Experimental investigations on the gas transfer efficiency at low-head hydraulic structures

Agnieszka Rajwa-Kuligiewicz, Robert J. Bialik, Paweł M. Rowiński

Department of Hydrology and Hydrodynamics
Institute of Geophysics
Polish Academy of Sciences

Goals

- quantify gas transfer characteristics of hydraulic structures under small oxygen deficit;
- assess the impact of hydraulic structures on downstream DO conditions.

Oxygen transfer	$$\frac{dC}{dt} = K_L a \underbrace{(C_s - C)}_{O_2 \text{ deficit}}$$
Deficit ratio	$$r = \frac{C_s - C_{US}}{C_s - C_{DS}} = \exp\left[\int_{up}^{down} K_L a \, dt\right]$$
Gas transfer efficiency ratio	$$E = \frac{C_{DS} - C_{US}}{C_S - C_{US}} = 1 - \frac{1}{r}$$ *(Gameson 1957)*

K_L – reaeration coefficient

a – specific surface area

C_S – O_2 saturation concentration

C – O_2 concentration in water

C_{US} – O_2 concentration upstream

C_{DS} – O_2 concentration downstream

Temperature corrected gas transfer efficiency ratio	$E_{20} = 1 - (1 - E)^{\frac{1}{f}};$ $f = 1 + \alpha(T - 20) + \beta(T - 20)^2$ *(Gulliver et al. 1990)*
Uncertainty in E	$U_E = \frac{\left({W_{C_{DS}}}^2 + \left(W_{C_{US}}(1 - E)\right)^2 + (B_C E)^2 + (B_{Cs} E)^2\right)^{\frac{1}{2}}}{C_s - C_{US}}$ *(Gulliver and Rindels 1993)*

$\alpha = 2.103 \cdot 10^{-2}$

$\beta = 9.261 \cdot 10^{-5}$

U_E – total unceratinty in E

Wc_{US}, Wc_{DS} – precision unceratainties in C_{US} and C_{DS}

B_C – bias unceratainty in the measurements of C_{US} and C_{DS}

B_{Cs} – bias uncenrtainty in C_s

Fig. 1 Weir (the Narew River)

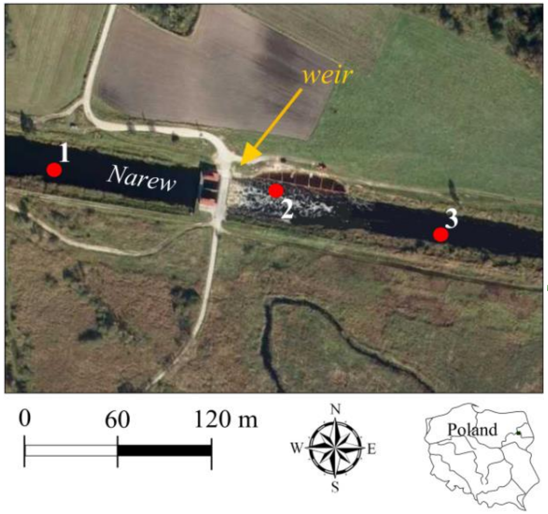
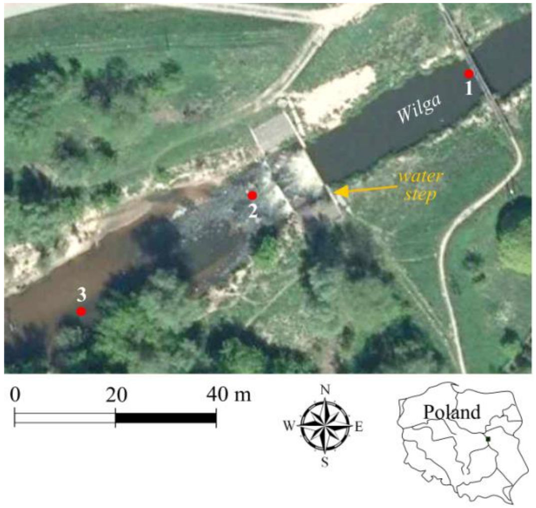


