature
Advection term	$u\frac{\partial T}{\partial x}$	describes heat transport caused by river flow, where u is the velocity of river
Diffusion term	$\alpha\frac{\partial^2 T}{\partial x^2}$	Represents turbulent heat mixing within the river, where α is the thermal dispersion coefficient
Point source	$\frac{Q_s(t)\left[T_s(t)-T\right]}{A}\cdot\delta(x-x_0)$	Represents industrial wastewater heat entering the river only at the discharge point. Here, A is the river cross-sectional area, $Q_s(t)$ is the wastewater discharge flow rate, and $T_s(t)$ is the wastewater temp
Surface cooling	$-\frac{H}{\rho C_p h}(T-T_a)$	Describes heat exchange between the river and the atmosphere. Here, h is the average water depth, $\rho=1000kg/m^3$ is the water density, $O_p=4189J/(kg\bullet^\circ C)$ is the specific heat capacity of water, H is the overall heat transfer coefficient, and T_a is the ambient air temperature.

2.4. Model parameters and scenarios

Table 2 summarizes the key model parameters [6]. Two seasonal scenarios were defined based on observed monitoring data (Section 3.4): summer (high background temperature ~32°C, low flow velocity ~0.4 m/s) and winter (low background temperature ~17°C, high flow velocity ~0.6 m/s). A range of dispersion coefficients (α = 1 to 2500 m²/s) was tested for sensitivity analysis.

Table 2. Key model parameters used in numerical simulations

Parameter	Symbol	Value / Range
Background temperature	T_0	17.0–32.1 °C
Flow velocity	u	0.4–0.6 m/s
Dispersion coefficient	α	1–2500 m²/s

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Table 2. (continued)

Cross-sectional area	A	3160 m²
Heat exchange coefficient	H	60 W/(m²·°C)
Water depth	h	4 m
Discharge temperature rise	ΔT_discharge	5–12 °C

3. Results

This section presents the main simulation results showing how thermal pollution spreads, transports, and decays in the Brisbane River under different seasonal conditions.

3.1. Seasonal variation in river background and hydrodynamic conditions

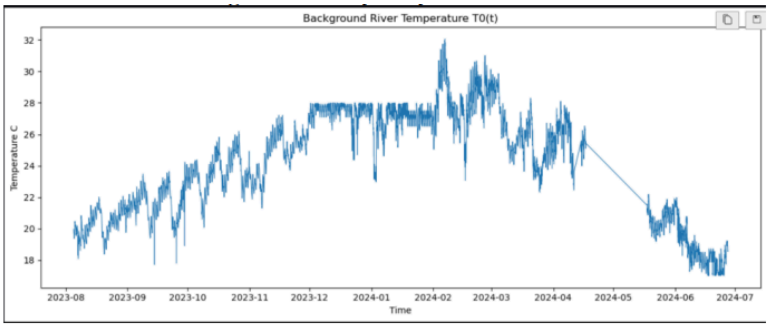


Figure 1.(a)

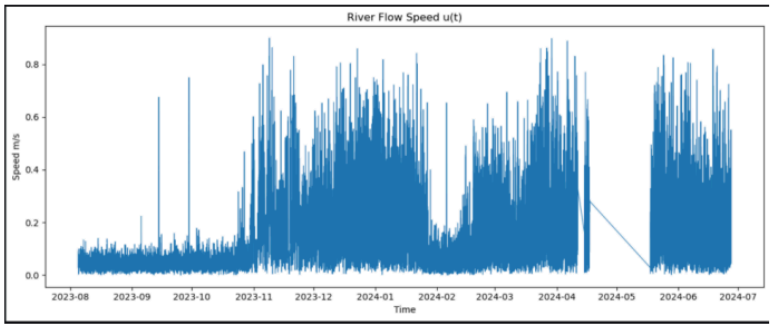


Figure 1.(b)

Figure 1. Observed spatiotemporal time-series of environmental baseline conditions in the Brisbane River from August 2023 to July 2024: (a) background water temperature $T_0(t)$, and (b) river flow velocity $u\,(t)$

In order to reflect the actual boundary conditions in the one-dimensional thermal pollution model, the high-frequency continuous monitoring data of the Brisbane River (August 2023 to July 2024，with an interval of every 30 minutes) is analyzed, as shown in Figure 1.

