Joint 34th ICP Waters and 26th ICP IM Task Force Meeting, Warsaw, Poland, 7-9 May 2018

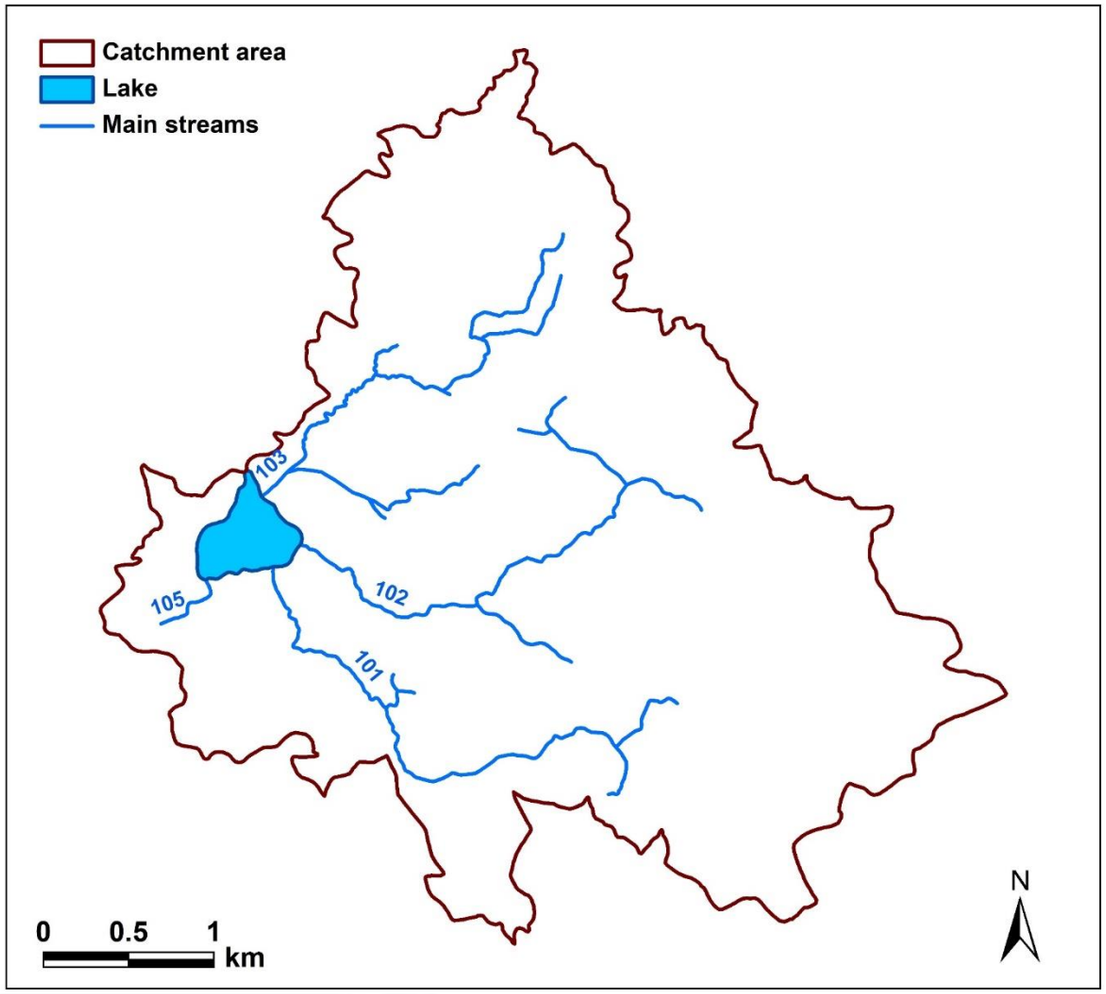
Nitrogen budget at the IM station "Puszcza Borecka“

Rafał Ulańczyk
Krzysztof Skotak
Tomasz Pecka
Anna Degórska
Agnieszka Pasztaleniec
Agnieszka Kolada

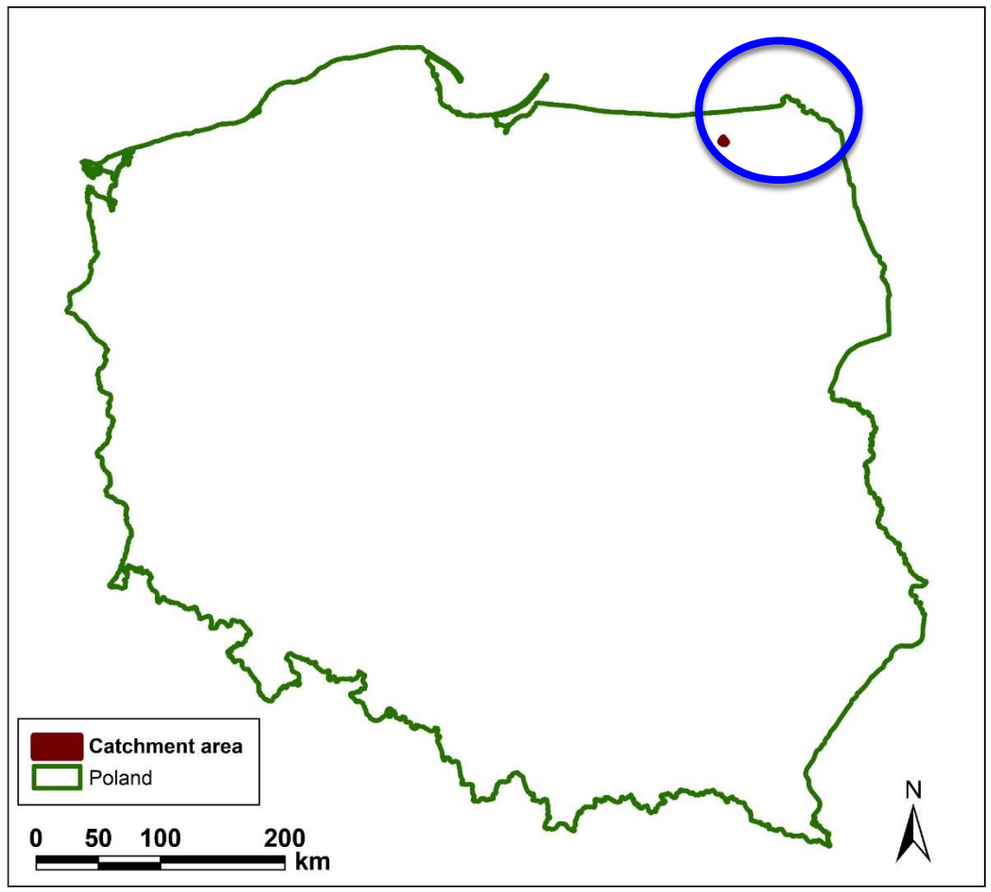
Institute of Environmental Protection – National Research Institute

IM „Puszcza Borecka”

- **Area** of the monitored catchment: 13.268 km^2
- **86%** of catchment belongs to the **protected** area Puszcza Borecka
- **100% Natura 2000**
- **EMEP station** (PL05 „Diabla Góra”)



- **Lake (Łękuk Wielki)** located at the outflow
- Area of lake: 21.297 ha
- **4 main streams** flowing into the lake (partially of seasonal character)
- **Elevation:** 127.3 – 198.8 m a.s.l. (station at 157.5)

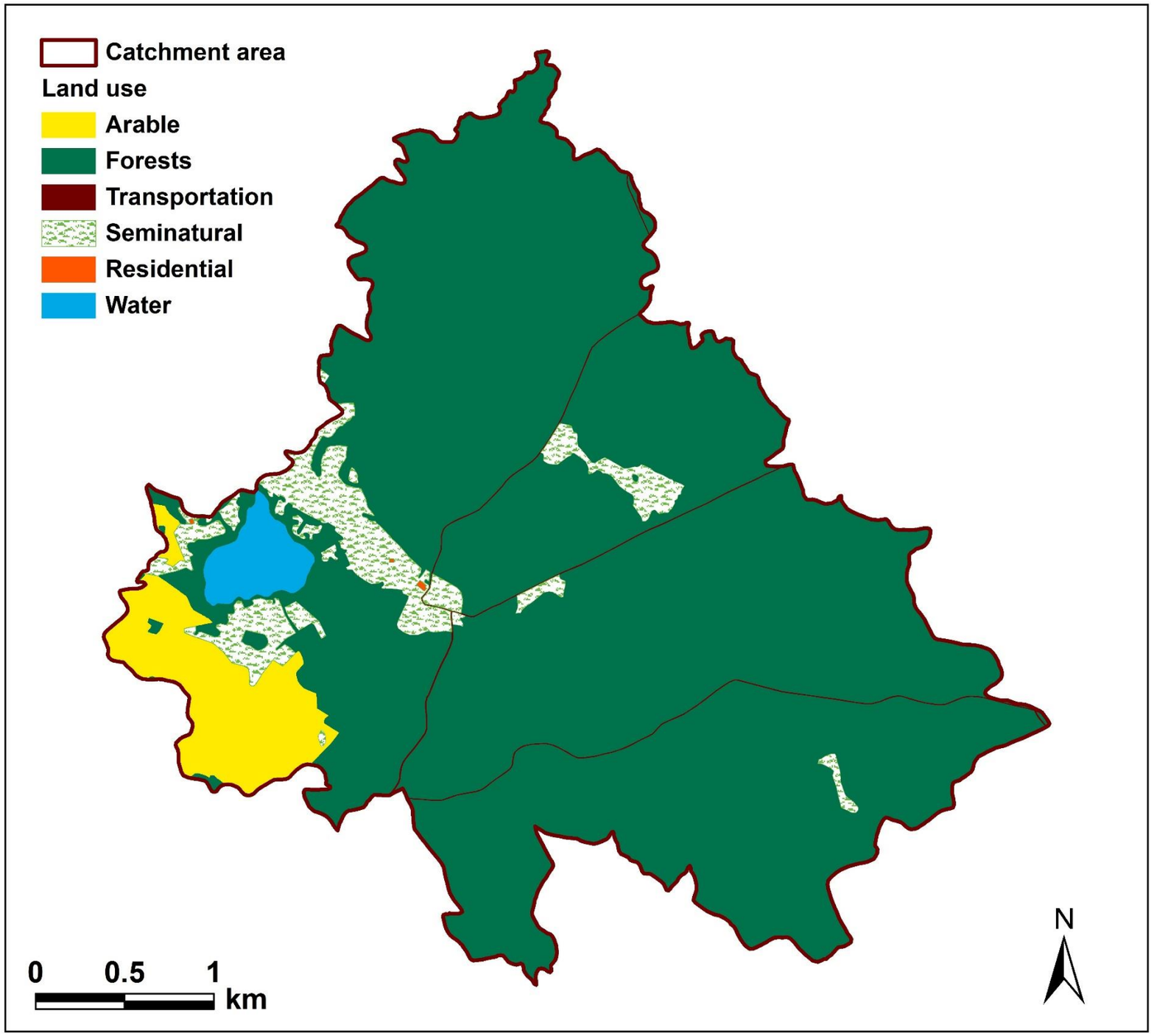


IM „Puszcza Borecka”

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Land use:

- Forests: 78%
- Agriculture: 5.6%
- Seminatural: 14.3%
- Water: 1.6%
- Residential: 0.2% (low density)



Monitoring of nitrogen

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Scope:

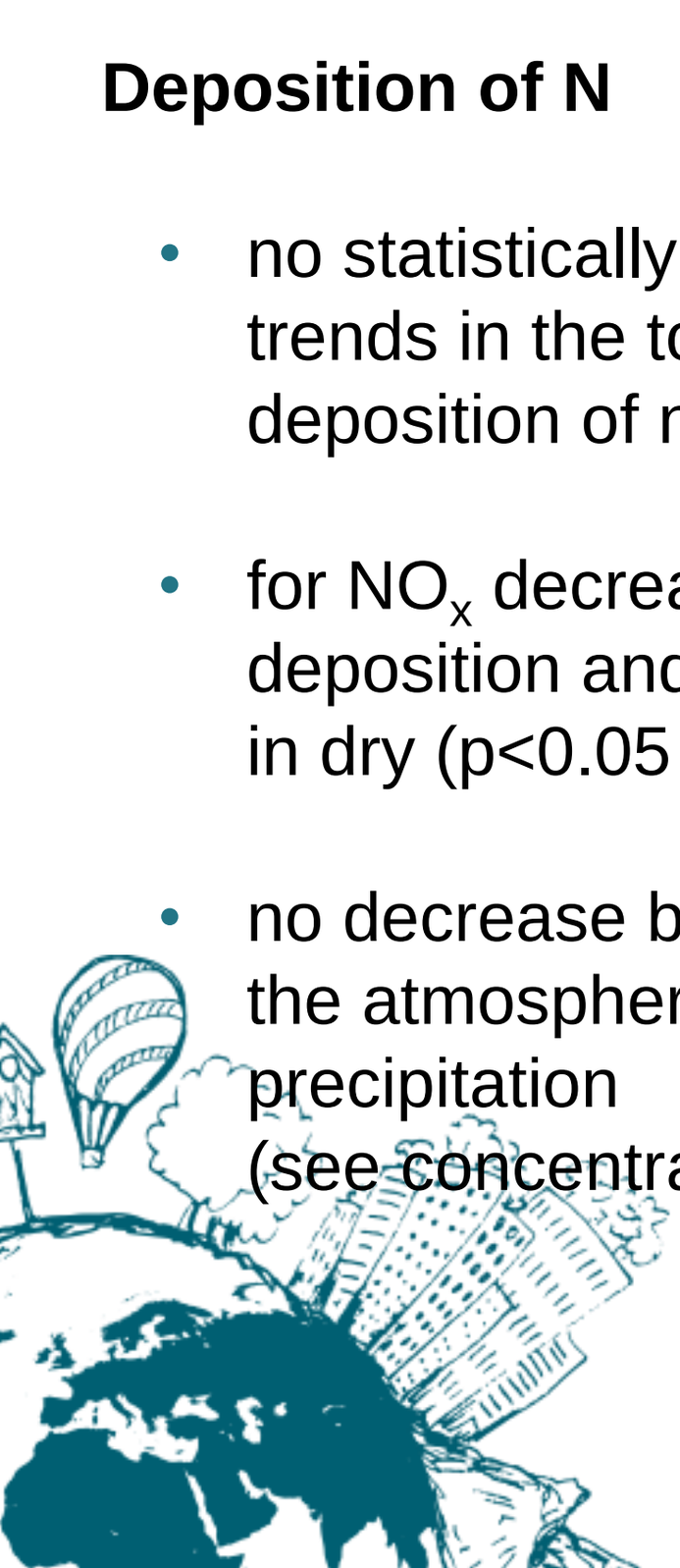
- Concentration of N-$NO_{2,3}$ and N-NH_4 in **air and precipitation** and wet deposition (daily since 1994)
- Concentration of N-NO_3 and N-NH_4 in:
  - **troughfall** (monthly since 2005)
  - **stemflow** (monthly since 2004)
  - **litterfall** (monthly sampling, yearly analyses since 2004)
  - **Soil water** at 3 depths: 20, 50 and 80 cm (2-9 samples/year since 2010)
  - **groundwater** (1-8 samples/year since 1995)
  - **lake** + outflow (1-8 samples/year since 1991, outflow since 1995)
  - **streams** (1-10 samples/year since 1995, discontinued)