Fig. 2 Water step (the Wilga River)



High-frequency in-situ measurements of:

- ✓ dissolved oxygen;
- ✓ water temperature;
- ✓ air pressure;

Tab. 1 Hydraulic characteristics of rivers before the hydraulic structures

River	B (m)	H (m)	T (°C)	Q (m^3s^{-1})	U (ms^{-1})	Re	Fr
Wilga	9.5	0.5	5.5	1.16	0.25	12×10^4	0.17
Narew	15.0	2.5	13.0	5.32	0.17	51×10^4	0.05

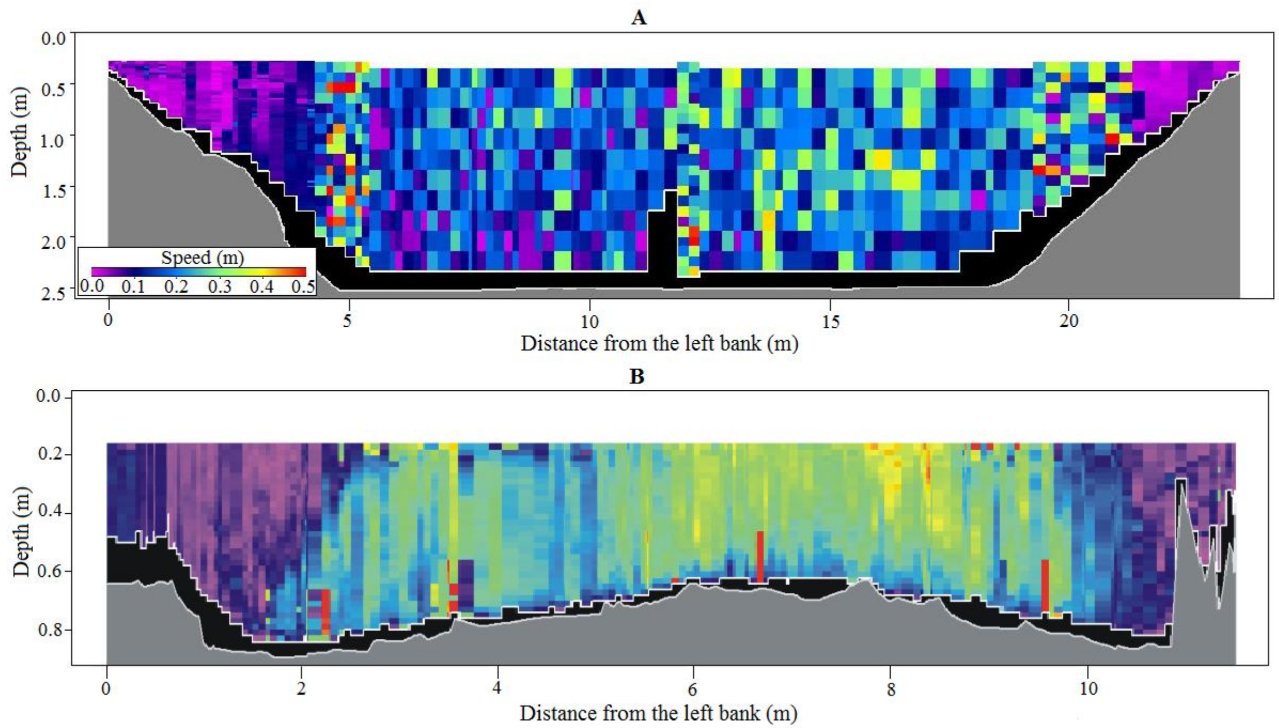


Fig. 3 Flow structure and bathymetry before the weir (A) and water step (B).