The background river temperature $T_0(t)$ shows the obvious seasonal fluctuations of the characteristics of the southern hemisphere (as shown in Figure 1. (a)). The baseline temperature gradually rises from about 18°C in August (winter) to a peak of more than 32°C in February (summer) and then drops back to about 17°C by mid-2024.

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At the same time, the river flow rate $u(t)$ shows strong time dynamics, from near-stagnation conditions (~0.01 m/s) to high-flow events of more than 0.8 m/s (as shown in Figure 1. (b)). It is worth noticing that most low flow rates are observed between August and November, while high river velocities occur more frequently in summer in Australia.

These empirical observations prove the parameters selected for seasonal scenario modeling in Table 1: the combination of increased baseline temperature ($T_0 \approx 32.1^{\circ}C$) and low flow velocity ($u \approx 0.4\ \mathrm{m/s}$) represents the worst case of heat capacity and ecological stress.

3.2. Seasonal thermal impact and regulatory discharge limit

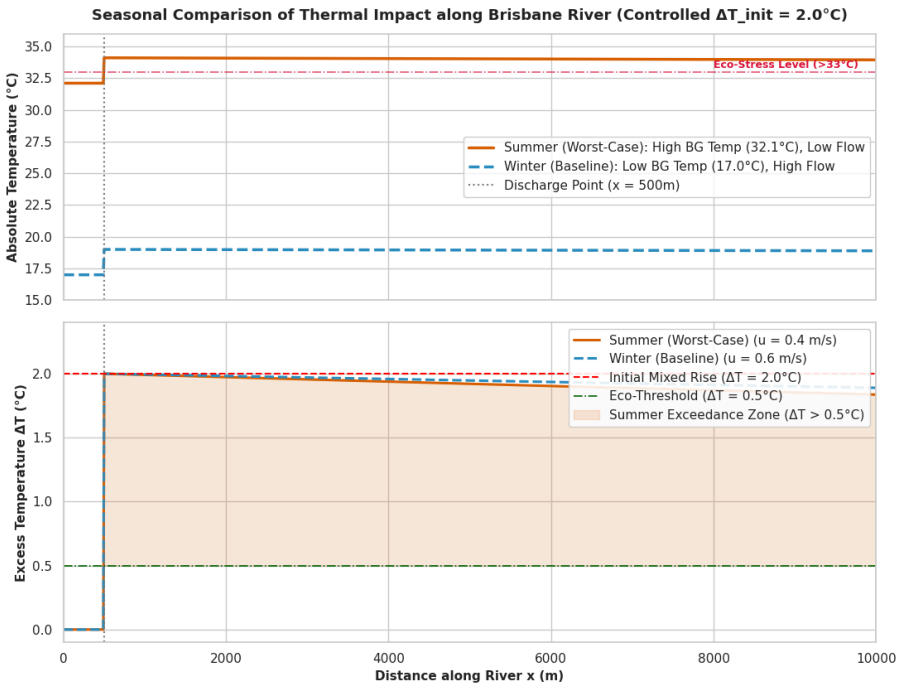


Figure 2. Seasonal comparison of thermal discharge impact along the Brisbane River under a controlled initial temperature rise (ΔTinit=2.0℃ when x=500m). Top panel: Absolute water temperature profile for summer (solid orange line) and winter (dashed blue line) scenarios. The red dash-dotted line marks the critical ecological stress threshold (33.0 °C). Bottom panel: Spatial attenuation of excess water temperature (ΔT). The green dash-dotted line represents the regulatory eco-threshold (ΔT=0.5℃), and the shaded area highlights the extended downstream summer exceedance zone

The absolute thermal stress and its geographical distribution were numerically estimated assuming the controlled thermal discharge into the Brisbane River ($\Delta T_{init} = 2.0℃\ at\ x = 500m$) as seen from Figure 2.

