swarm

Co-funded by the Erasmus+ Programme of the European Union

Assessment of Proper Wastewater Treatment Level according to Marine Ecosystem State

Goran Volf
Faculty of Civil Engineering, Rijeka

Theme-based training of teaching staff for acquiring new teaching and learning methods, Rijeka, 19/09/2019

University of Nis

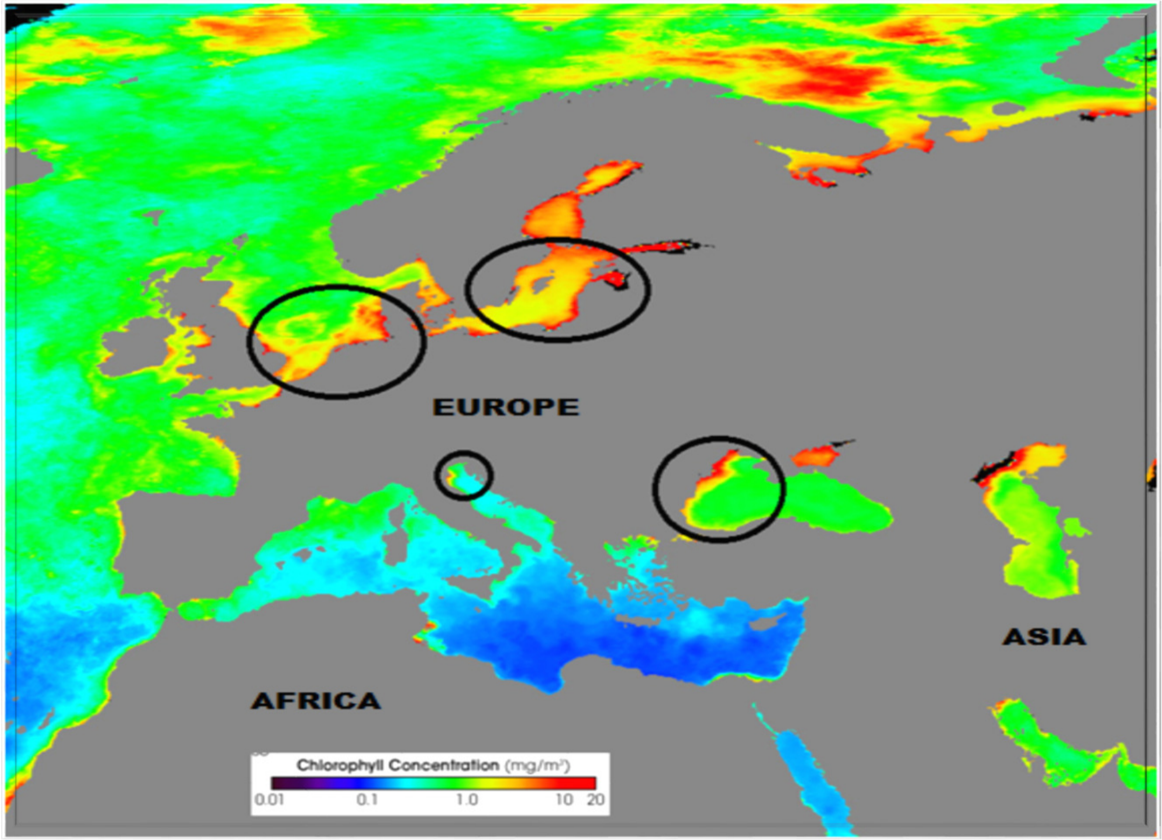
www.swarm.ni.ac.rs

Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders
Project number: 597888-EPP-1-2018-1-RS-EPPKA2-CBHE-JP

1. Introduction

• Marine Ecosystem Management

- EEA
- Directives:
  - WFD
  - UWWTD
  - MSFD
- GES



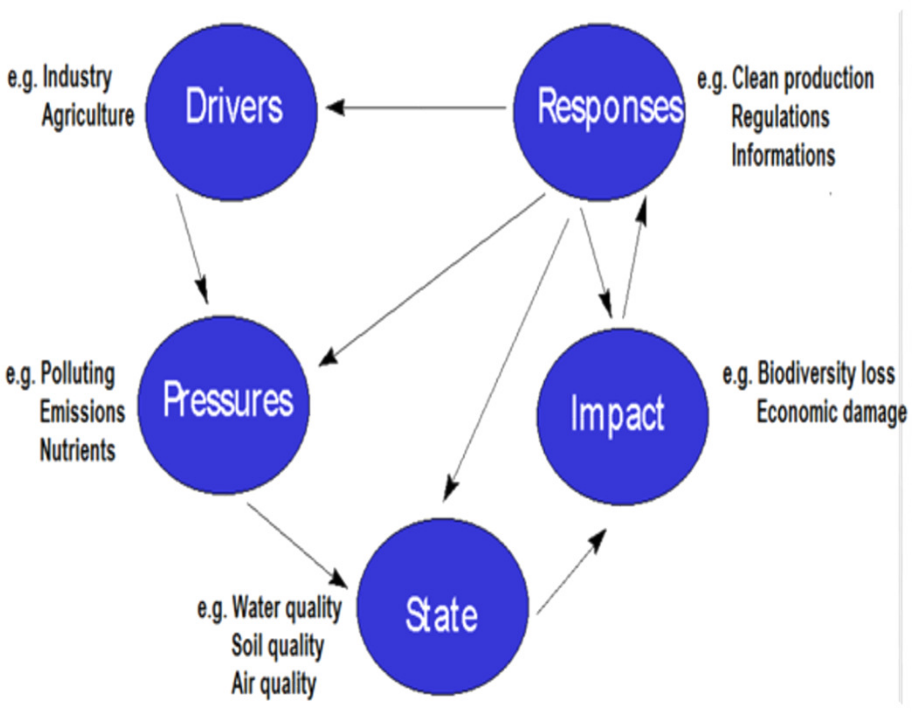
- **WWTP and their influence on Marine Ecosystems**

- Watewater Treatment levels
- UWWTD
- WWTP influences on Marine Ecosystems:
  - Positive
  - Negative
- **Eutrophication**… link between nutrients and increased organic production that results in low oxygen level.

- Removal of pollutants by WWT level:

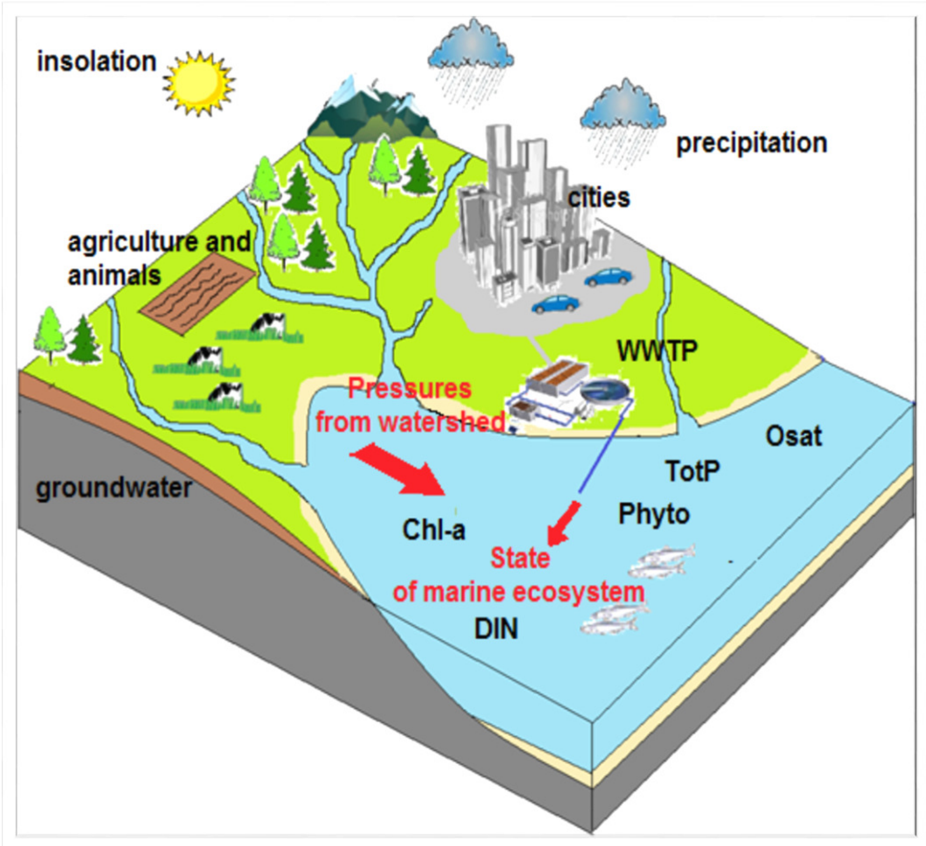
WWT Level / Pollutant	Preliminary	Primary (1)	Secondary (2)	Tertiary (3)
BOD*	30	50-70	90-95	>95
TSS**	60	80-90	90-95	>95
TN***	15	25	40	>90
TP****	5	10	30	>90

- **DPSIR framework…**
- The **State** (**S**) is the result of specific **Drivers** (**D**) and **Pressures** (**P**), positive or negative, which **Impact** (**I**) the environment. The **Responses** (**R**) represent the solutions (e.g. policies, investments) that should then be done to improve or maintain that state (*EEA*).



- **Purpose of the work**

- Proper WWT level
- DPSIR framework
- UWWTD
- Management tool
- Tasks…



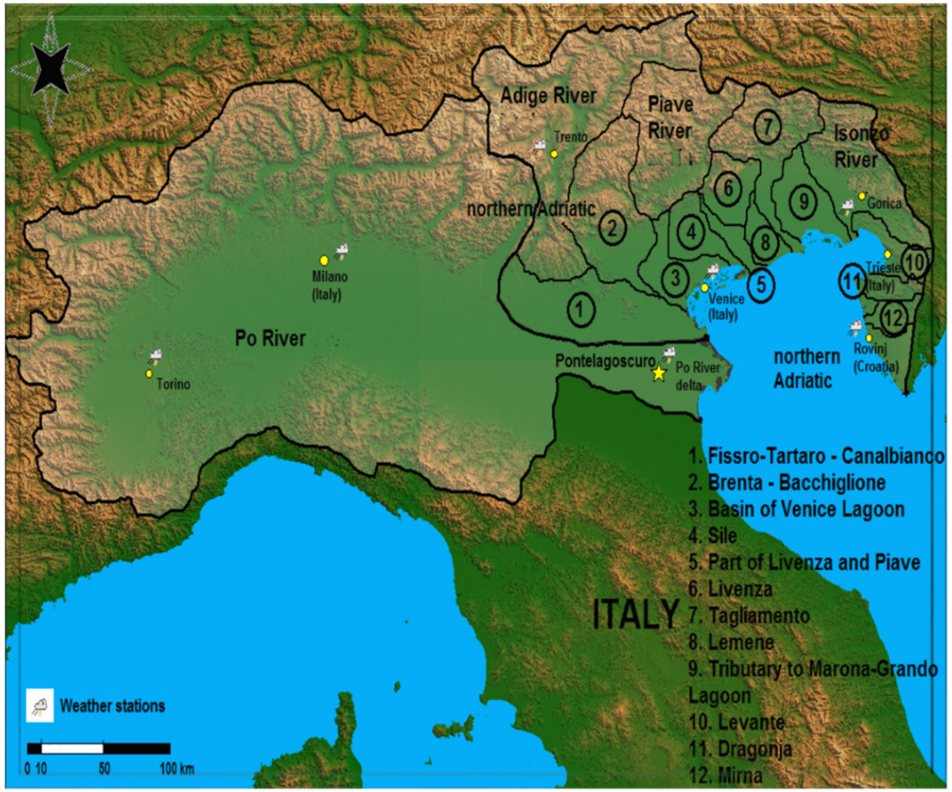
2. Study area and problem descripton

- **Northern Adriatic**

- Long period of measured data (CIM Rovinj)
- Area of 32.000 km^2
- The most productive part of Adriatic Sea
- Big amounts of nutrients
- **Problems of eutrophication and algal blooms…**

- **Northern Adriatic watershed**

- Area of 110.600 km^2
- Different anthropogenic pressures and levels of urbanization
- Large inflow of nutrients by numerous rivers
- **351.000 tN/y** and **12.000 tP/y**.



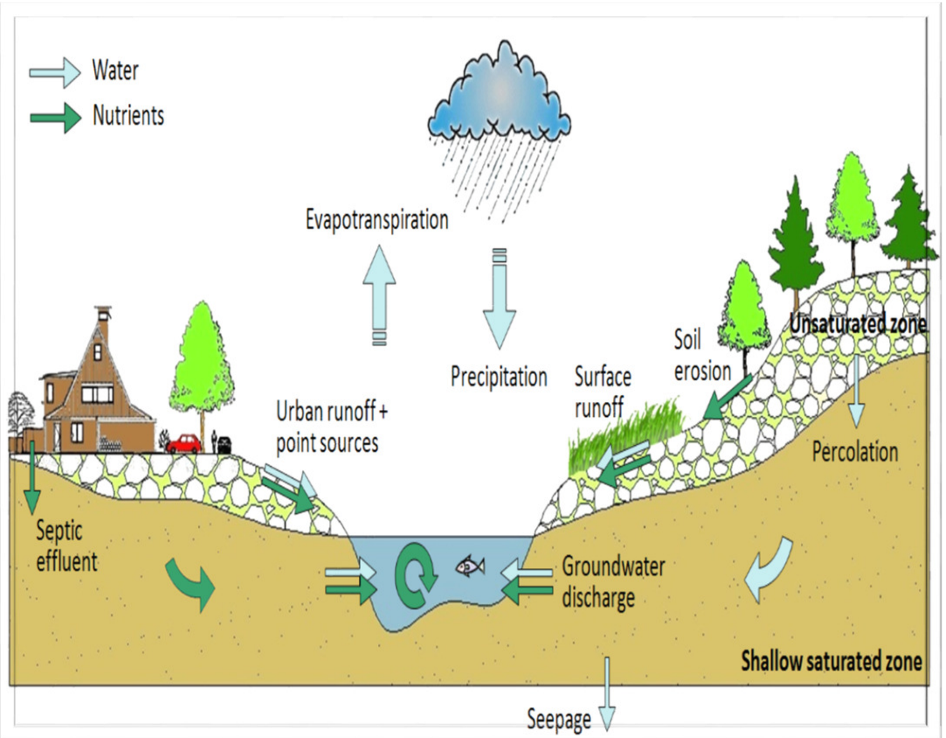
3. Modelling tools and data descripton

- **Watershed simulation model AVGWLF** (*Evans et.al 2002*)

