



AKADEMIA GÓRNICZO-HUTNICZA
IM. STANISŁAWA STASZICA W KRAKOWIE

AGH UNIVERSITY OF SCIENCE
AND TECHNOLOGY

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Triple isotope balance of groundwater controlled lake

Kazimierz Rozanski, Anna Pierchala, Marek Dulinski, Zbigniew Gorczyca,
Robert Czub



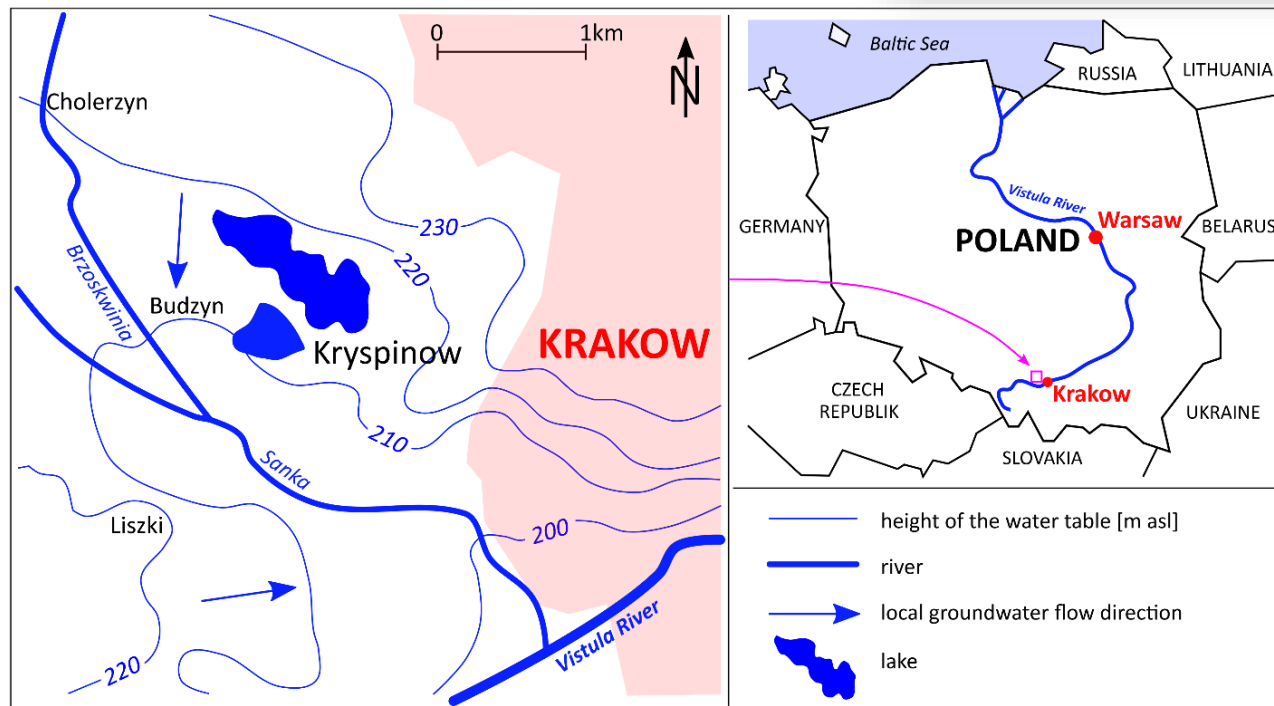
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Comprehensive, triple isotope (^2H , ^{18}O , ^{17}O) study of hydrological balance of groundwater-controlled lake located in central-eastern Europe