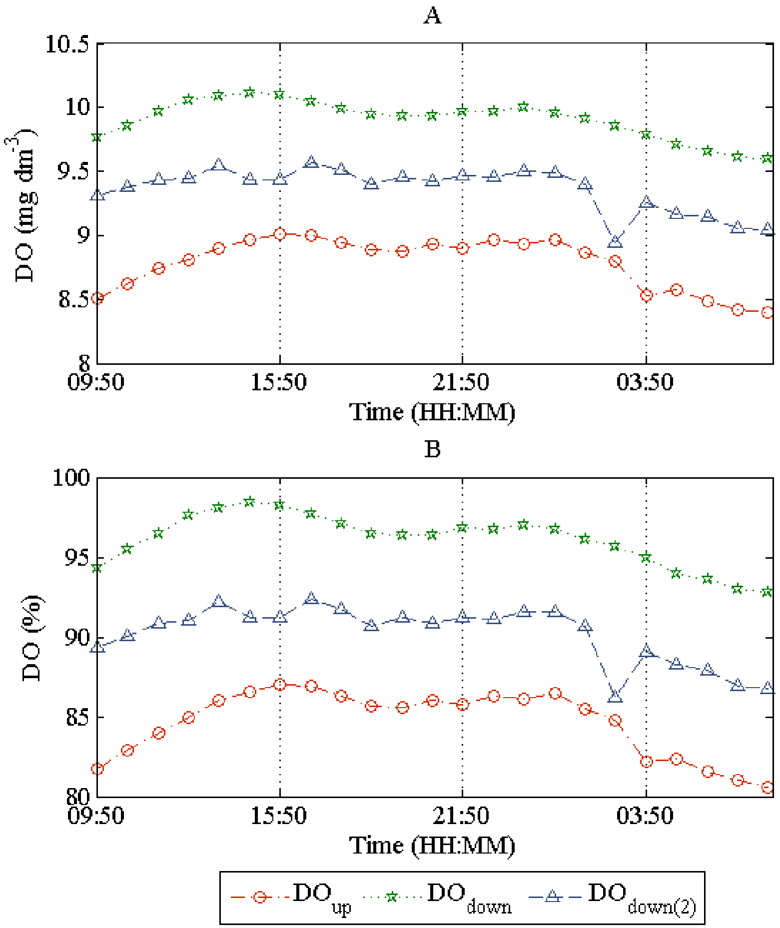


Fig. 4 DO curves for the weir:
(A) DO concentration, (B) DO saturation

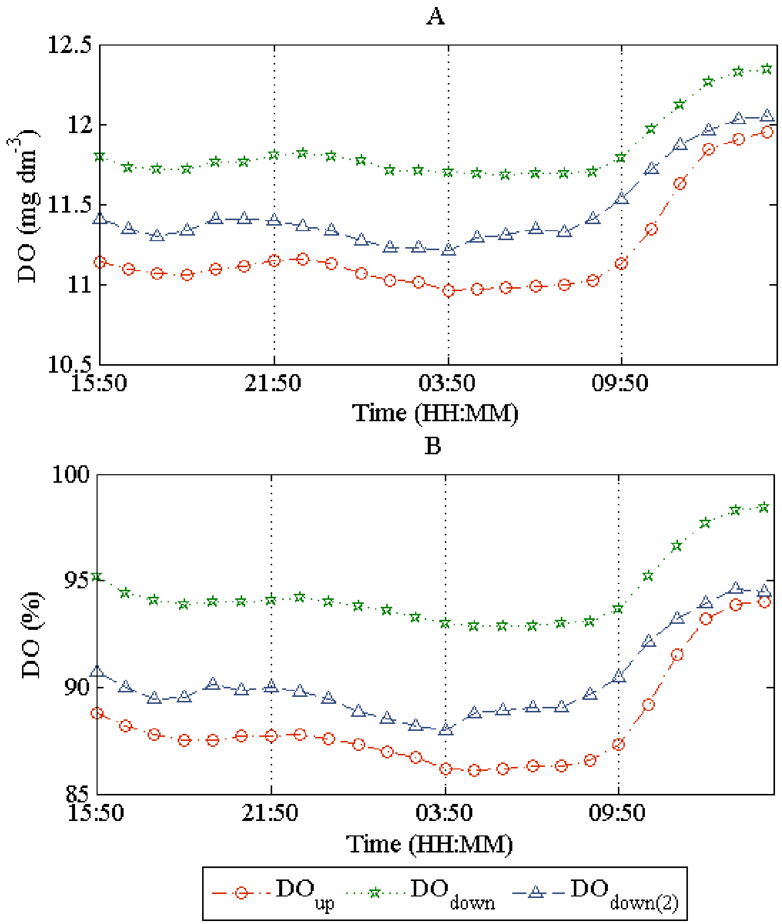


Fig. 5 DO curves for the water step:
(A) DO concentration, (B) DO saturation