A significant difference between the seasons in terms of the degree of the ecosystem vulnerability can be observed. In particular, in the case of the worst-case summer scenario ($T_0 = 32.1,\ u = 0.4m/s$), the temperature due to the thermal discharge exceeds the absolute limit of 34.1 $^{\circ}C$, thus exceeding the critical limit for the ecological stress ($T = 33.0^{\circ}C$) [7] (Figure 2, top). Such an increased value of the river temperature is maintained within the entire modeling area ($> 10km$) owing to the lack of geographical temperature dissipation and the presence of elevated background temperature values. On the contrary, under the winter baseline scenario (

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$T0 = 17.0^{\circ}C, u = 0.6m/s$), the maximum absolute water temperature reaches $19.0^{\circ}C$, thus staying within safe thermal limits for the local ecosystem.

Moreover, the analysis of the extra temperature (ΔT) shows that slower flows in summer impede thermal dilution processes, so the excess temperature is kept above the $\Delta T = 0.5^{\circ}C$ limit through the entire $10km$ of the river reach (Figure 2, bottom; shaded area). It demonstrates that the background temperature and low seasonal flow velocity set the limits for the thermal carrying capacity of the river in summer.

3.3. Maximum allowable thermal discharge power

Figure 2 depicts the maximum allowable thermal discharge power (Pmax) that Brisbane River can handle without violating the $33^{\circ}C$ ecologically critical value. This maximum allowable heat load (Pmax) is solely determined from the governing heat balance equation based on measured values only: $Pmax = \rho \cdot Cp \cdot (33 - T_0) \cdot (u \cdot A)$. For the summer season ($T_0 = 32.1^{\circ}C, u = 0.4m/s$), the maximum allowable thermal power is around $4{,}760MW$. But for winter season ($T_0 = 17.0^{\circ}C, u = 0.6m/s$), it goes up to about $127{,}000MW$ – a factor of 27 increase due to the extra thermal margin and greater flow in the river. A 500 MW coal-fired power plant rejects about 1000-1500 MW of heat energy that exceeds the summer but stays within the winter limit. The above calculations give the regulatory bodies an idea in a single number: maximum summer thermal discharge must not be more than ~5000 MW.

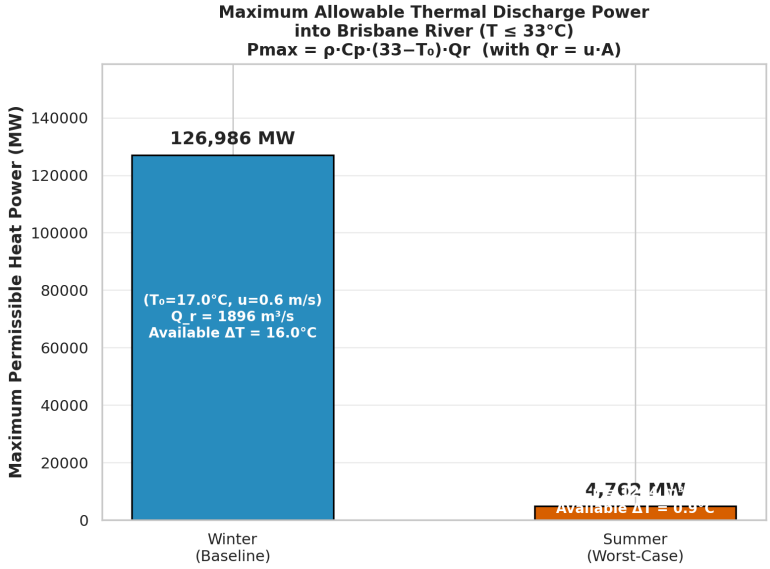


Figure 3. Maximum allowable thermal discharge power into the Brisbane River without exceeding the 33°C ecological threshold, calculated from Pmax = ρ·Cp·(33−T₀)·Qr