STUDY AREA

Kryspinow Lake – small groundwater controlled lake

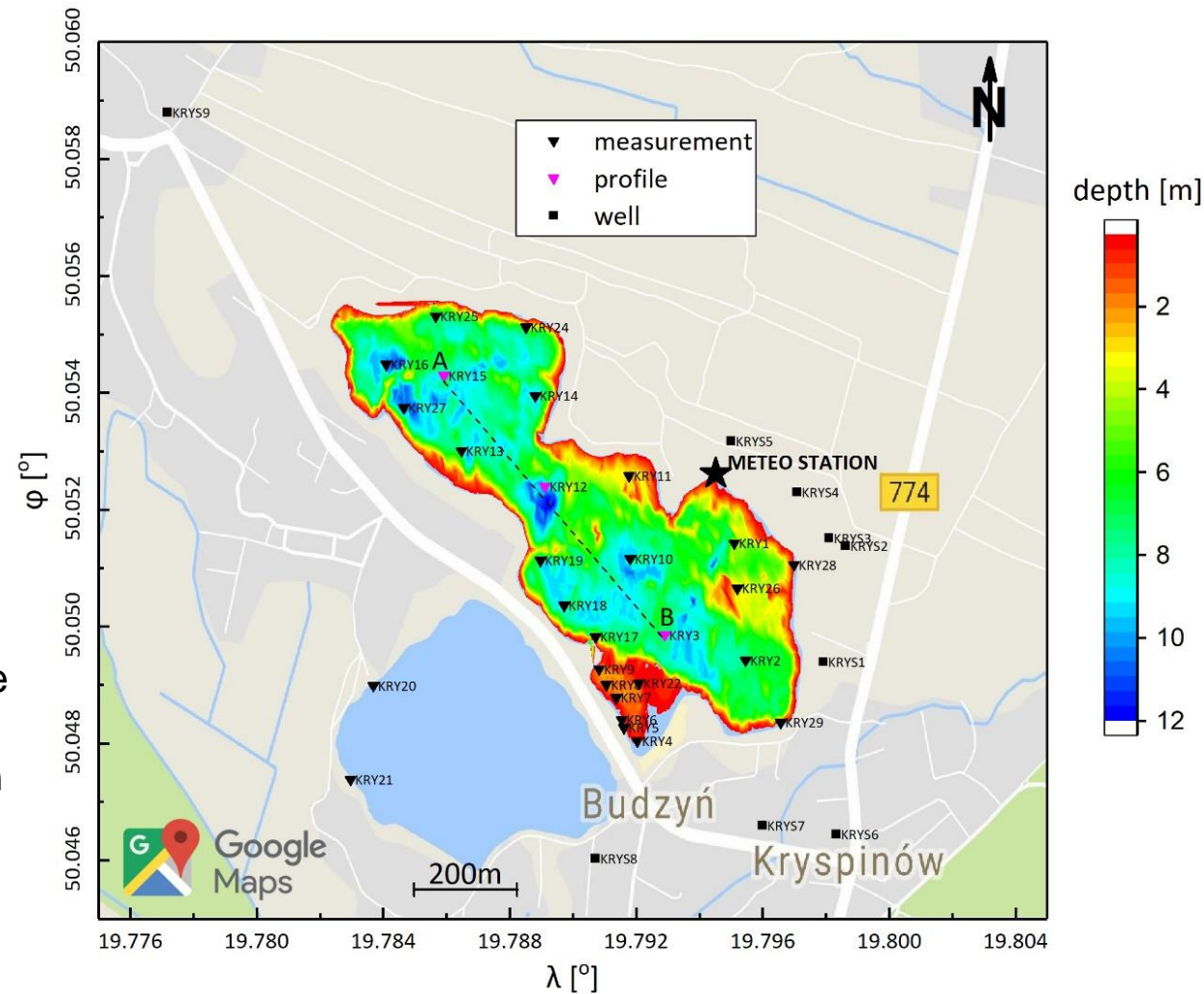
- surface area: ~40ha
- mean depth ~5.2m
- no surface inflows and outflows
- moderate, continental climate
 - ✓ T_{annual} : 8.5°C
 - ✓ P_{annual} : 647 mm
 - ✓ RH_{annual} : 80%



Kryspinow lake is an artificial lake formed as a result of excavation of sand (dredging lake). The lake is heavily exploited during summer season for recreational purposes.