E_{20} - the capability of water to absorb O_2 from the air (corrected by water temperature)

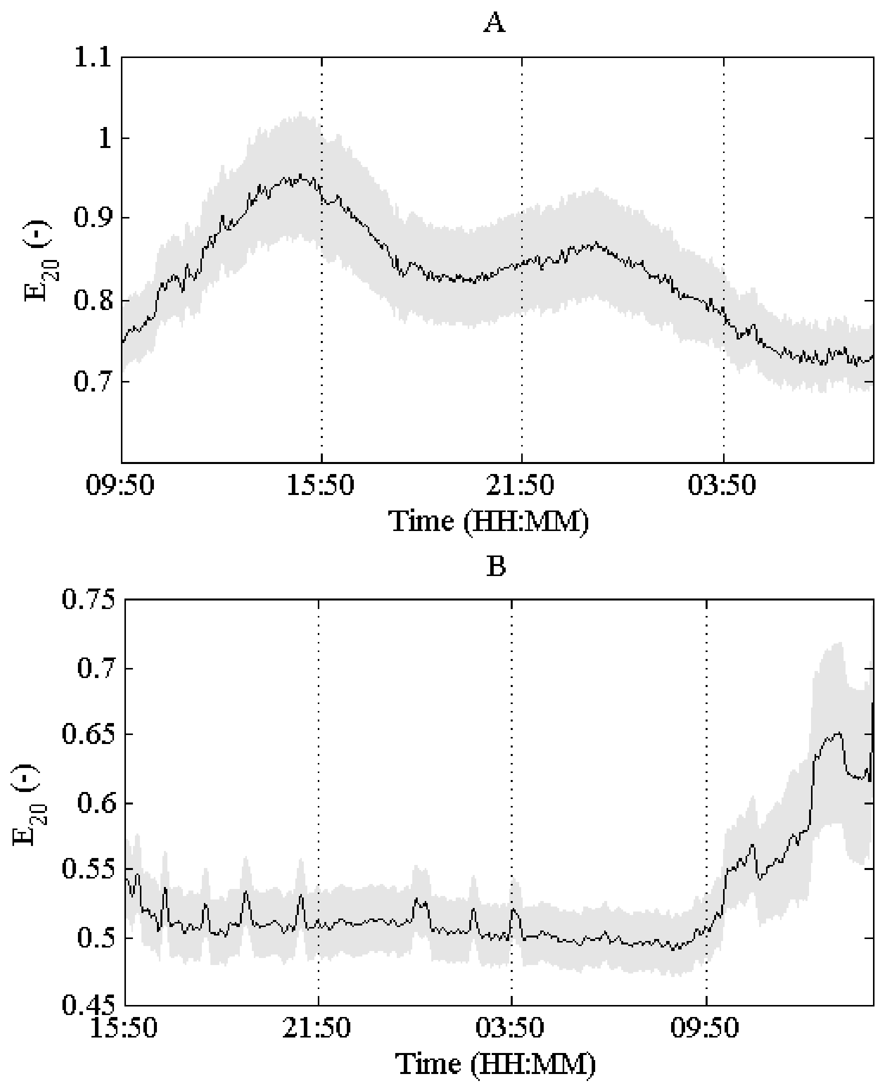


Fig. 6 Gas transfer efficiency (E_{20}) fluctuations over time (black line) with uncertainty (grey area): (A) weir, (B) water step.