Dissolved and solid phase nutrient load:

$$LD_n = DP_n + DR_n + DG_n + DS_n$$

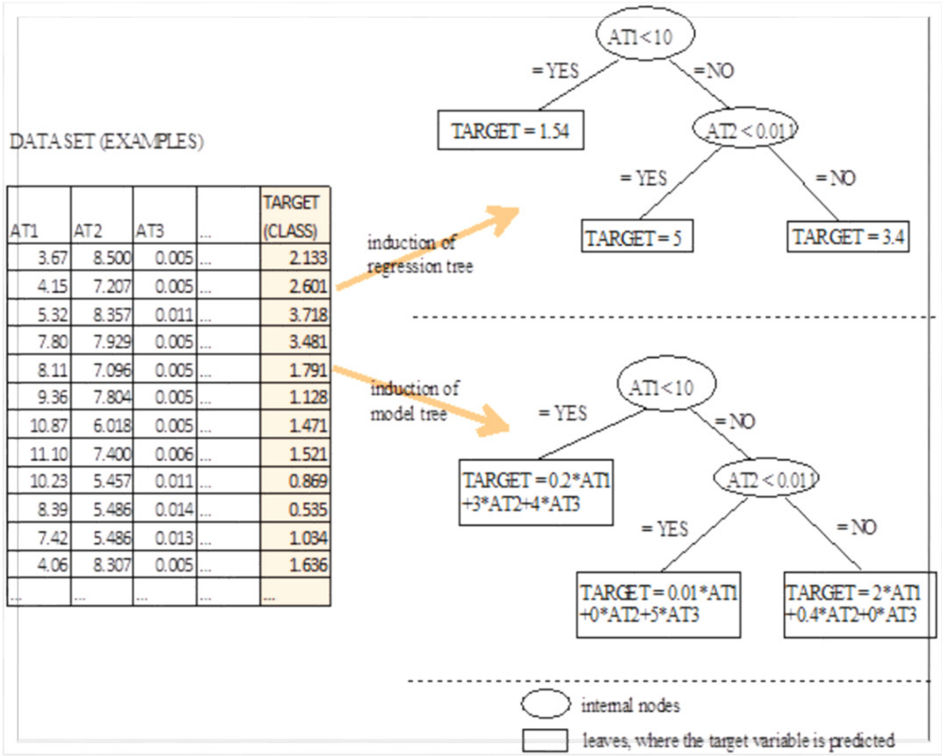
$$LS_n = SP_n + SR_n + SU_n$$



- **Machine learnig tools**

- Buildng of regression and model trees, rules…

- **Weka** (*Witten and Frank, 2000*)
- **Cubist** (http://www.rulequest.com/cubist-info.html)
- **MTSMOTI** (*Appice and Džeroski, 2007*)

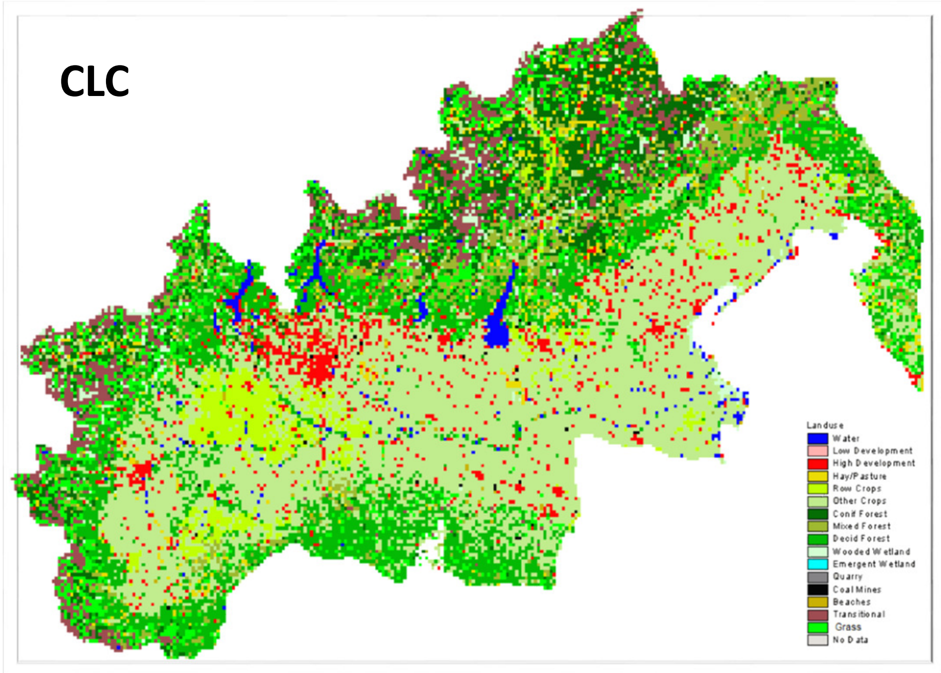


AT1	AT2	AT3	...	TARGET (CLASS)
3.67	8.500	0.005	...	2.133
4.15	7.207	0.005	...	2.601
5.32	8.357	0.011	...	3.718
7.80	7.929	0.005	...	3.481
8.11	7.096	0.005	...	1.791
9.36	7.804	0.005	...	1.128
10.87	6.018	0.005	...	1.471
11.10	7.400	0.006	...	1.521
10.23	5.457	0.011	...	0.869
8.39	5.486	0.014	...	0.535
7.42	5.486	0.013	...	1.034
4.06	8.307	0.005	...	1.636
...	...	...	...	...

- **Data**

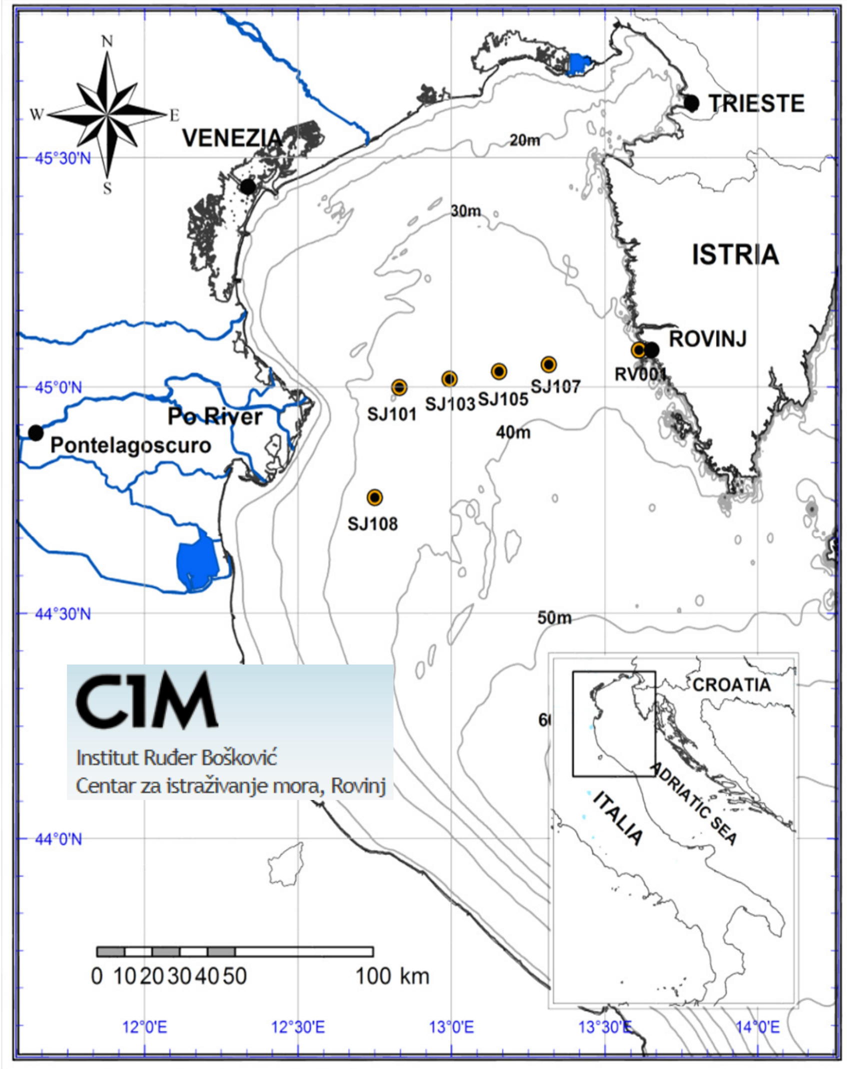
- **Data used for modeling pressures in NA watershed:**

- CLC
- DMT
- Soil data
- Hydro-meteorological data
- Population and wastewater generation data
- WWTP data
- Water quantity and quality data (flows, nutrients…)
- …



- **Data used for modeling the state of NA:**

- Water temperature
- Salinity
- Density
- pH
- Nitrate
- Nitrite
- Amonium
- Total P
- Orthophosphate
- Total inorganic nitrogen
- Chlorophyll-a
- Phytoplankton
- …