3.4. Sensitivity to dispersion coefficient α

Figure 4. illustrates the variation of the thermal plume with respect to the longitudinal dispersion coefficient α varying by several orders of magnitude ($\alpha = 1 to 2500 m^2/s$). Figure 4(a) represents the downstream steady-state temperature distribution. With increasing α, the increase of turbulent mixing lowers the maximum temperature excess. In Figure 4(b), the behavior of the plume in the upstream zone is presented. The larger α values allow the heat to move up-stream in opposition to

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the flow direction, which does not happen for smaller α. Figure 4(c) depicts the plume state after its discharge with the increased α causing faster longitudinal expansion.

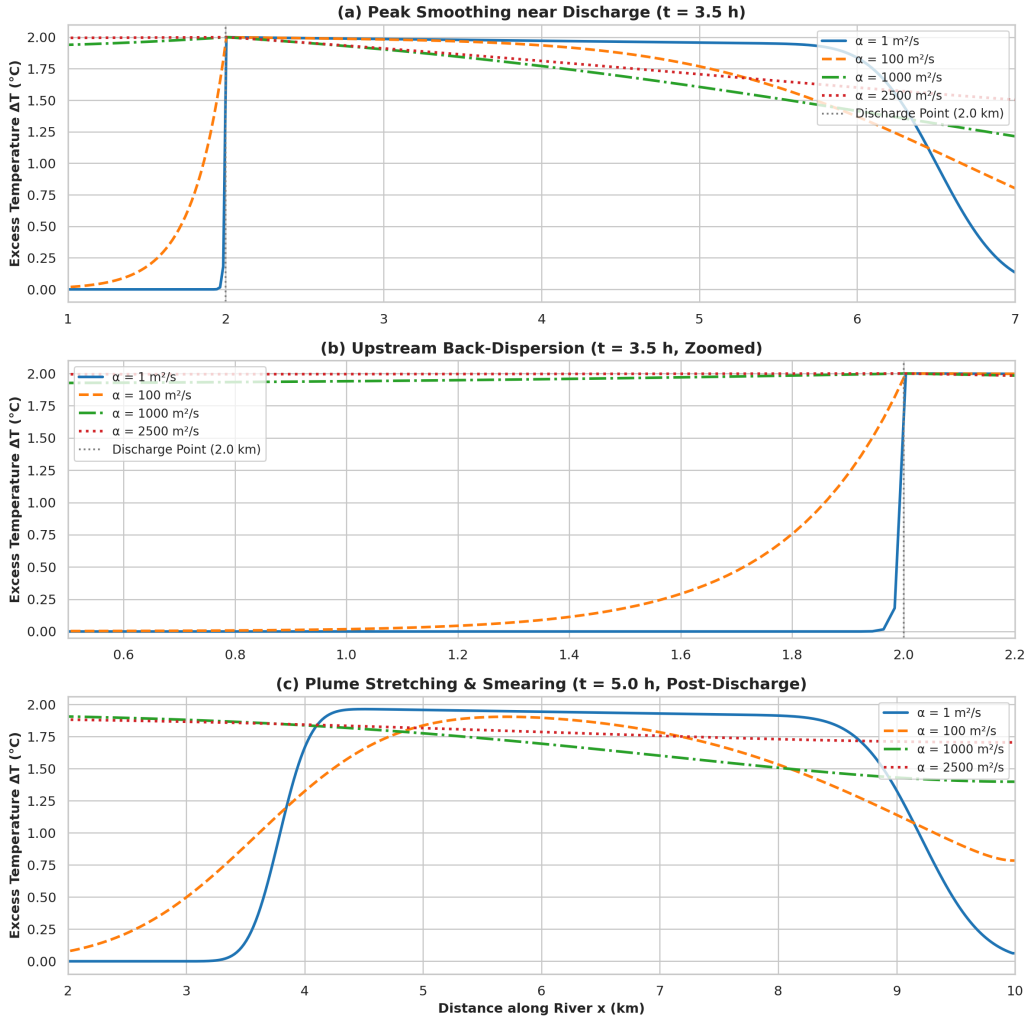


Figure 4. Sensitivity analysis of dispersion coefficient α on thermal plume characteristics: (a) peak smoothing, (b) upstream back-dispersion, (c) post-discharge plume stretching.α=1 to 2500m²/s