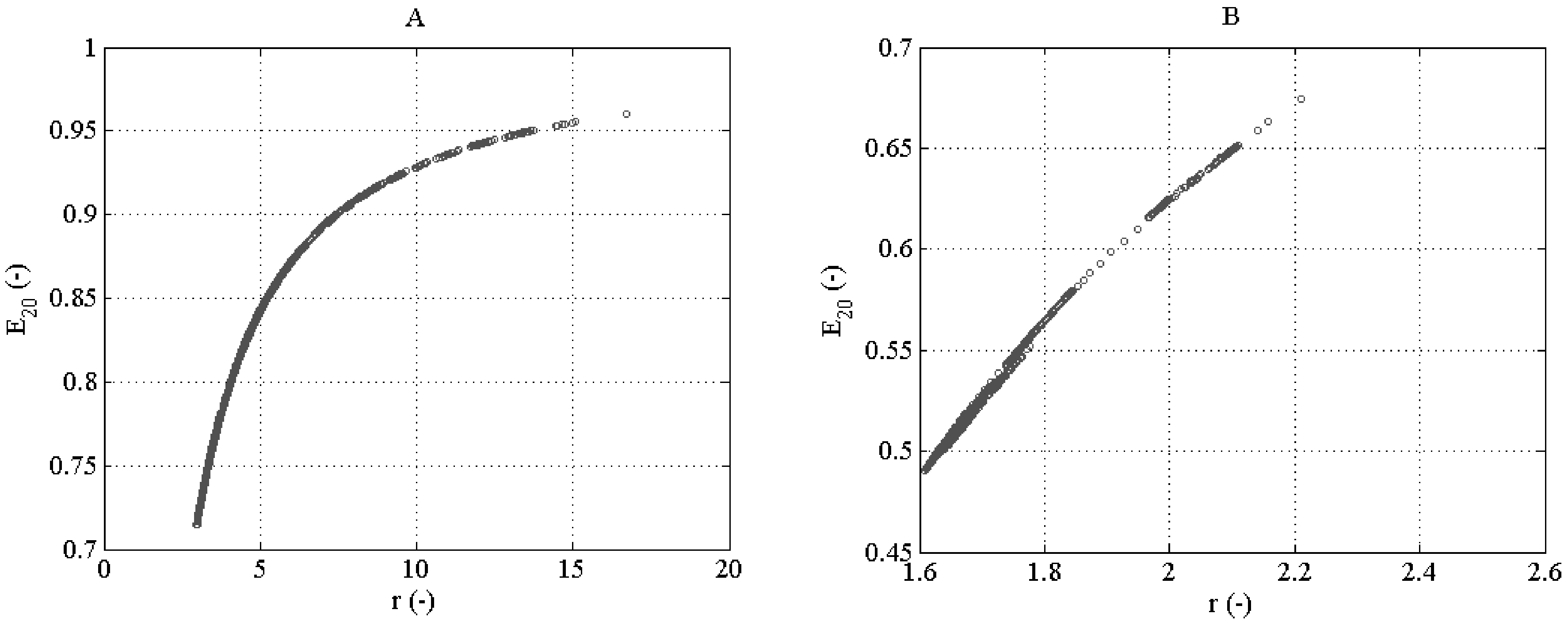
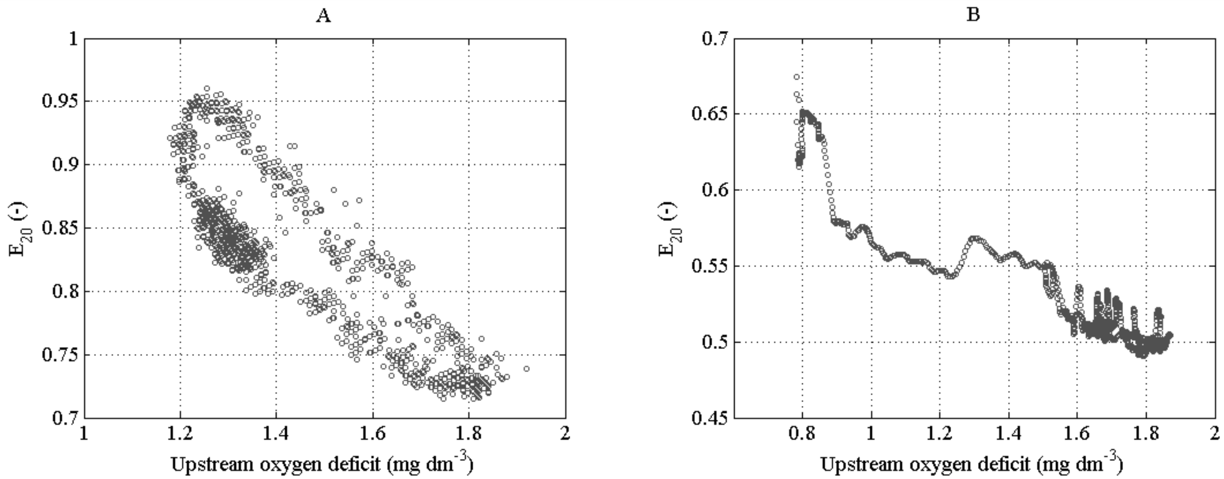


