UNIVERSITY OF ARCHITECTURE CIVIL ENGINEERING AND GEODESY

Università degli Studi di Napoli Federico II

Two case studies-in Bulgaria and in Italy- for phosphorus removal in WWTPs: Assessment of phosphorus water footprint and selection of appropriate advanced removal technologies

MSc thesis

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1. Assessment of Phosphorus Water Footprint

- **Aim of the study**
- **Definition of Phosphorus Gray Water Footprint**

2. Selection of methods for Phosphorus Gray Water Footprint calculation

Method 1: Approach recommended by "The Water Footprint Assessment Manual" (Hoekstra et. Al. 2011)

Method 2: Approach recommended by: "Water footprint assessment in wastewater treatment plants" (S. Morera et. al. 2014)

Method 3, Approach recommended by: "Gray Water Footprint: Taking Quality, Quantity, and Time Effect into Consideration" (Yifan Gu et. al. 2014)

Method 4: Approach recommended by: "Past and future trends in grey water footprints of anthropogenic nitrogen and phosphorus inputs to major world rivers" (Cheng Liua et. al. 2011)

Method 5: Approach recommended by: "Gray water Footprint Accounting" (N.A. Franke et. al. 2013)

Selection of the method

Based on the comparison of the methods, we will use Method 2 (S. Morera et.al. 2014), because it represents the best modeling regarding the case of study.

$$Q_e * C_{ep} + GWF * C_{natp} = (Q_e + GWF_p) * C_{maxp}$$

$$GWF = MAX[GWF_p] = [Q_e * (C_{ep} - C_{maxp})/(C_{maxp} - C_{natp})]$$

3. Data Collection

Sampling campaingn in Bulgaria – river Djerman

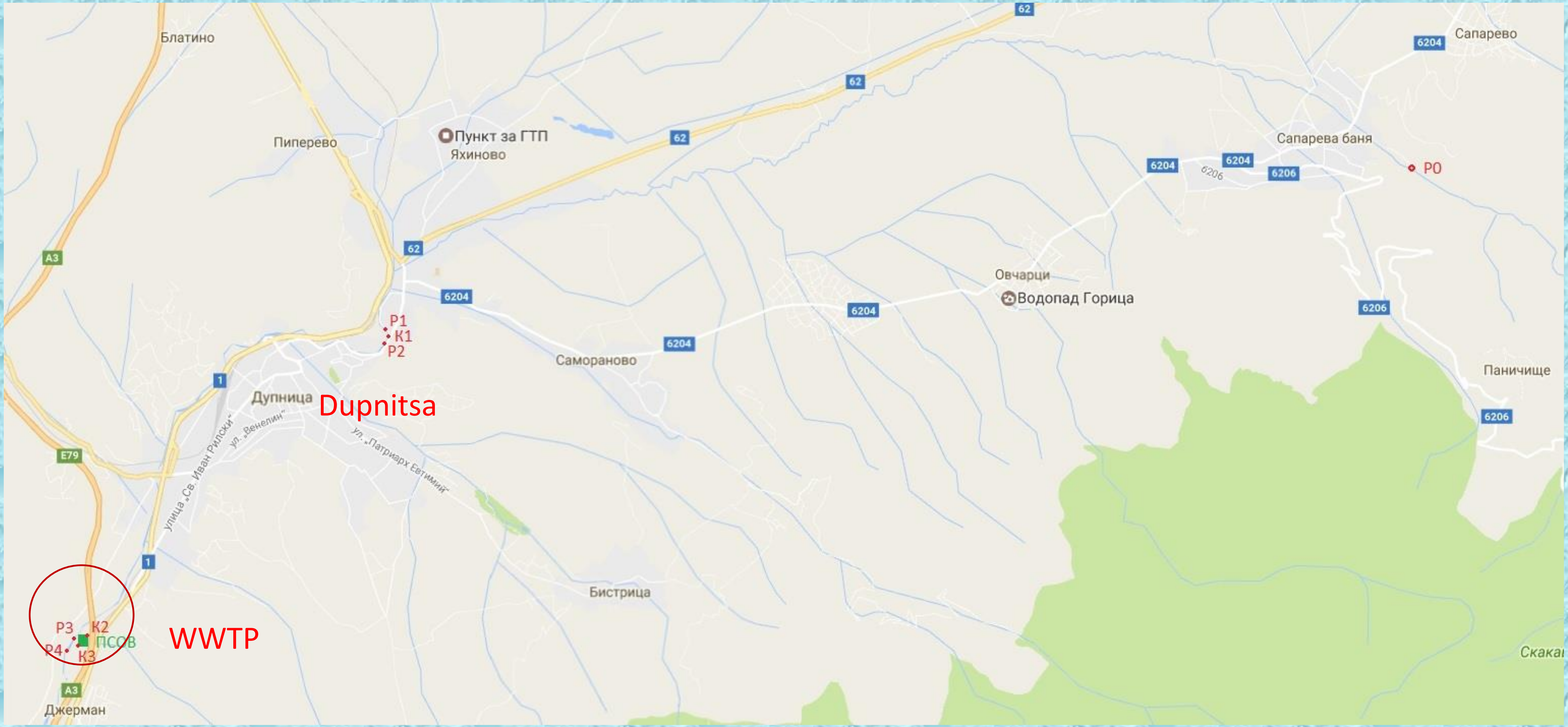
Three sampling points were chosen along the river path:

- At WWTP of Dupnitsa – 20-30m after discharge point and 50-70m before it.
- Non-treated wastewater discharge point at Dupnitsa city centre – 20m before and after discharge point.
- Before the urban settlment of Sapareva Banya, close to the spring of the river.

Sampling points chosen along the river path:

P_0	Sample taken from the Djerman River before Sapareva Banya
P_1	Sample taken from the Djerman River 20m before the waste water discharge point
K_1	Sample taken from the waste water discharge
P_2	Sample taken from the Djerman River 20m after waste water discharge point
P_3	Sample taken from the Djerman River 50-70m before the WWTP discharge
K_3	Sample taken from the output channel of the WWTP
P_4	Sample taken from the Djerman River 20-30m after the WWTP discharge

Map with the sampling points



Sampling points

For all the samples it was determined:

COD (mg/l)

BOD_5 (mg/l)

TN (mg/l)

TP (mg/l)

Chemical analysis for phosphorus determination

WWTP of Marina Grande di Sorrento

From Water Operator

- **Analisys data related to the years 2014, 2015 and 2016: the plant internal laboratory control provided inlet and outlet values of Flow, COD, BOD_5, TP**

4. Phosphorus Balance

Phosphorus balance in WWTP Dupnitsa and in WWTP of Sorrento

$$L = Q*TP$$

$$B = L_{in} – L_{out}$$

$$\eta = \frac{L_{in} - L_{out}}{L_{in}}$$

WWTP Dupnitsa

	INLET			OUTLET			BALANCE	
	Q	TP	LOAD	Q	TP	LOAD	Lin-Lout	η
	m^3/d	kg/m^3	kg/d	m^3/d	kg/m^3	kg/d	kg/d	
04/04/17	16900	0,0023	39,9	16900	0,0015	26,5	13,3	0,3
23/04/17	15500	0,0019	30,1	15500	0,0011	18,5	11,6	0,3
04/05/17	17400	0,0034	59,3	17400	0,00091	15,8	43,5	0,7
20/05/17	16500	0,0029	48,7	16500	0,00093	15,4	33,3	0,6
Average	16600	0,0026	44,5	16600	0,0011	19,1	25,4	0,57