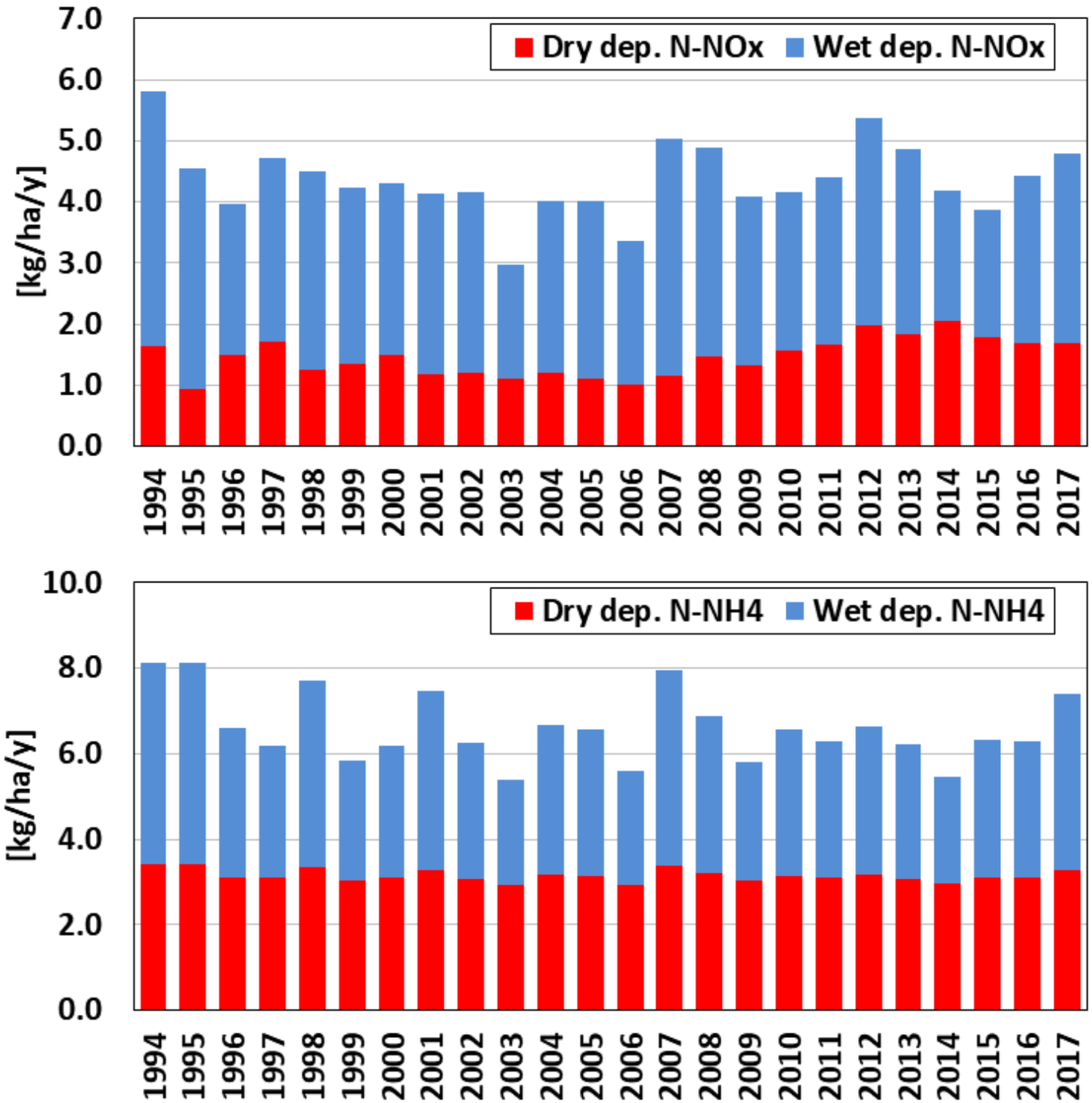
Monitoring of nitrogen – basic results, trends

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Deposition of N

- no statistically significant trends in the total deposition of nitrogen
- for NO_x decrease in wet deposition and increase in dry ($p<0.05$ and $p<0.1$)
- no decrease because of the atmospheric precipitation (see concentrations)





Monitoring of nitrogen – basic results, trends

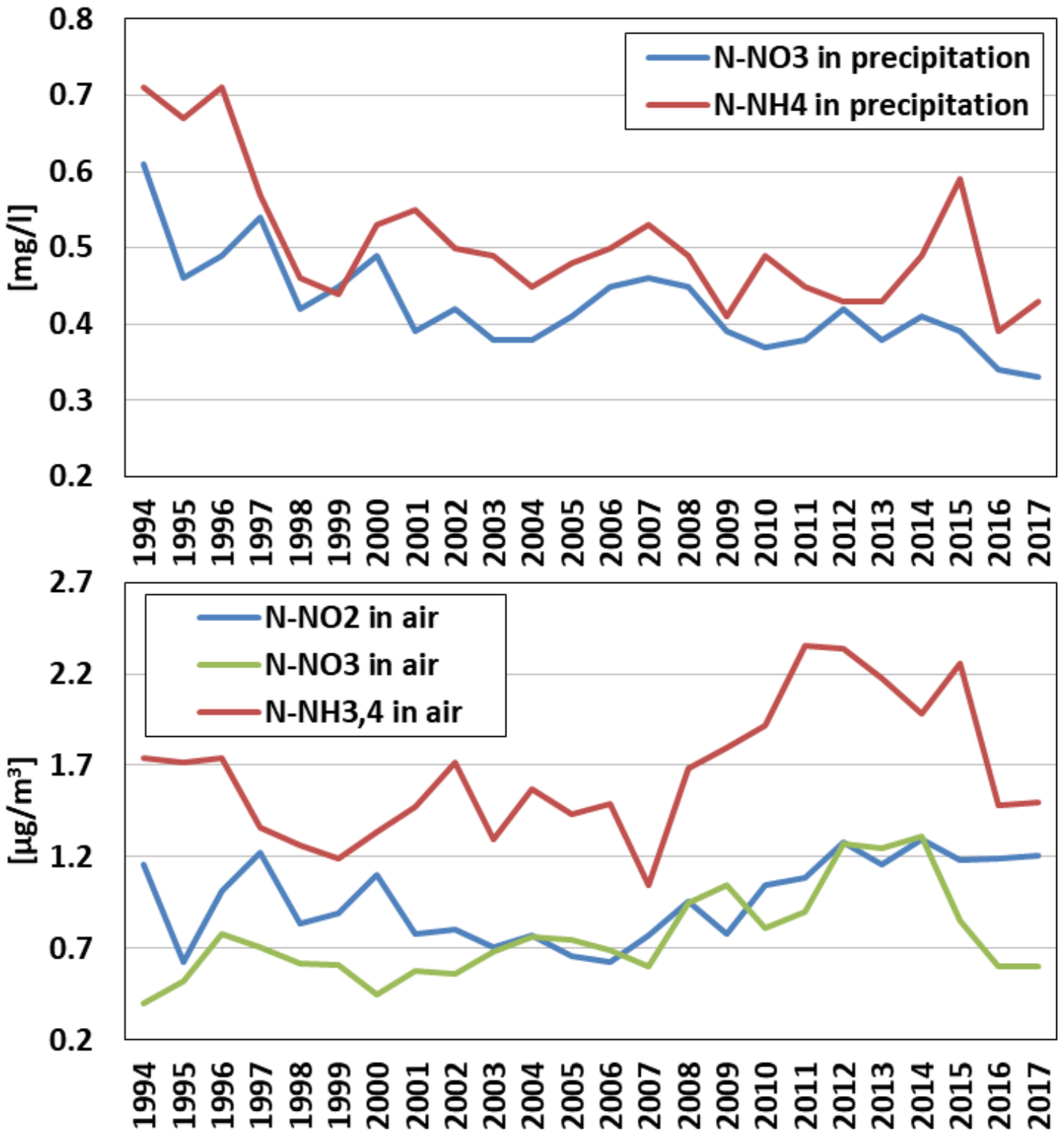
IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

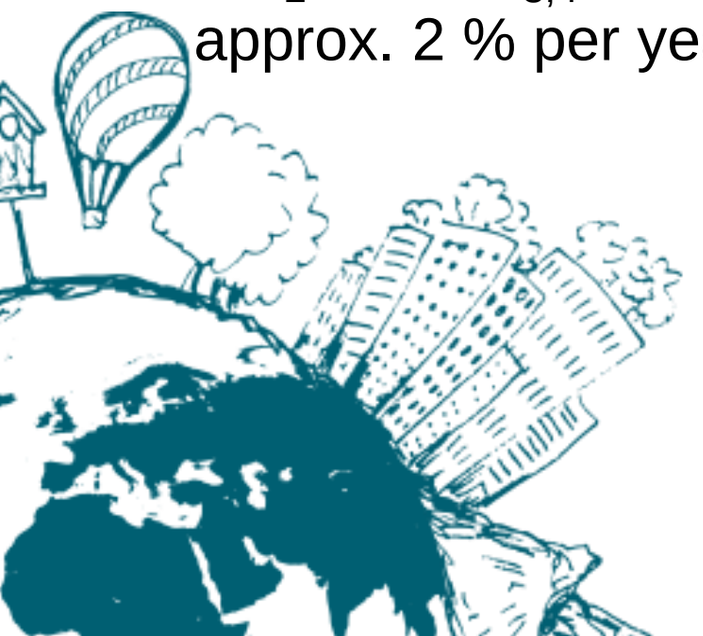
Concentration of N in precipitation

- Significant **decrease** in the N concentrations ($p<0.001$, decrease nearly 1.5 % per year)

Concentration of N in air

- Significant **increase** in the N concentrations ($p<0.01$ for NO_3, $p<0.025$ for NO_2 and $NH_{3,4}$, increase approx. 2 % per year)





Monitoring of nitrogen – N inputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

		Yearly average	Unit	Trend	n	Significance*
$N\text{-}NO_3$	Dry deposition	1.46	kg/ha/y	▲ 1.63% / year	24	p=0.015
	Wet deposition	2.91		▼ 0.75% / year	24	p=0.059
	Troughfall	4.28		▼	13	N. s.
	Stemflow	0.49 Hornbeam 0.92 Oak 2.73 Spruce	mg/l	▼ ▲ ▲ 7.54% / year	14	N. s. N. s. p=0.018
$N\text{-}NH_4$	Dry deposition	3.15	kg/ha/y	▼	24	N. s.
	Wet deposition	3.45		▼	24	N. s.
	Troughfall	4.72		▲	13	N. s.
	Stemflow	0.75 Hornbeam 1.21 Oak 2.71 Spruce	mg/l	▲ ▲ ▲ 4.80% / year	14	N. s. N. s. p=0.063
N tot.	Litterfall	53.53	kg/ha/y	▼	5	N. s.

* “N. s.” (not significant) means p<0.1 in the Mann-Kendall test

Monitoring of nitrogen – N outputs (sinks)

			Yearly average	Unit	Trend	n	Significance *
$N\text{-}NO_3$	Soil water at:	20 cm	0.546	mg/l	▼ 24.19% / year	7	p=0.064
		50 cm	0.203		▼	7	N. s.
		80 cm	0.141		▼	7	N. s.
	Groundwater		0.060		▲	20	N. s.
	Surface water outflow		0.334		-	17	N. s.
	Surface water outflow		**0.523**	kg/ha/y	Not analysed**		
	Lake at:	-1 m	0.356	mg/l	▲ 6.66% / year	13	p=0.071
		-5 m	0.665		▲	7	N. s.
		-11 m	0.628		▲	13	N. s.
$N\text{-}NH_4$	Soil water at:	20 cm	0.141	mg/l	▲ 23.28% / year	7	p=0.008
		50 cm	0.055		▲ 21.28% / year	7	p=0.017
		80 cm	0.086		▲ 26.70% / year	7	p=0.017
	Groundwater		0.090		▲ 3.91% / year	21	p=0.054
	Surface water outflow		0.174		▲ 14.26% / year	13	p=0.004
	Surface water outflow		**0.070**	kg/ha/y	Not analysed**		
	Lake at:	-1 m	0.165	mg/l	▲ 12.24% / year	13	p=0.016
		-5 m	0.301		▲	7	N. s.
		-11 m	0.861		▲ 10.51% / year	13	p=0.001

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

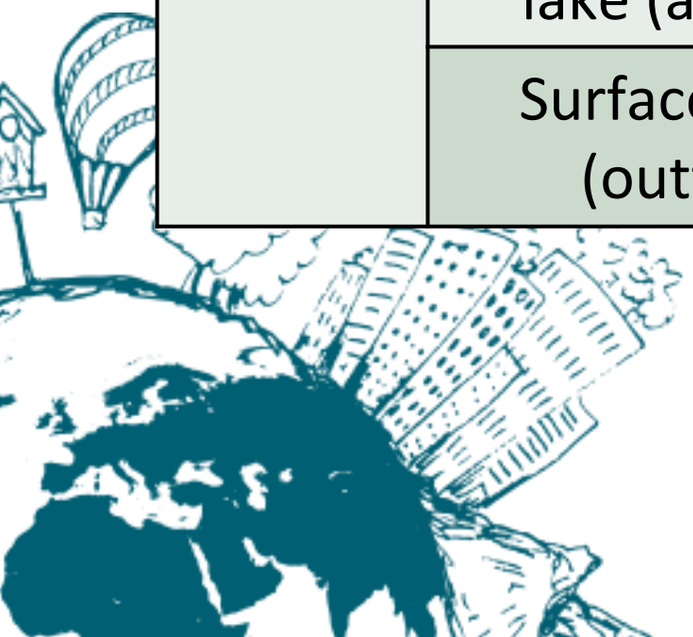
* "N. s." (not significant) means p<0.1 in the Mann-Kendall test

** reliable flow rate data available to 2008.

Monitoring of nitrogen – correlations between sources and sinks of N

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

What	Input	Output	Correlation*
$N\text{-}NO_3$	lake (at 11 m)	dry deposition	moderate
		concentration in air	moderate
		concentration in troughfall	moderate
$N\text{-}NH_4$	soil water at all depths	dry / wet / total deposition	moderate
		load in troughfall	moderate
	lake (at 1 m)	concentration in air	high
	lake (at 5 m)	concentration in troughfall	moderate
	lake (at 11 m)	concentration in air	moderate
	Surface water (outflow)	concentration in air	high



* Pearson coefficient:
Moderate: $0.5 \leq R < 0.75$
High: $0.75 \leq R$

Monitoring of nitrogen – limitations of the data interpretation

- Usually **not all desired forms of N are measured** or measurable (e.g. nitrogen uptake)
- Usually **not all processes affecting the N** transport are **measured** (e.g. percolation) or measurable (e.g. lateral flow)
- **Monitoring periods** are can be different for different parameters
- **Gaps** in data
- **Frequency** of monitoring may not be enough to analyse dynamic processes
- **Assessment** of interdependences between variables is usually **limited to statistical analyses and expert judgements**

Modelling of nitrogen dynamics – what for?