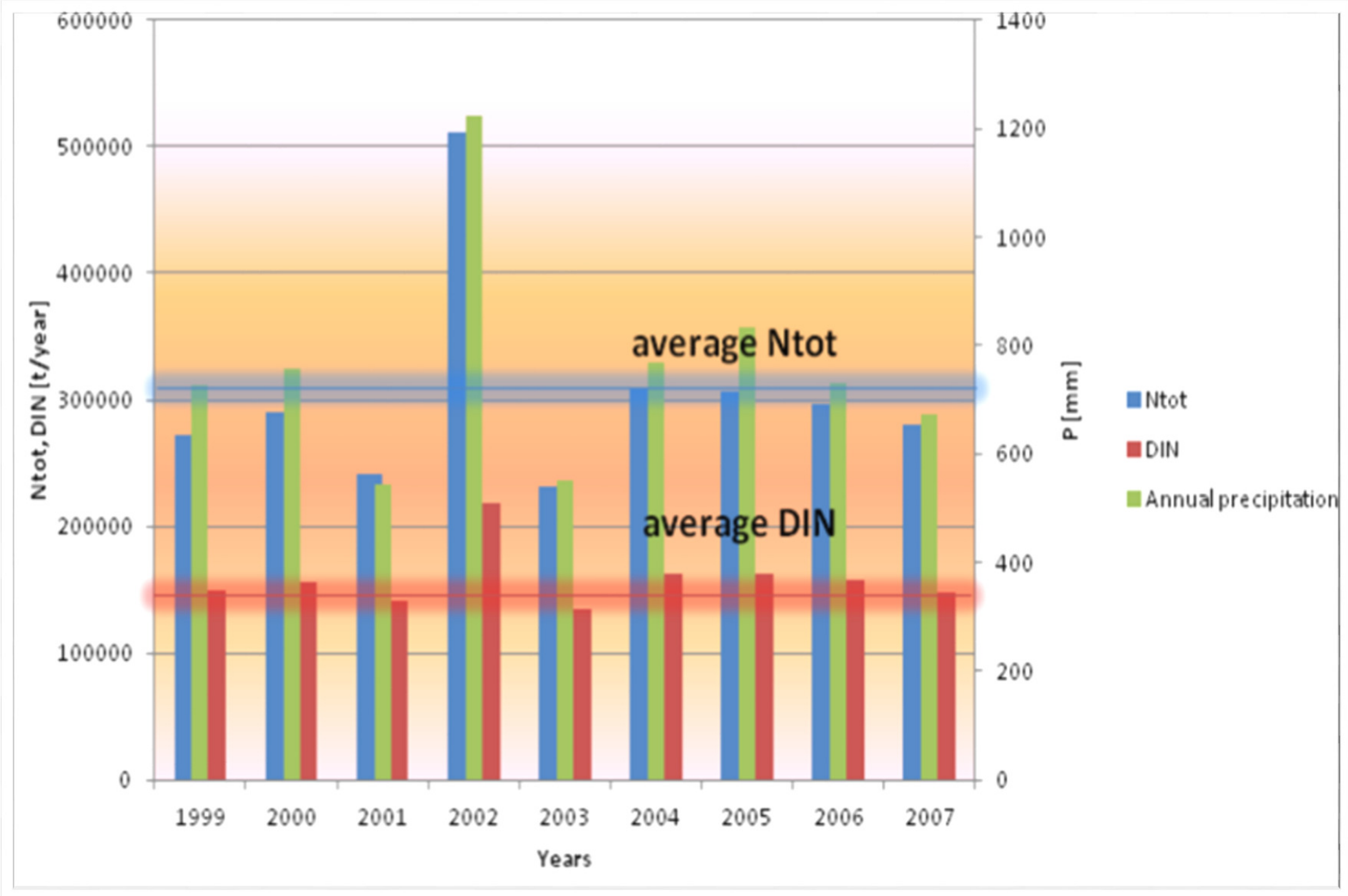
DPSIR

4. Modeling Pressures from NA watershed

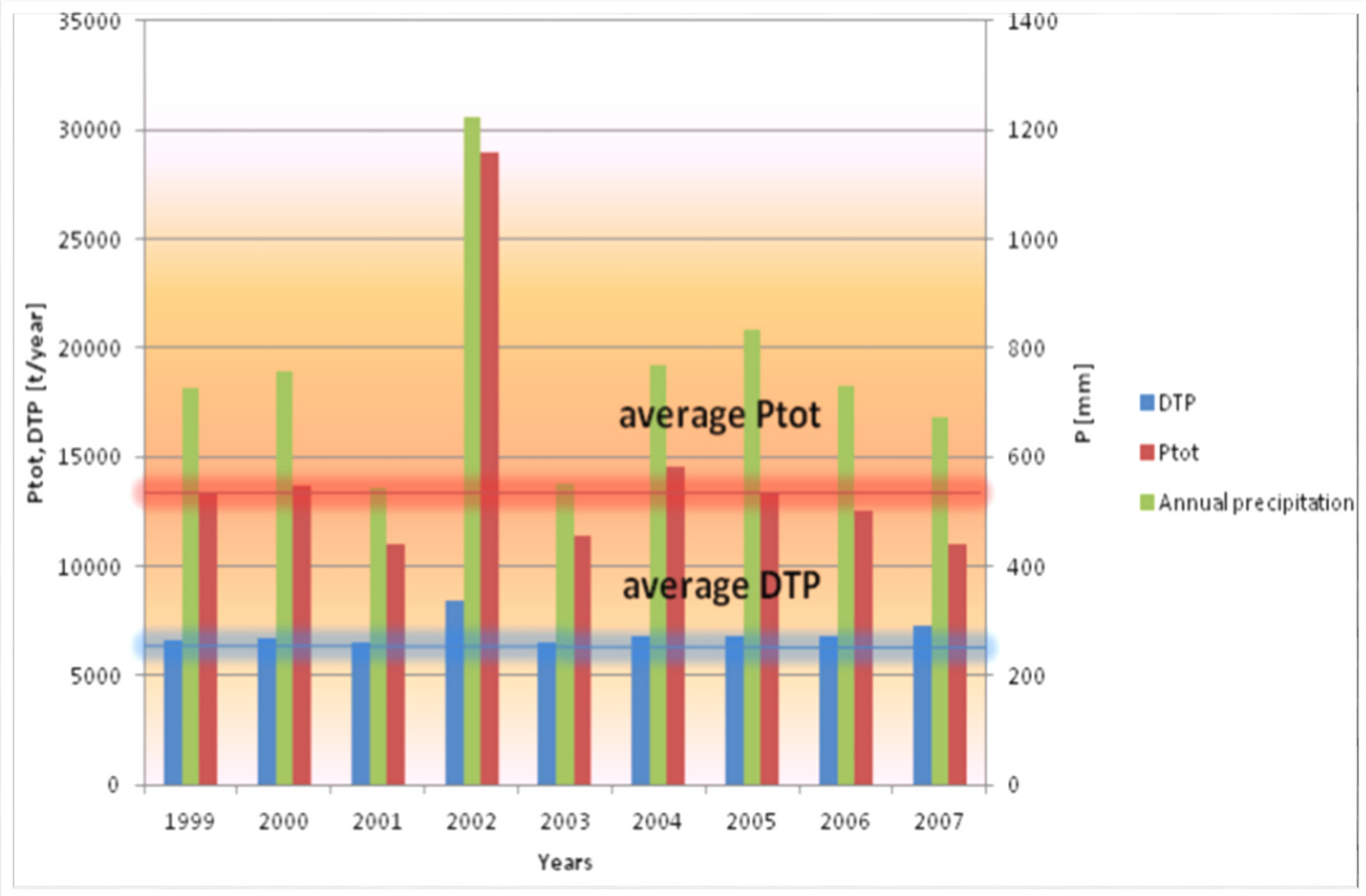
- **Model setup:**

- 17 watersheds
- Levels of WWT
- Retention of nutrients in watersheds
- GW
- TD
- …

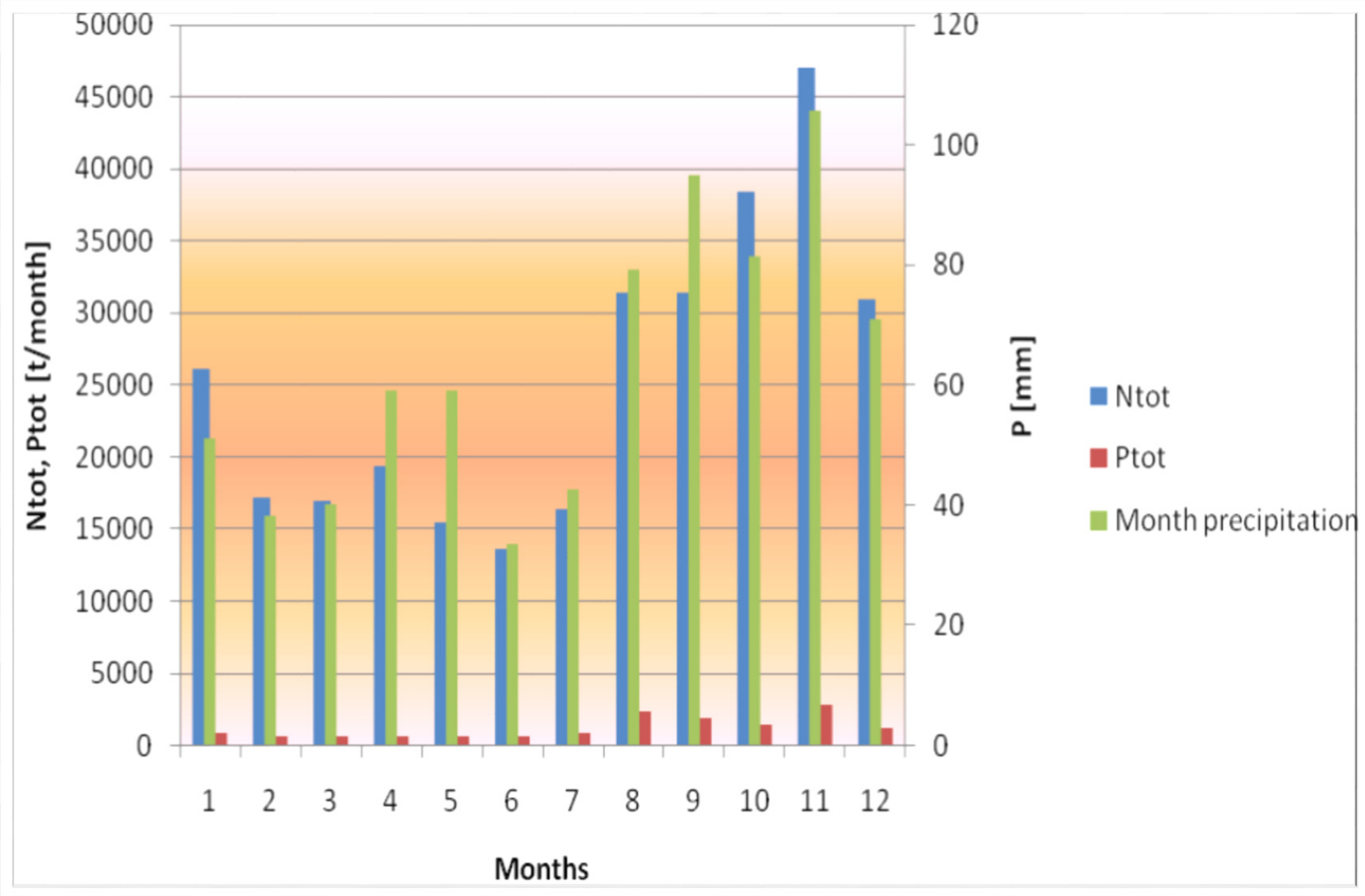
Model calibration (Po River data):



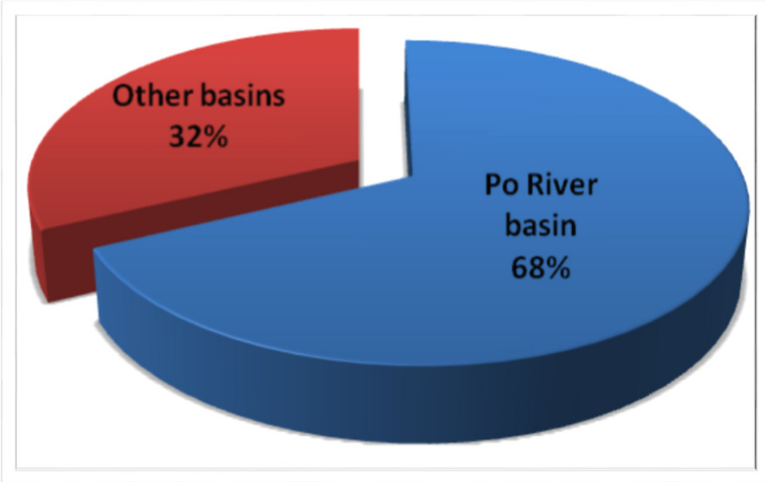
Simulated dissolved and total N in t/year



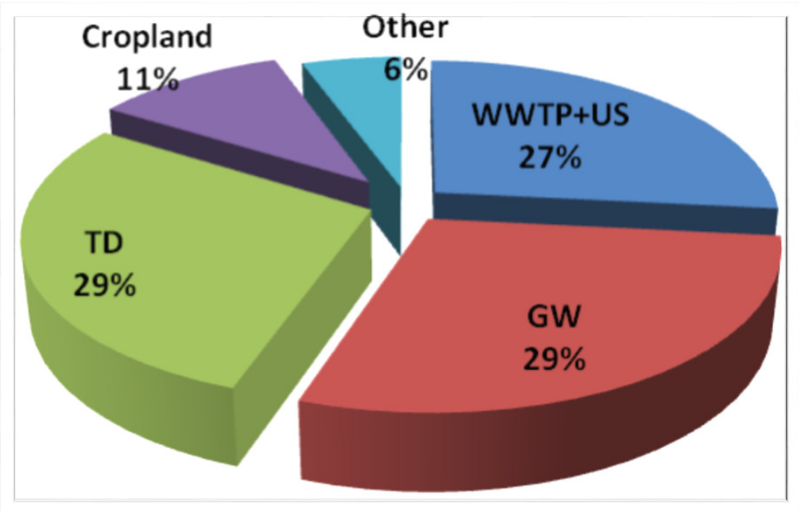
Simulated dissolved and total P in t/year