Fig. 7 Scatter plots of E_{20} vs. deficit ratio: (A) weir, (B) water step.



Oxygen deficit = Cs - C

Fig. 8 Scatter plots of E_{20} vs. upstream oxygen deficit: (A) weir, (B) water step.

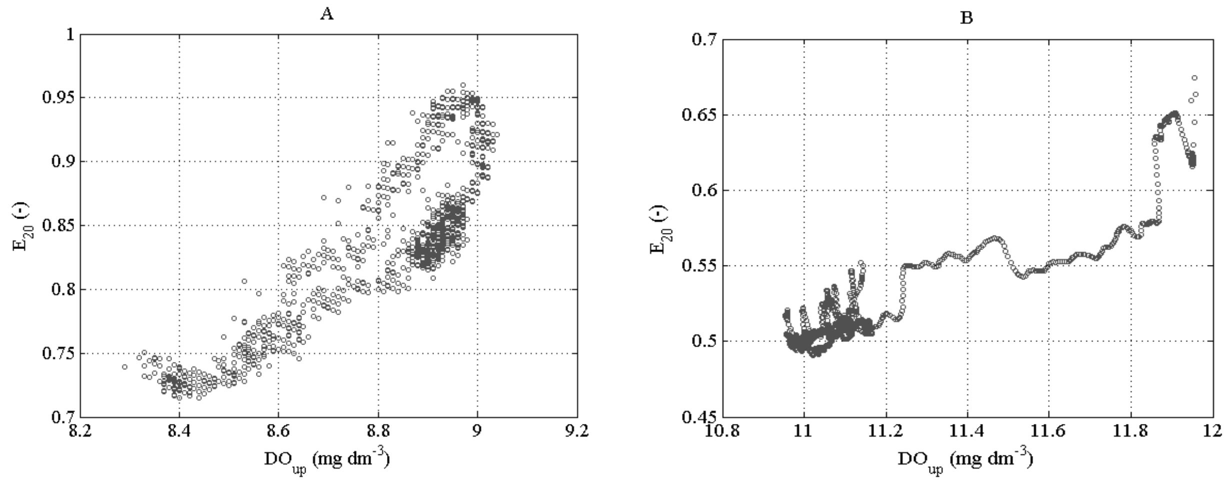


Fig. 9 Scatter plots of E_{20} vs. upstream DO concentration: (A) weir, (B) water step.