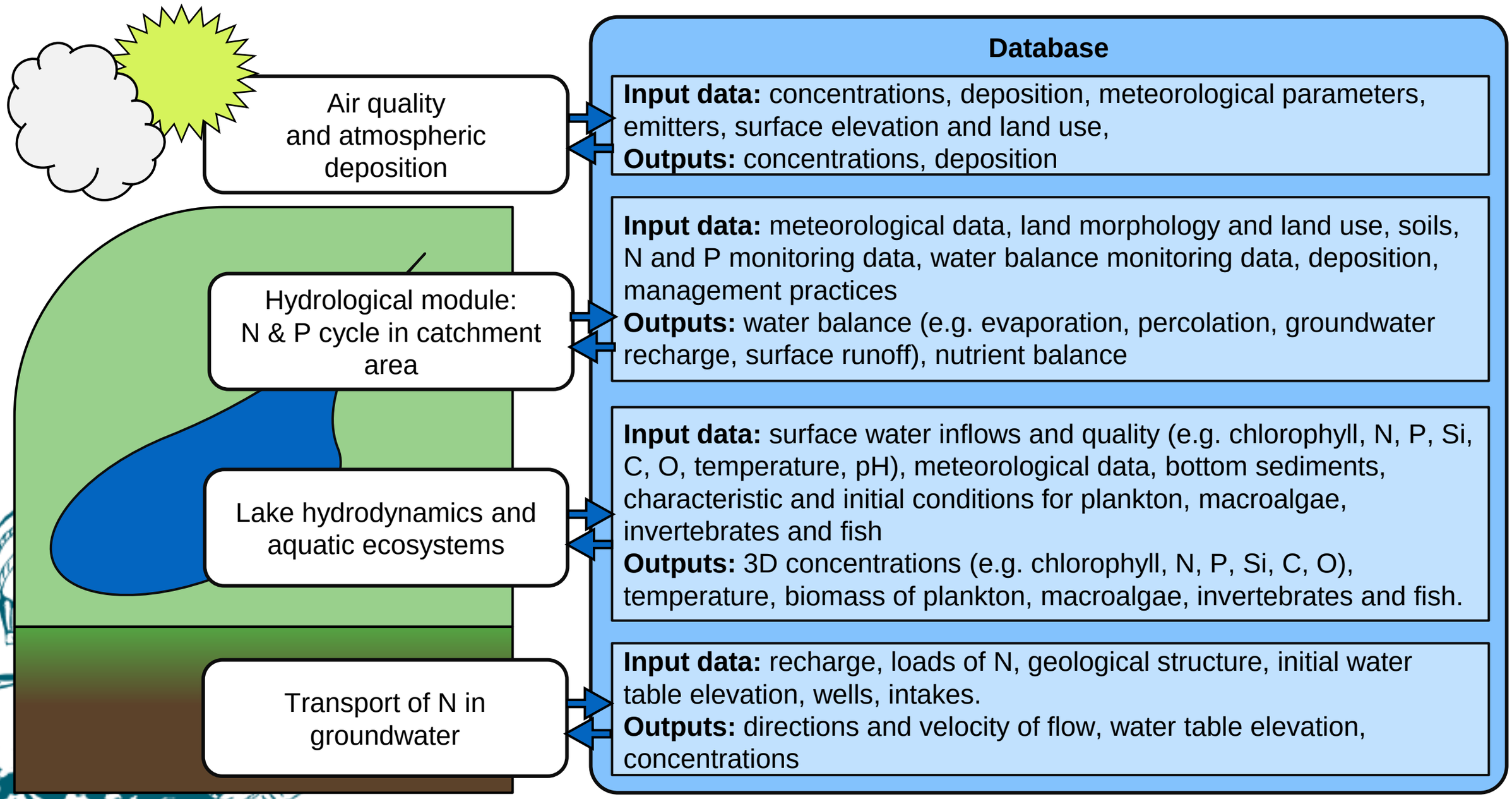
- Usually **not all desired forms of N are measured** or measurable (e.g. nitrogen uptake)
- Usually **not all processes affecting the N** transport are **measured** (e.g. percolation) or measurable (e.g. lateral flow)
- **Monitoring periods** can be different for different parameters
- **Gaps** in data
- **Frequency** of monitoring may not be enough to analyse dynamic processes
- **Assessment** of interdependences between variables is usually **limited to statistical analyses and expert judgements**

- **All desired forms of N** can be **included**
- **All desired processes** can be **included** in deterministic models
- **All processes** are simulated for **the same period**
- **No gaps** in outputs
- **Frequency** of outputs can be **adjusted to needs** (usually)
- Statistical analyses and expert judgements can be complemented with **complex physically based calculations**

Integrated assessment of environmental processes
– conceptual design of the system in Puszcza Borecka

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

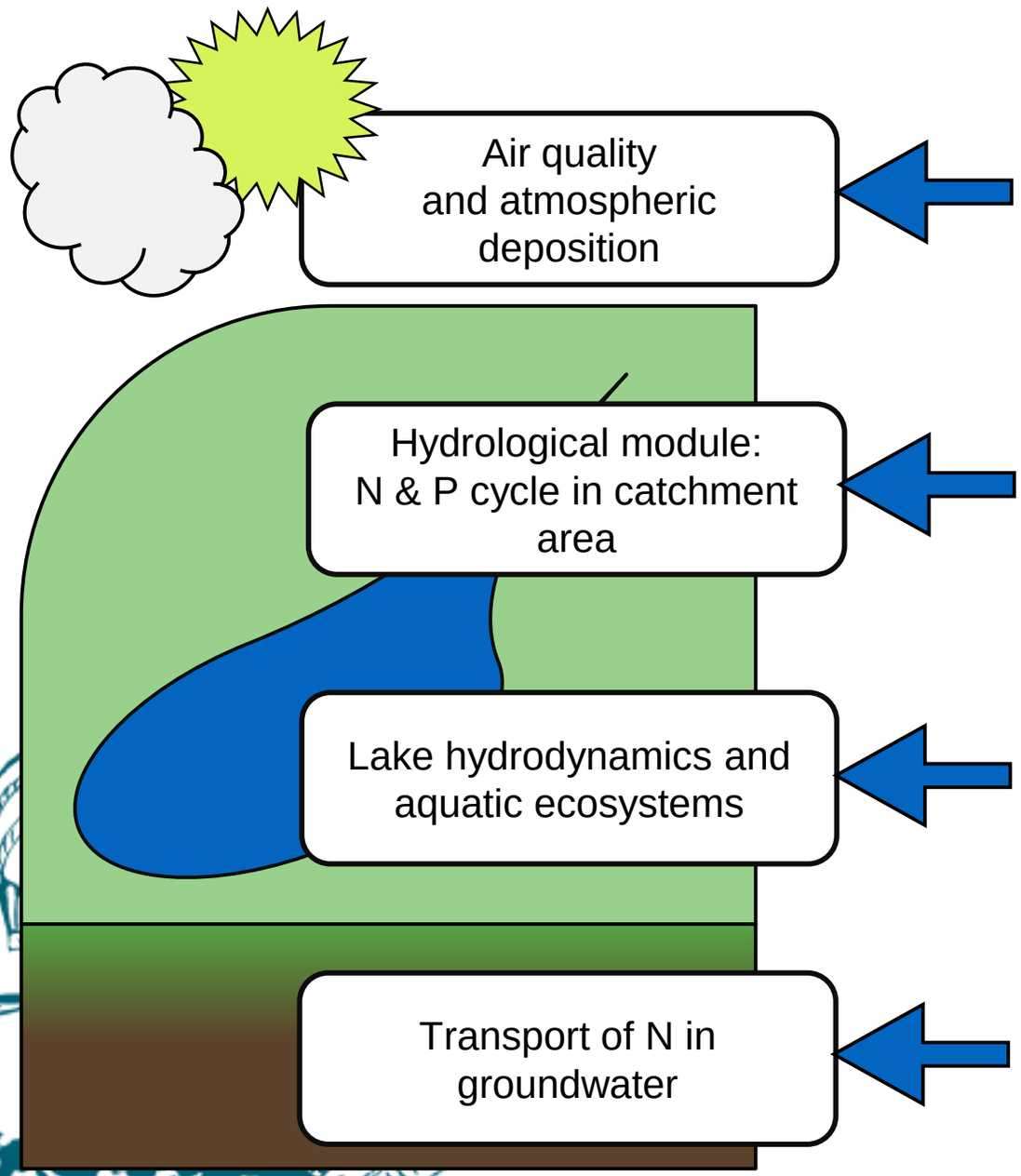
Four main modules (models)



Integrated assessment of environmental processes
– conceptual design of the system in Puszcza Borecka

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Models (to be) **used**



CALMET-CALPUFF (2019)

SWAT (2017-2018)

AEM3D (2017-2018)

MODFLOW-MT3D (2018-2019)

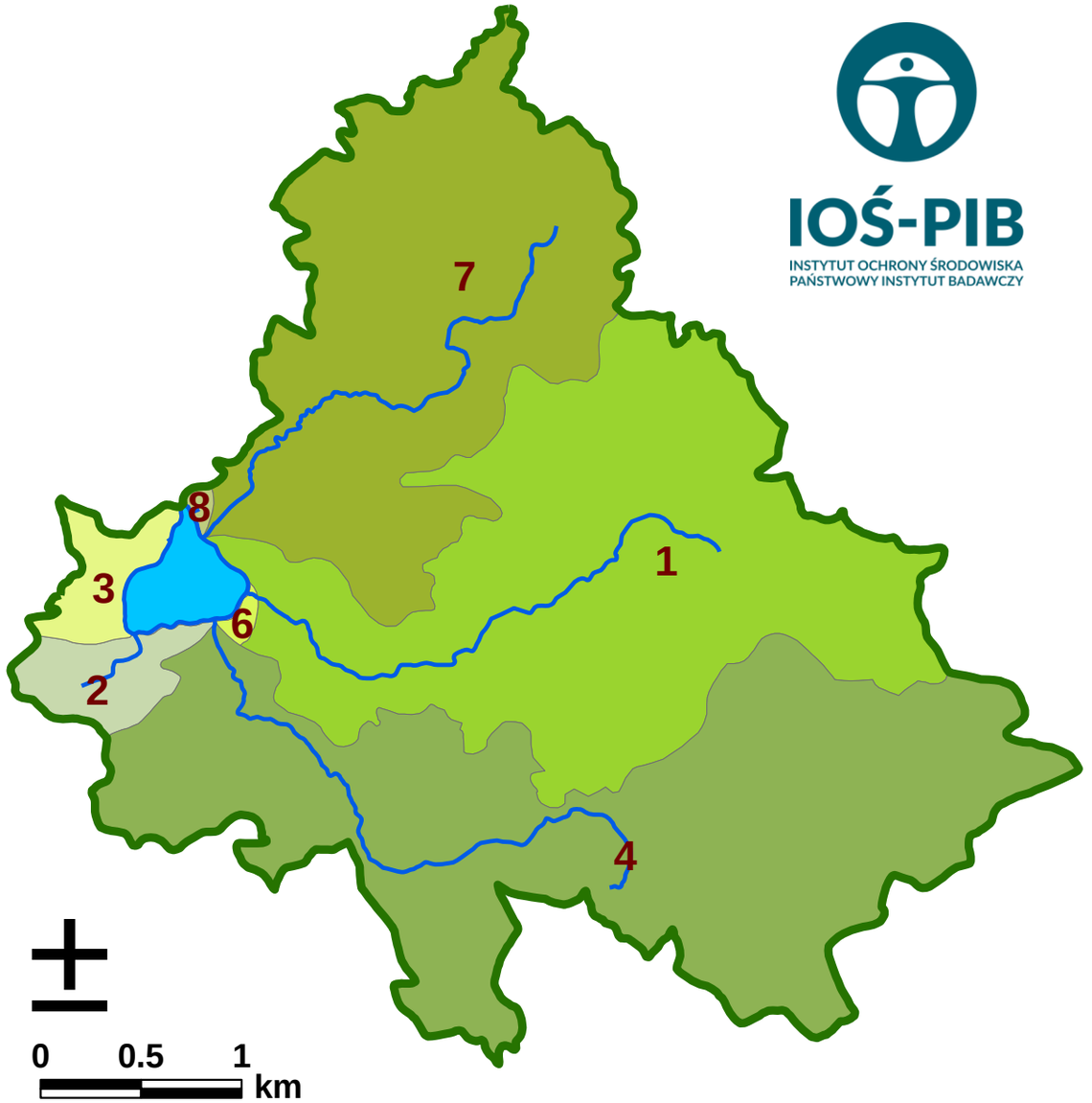
Model of the Łękuk Wielki **catchment area**

Model:

Soil and Water Assessment Tool (SWAT)

Main features:

- Subbasins of 4 main inflows
- Direct catchment area of the lake
- 265 hydrological response units (unique combinations of land use
- Soil type and land slope)
- Time step: 1 day – 1 year
- Analysed period: 1995-2014

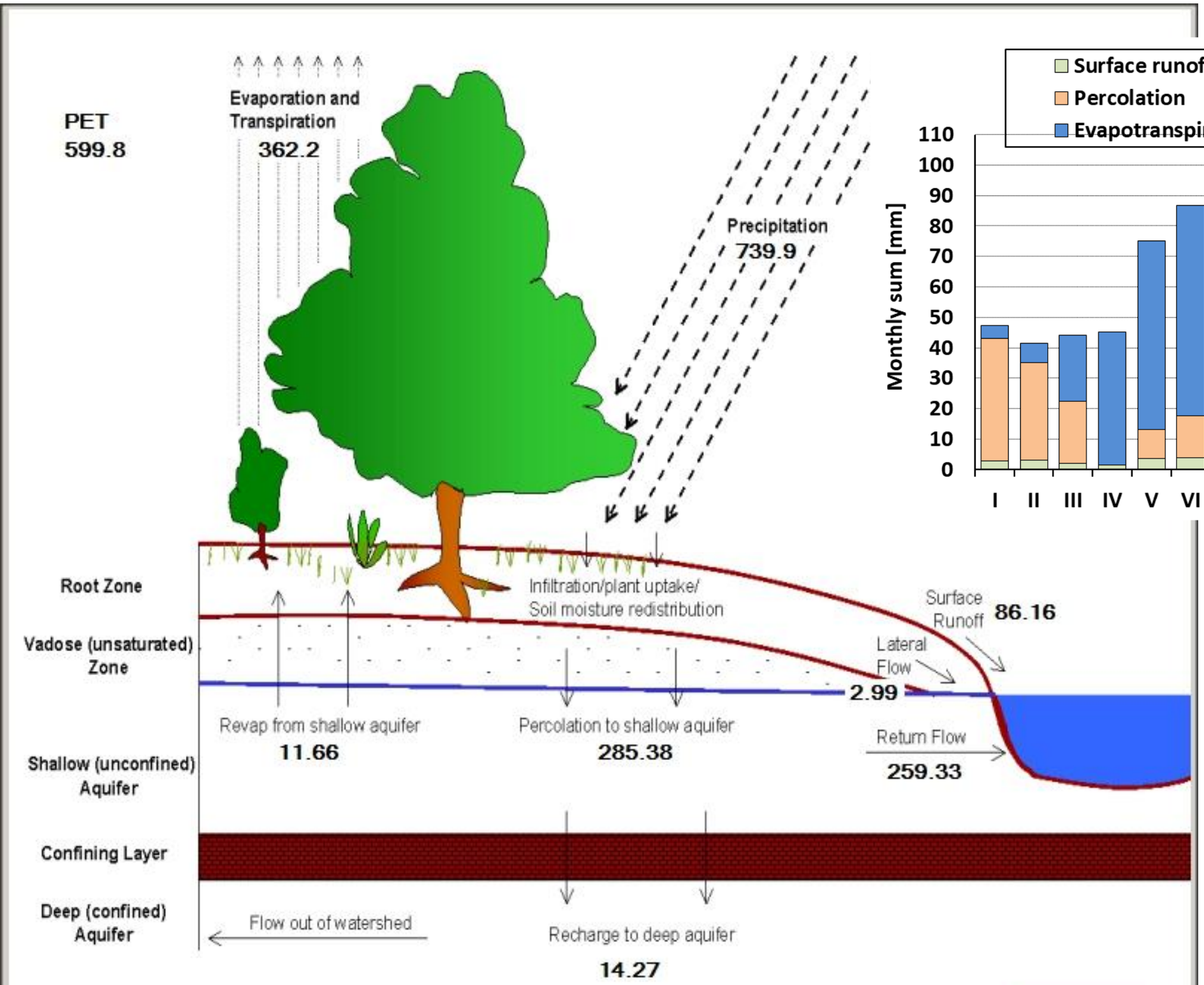


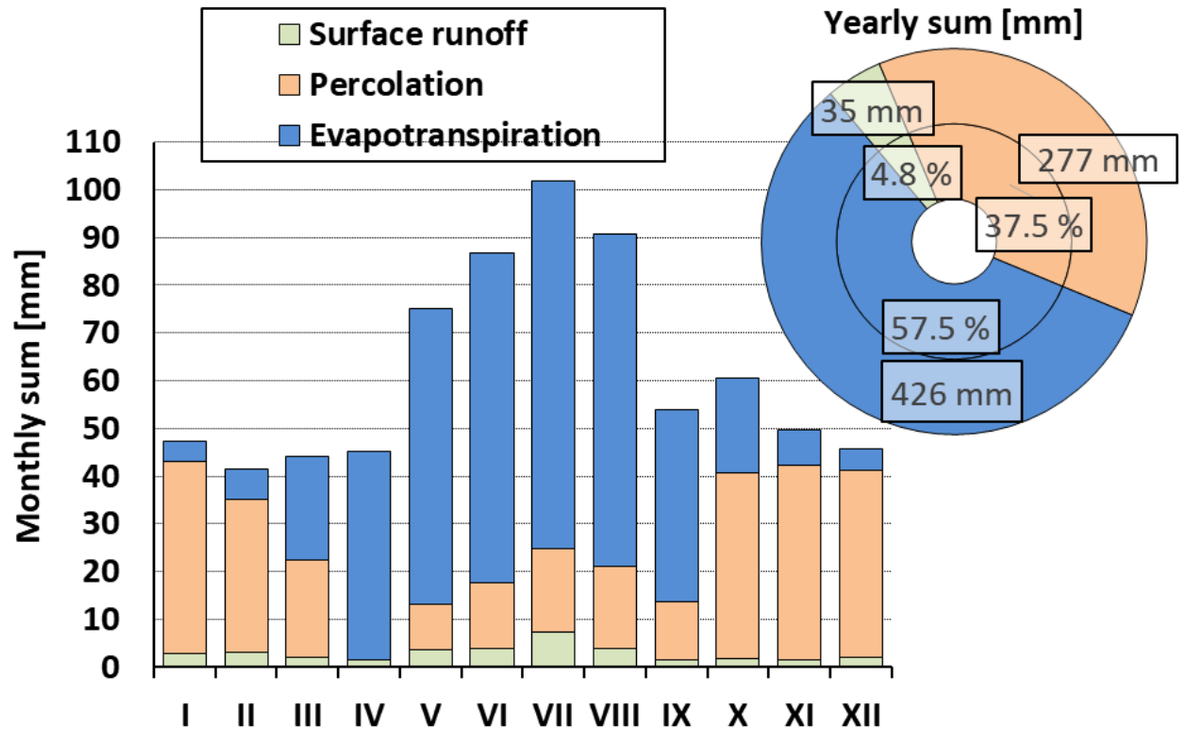
Main inputs:

- Land use
- Digital elevation model
- Hydrographic maps
- Soil parameters
- Fertilisers
- Deposition
- Meteorological data
- Flow rate in streams (for calibration)
- Concentrations of N in streams (for calibration)

Model of the Łękuk Wielki **catchment area** - calculated water balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY





Yearly average

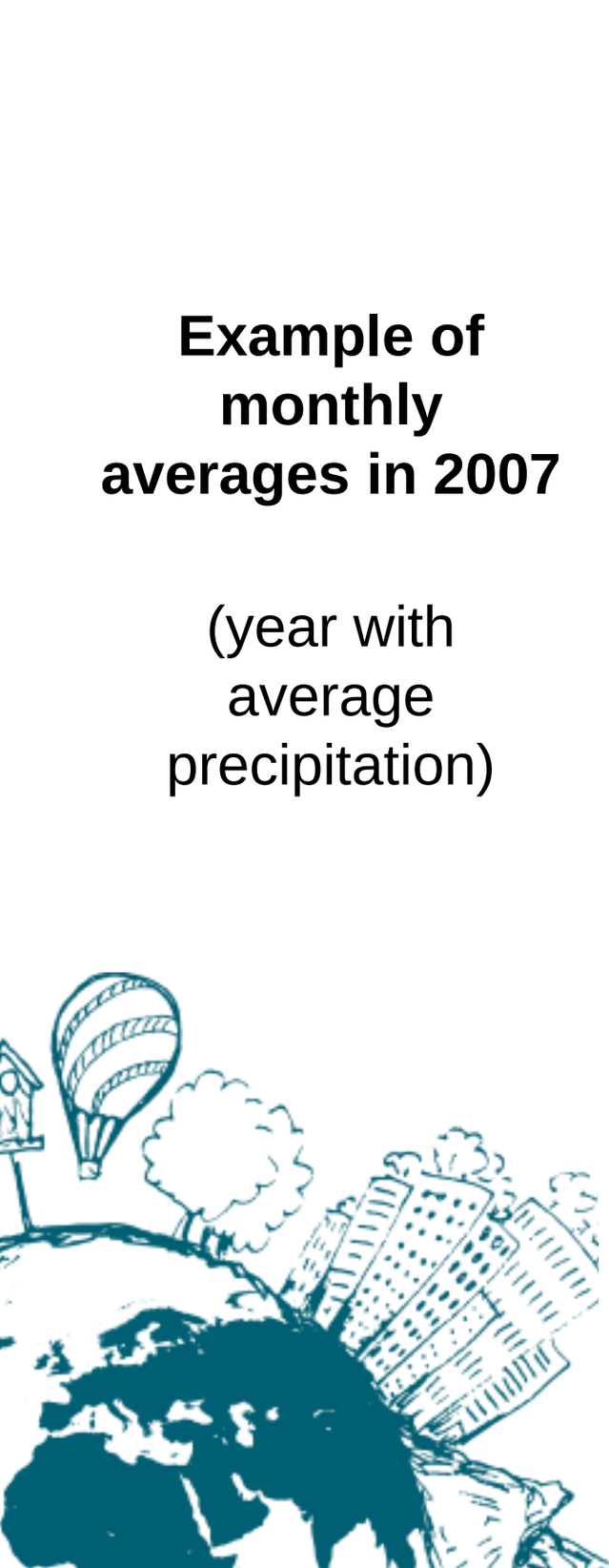
Period:
1995-2014

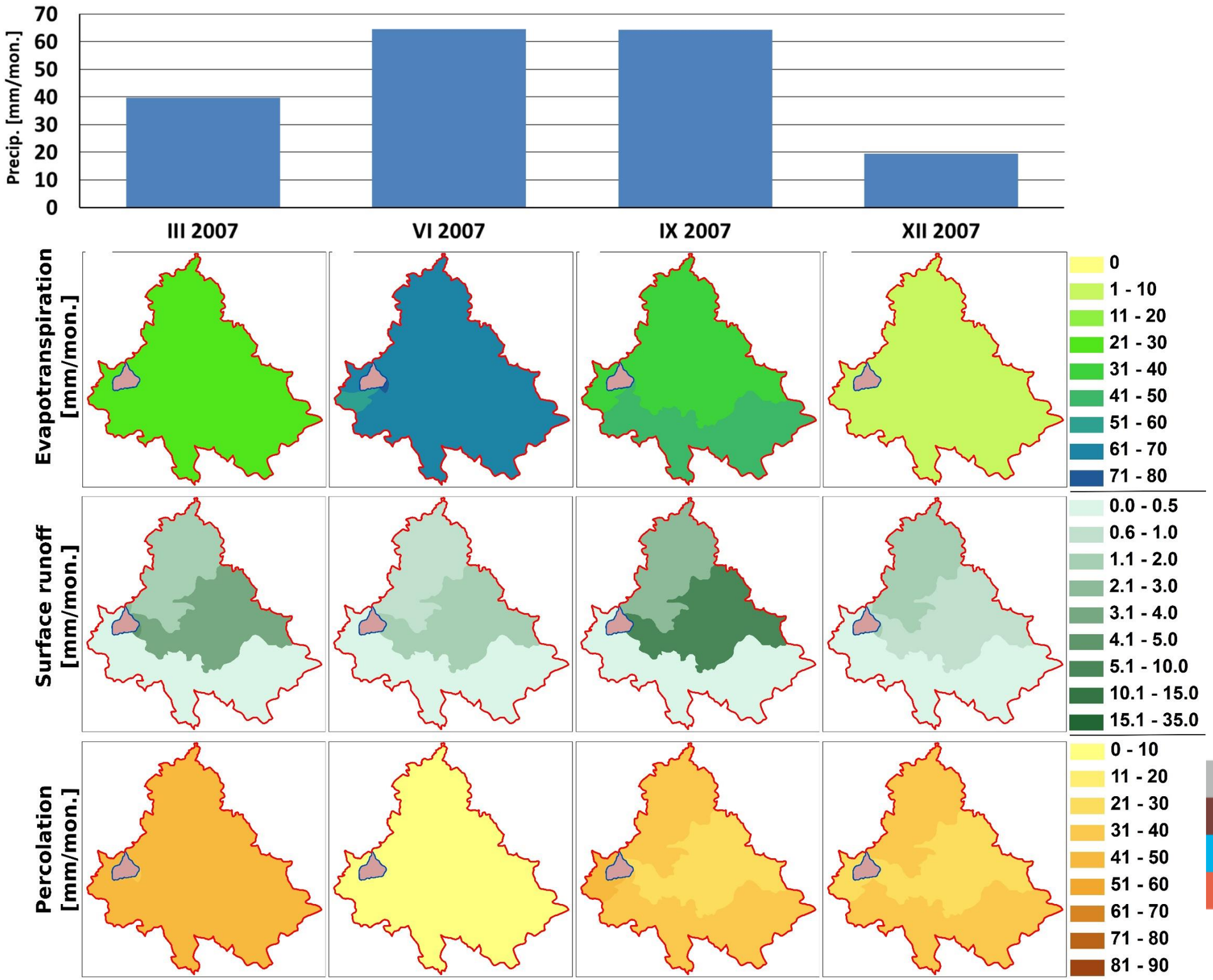
Unit:
mm/y

Model of the Łękuk Wielki **catchment area** - calculated water balance

Example of monthly averages in 2007

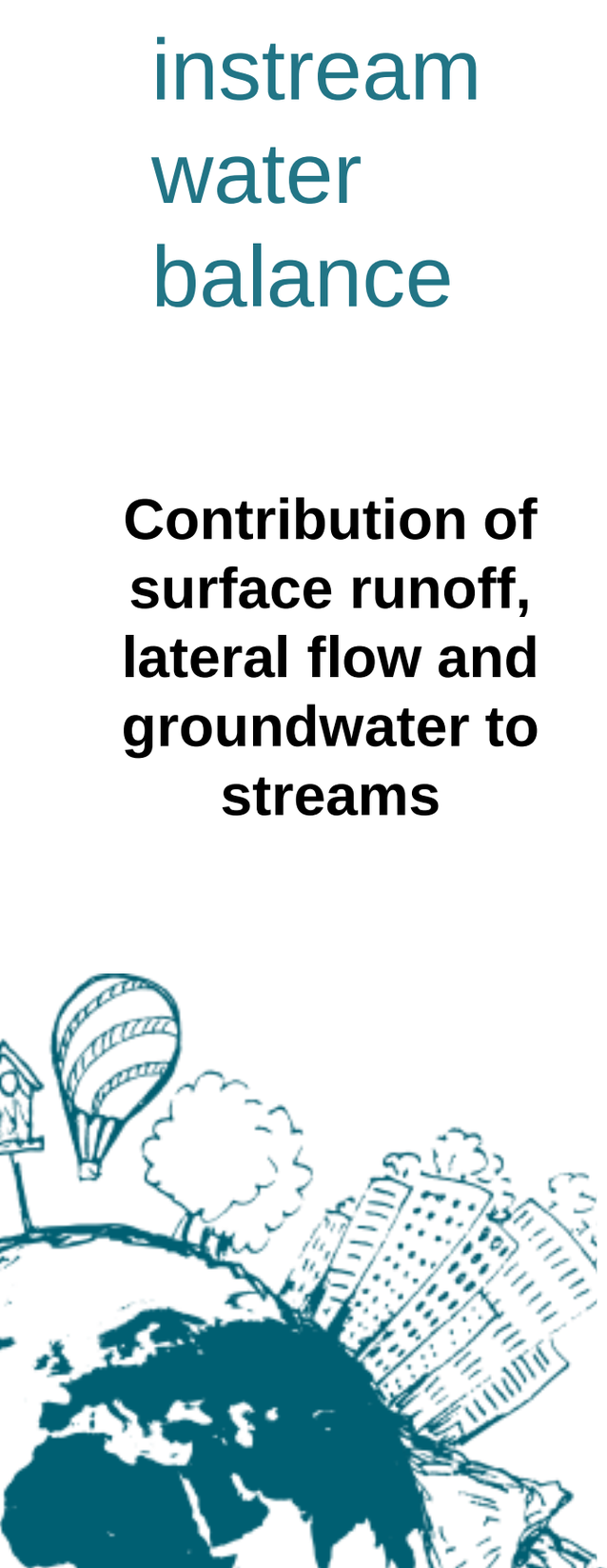
(year with average precipitation)