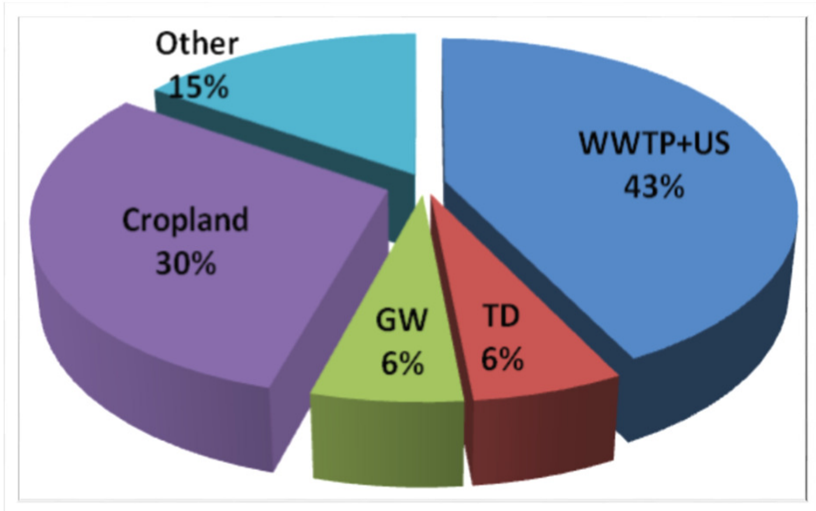
Simulated total N and P in t/month



Percent of nutrients in NA watershed



Main sources of total N



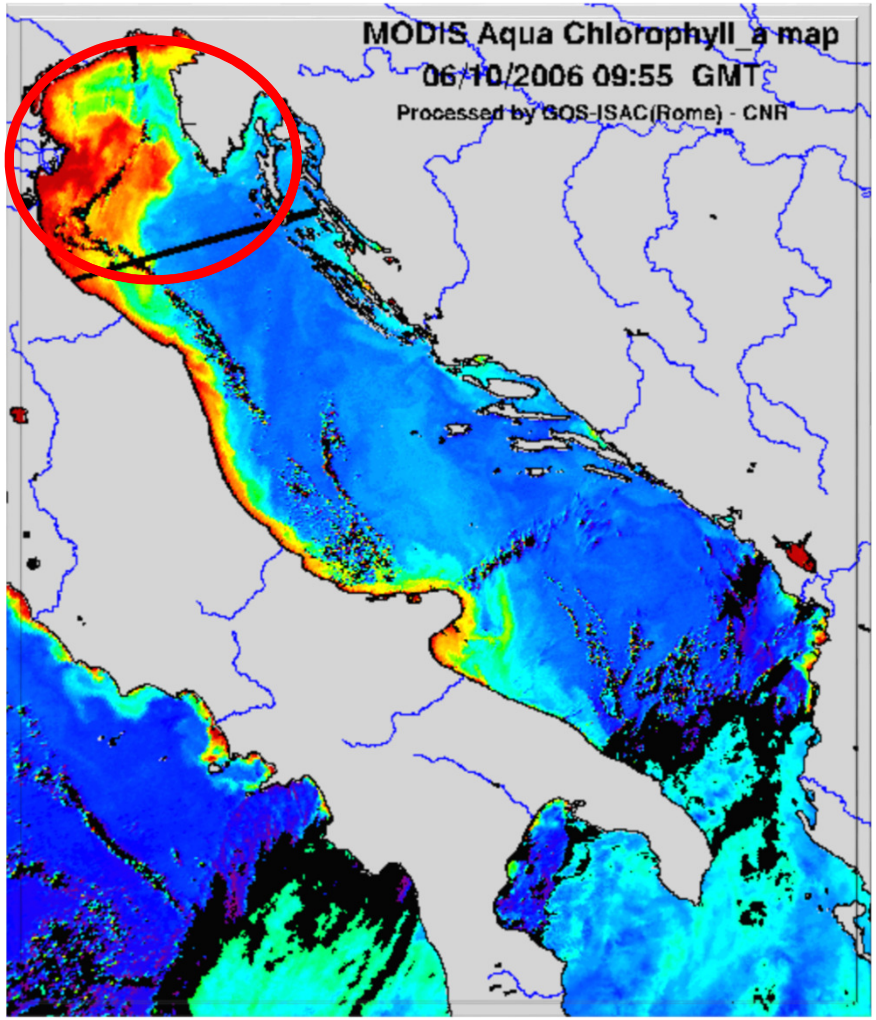
Main sources of total P

Co-funded by the Erasmus+ Programme of the European Union

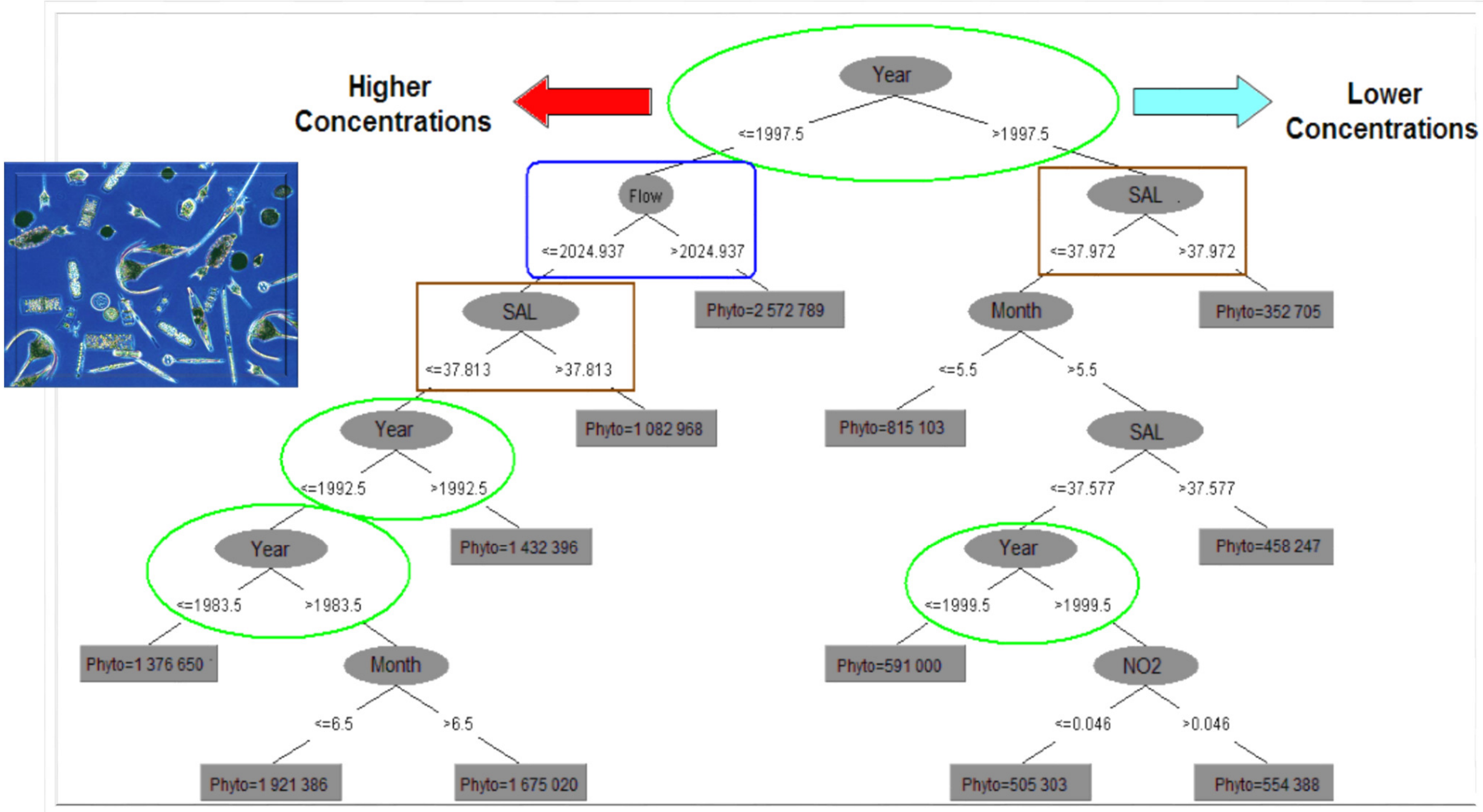
DPSIR

5. NA State assessment

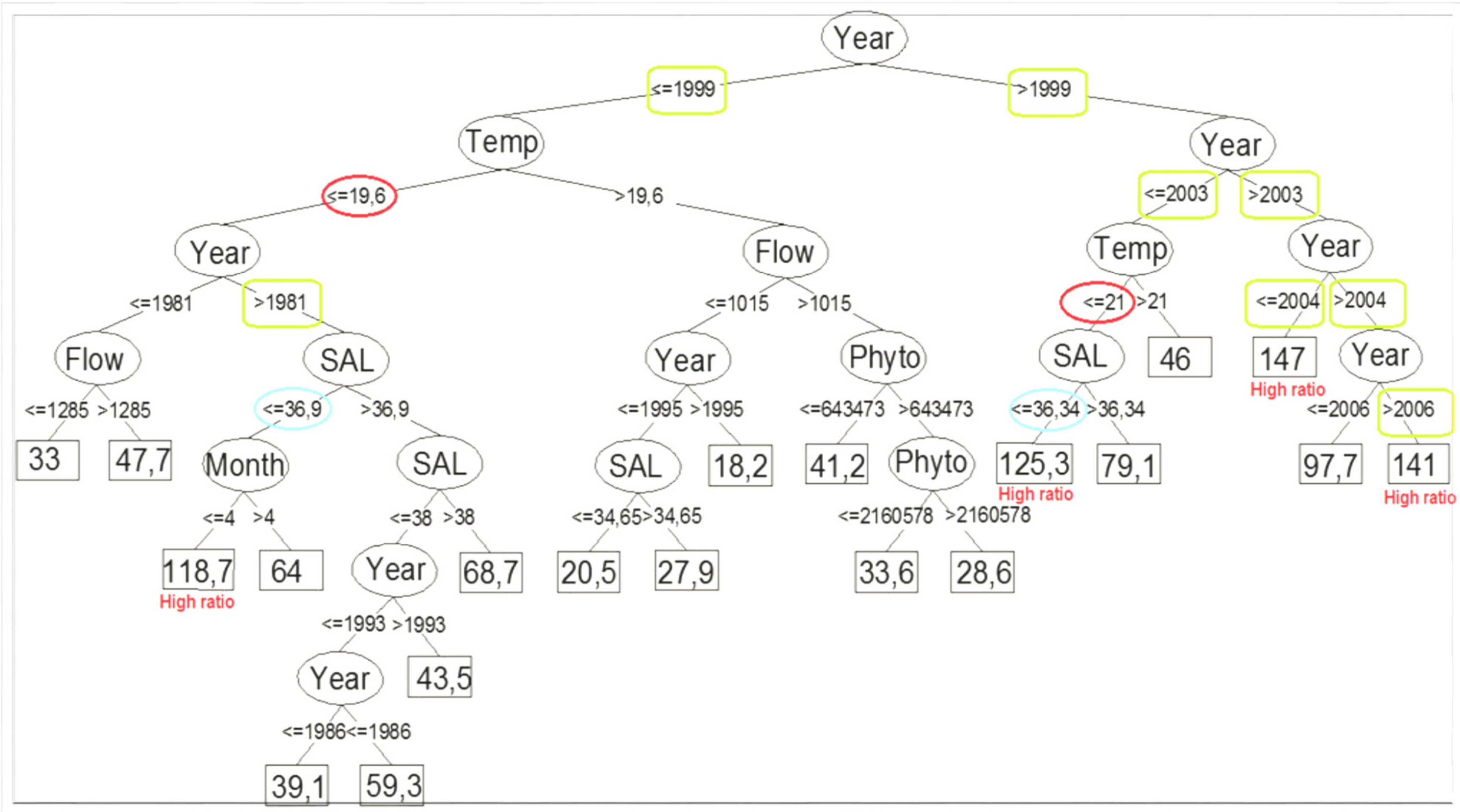
- **NA is the most productive part**
- **Problems of eutrophiction and algal blooms**

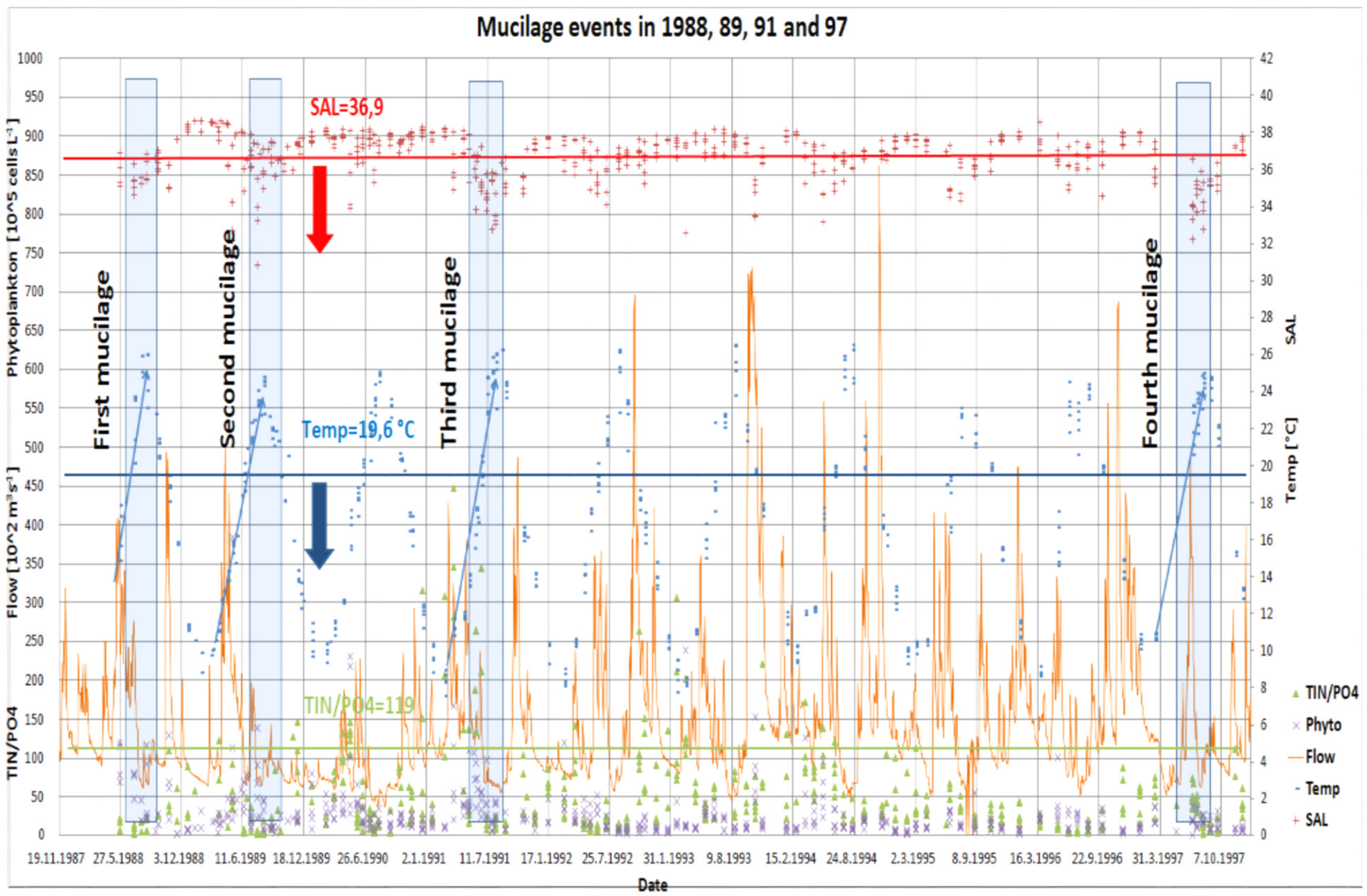


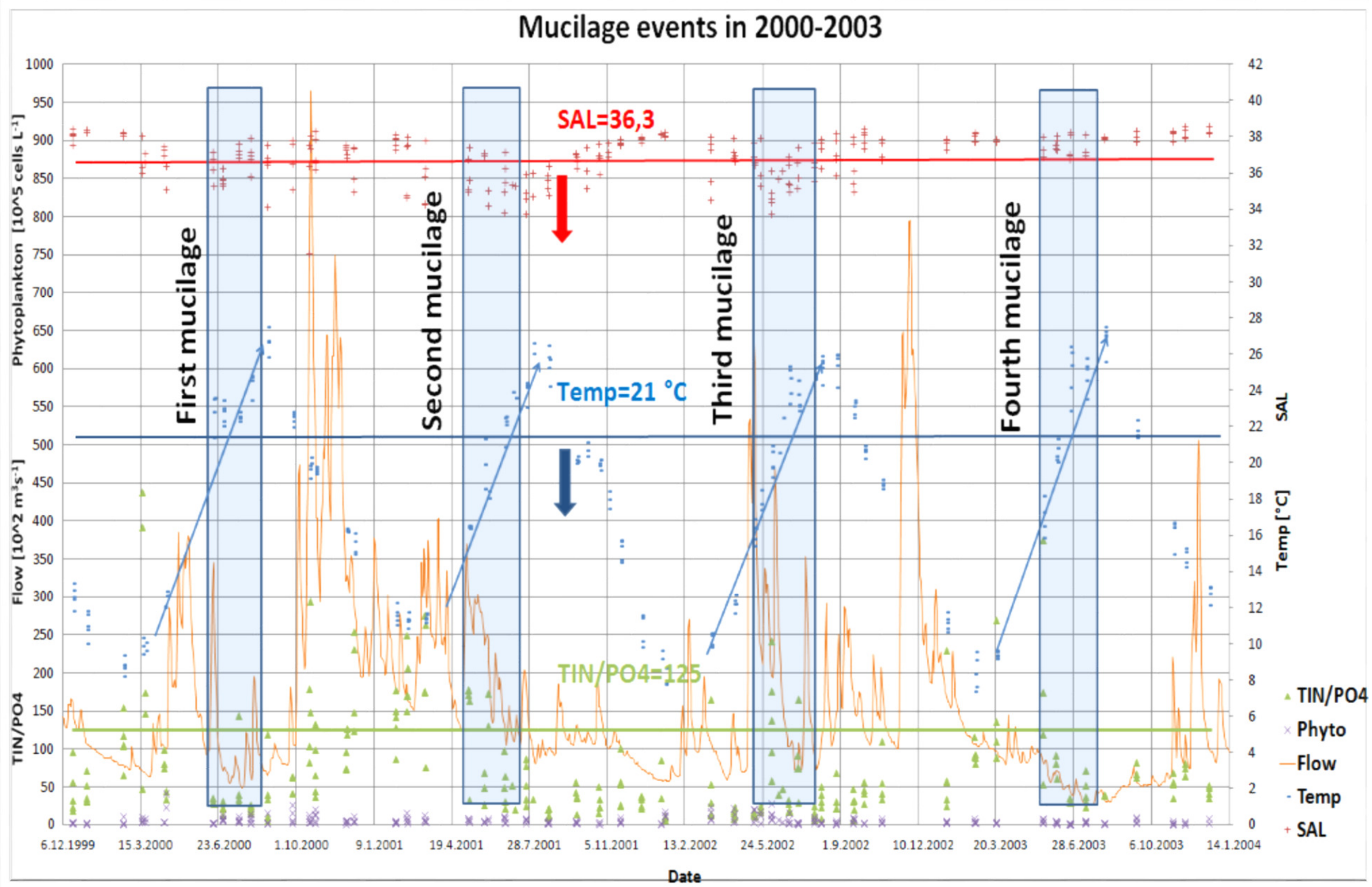
Phytoplankton concentration descriptive model (*Weka*)