25,4 kgTP/d

Which corresponds to 57% of Phosphorus Removal

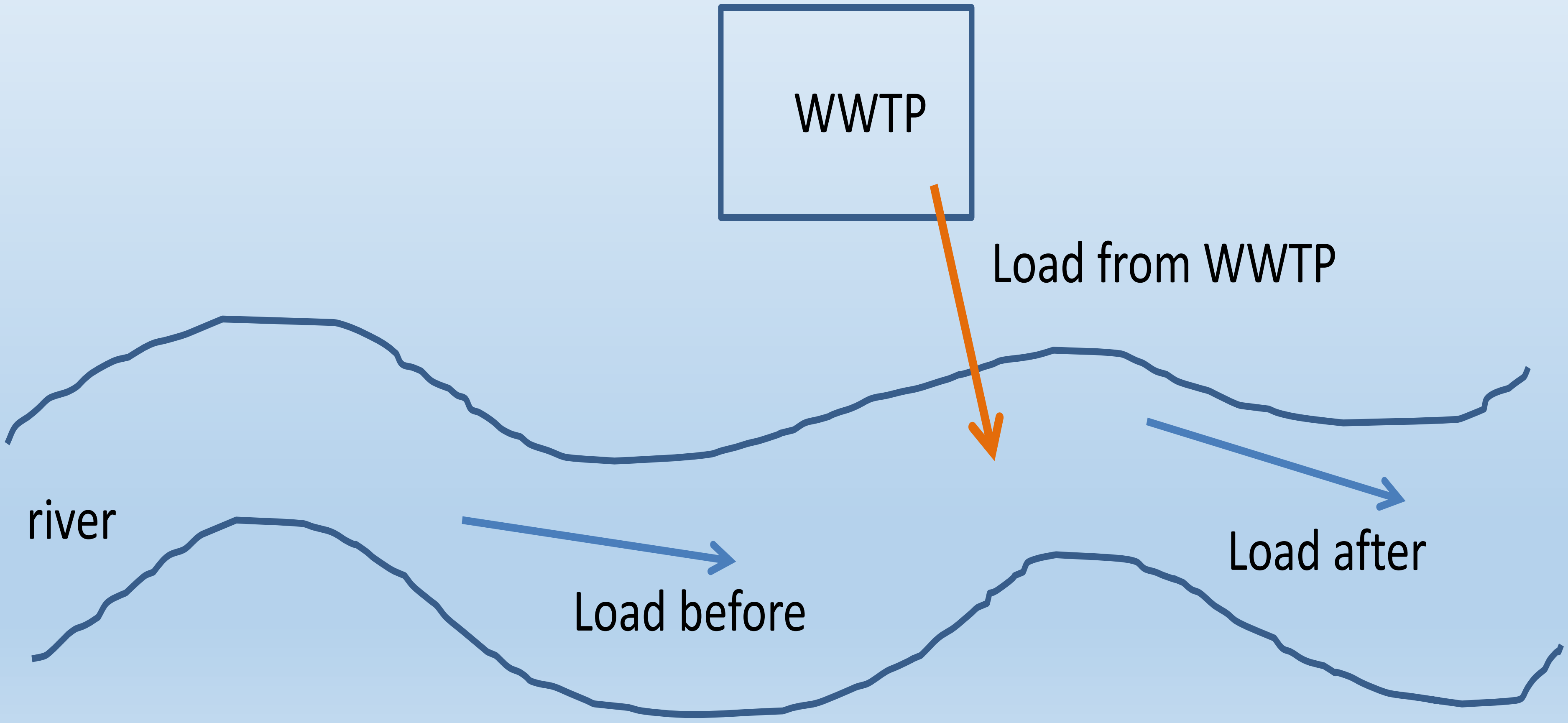
WWTP of Sorrento

	INLET			OUTLET			BALANCE	
	Q	TP	LOAD	Q	TP	LOAD	Lin-Lout	η
	m^3/d	kg/m^3	kg/d	m^3/d	kg/m^3	kg/d	kg/d	
11/02/14	5995	0,0088	52,7	5995	0,0017	10,1	42,5	0,8
09/04/14	6388	0,0054	34,4	6388	0,0009	5,7	28,7	0,8
12/05/14	4662	0,0081	37,9	4662	0,00037	1,7	36,2	0,9
19/05/14	4879	0,0018	8,7	4879	0,0012	5,8	2,9	0,3
03/06/14	4536	0,0047	21,5	4536	0,0021	9,7	11,7	0,5
11/06/14	5055	0,0038	19,5	5055	0,0016	8,8	11,4	0,5
07/07/14	6692	0,0052	34,7	6692	0,0001	0,6	34,1	0,9
07/10/14	4925	0,0033	16,2	4925	0,0003	1,4	14,7	0,9
11/11/14	4839	0,0051	24,6	4839	0,0014	7	17,6	0,7
09/12/14	3718	0,0042	15,6	3718	0,0016	5,9	9,6	0,6
12/01/15	7316	0,004	29,4	7316	0,0026	19,5	9,8	0,3
03/03/15	3735	0,0032	12,1	3735	0,0019	7,2	4,8	0,4
10/02/16	4683	0,0028	13,3	4683	0,0019	9,2	4,1	0,3
13/09/16	5480	0,0061	33,5	5480	0,0003	1,6	31,9	0,9
Average	5200	0,0047	25,3	5200	0,0013	6,7	18,6	0,73