METHODS

- **Monitoring of the lake:**
Oct. 2018 – Sept. 2019
- **Four sampling campaigns** – one in each season – collecting lake water and groundwater for isotope analyses
- **Regular observations of lake water temperature and meteorological parameters**
- air temperature, precipitation amount, relative humidity, wind speed measured on the lake shore
- **Collecting monthly precipitation samples on the lake shore**
- **Isotope analyses of lake water, groundwater and precipitation samples**
($\delta^2\text{H}$, $\delta^{18}\text{O}$, $\delta^{17}\text{O}$) Picarro L2140-*i* laser spectrometer



METHODS

The studied lake has no surface inflows and outflows. Its hydrological balance is controlled by precipitation (P), evaporation (E) and groundwater fluxes: inflow (I_G) and outflow (O_G). The steady-state mass and isotope balance equations lead to the following expressions for groundwater fluxes [1]:

$$O_G = I_G + P - E \quad (1)$$

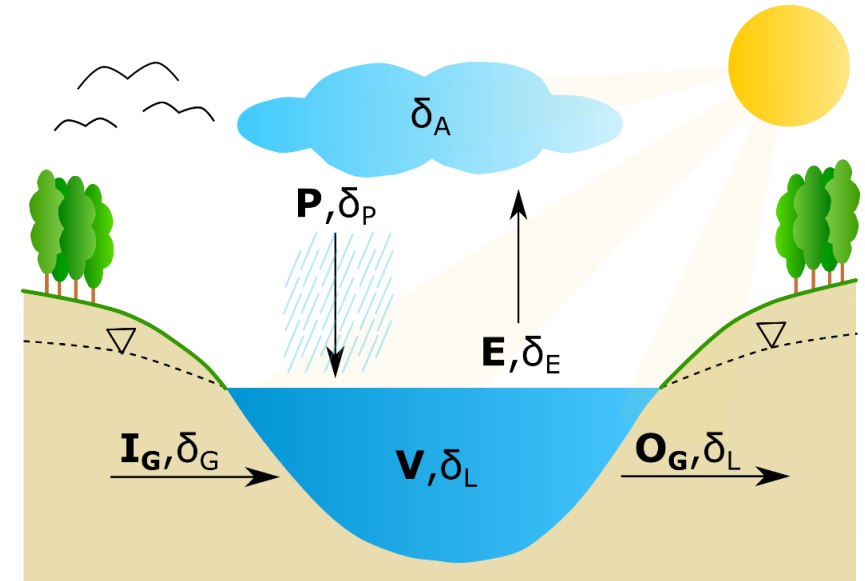
$$I_G = \frac{\delta_L - \delta_P}{\delta_{IG} - \delta_L} \cdot P + \frac{\delta_E - \delta_L}{\delta_{IG} - \delta_L} \cdot E \quad (2)$$

Isotopic composition of net evaporation flux (E) is calculated based on the Craig-Gordon model [2]:

$$\delta_E = \frac{\alpha_{eq} \delta_L - h_N \delta_A + \varepsilon_{eq} + \varepsilon_{kin}}{1 - h_N - \varepsilon_{kin}} \quad (3)$$

$$\varepsilon_{kin} = n \varepsilon_{diff} (1 - h_N) \quad (4)$$

where (δ_L) is the isotopic composition of the lake, h_N signify relative humidity over the lake, normalized to the lake temperature and $\alpha_{eq} = \varepsilon_{eq} + 1$ stands for fractionation factor between liquid and gaseous phase of water at thermodynamic equilibrium. Isotopic composition of atmospheric moisture (δ_A) can be calculated from the isotope composition of precipitation (δ_P), assuming isotopic equilibrium at ground level temperature [3]. The kinetic fractionation, ε_{kin} , is a function of relative humidity and turbulence parameter, n , which varies between 0.5 and 1. For lake studies usually $n = 0.5$ is selected [4]. ε_{diff} stands for diffusive kinetic fractionation and is equal 25.1 ‰, 28.5 ‰ and 14.6 ‰, for ^2H and ^{18}O [5] and ^{17}O [6], respectively.