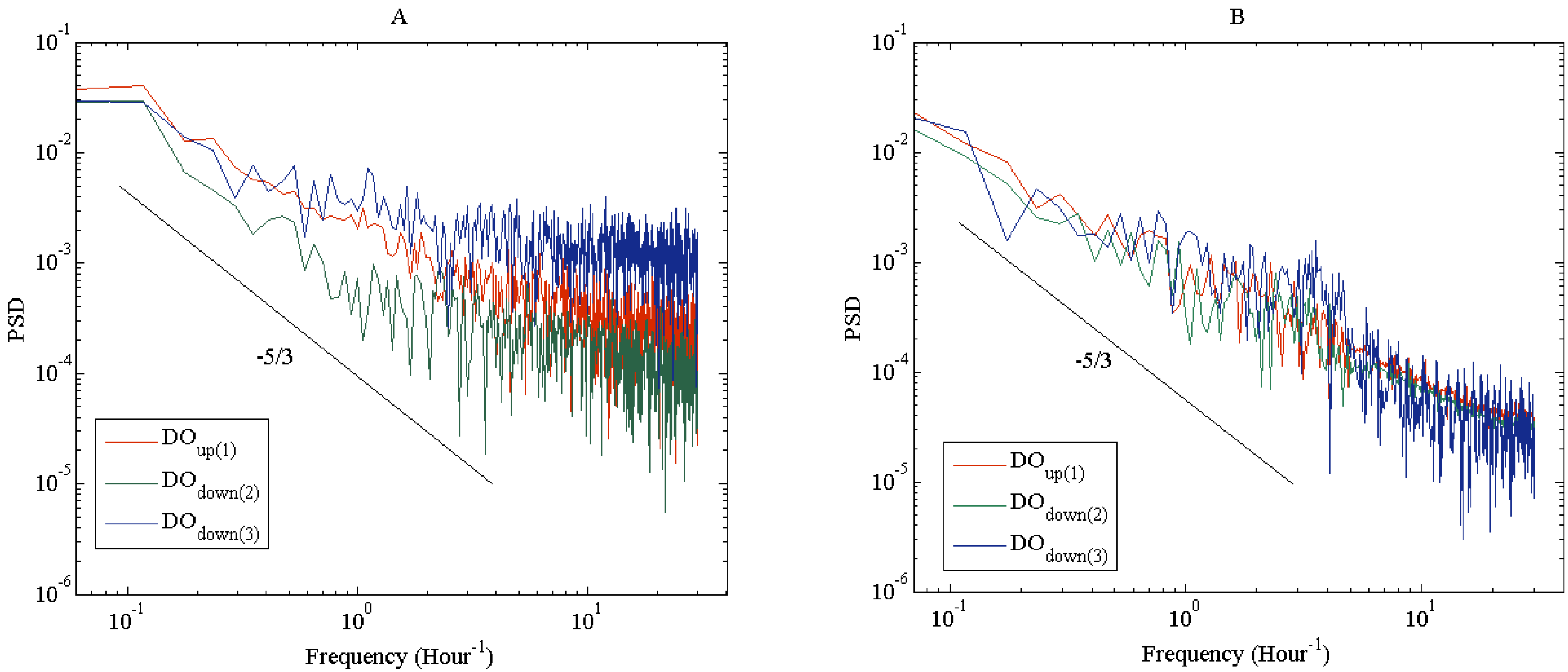


Fig. 10 Power spectral density of DO time curves: (A) weir on the Narew river, (B) water step on the Wilga river.

- ✓ High frequencies -> the noise affects the shape of the spectra;
- ✓ Two slopes in the PSD of $DO_{down(2)}$;
- ✓ Low frequency range (weir) -> sharp decay (~power function).