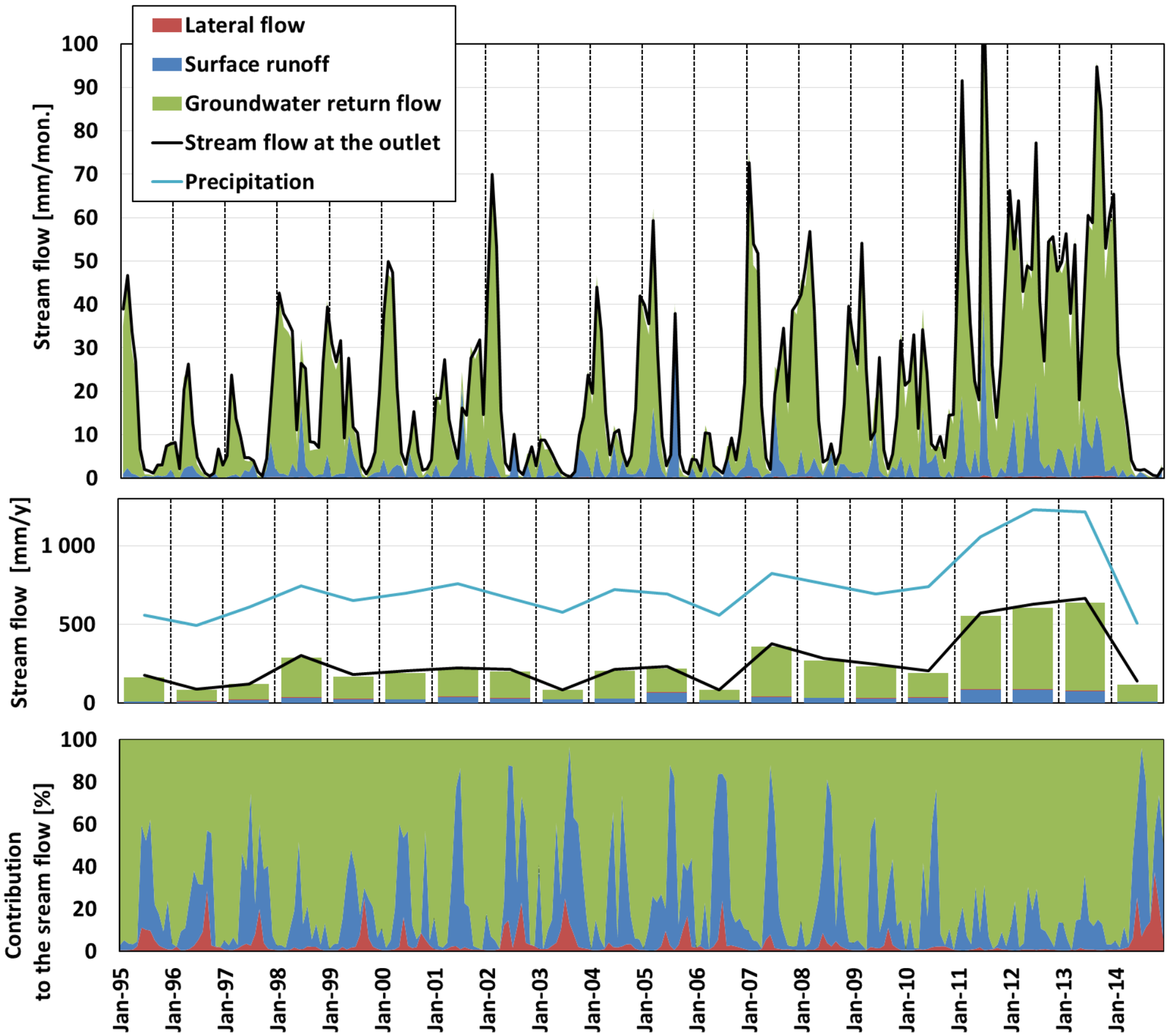




Model of the Łękuk Wielki **catchment area** - calculated instream water balance

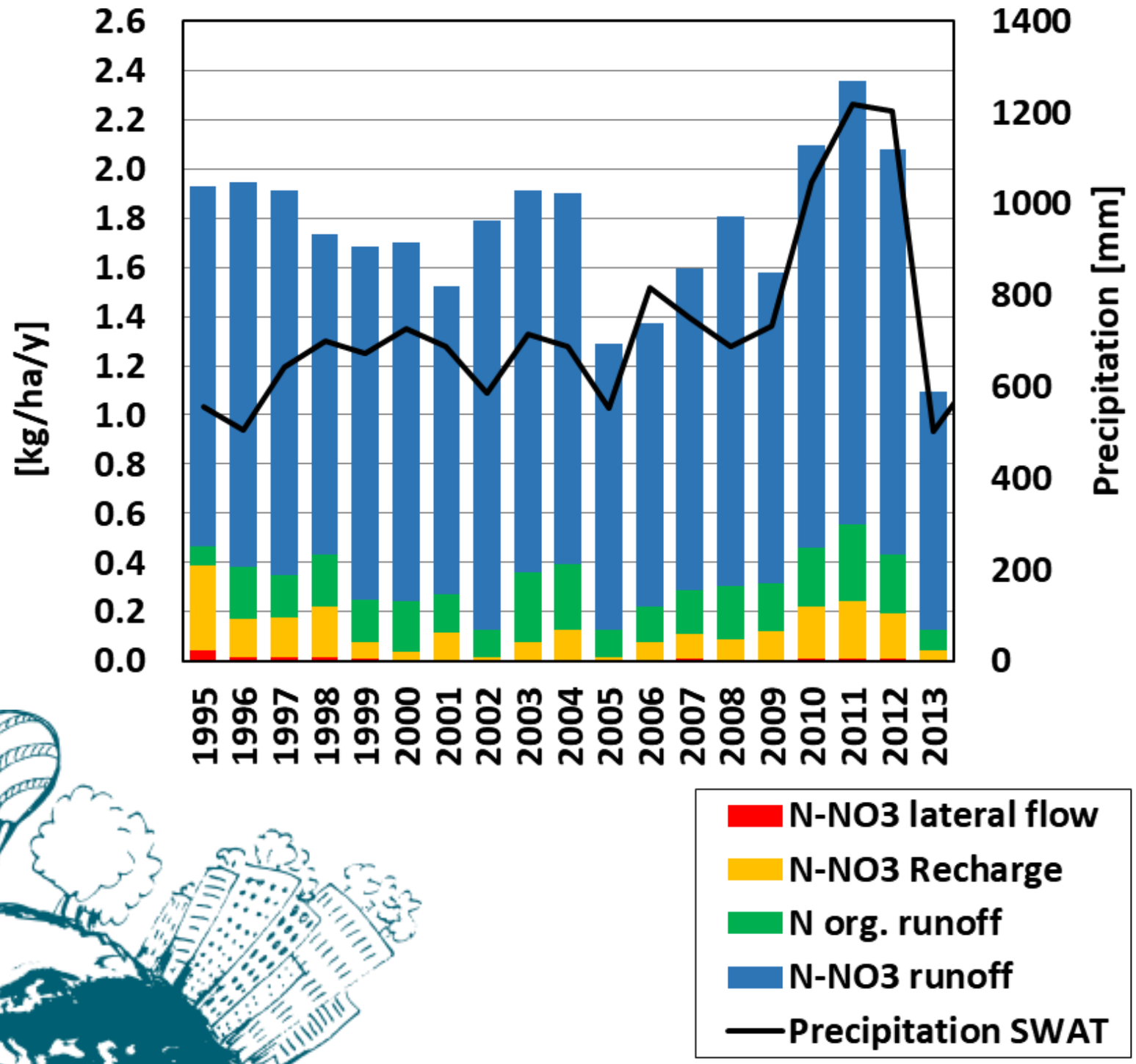
Contribution of surface runoff, lateral flow and groundwater to streams





Model of the Łękuk Wielki **catchment area** - calculated nitrogen balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY



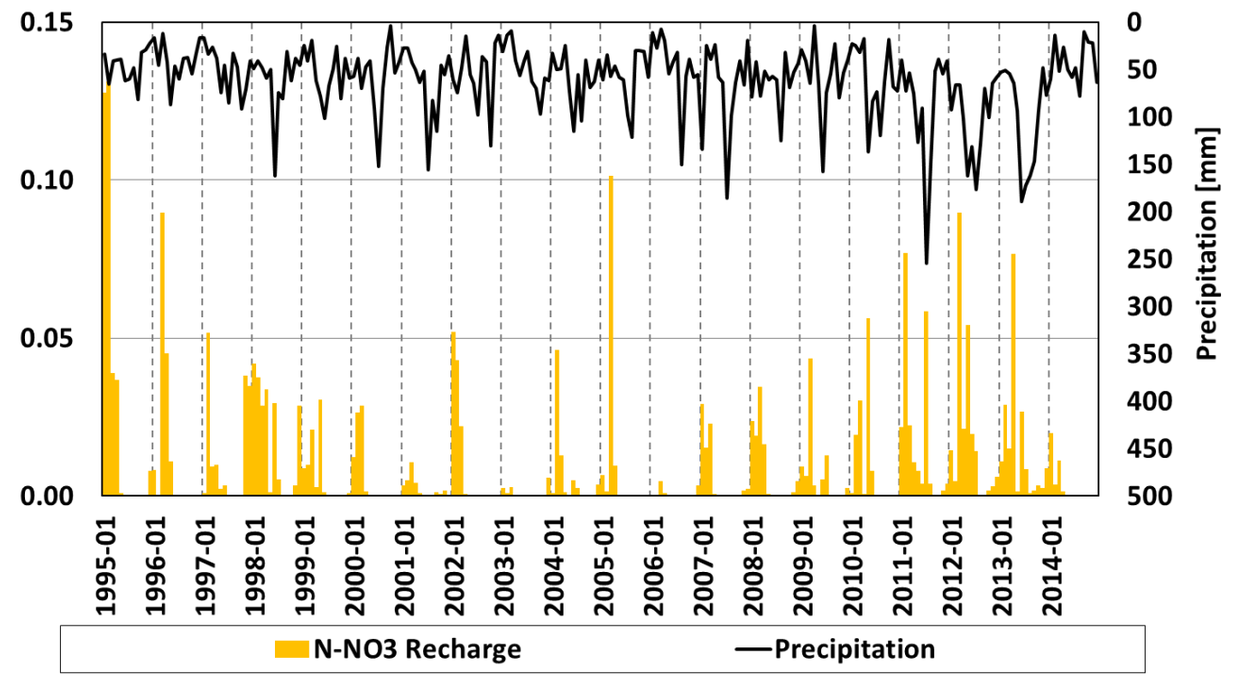
Initial results:

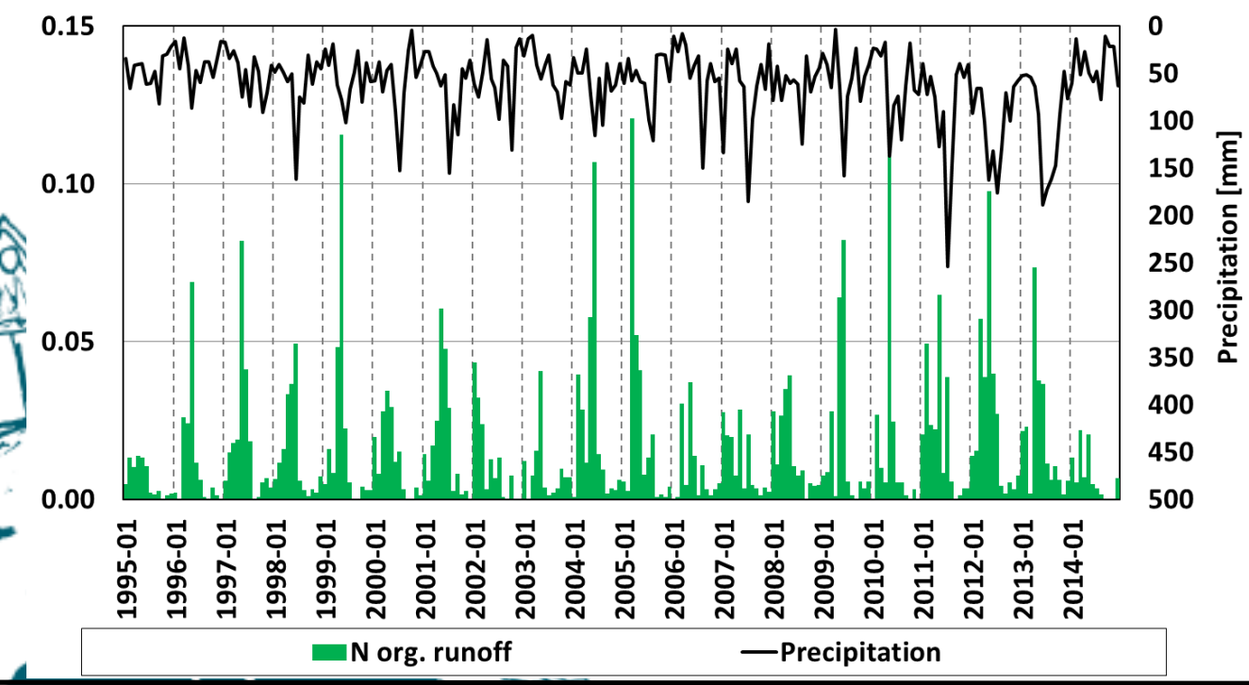
Yearly outflows of the nitrogen

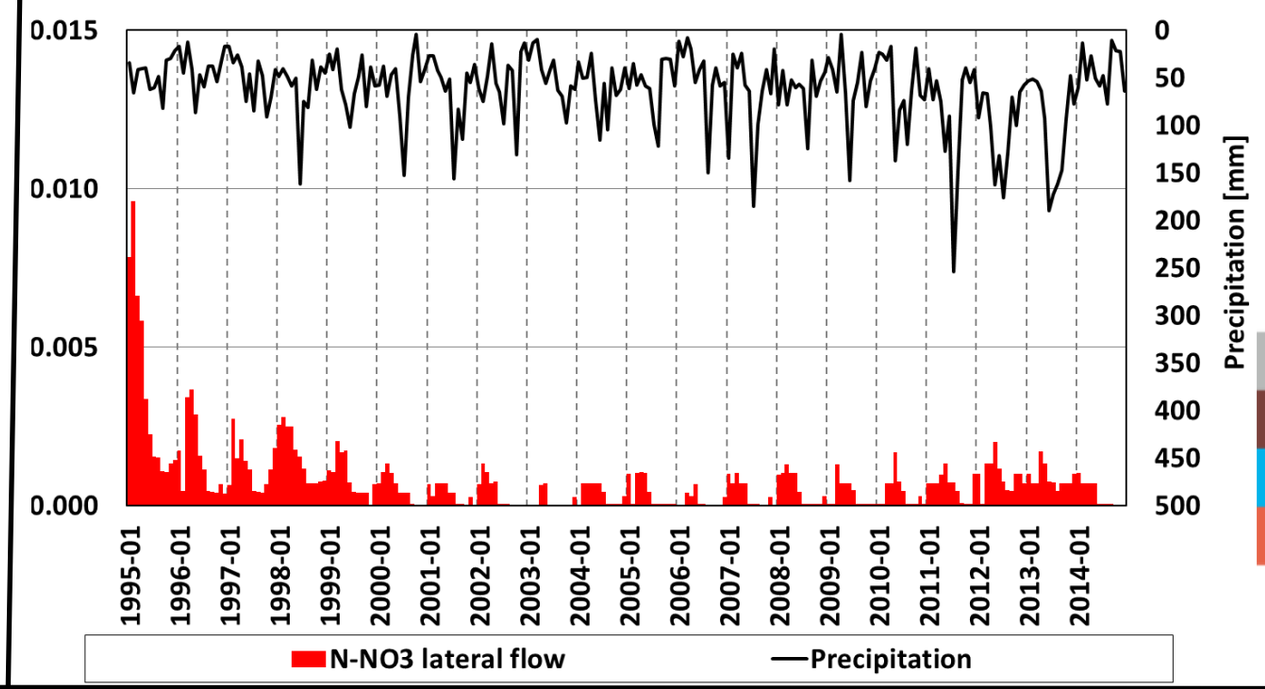
Model of the Łękuk Wielki **catchment area** - calculated nitrogen balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Initial results:
Monthly outflows of the nitrogen kg/ha/mon.





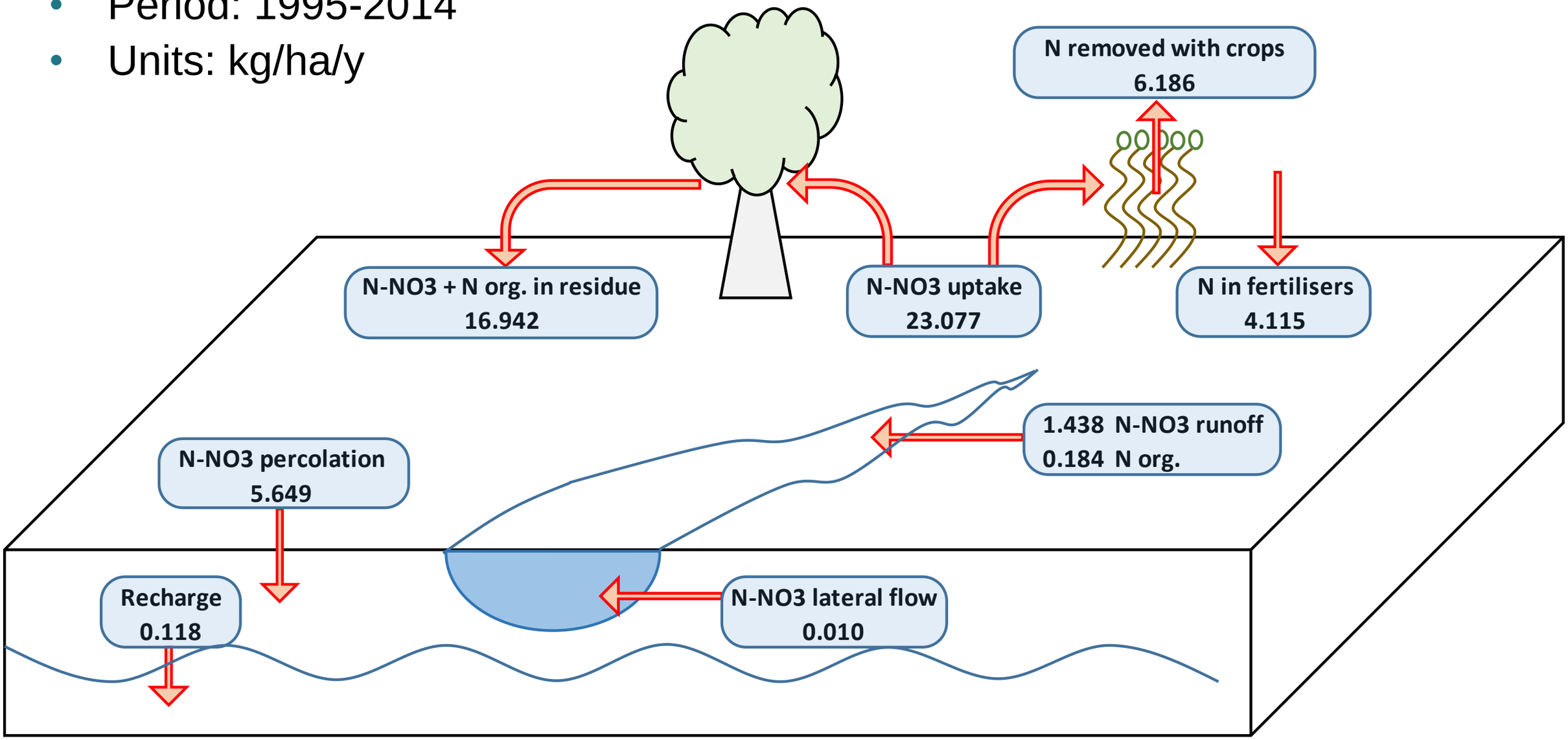


Model of the Łękuk Wielki **catchment area** - calculated nitrogen balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Initial outputs:

- Yearly average loads of nitrogen
- Period: 1995-2014
- Units: kg/ha/y

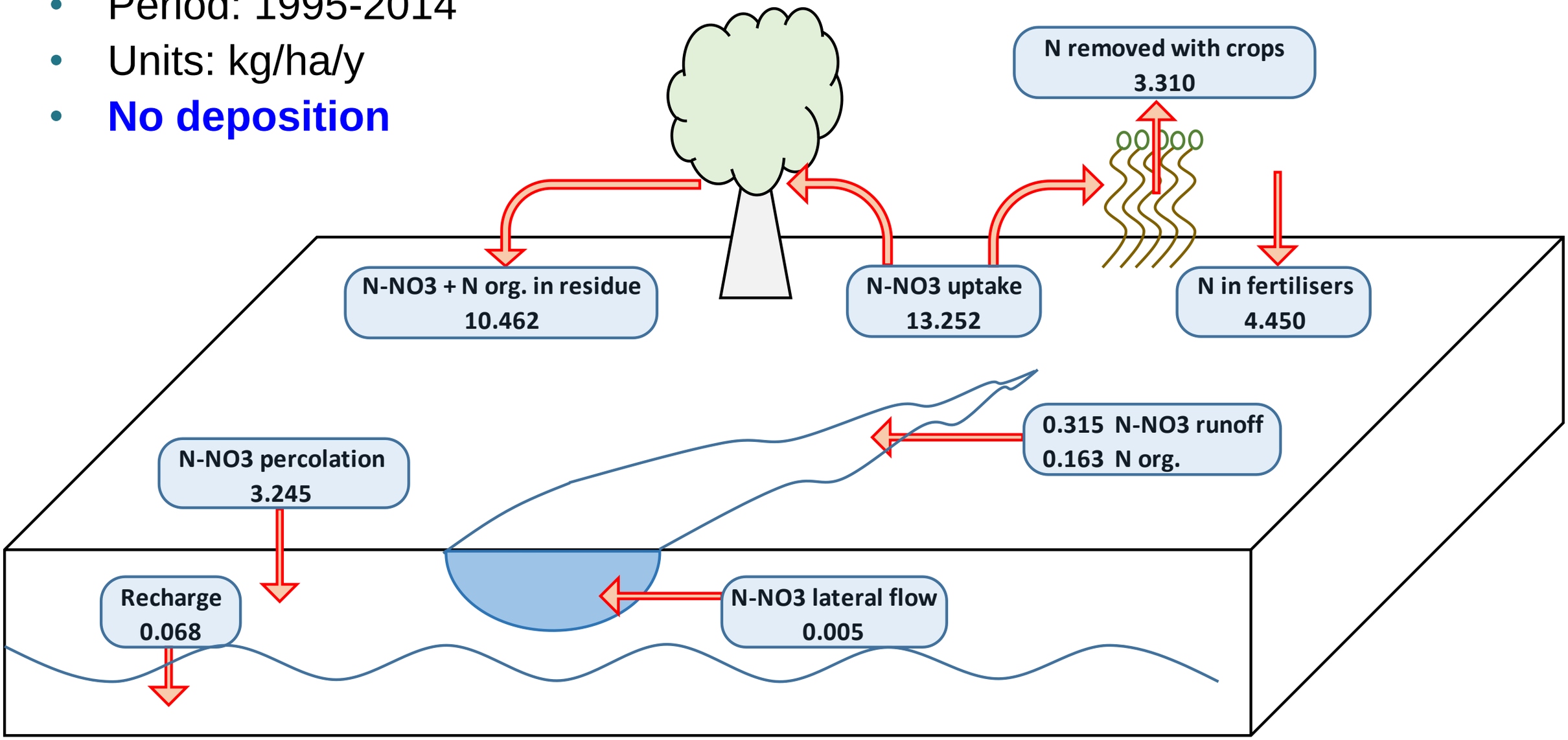


Model of the Łękuk Wielki **catchment area** - calculated nitrogen balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Initial outputs:

- Yearly average loads of nitrogen
- Period: 1995-2014
- Units: kg/ha/y
- **No deposition**

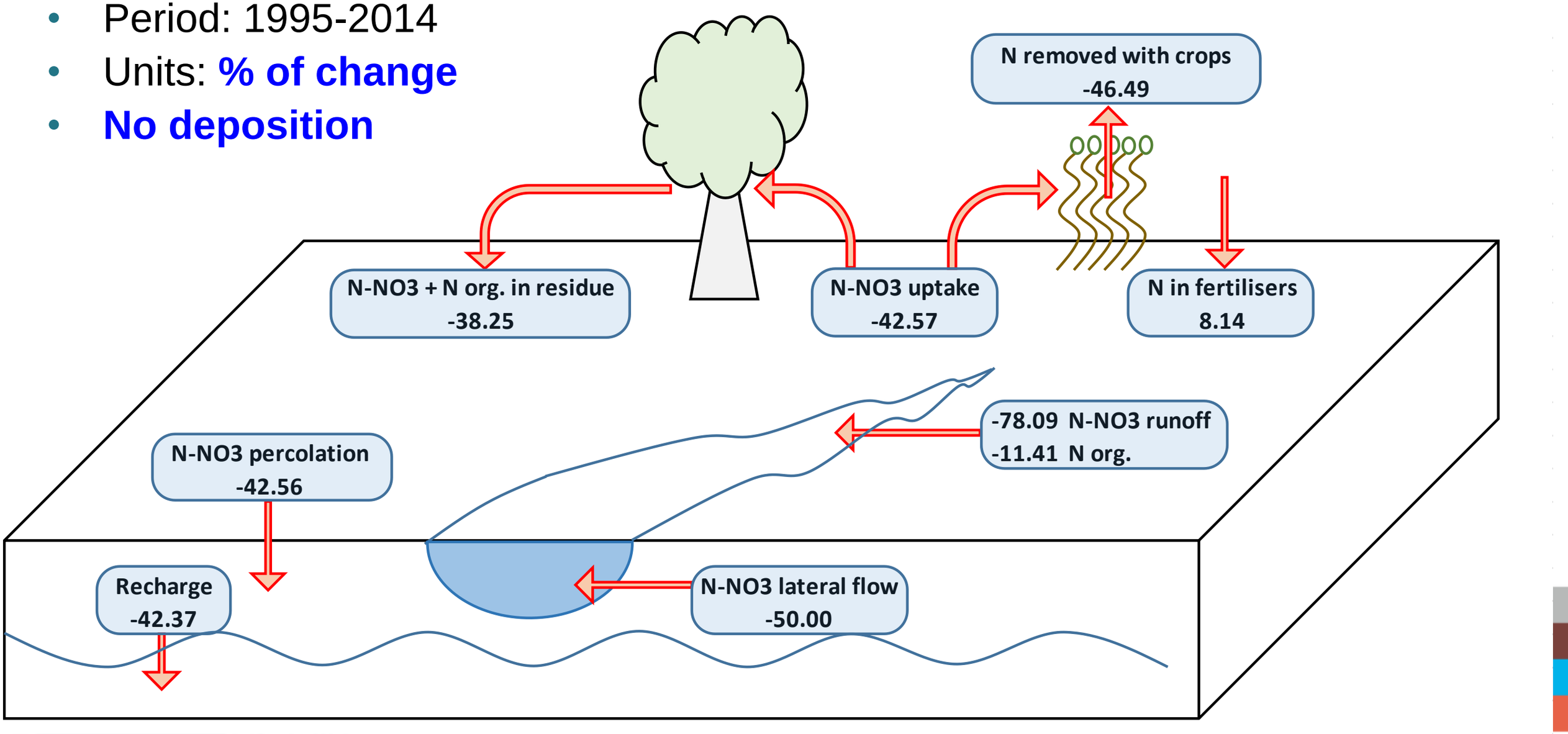


Model of the Łękuk Wielki **catchment area** - calculated nitrogen balance

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Initial outputs:

- Yearly average loads of nitrogen
- Period: 1995-2014
- Units: **% of change**
- **No deposition**



Model of the Łękuk Wielki **Lake**

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

The model is aimed to simulate:

1. **flow** in the lake taking intro account inflows, outflow and meteorological conditions
2. changes in the water **temperature** (and stratification) inflows, outflow and meteorological conditions
3. impact of inflows on the **water quality** (including nutrients)
4. impact of inflows and meteorological conditions on **ecosystems** (mainly phytoplankton and zooplankton)

Model of the Łękuk Wielki **Lake**

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

The model is aimed to simulate:

1. **flow** in the lake taking intro account inflows, outflow and meteorological conditions
2. changes in the water **temperature** (and stratification) inflows, outflow and meteorological conditions

DONE

3. impact of inflows on the **water quality** (including nutrients)
4. impact of inflows and meteorological conditions on **ecosystems** (mainly phytoplankton and zooplankton)

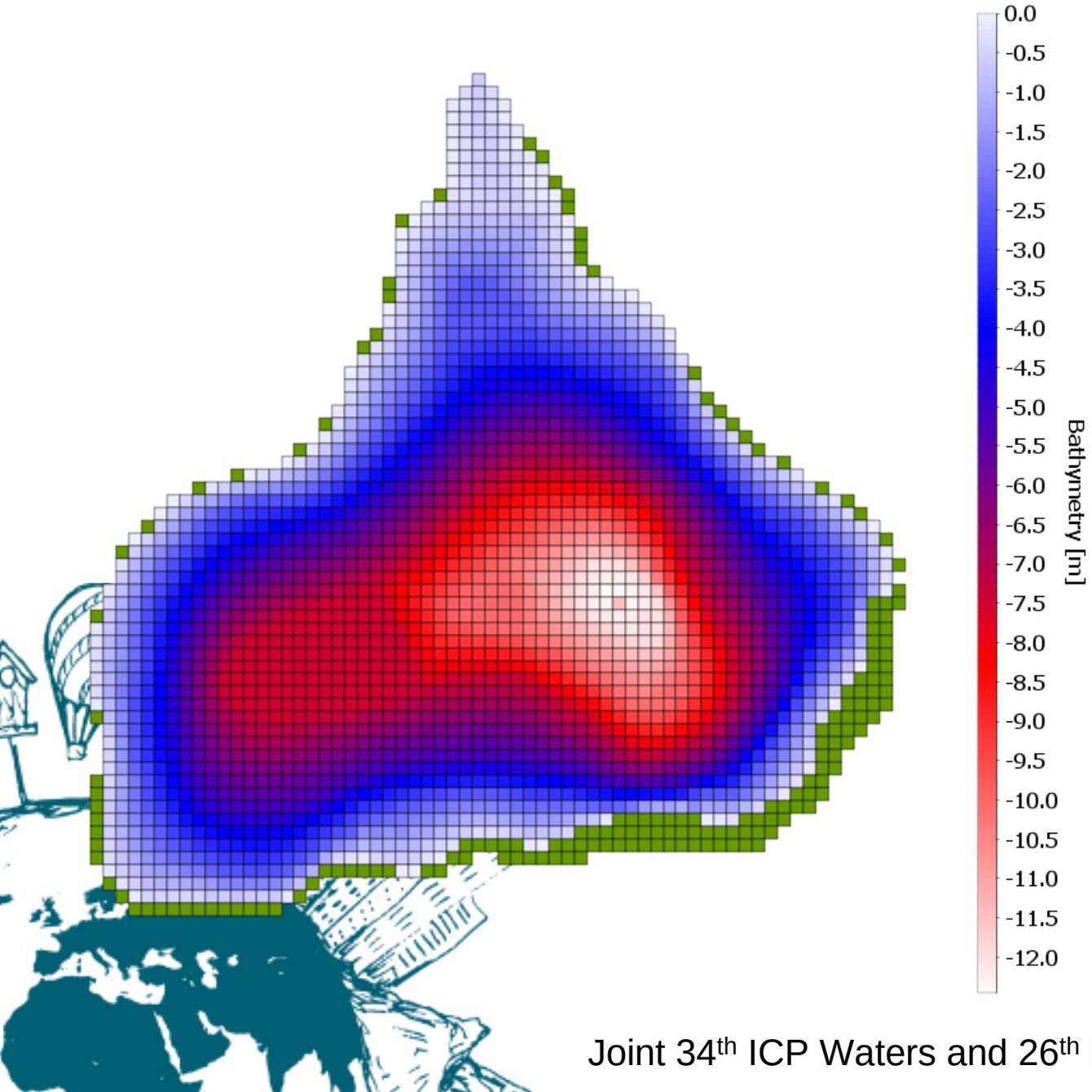
ONGOING

Model of the Łękuk Wielki **Lake**

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Model:

Aquatic Ecosystem Model (AEM3D)



Main features:

- Horizontal resolution: 10 m
- Number of layers: 21
- Thickness of layers: 0.25 – 1.00 m
- Total calculation cells: 33 622
- Time step: 0.5 min.
- Analysed period:
  April 2004 – March 2006
- Includes:
  - 4 inflows (streams),
  - 2 direct catchments,
  - groundwater inflow/outflow,
  - main outflow

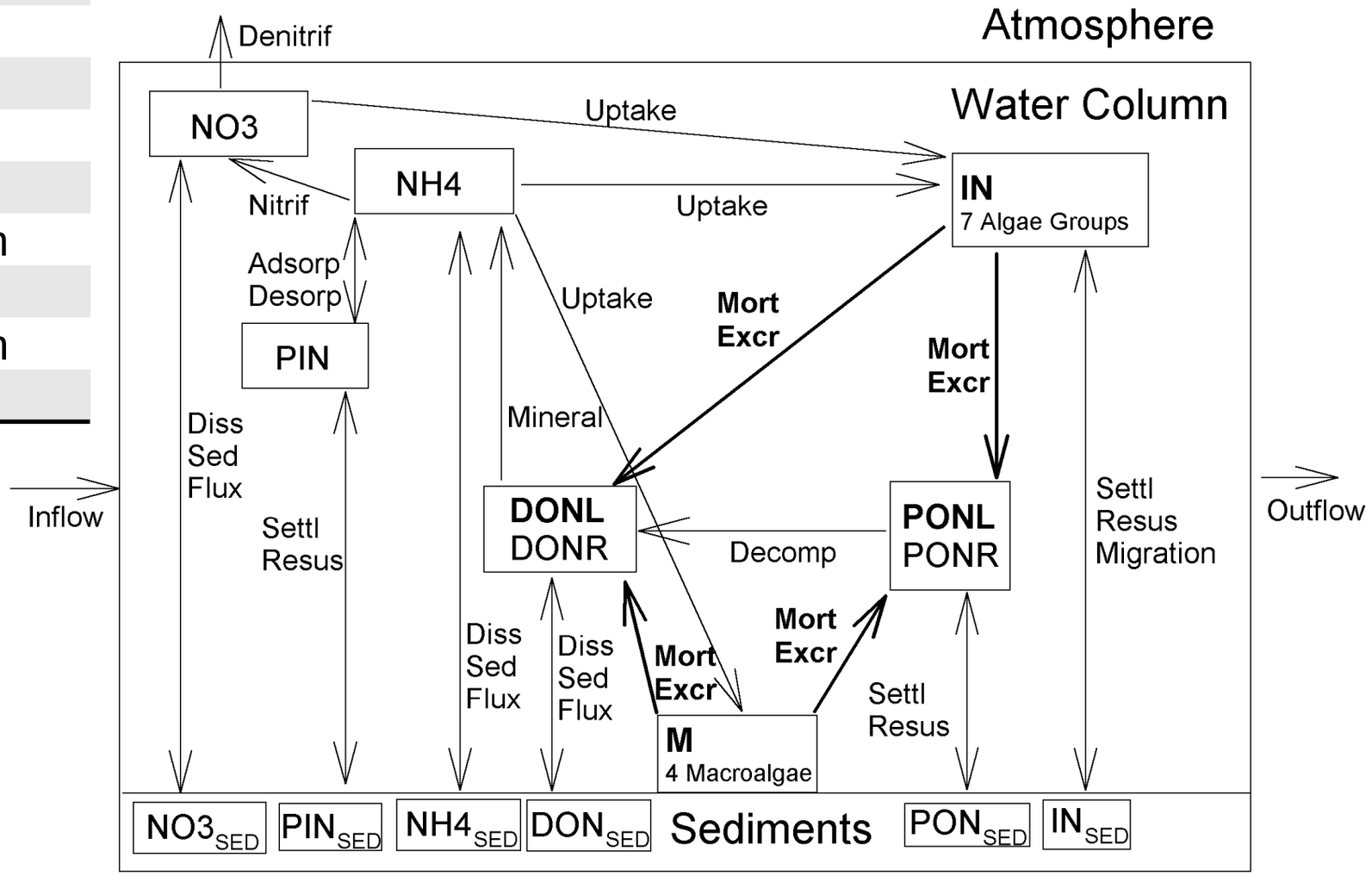
Model of the Łękuk Wielki **Lake**

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Nitrogen in AEM3D

Variable	Description
NO3	Nitrate + Nitrite
NH4	Ammonium
DON	Dissolved Organic Nitrogen
PON	Particulate Organic Nitrogen
AIN	Algal Internal Nitrogen
PIN	Particulate Inorganic Nitrogen
BIN	Bacterial Internal Nitrogen
ZIN	Zooplankton Internal Nitrogen
FIN	Fish Internal Nitrogen