RESULTS – APPROACH 1:

- Groundwater inflow and outflow rates (annual averages) were derived from equations (1 – 4) separately for each isotope tracer in use (^2H , ^{18}O , ^{17}O)

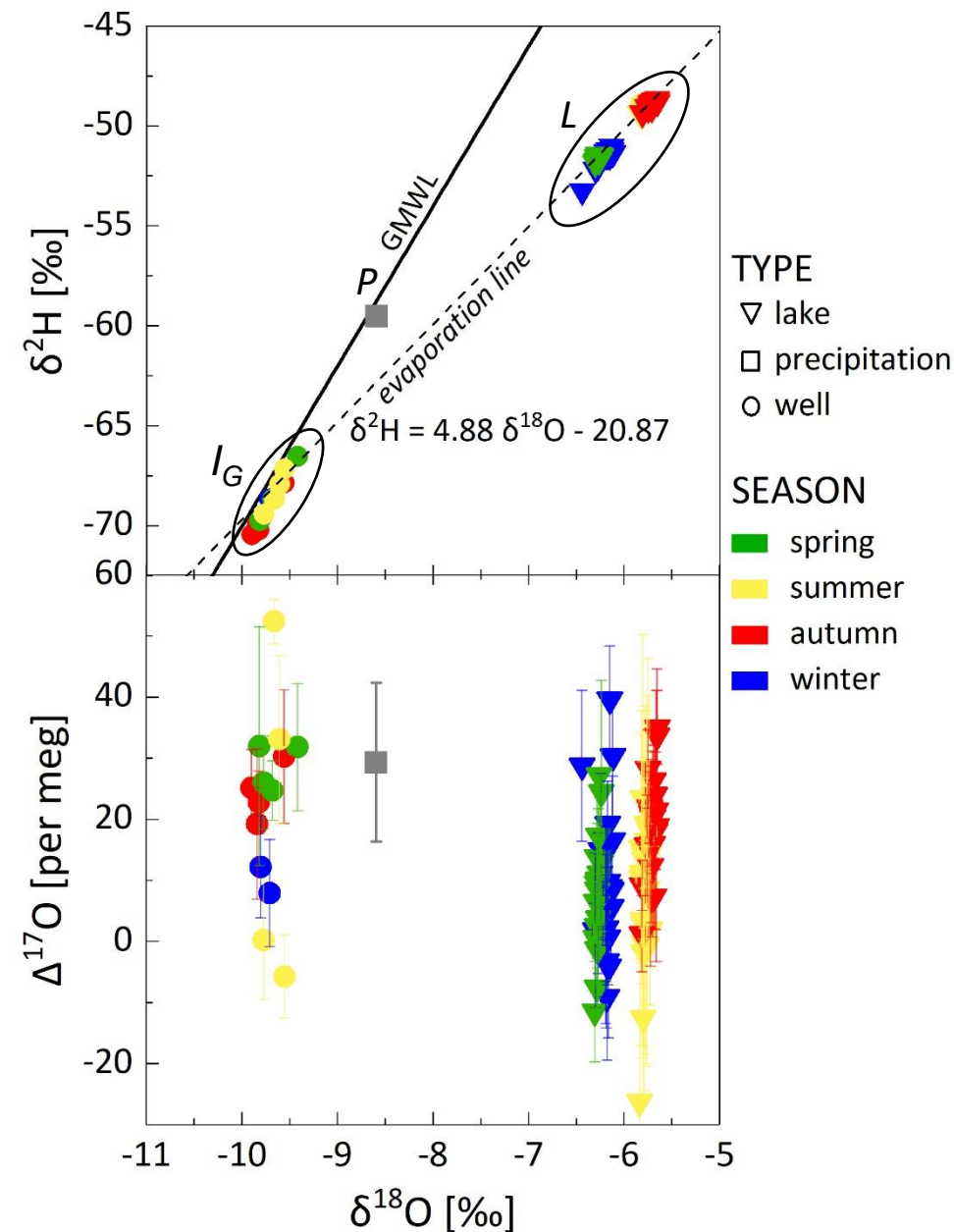
APPROACH 1

ASSUMPTION: Atmospheric water vapor "seen" by the evaporating lake is a local free-atmosphere moisture, which is in isotopic equilibrium with the local precipitation at ground-level temperature

Groundwater fluxes derived from ^2H -based budget deviate substantially from those obtained for ^{18}O and ^{17}O -based budgets:

	^2H	^{18}O	^{17}O
δ_A [‰]	-138.30	-18.610	-9.852
δ_E [‰]	-127.84	-26.27	-13.77
I_G [mm]	2868	3757	3709
O_G [mm]	2770	3659	3611

REASON?