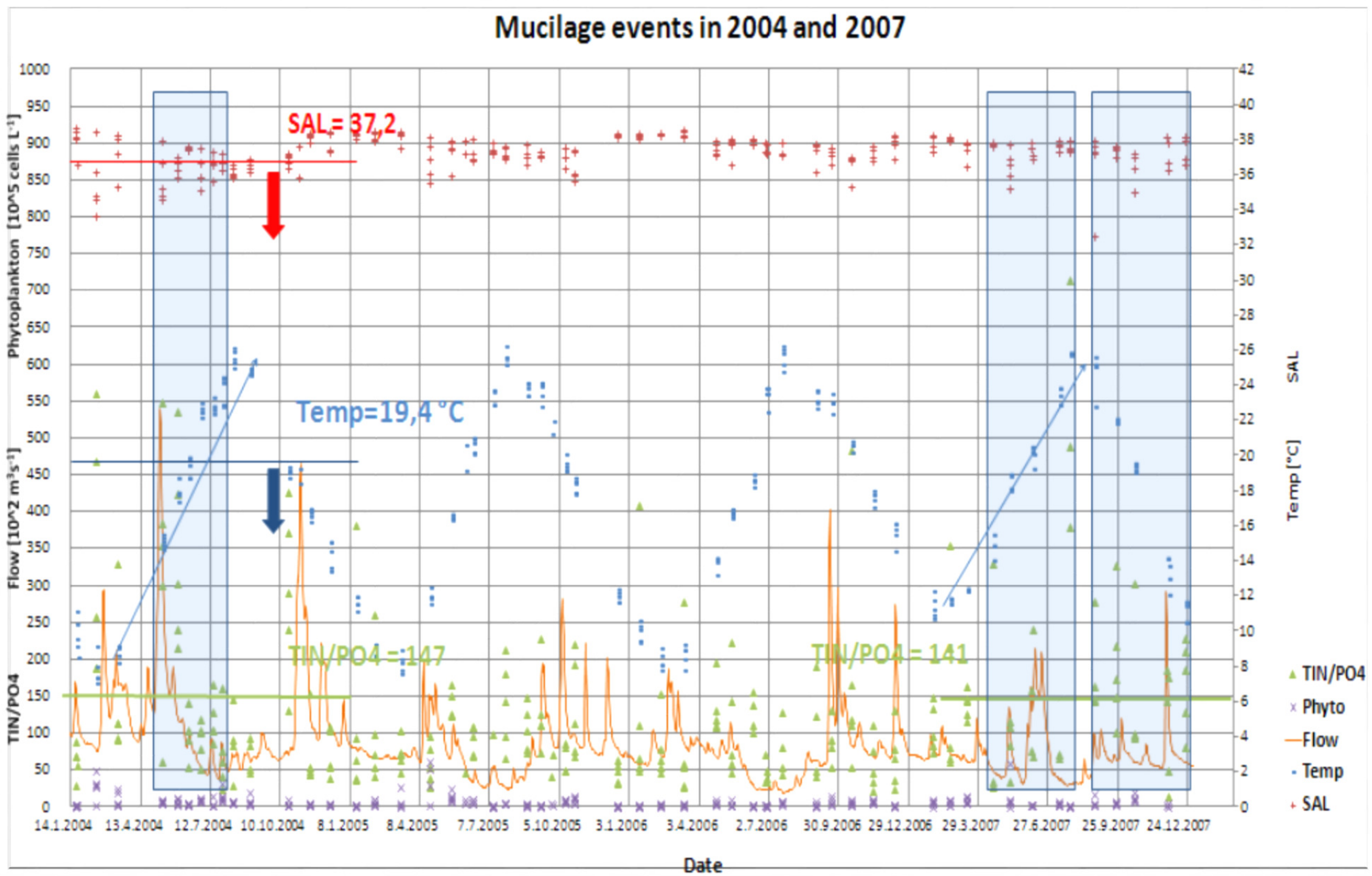


TIN/PO_4 model (*Weka*)




Mucilage events in 1988, 89, 91 and 97
SAL=36,9
Temp=19,6 °C
TIN/PO4=119
First mucilage
Second mucilage
Third mucilage
Fourth mucilage
Phytoplankton [10^5 cells L⁻¹]
Flow [10^2 m³s⁻¹]
TIN/PO4
SAL
Temp [°C]
Date
TIN/PO4
Phyto
Flow
Temp
SAL
19.11.1987 27.5.1988 3.12.1988 11.6.1989 18.12.1989 26.6.1990 2.1.1991 11.7.1991 17.1.1992 25.7.1992 31.1.1993 9.8.1993 15.2.1994 24.8.1994 2.3.1995 8.9.1995 16.3.1996 22.9.1996 31.3.1997 7.10.1997

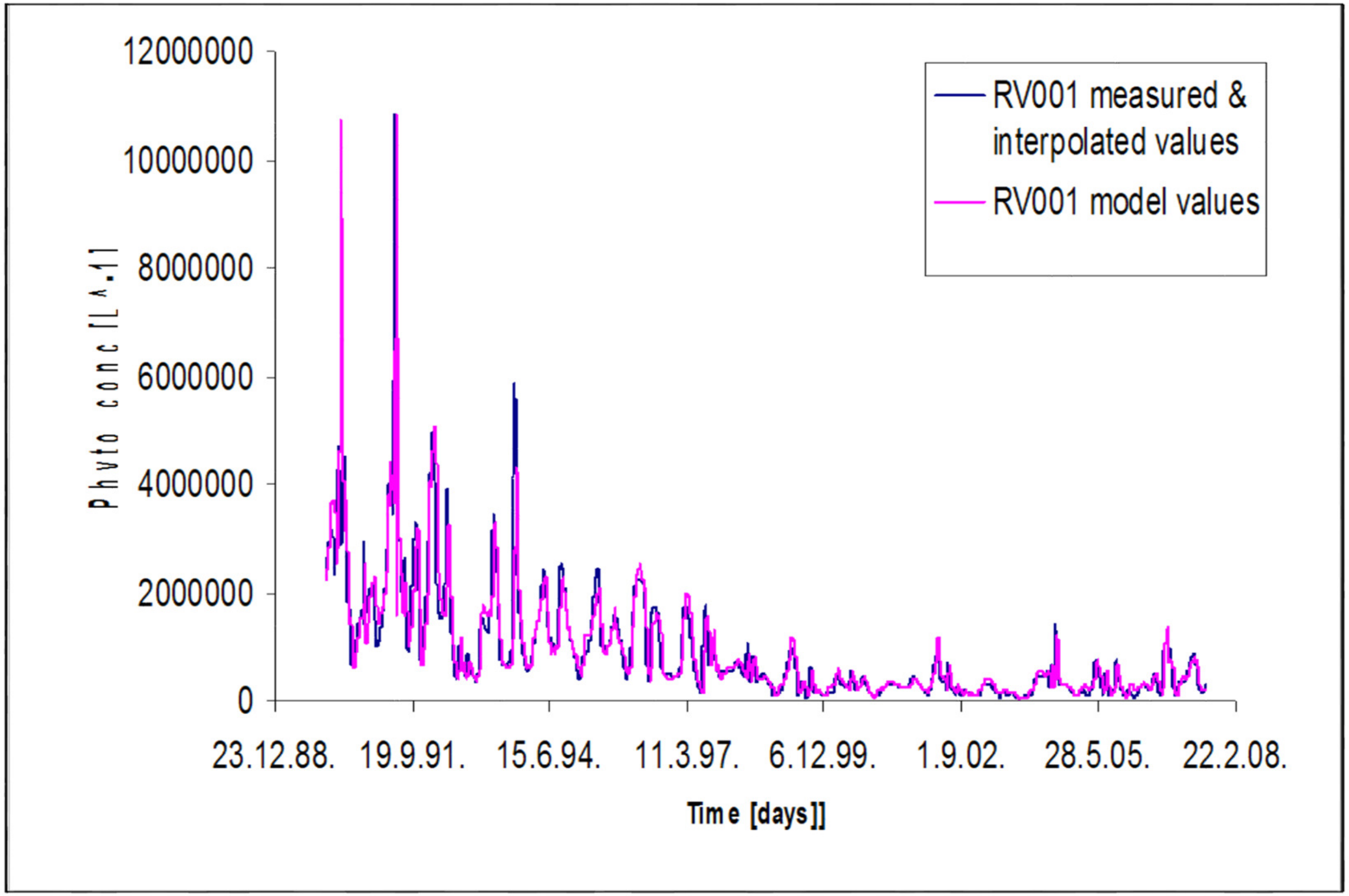

Mucilage events in 2000-2003
First mucilage
Second mucilage
Third mucilage
Fourth mucilage
SAL=36,3
Temp=21 °C
TIN/PO4=125
Phytoplankton [10^5 cells L⁻¹]
Flow [10^2 m³s⁻¹]
TIN/PO4
SAL
Temp [°C]
Date
TIN/PO4
Phyto
Flow
Temp
SAL
6.12.1999
15.3.2000
23.6.2000
1.10.2000
9.1.2001
19.4.2001
28.7.2001
5.11.2001
13.2.2002
24.5.2002
1.9.2002
10.12.2002
20.3.2003
28.6.2003
6.10.2003
14.1.2004


Mucilage events in 2004 and 2007
SAL= 37,2
Temp=19,4 °C
TIN/PO4 =147
TIN/PO4 = 141
Phytoplankton [10^5 cells L⁻¹]
Flow [10^2 m³s⁻¹]
TIN/PO4
SAL
Temp [°C]
Date
TIN/PO4
Phyto
Flow
Temp
SAL
14.1.2004
13.4.2004
12.7.2004
10.10.2004
8.1.2005
8.4.2005
7.7.2005
5.10.2005
3.1.2006
3.4.2006
2.7.2006
30.9.2006
29.12.2006
29.3.2007
27.6.2007
25.9.2007
24.12.2007

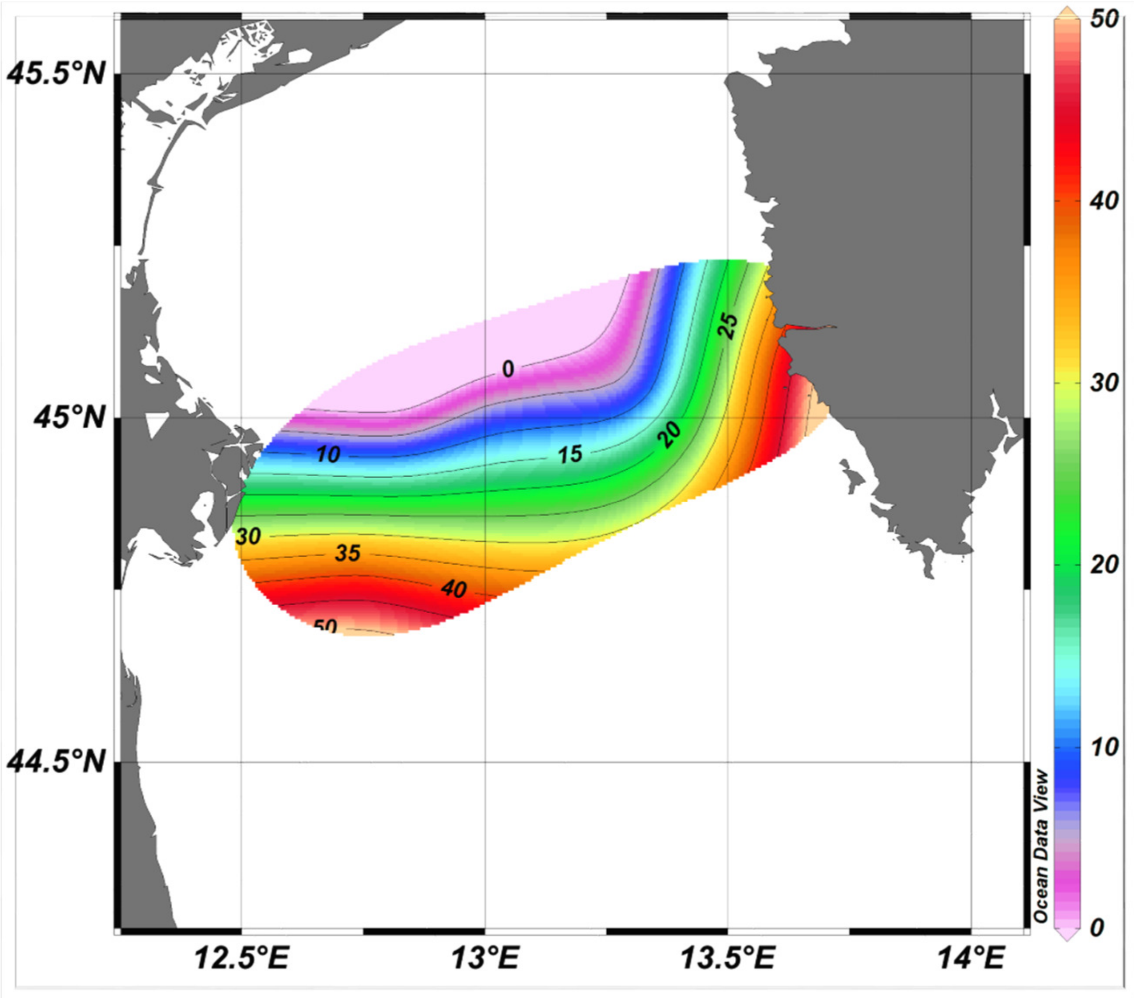
Co-funded by the Erasmus+ Programme of the European Union

Prediction model of phytoplankton concentration (*Cubist*)