L	Labile
R	Refractory (optional)



Hipsey, M.R., 2010, Computational Aquatic Ecosystem Dynamics Model: CAEDYM v3, v3.2 Science Manual (DRAFT), Centre for Water Research, University of Western Australia, September 29, 2010

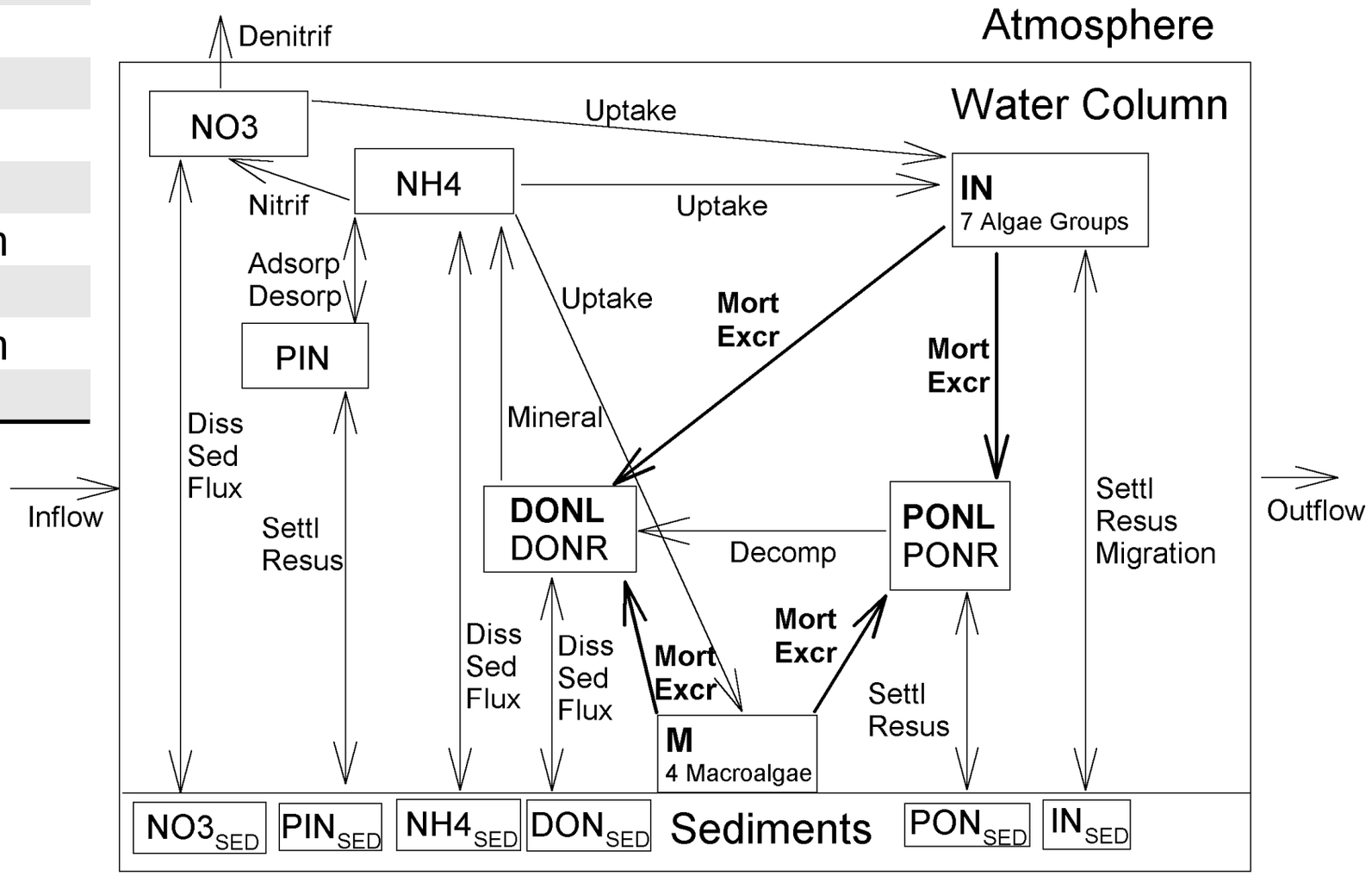
Model of the Łękuk Wielki **Lake**

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Nitrogen in AEM3D

Variable	Description
NO3	Nitrate + Nitrite
NH4	Ammonium
DON	Dissolved Organic Nitrogen
PON	Particulate Organic Nitrogen
AIN	Algal Internal Nitrogen
PIN	Particulate Inorganic Nitrogen
BIN	Bacterial Internal Nitrogen
ZIN	Zooplankton Internal Nitrogen
FIN	Fish Internal Nitrogen

L	Labile
R	Refractory (optional)

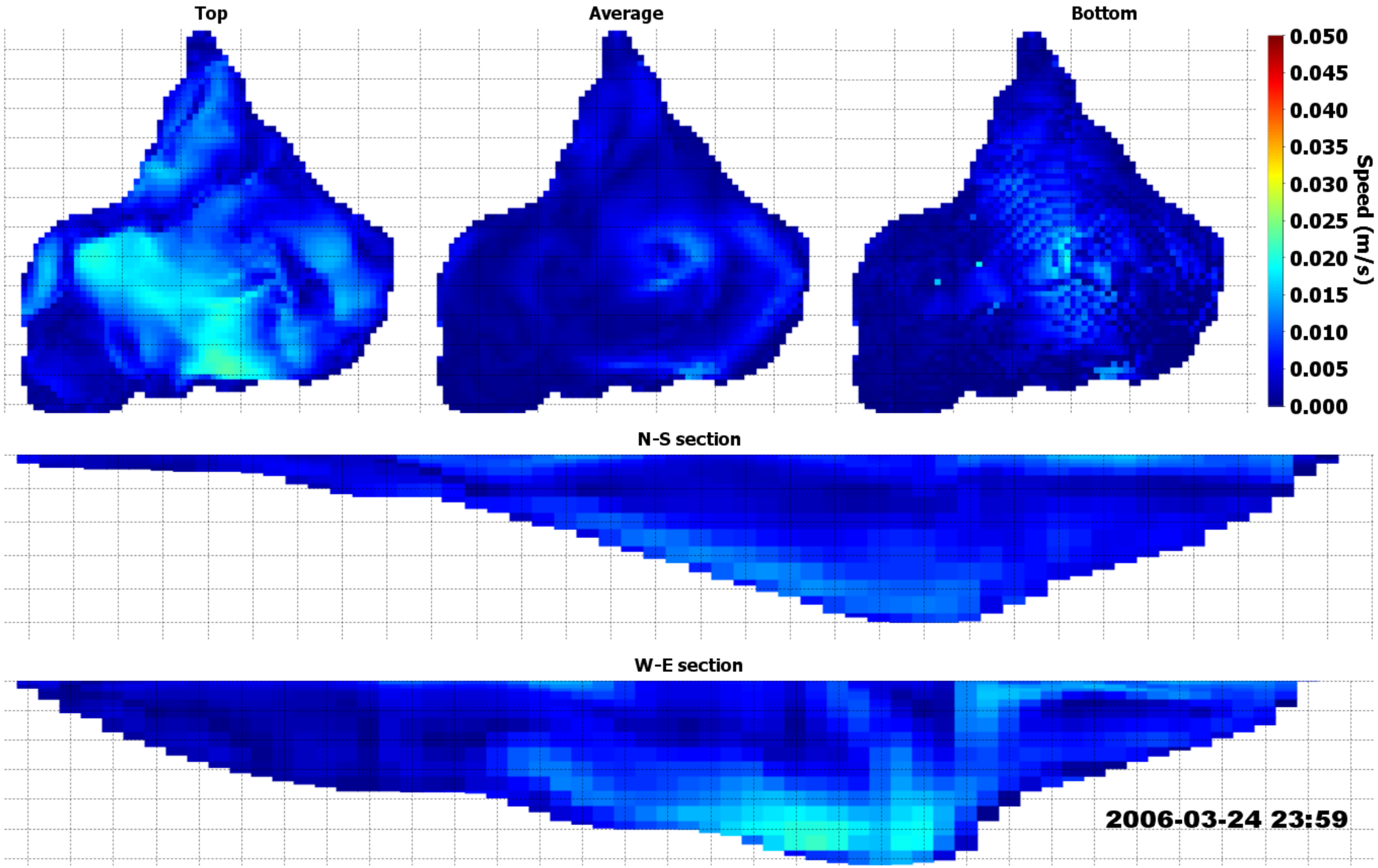


Hipsey, M.R., 2010, Computational Aquatic Ecosystem Dynamics Model: CAEDYM v3, v3.2 Science Manual (DRAFT), Centre for Water Research, University of Western Australia, September 29, 2010

Model of the Łękuk Wielki **Lake**
- Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

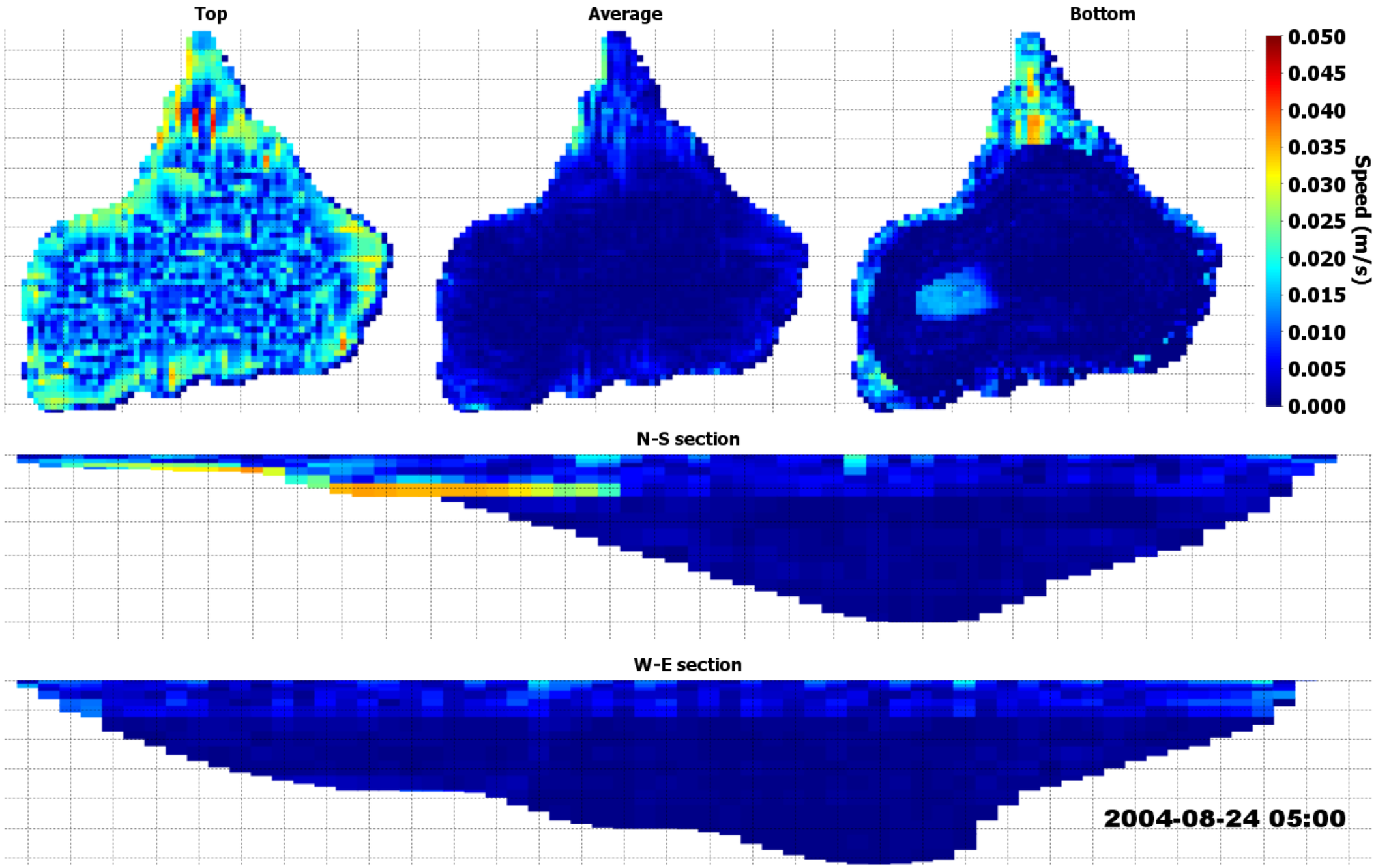
Flow velocity in the cold season (Similar velocity at different depths)



Model of the Łękuk Wielki **Lake** - Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

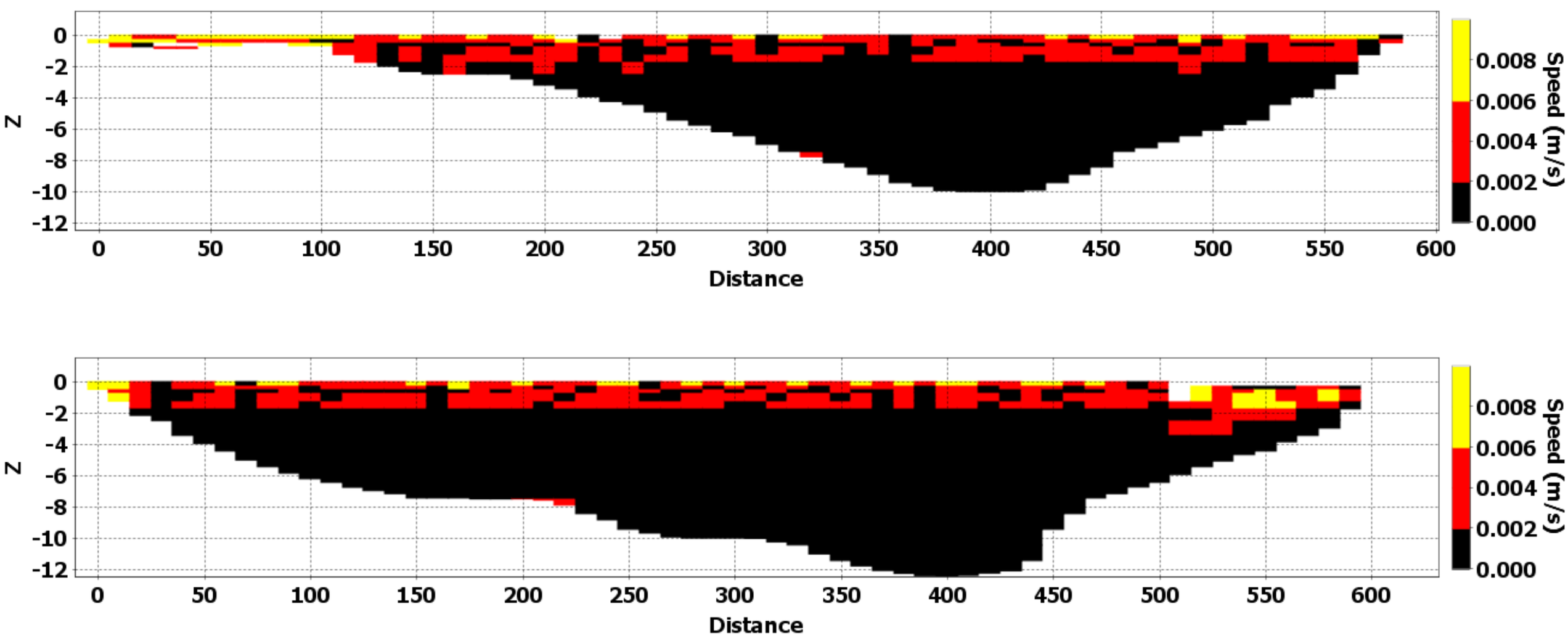
Flow velocity in the warm season (Increased velocity near the surface)



Model of the Łękuk Wielki **Lake**
- Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