- ✓ F_j
- ✓ Re_j
- ✓ F_j
- ✓ head loss
- ✓ unit discharge
- ✓ tail-water depth
- ✓ critical water depth

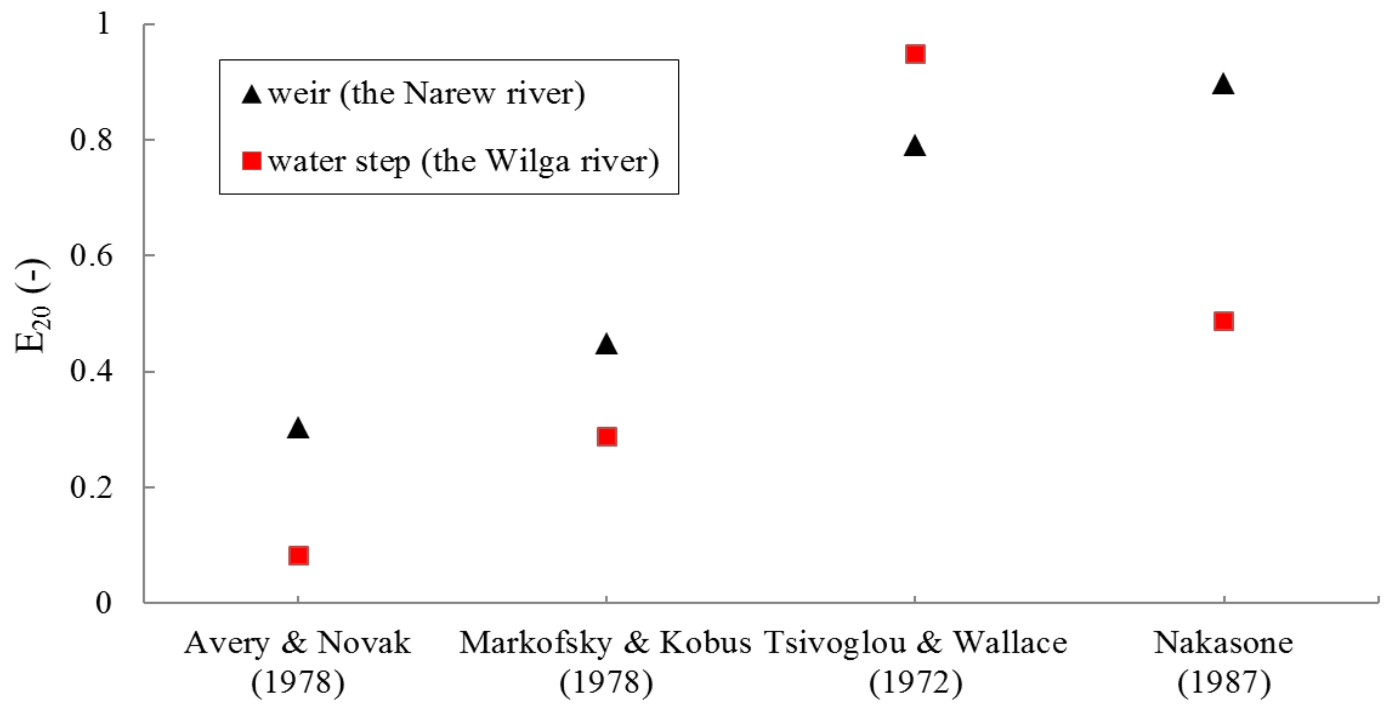


Fig. 11 Aeration efficiencies derived from predictive equations

- Gas transfer efficiencies can be calculated with a fair degree of accuracy;
- Hydraulic structures elevate DO concentrations downstream and attenuate daily variations of DO resulting from the changes of water temperature and biological activity.
- Transfer efficiency ratio varies within each day (under constant head loss and discharge) depending on the oxygen deficit of the inflowing water -> these variations should be taken into account when predicting downstream oxygen concentration.

Thank you for your attention