Rule no.	Rules:	Equations:
Rule 1	If Phyto ≤ 804620	Phyto_pred = 732300 + 0,917 Phyto - 233140 Dene - 58205 Temp + 179186 SAL - 7782 Month
Rule 2	If Temp > 9,65 Temp ≤ 20,31 Phyto > 804620,5 Phyto ≤ 2807349	Phyto_pred = 5,24147e+006 + 0,931 Phyto - 84220 Temp - 57364 Dene - 199934 NO_2 - 20263 NO_3 - 7368 TIN/SiO_4+ 29 Flow - 368417 pH + 88810 NH_4 + 19504 SAL
Rule 3	If Temp > 20,31 Phyto > 804620,5	Phyto_pred = -2,76291e+006 + 0,716 Phyto + 359934 Dene + 103143 Temp + 135511 Month - 256581 SAL - 1125 TIN/PO_4 + 7567 TIN/Si
Rule 4	If Temp ≤ 9,65 Phyto > 804620 Phyto ≤ 2807349	Phyto_pred = -6,68528e+006 + 0,87 Phyto - 390486 Dene + 386746 SAL - 80868 Temp + 218220 NH_4 - 852 TIN/PO_4 + 21132 NO_3 - 12263 Month + 559168 pH
Rule 5	If TIN/PO_4 ≤ 62,35 Phyto > 2807349	Phyto_pred = 1,16131e+007 + 0,664 Phyto - 141666 Temp - 6625 TIN/PO_4 - 147108 NO_3 - 97863 Dene+ 406748 NO_2 + 17884 TIN/SiO_4 - 660243 pH + 87424 NH_4
Rule 6	If Month > 4 TIN/PO_4 > 62,35 Phyto > 2807349 Phyto ≤ 1,13e+007	Phyto_pred = 7,14367e+007 - 1,18988e+006 Temp - 3,28797e+006 Dene + 2,00528e+006 SAL + 0,831 Phyto - 4,86272e+006 NO_2 - 278807 Month + 2,30991e+006 NH_4 - 258224 NO_3 - 55637 TIN/SiO_4 - 4,16418e+006 pH + 2917 TIN/PO_4 - 57 Flow
Rule 7	If Temp ≤ 12,28 NH_4 ≤ 0,31 TIN/PO_4 > 62,35 Phyto > 2807349	Phyto_pred = 3,97828e+007 + 8,67119e+006 Dene + 1,92162e+006 Temp - 5,92294e+006 SAL - 8,71454e+006 NH_4 + 797894 NO_3 + 1566 Flow + 0,8 Phyto - 1,05622e+007 pH - 10620 TIN/PO_4 + 2,05592e+006 NO_2
Rule 8	If Temp ≤ 12,28 NH_4 > 0,31 TIN/PO_4 > 62,35 Phyto > 2807349	Phyto_pred = 1,26724e+008 - 3,25732e+007 Dene - 7,30295e+006 Temp + 2,64069e+007 SAL - 7,87193e+006 NO_2 + 0,78 Phyto + 610748 NO_3 - 1,16366e+007 pH - 2,89067e+006 NH_4
Rule 9	If Month <= 4 Temp > 12,28 TIN/PO_4 > 62,35 Phyto > 2807349	Phyto_pred = 1,3374e+008 + 4,30887e+006 Dene - 4,10462e+006 SAL + 1,756 Phyto - 815924 NO_3 - 4,89689e+006 NO_2 - 1,19144e+007 pH - 4543 Temp
Rule 10	If Month > 4 TIN/PO_4 > 62,35 Phyto > 1,13e+007	Phyto_pred= -4,05262e+008 - 4,50557e+006 Temp + 19140 Flow + 5,66287e+007 pH - 1,05564e+007 NH_4 + 36997 TIN/SiO_4



Measured and simulated data, CC=0,9



Differences between measured and simulated data in %

Co-funded by the Erasmus+ Programme of the European Union

6. Connecting State of NA with Pressures from watershed

- **TRIX value (*Vollenweider et al.., 1998*)**

- **TRIX = (Log10[Chl-a · |D%O| · TIN · TotP] + k) / m**

- **Classification (*Navarro et al., 2009*):**

TRIX	State	Trophic conditions
0-4	High	Ultra-oligotrophic
4-5	Good	Oligotrophic
5-6	Moderate	Mesotrophic
6-8	Poor	Eutrophic
8-10	Bad	Hypereutrophic

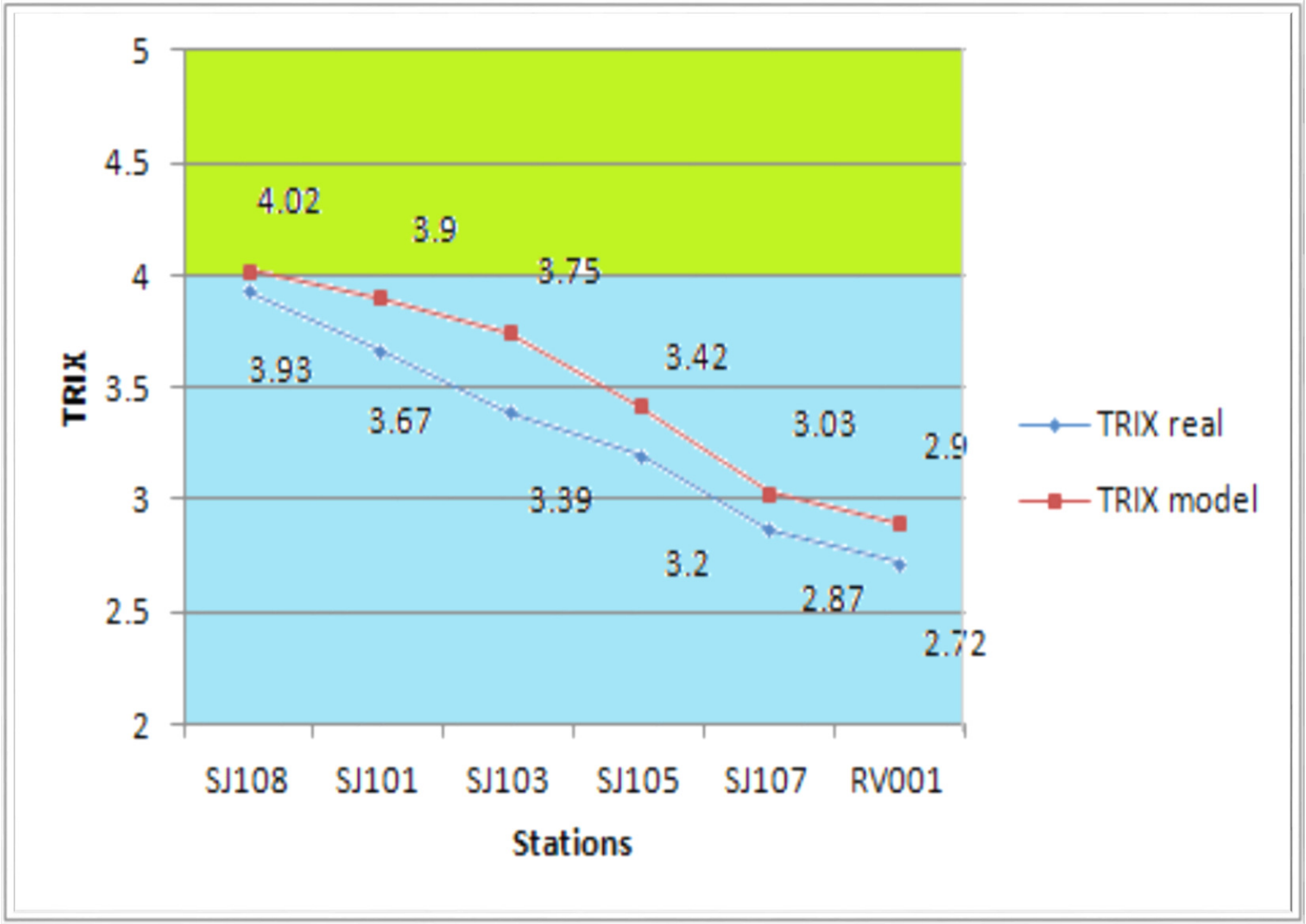
- **MTSMOTI (*Appice and Džeroski, 2007*)**

P

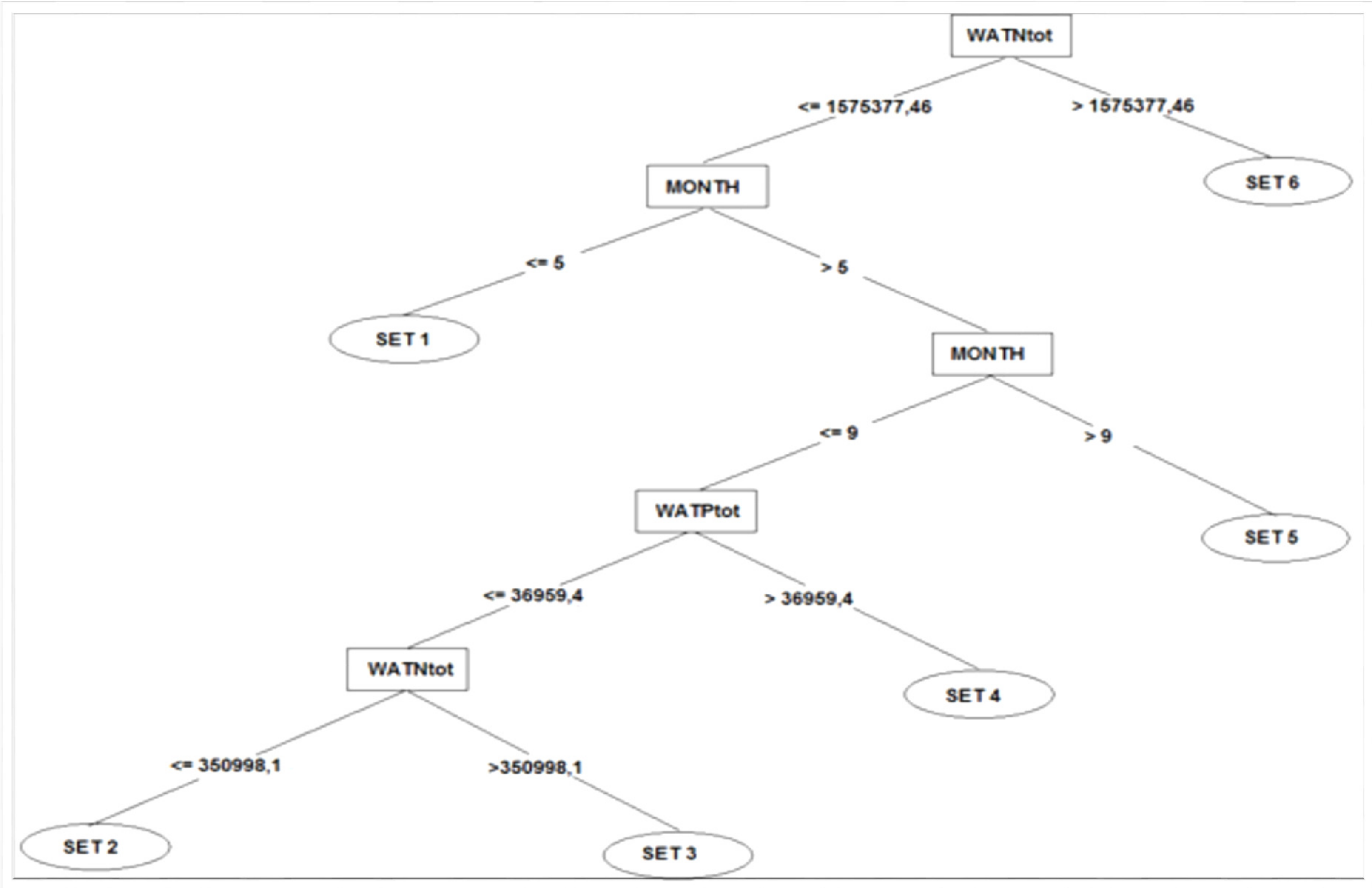
Pressures:
WATNtot
WATPtot

State of NA:
CHL-a
TotP
TIN
Osat

S



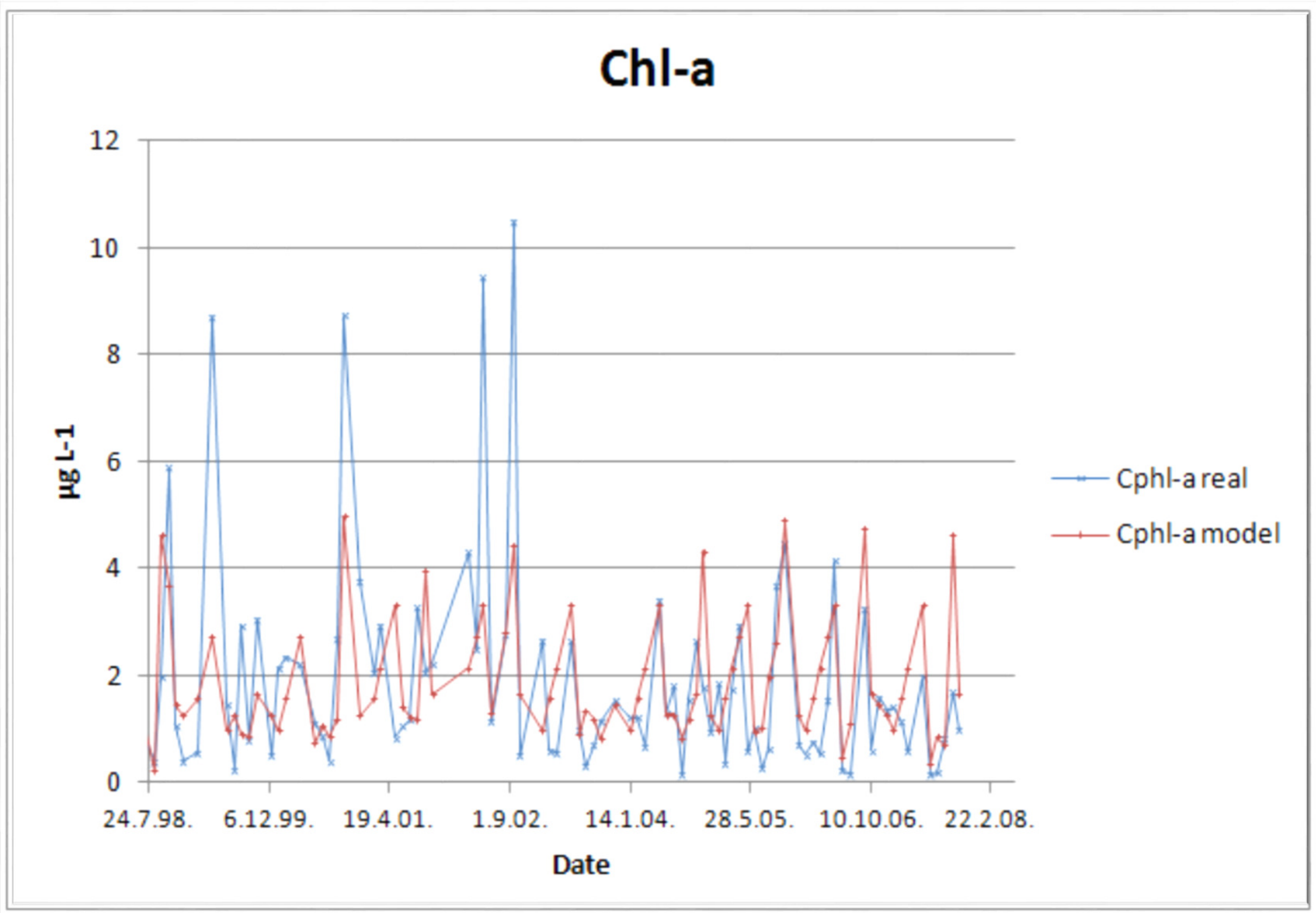
TRIX values (average for period 1999-2007)