3.5. Spatiotemporal evolution of unbroken thermal plume under continuous discharge

To simulate the dynamic propagation and recovery of thermal pollution following discharge, a continuous 4-hour discharge scenario was modeled. Figure 5 illustrates the spatiotemporal variation of ΔT along the downstream reach over an 8-hour period (t=0 to 8 h) across a distance of 0 to 10 km ."

Before discharge ($t < 1.0h$), the river experiences its normal thermal state where $\Delta T = 0^{\circ}C$. Upon the commencement of the discharge at $x = 0.5km$ and $t = 1.0h$, the formation of the continuous hot plume starts immediately and travels downstream. In the 4-hour duration of the discharge at $t = 1.0\ to 5.0h$, the advective transport pushes the thermal front and sets a continuous thermal stress area. Near the outfall, the excess temperatures range from $\Delta = 1.95^{\circ}C$~$2.00^{\circ}C$, and the spatial attenuation reduces the intensity of thermal effect in the advancing plume front.

At $t = 5.0h$, the discharge ceases and the thermal plume source ends; the back edge of the thermal plume separates from $x = 0.5km$. After $t = 5.0h$, the separated thermal slug travels

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downstream as an isolated pulse while dissipating through the heat exchange with the atmosphere and turbulent mixing. For example, at $t = 5.0h$, the localized $\Delta T = 1.90℃$ at $x = 6.3km$, which represents the attenuation process. The whole thermal load of the upstream reach has been cleaned, indicating the self-purification ability of the river.

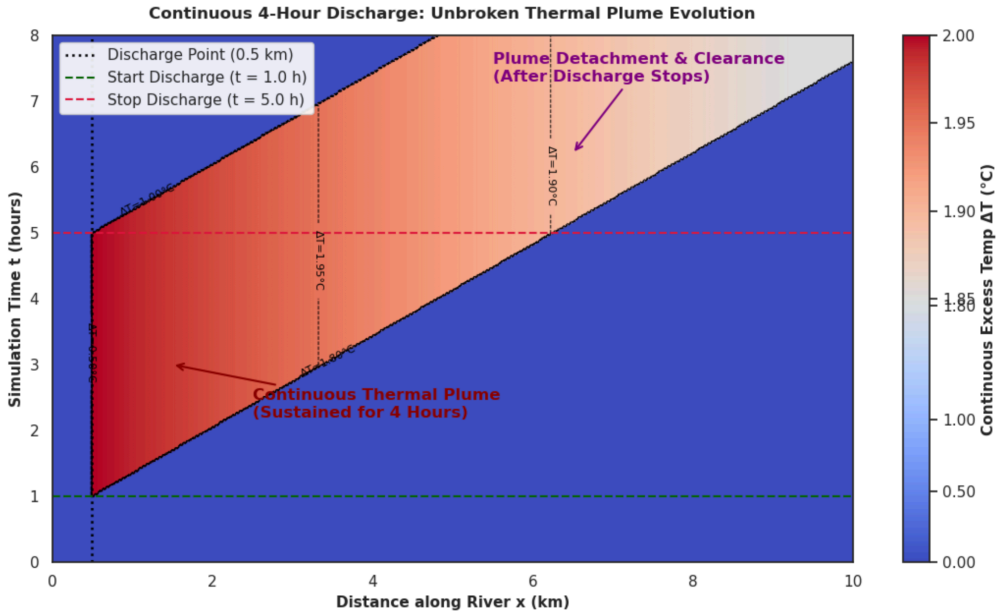


Figure 5. Spatiotemporal evolution of excess water temperature (ΔT) resulting from a continuous 4-hour thermal discharge in the Brisbane River. The horizontal axis represents downstream distance x, and the vertical axis indicates simulation time t. Black dotted line marks the discharge outfall at x=0.5km. Green dashed line indicates the discharge start time at t=1.0h, and red dashed line indicates the discharge stop time at t=5.0h. The heatmap illustrates the initial plume propagation from 1.0 to 5.0 h followed by plume detachment and clearance downstream after the source is shut off after t=5.0h