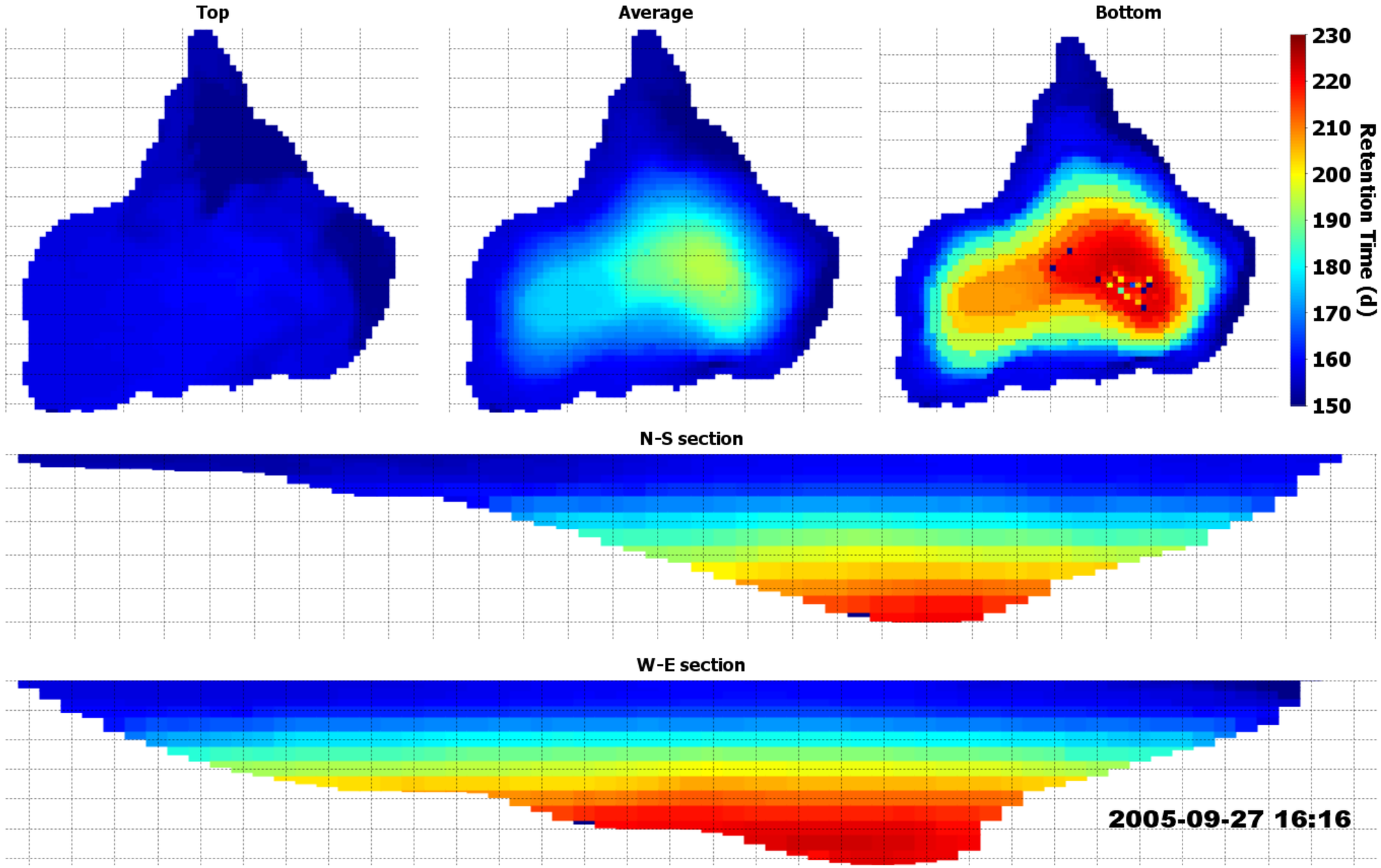
Flow velocity in N-S and W-E cross-sections (average for 2 years)



Model of the Łękuk Wielki **Lake**
- Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

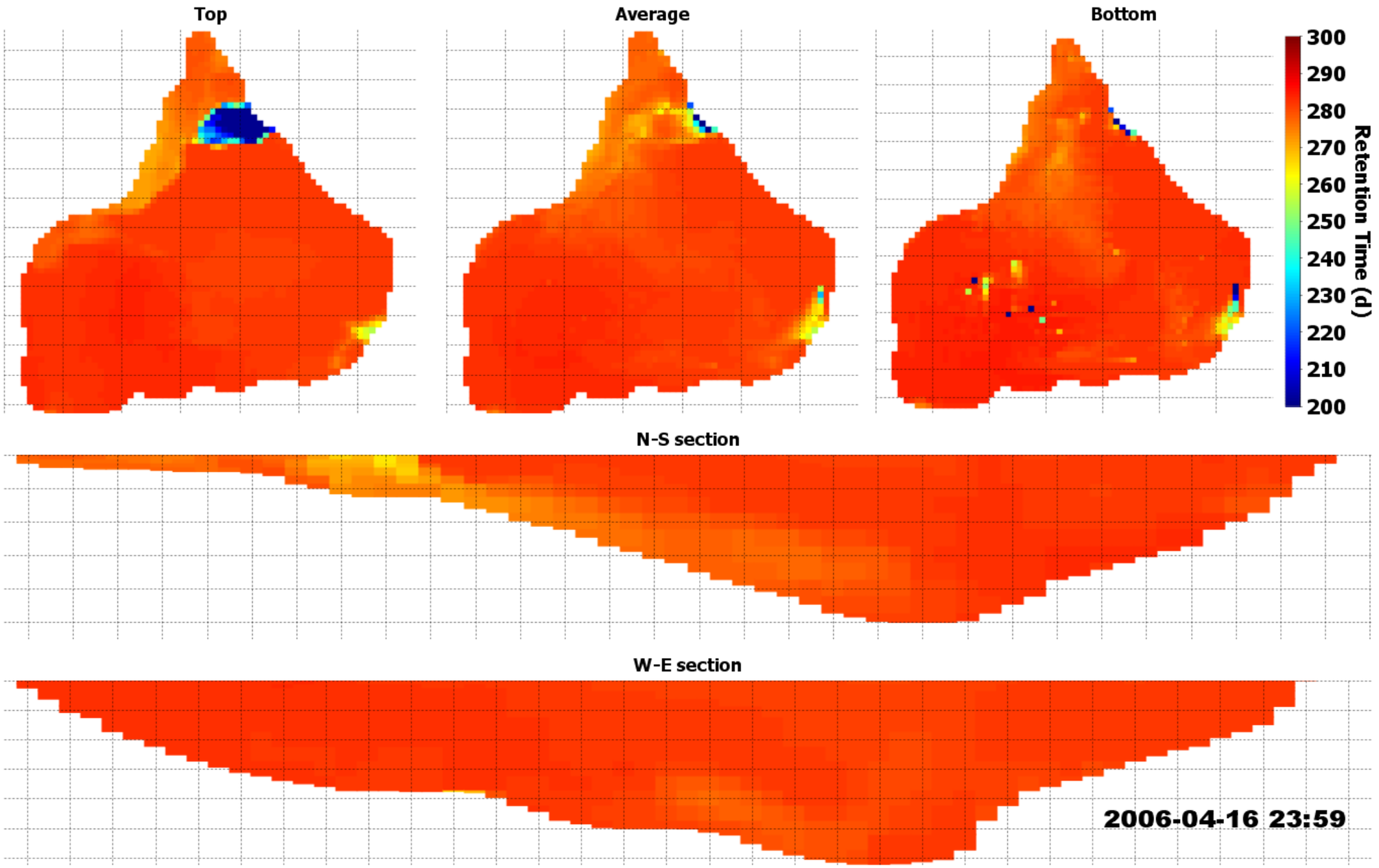
Water retention time in warm season after 1.5 year simulation (approx. 150 days near the surface, and 220 days in the deepest part)



Model of the Łękuk Wielki **Lake**
- Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

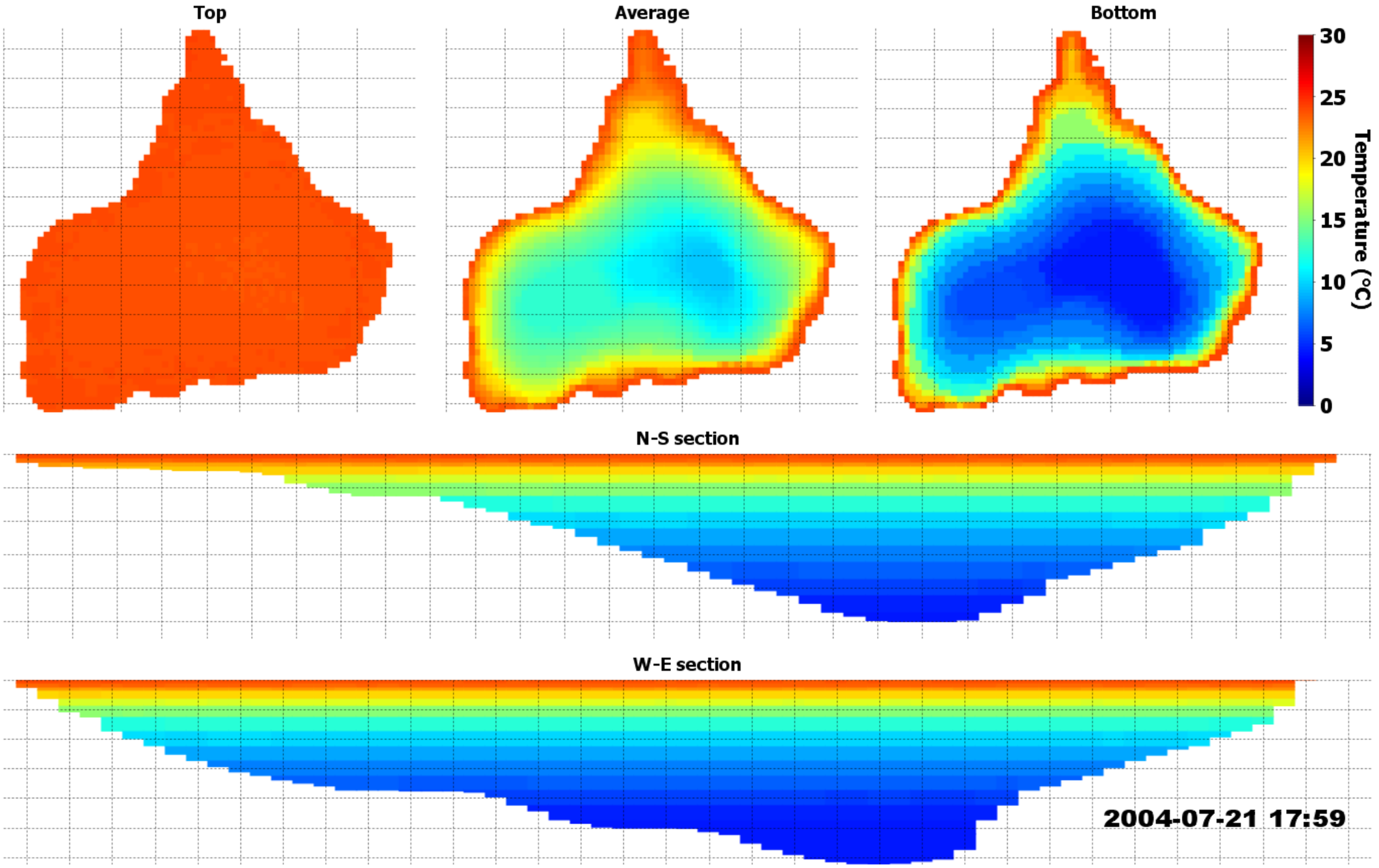
Water retention time after 2 years
(approx. 280 days in the entire lake except areas near main inflows)



Model of the Łękuk Wielki **Lake** - Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

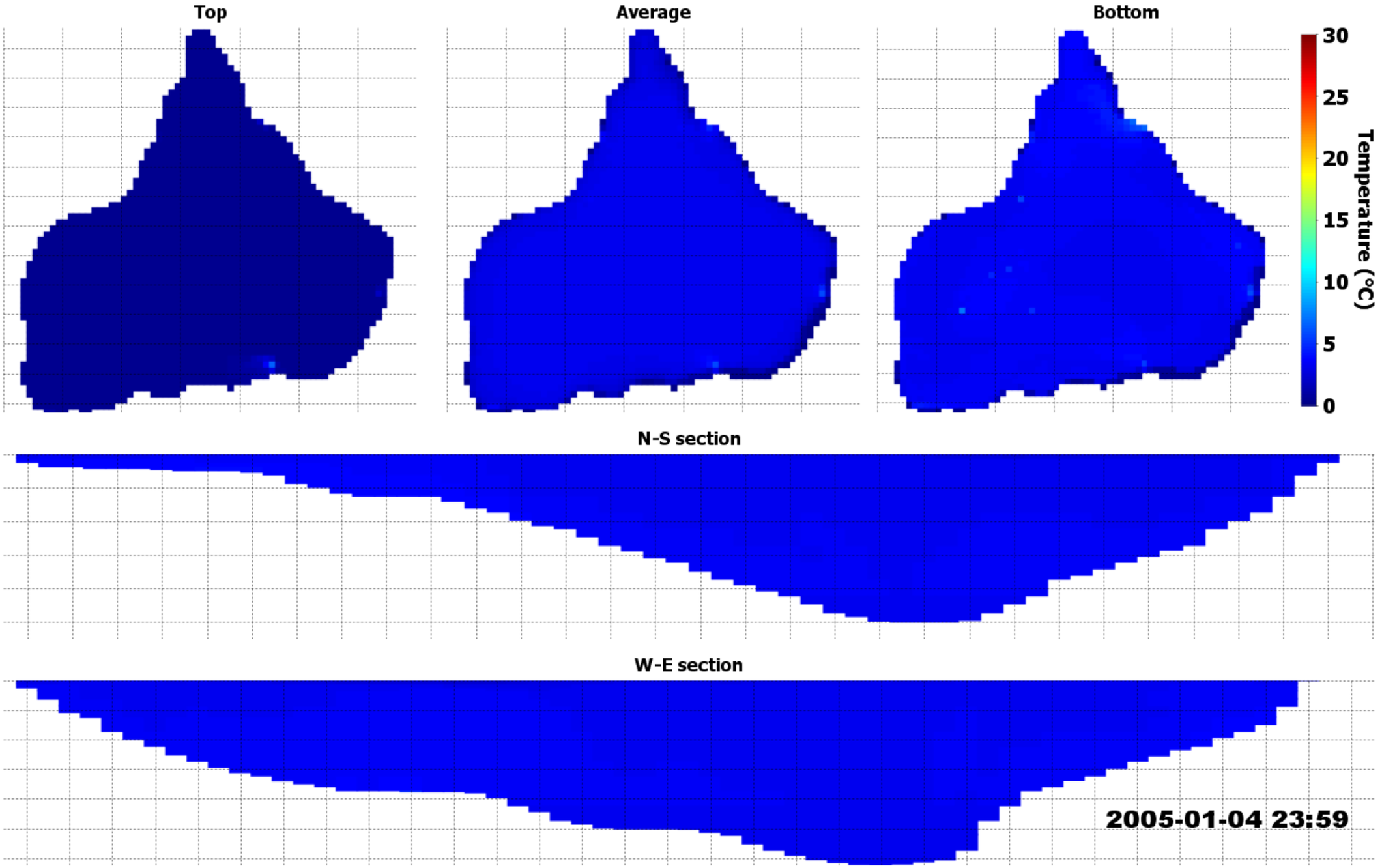
Water temperature - warm season



Model of the Łękuk Wielki **Lake** - Examples of outputs

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY

Water temperature - cold season



Conclusions:

- Wide range of monitoring data available for the “Puszcza Borecka” station (since early 1990’s)
- It is difficult to assess the impact of atmospheric deposition of nitrogen on ecosystems and water quality based on the monitoring data only
- SWAT model was used to simulate the nitrogen cycle in analysed area (first step to assess the impact of deposition has been taken)
- AEM3D model was used to simulate the lake’s hydrodynamics and thermodynamics and to give a basis for the assessment of impact od the deposition on water quality and aquatic ecosystems.

Thank You

Rafal.Ulanczyk@ios.edu.pl

Nitrogen budget at the IM station "Puszcza Borecka"

Joint 34th ICP Waters and 26th ICP IM Task Force Meeting, Warsaw, Poland, 7-9 May 2018

IOŚ-PIB
INSTYTUT OCHRONY ŚRODOWISKA
PAŃSTWOWY INSTYTUT BADAWCZY