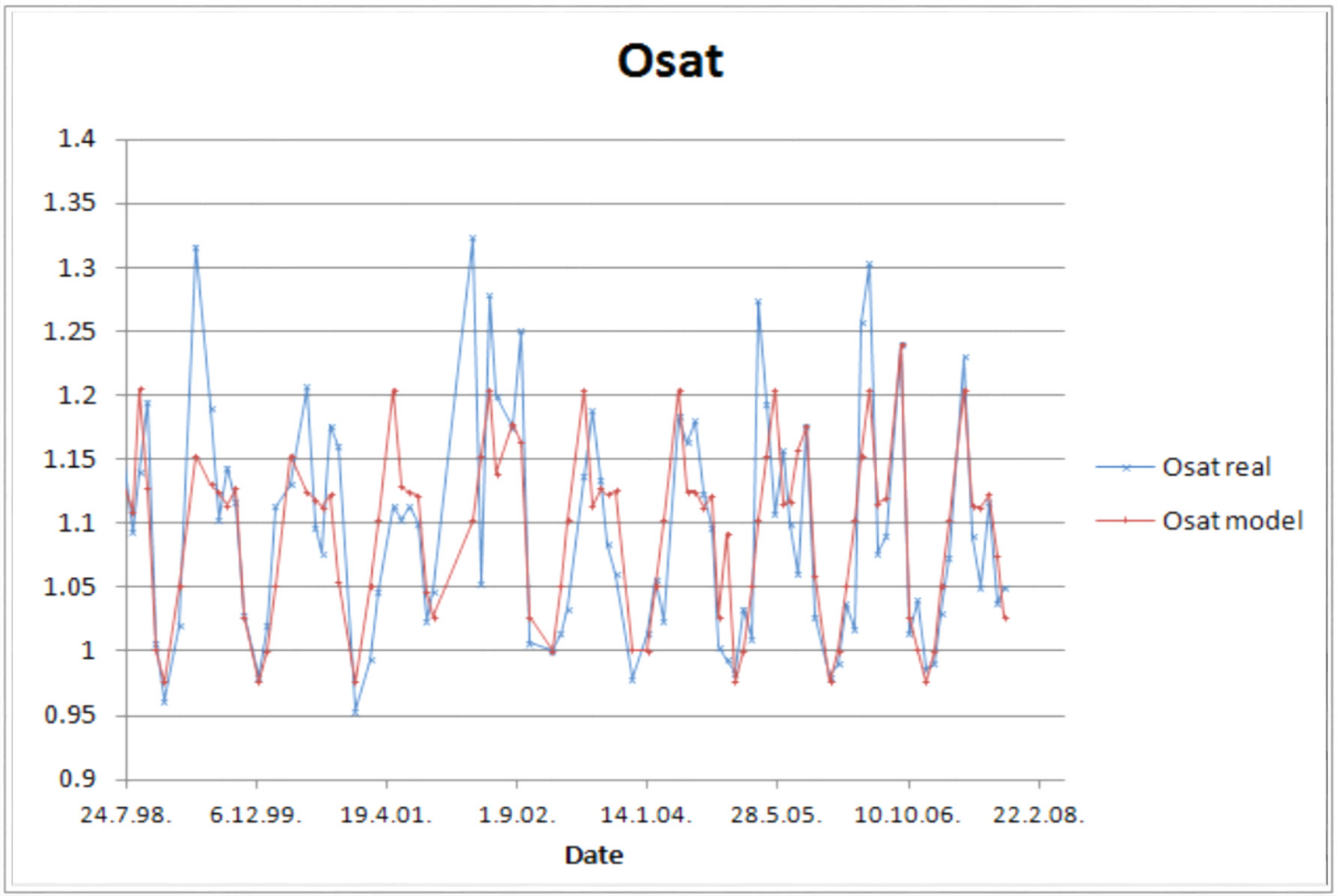
Model tree for station SJ108 (CC=0,6-0,8)

Equations:

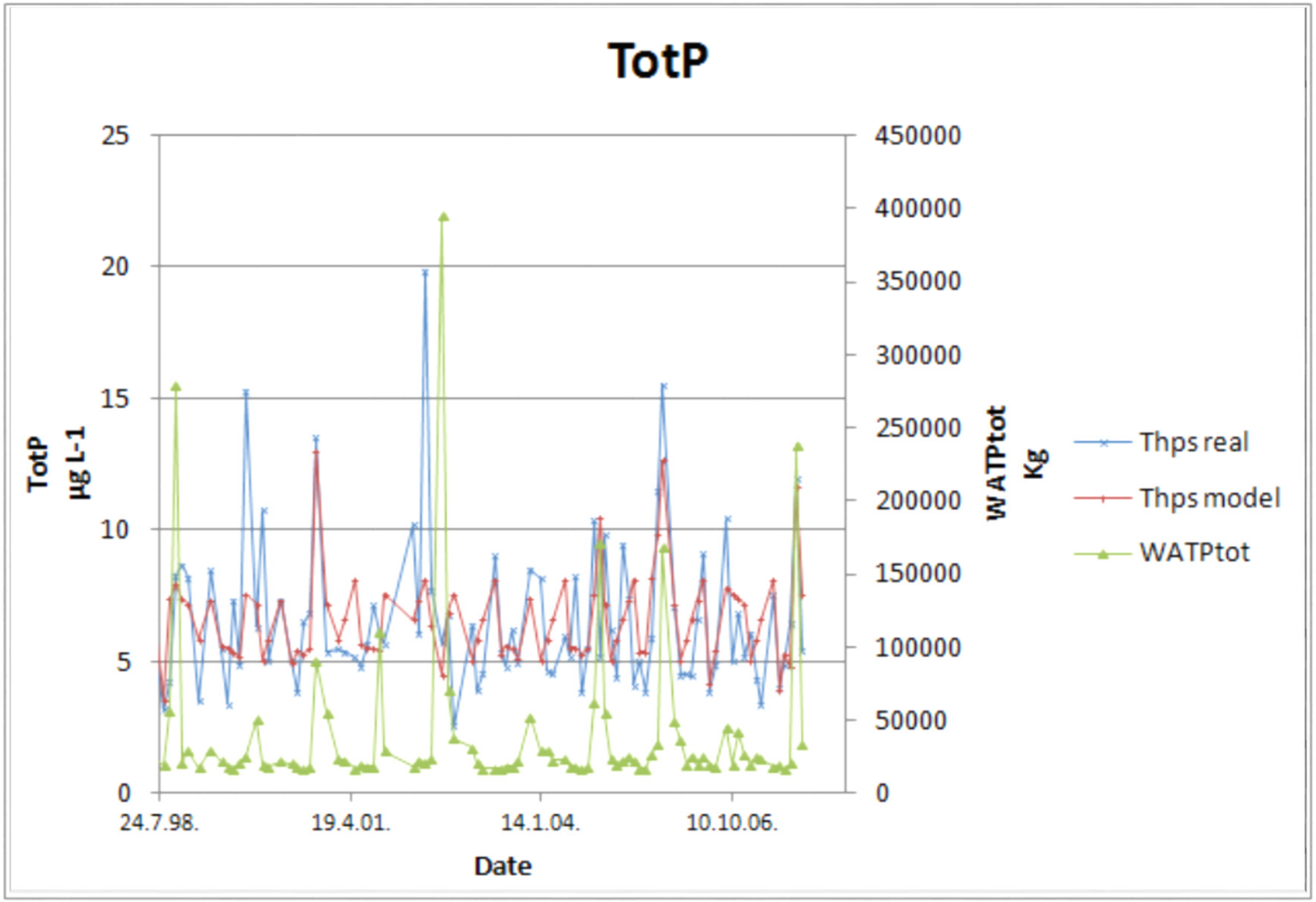
Set 1. Osat=0,948+0,051*(Month) TotP=4,309+0,760*(Month) TIN=71,937+0,318*(Month) Chl-a=0,396+0,581*(Month)	**Set 4.** Osat=1,372+-2,934E-6*(WATPtot) TotP =9,411+-3,574E-5*(WATPtot) TIN =52,410+-2,973E-4*(WATPtot) Chl-a=5,281+-1,178E-5*(WATPtot)
Set 2. Osat=1,090+9,480E-8*(WATNtot) TotP =4,836+1,973E-6*(WATNtot) TIN =-8,110+7,684E-5*(WATNtot) Chl-a=0,122+3,205E-6*(WATNtot)	**Set 5.** Osat=1,279+-0,025*(Month) TotP =9,522+-0,196*(Month) TIN =85,558+-1,301*(Month) Chl-a=3,627+-0,197*(Month)
Set 3. Osat=1,071+9,388E-8*(WATNtot) TotP =-0,0865+9,004E-6*(WATNtot) TIN =6,024+1,244E-5*(WATNtot) Chl-a=-1,143+3,376E-6*(WATNtot)	**Set 6.** Osat=0,955+4,969E-8*(WATNtot) TotP =19,894+-3,454E-6*(WATNtot) TIN =503,618+-1,244E-4*(WATNtot) Chl-a=6,744+-8,843E-7*(WATNtot)