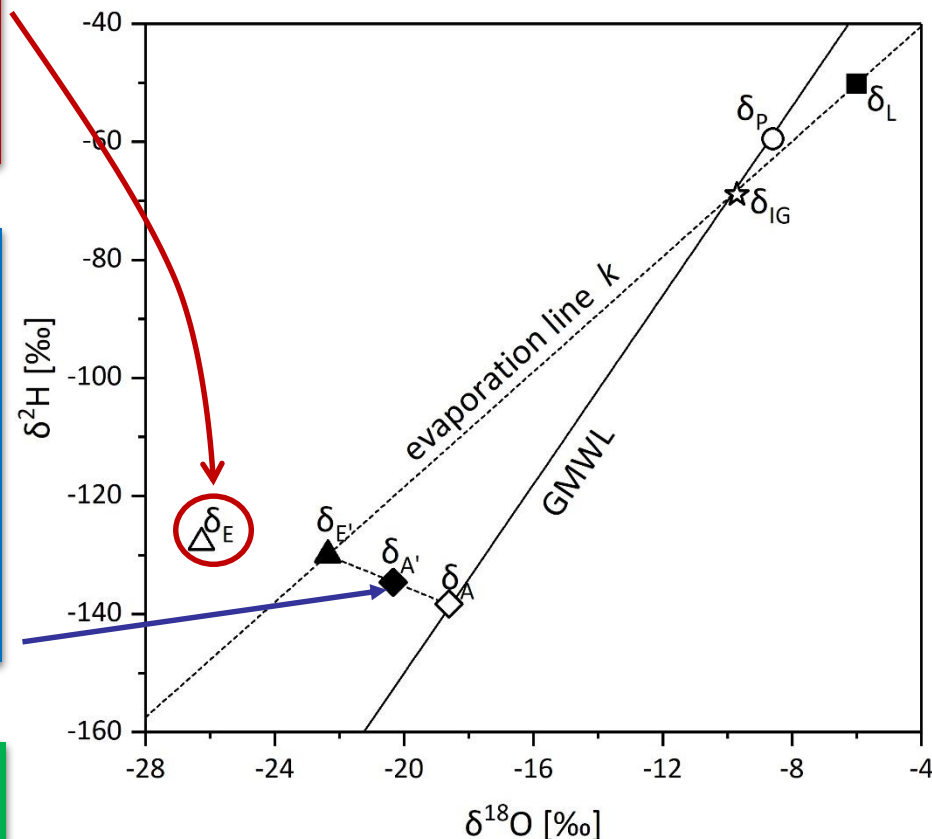
RESULTS – APPROACH 2:

The calculated isotopic composition of net evaporation flux δ_E derived from the first approach doesn't fit the lake's evaporation line as it should be

APPROACH 2:

ASSUMPTION: Local water vapor “seen” by the lake (A') is a mixture of local free atmospheric moisture (A) which is in isotopic equilibrium with local precipitation and the vapor produced by the lake itself (E').

Consistent water budget for three isotope systems (^2H , ^{18}O , ^{17}O) was obtained:



	^2H	^{18}O	^{17}O
δ_A [‰]	-134.63(1.1)	-20.26(0.30)	-10.72(0.46)
δ_E [‰]	-130.0(1.2)	-22.36(0.33)	-11.69(0.50)
I_G [mm]	2960(270)	2940(290)	2890(340)
O_G [mm]	2860(290)	2840(300)	2790(350)

CONCLUDING REMARKS:

①

Heavy isotopes of water (^2H and ^{18}O) are powerful tracers to quantify water budgets of surface water bodies (lakes, ponds, reservoirs, etc.). They are particularly useful for deriving underground components of those budgets, difficult to obtain using classical hydrological methods.

②

The long-standing controversy with respect to inconsistencies of lake balance components derived separately from ^2H and ^{18}O -based budgets can be resolved assuming that atmospheric water vapor "seen" by the lake is a mixture of local free atmospheric moisture which is in isotope equilibrium with local precipitation and the vapor produced by the lake itself.

③

Nowadays, laser-based technologies enable simultaneous analyses of three heavy isotopes of water molecules (^2H , ^{18}O and ^{17}O). Adding third tracer (^{17}O) to isotope studies of surface water bodies increases reliability of water balance components of those systems derived from isotope-mass balance equations.

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