4. Discussion

Simulation results show that the one-dimensional advection-diffusion model successfully represents the key processes of thermal pollution transportation in rivers. The season-wise analysis showed that there is a higher environmental hazard in summer: even though the flow velocity is lower than during the winter, the presence of the higher background temperature (32.1°C) and thermal pollution discharge makes the water in the river exceed the ecologically hazardous level (33°C) in the vicinity of the discharge. Spatiotemporal heatmap showed that thermal pollution is a time-dependent phenomenon where a front of the plume moves downstream. It is necessary to consider this feature in order to understand how long the aquatic organisms stay exposed to the pollution. Sensitivity analysis from $\alpha = 1 to 2500 m^2/s$ demonstrated that although more mixing causes larger pollution plume and upstream back-dispersion, the main mechanism for heat transportation is still the advective transport through the river flow.

Monitoring data analysis (Figure 4) confirmed theoretical assumptions about the model scenario of seasonal temperature.

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5. Conclusion

This study developed a one-dimensional advection-diffusion model to simulate seasonal thermal pollution transport in the Brisbane River. The model incorporates flow advection, turbulent diffusion, and surface heat exchange to predict how heated wastewater disperses and decays along the river.

Key findings include that summer conditions pose greater risk due to elevated background temperature which exceeds 33°C, seen as an ecological red line when combined with thermal discharge； while in winter, the thermal plume is allowed to travel further downstream due to higher flow velocity, despite of lower absolute temperatures. Also, the spatiotemporal analysis reveals the dynamic nature of thermal plume evolution; (4) Sensitivity analysis over $\alpha = 1 to 2500 m^2/s$ confirms that advection-dominated transport makes flow conditions the primary control on thermal plume extent.

The novelty of this work is that it provides a simple and quantitative framework for assessing seasonal thermal pollution using existing river monitoring data. It is also possible for locating the discharge source in upper stream.

The model can be extended by incorporating time-varying emission schedules, multiple discharge sources, and coupling with an ecological impact model to generate more specific cases, based on local hydrological and meteorological conditions.

Acknowledgement

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Authorship

Guorui Wang was responsible for the core modeling, data processing, and result analysis of this study. Specifically, G. Wang wrote and debugged the complete 1D model code, processed most raw hydrological data and designed the seasonal simulation scenarios. G. Wang also conducted parameter sensitivity analysis, calculated the maximum allowable thermal discharge power, created all data figures, and organize the Results, Model Parameters and Scenarios, and Discussion sections of the draft.

Rui Zhou was responsible for the overall organization and documentation of this study. Specifically, Rui Zhou wrote the Title, Abstract, Introduction. Rui Zhou also completed the Data Collection and Preprocessing, the Governing Equation, the Brief Term Explanation, the Model Parameters and Scenarios, the Acknowledgements, and the References sections. In addition, Rui Zhou coordinated the overall structure of the manuscript and ensured the accuracy and clarity of the whole paper.

Qiuhao Li's major contribution focuses on mathematical modeling and parameter calibration. He reviewed relevant literature to establish the theoretical basis of the governing equation and investigated local hydrological and weather conditions to support parameter determination. He participated in the organization and processing of the original data and determined the empirical

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constants within the governing function based on local geology. He established the fitting equation of the river channel geometry and computed the cross-sectional area based on the fitted image.

Boxuan Yuan is responsible for collecting and finding basic information related to rivers, confirming the simulation of positioning and distance in research, and determining the direction of research.At the same time, based on geographical knowledge, he studied and summarized the seasonal patterns of temperature, flow and other data, and was responsible for the part of seasonal variance and overall conclusion in the paper.

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