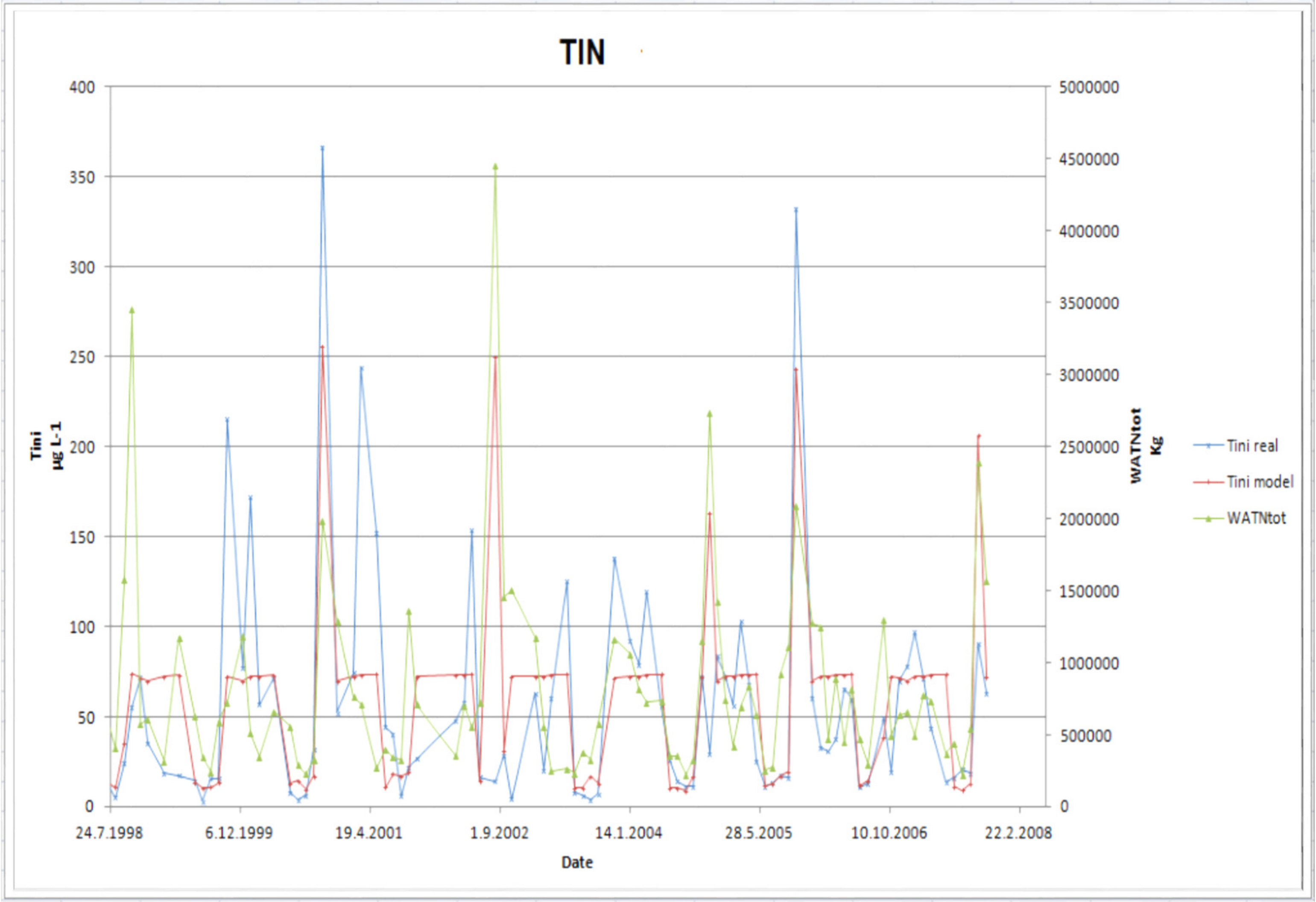
Chl-a for SJ108



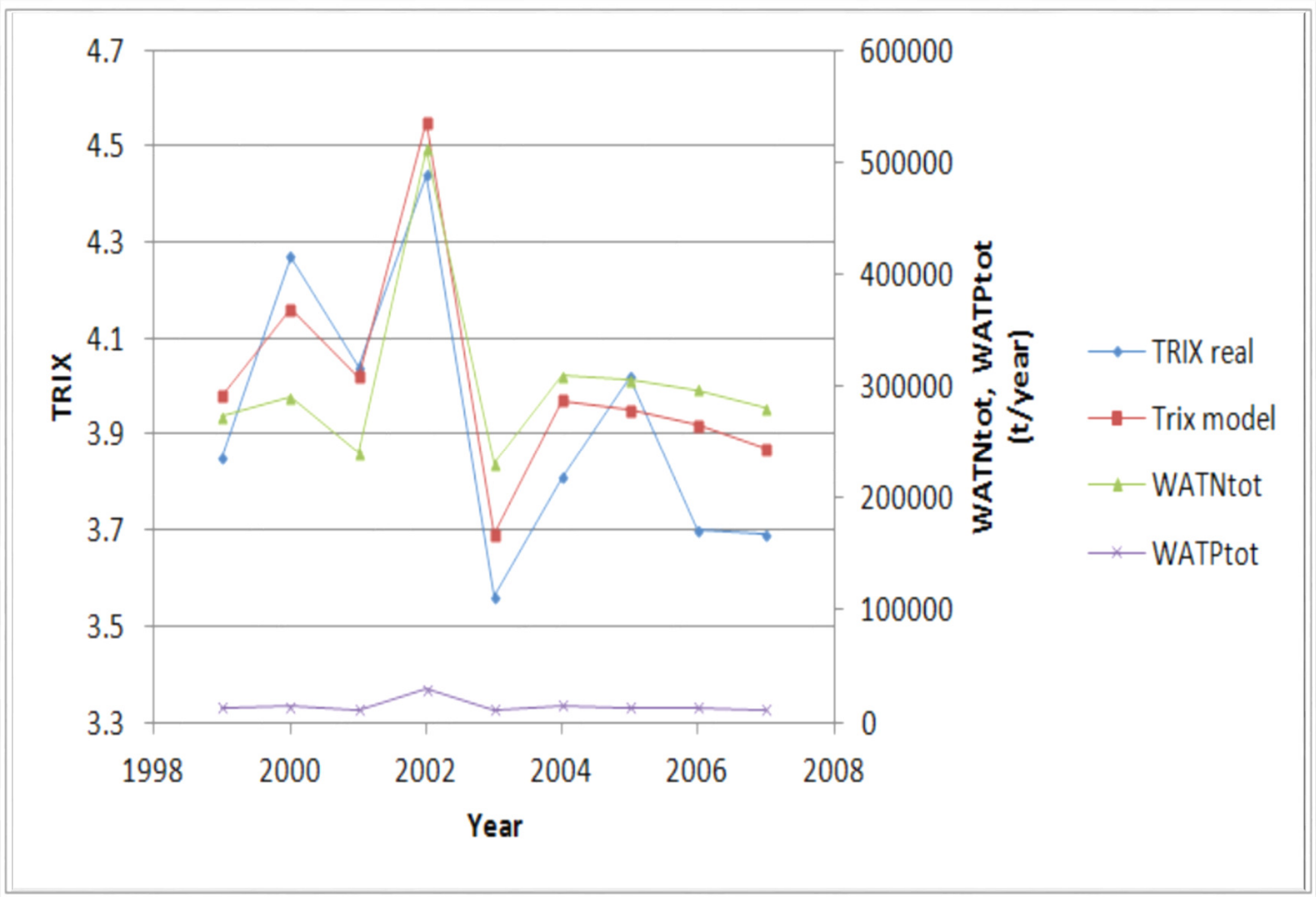
Osat for SJ108



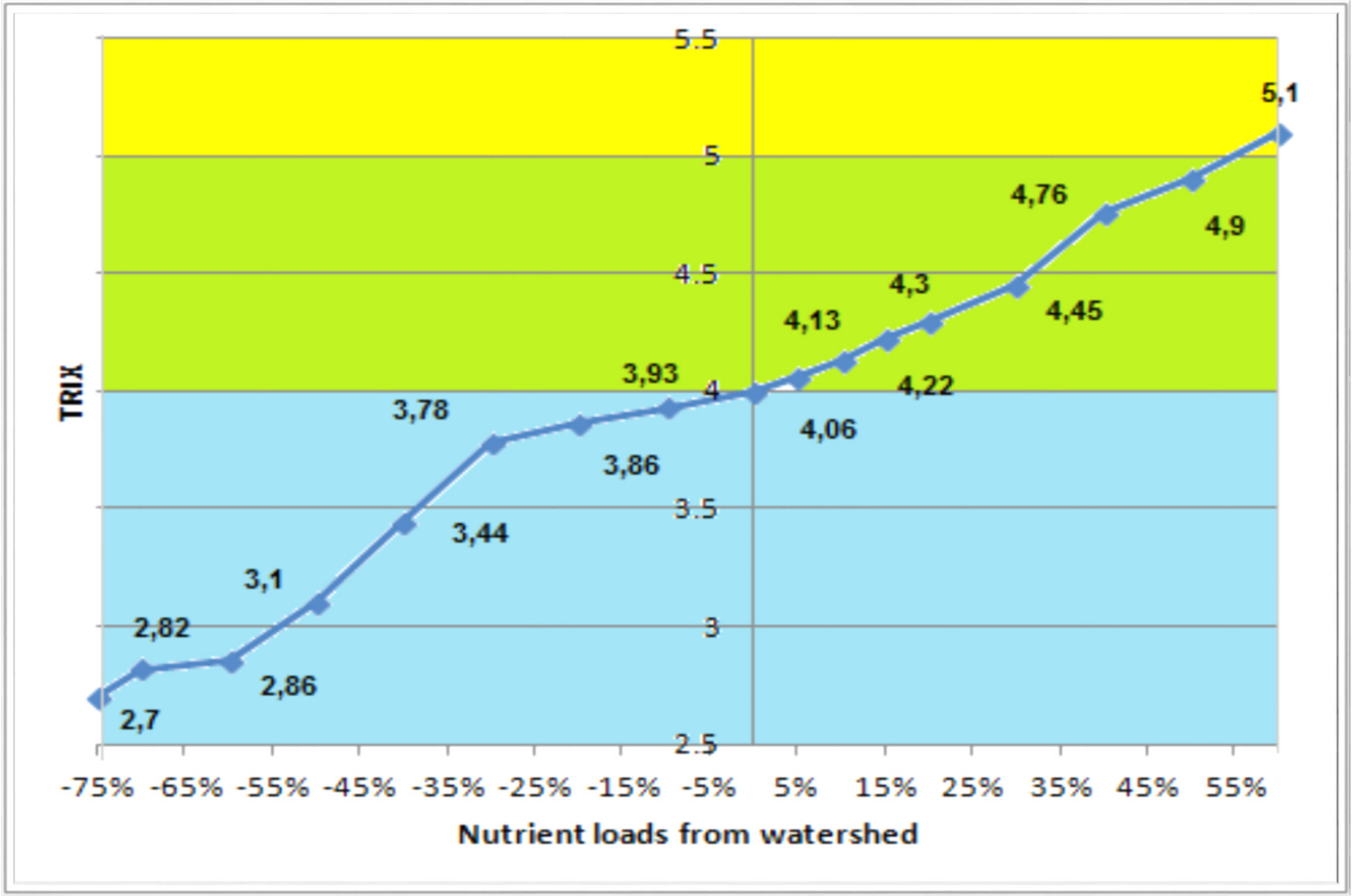
TotP for SJ108



TIN for SJ108



TRIX values and nutrients for SJ108



TRIX values, model operating baundaries for SJ108

Co-funded by the Erasmus+ Programme of the European Union

7. Results and discussion

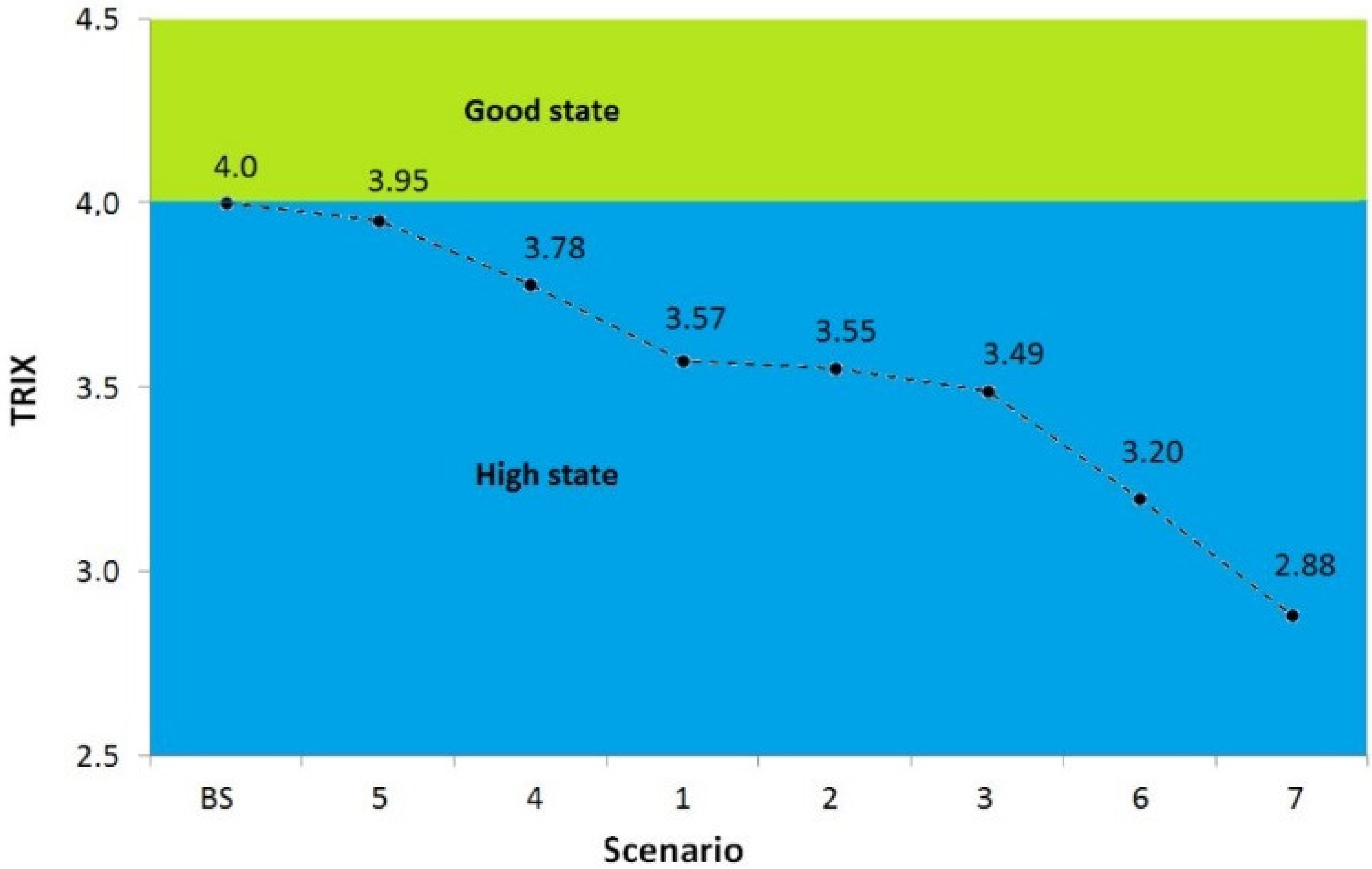
DPSI**R**

DPSI**R**

Scenarios evaluation:

Scenario	Description of the scenario
Base (Calibration) Scenario	For calibration period 1999-2007 (all inhabitants connected to secondary treatment)
Scenario 1	For period 2013-2014 (increase in population by 3.5 %; 82 % inhabitants connected to tertiary, 9 % to secondary and 9 % to primary treatment)
Scenario 2	Implementation of UWWTD (all inhabitants in agglomerations > 10,000 PE connected to tertiary treatment)
Scenario 3	All inhabitants in NA watershed connected to tertiary treatment
Scenario 4	Scenario 2 + increase in agriculture by 10 % (for both N and P)
Scenario 5	Scenario 2 + increase in agriculture by 20 % (for both N and P)
Scenario 6	Scenario 2 + reduction in agriculture by 10 % (for both N and P)
Scenario 7	Scenario 2 + reduction in agriculture by 20 % (for both N and P)

DPSIR



TRIX values for the presented scenarios

DPSI**R**

- Evaluation of the scenarios indicates that by 2014, the **UWWTD** had almost been fully implemented (**Scenario 1**), resulting in a 0.43 (i.e., 11 %) **decrease in TRIX** value as compared to period 1999-2007.
- Full implementation of the **UWWTD** would bring additional **reduction of TRIX** by 0.02 (**Scenario 2**) compared to **Scenario 1**.
- Connection of all inhabitants within NA watershed to tertiary treatment would further **decrease TRIX** value by 0.06 (**Scenario 3**).

DPSI**R**

- Scenario 2 was considered as reference for the assessment of agricultural impact scenarios. Results show that the reduction in agriculture by 10 % (**Scenario 6**) and 20 % (**Scenario 7**) would result in a **decrease of TRIX** value by 0.35 and 0.67, respectively.

- Increased agricultural loads by 10 % (**Scenario 4**) and 20 % (**Scenario 5**) would result in an increase of TRIX value by 0.23 and 0.40, respectively.

- **Agriculture** has significant impact and an increase of nutrient releases from agriculture over 20 % could push the state of the NA marine ecosystem to a lower state, in spite of the implementation of the **UWWTD**.

- Also, 20 % reduction of nutrient releases from agriculture significantly improves the ecosystem state (TRIX for Scenario 2 - 0.67).

DPSI**R**

- The latter improvement is even bigger than the one achieved by full implementation of the **UWWTD** throughout the NA watershed (**Scenario 2**), without considering nutrient reduction measures from the agriculture (TRIX for Base Scenario - 0.45).

DPSI**R**

- Given that the **UWWTD** is almost fully implemented in the NA watershed, further nutrient reduction strategies should focus on the **optimization of nutrient flows from agriculture**, which could be achieved by more rational use of fertilizers, as prescribed by the **Nitrates Directive**.

DPSI**R**

- In addition, special attention should be paid to the most **sensitive areas** within the NA watershed with high nutrient loads that are, or may become in the near future, eutrophic, especially if protective actions have not yet been taken (i.e., Po River delta and Venice lagoon).

- For these areas, wastewater treatment and agricultural recommendations should be made based on their **local conditions**.

8. Conclusions

- Tool for efficient **management of human activities** in a watershed was presented, driven by the state of the observed marine ecosystem.

- The tool is based on the hybridisation of the watershed model **AVGWLF**, the machine learning tool **MTSMOTI** and the **TRIX** equation.

- According to the scenario analysis, the implementation of the **UWWTD** has contributed significantly to the preservation and improvement of the NA marine ecosystem state. By 2014, 82 % percent of inhabitants within the NA watershed were already upgraded to tertiary treatment (Scenario 1).

- Compared with the predominantly secondary wastewater treatment period 1999-2007 (Base Scenario), TRIX value of the NA marine ecosystem had decreased by 11 % (Scenario 1).

- However, an increase in nutrients' releases from agriculture by 20 % at full implementation of the **UWWTD** (Scenario 5) would significantly influence the ecosystem state, i.e. it would increase the TRIX by 19 %.

- Thus, **agriculture** has significant impact to the NA ecosystem state, and since the **UWWTD** is close to its full implementation, attention should be put to controlling agricultural activities in order to maintain 'high' state of the marine ecosystem.

Thank you