18,6 kgTP/d

Which correspond to 73% of Phosphorus Removal

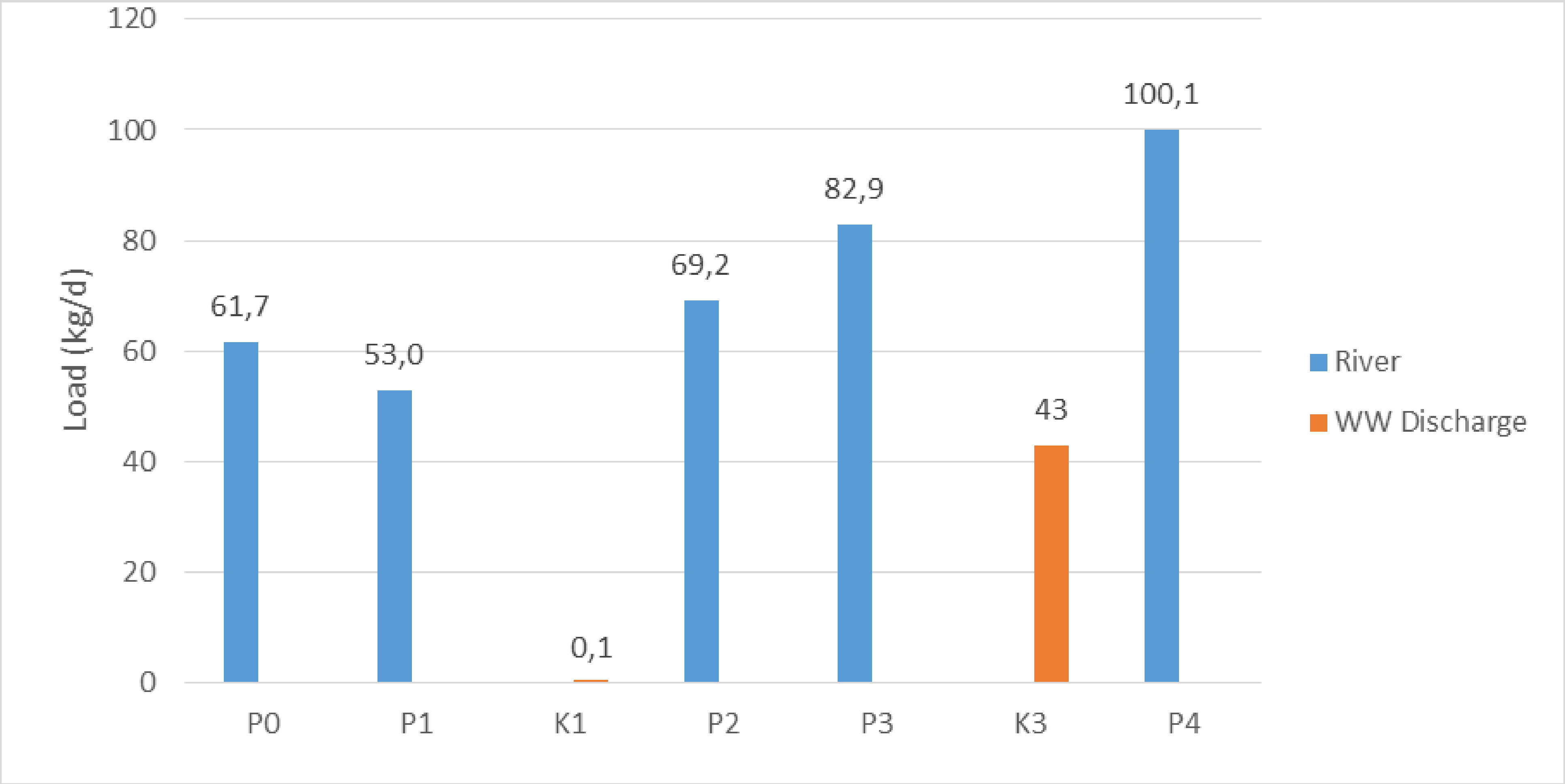
Phosphorus Balance in River Djerman



Phosphorus mass balances were performed using the following equations:

$$Q_{river}*C_{before\ (wwtp)} + Q_{wwtp}*C_{eff} = (Q_{wwtp}+Q_{river})*C_{after\ (wwtp)}$$

Phosphorus load trend in the river and wastewater discharges contribution



5. Phosphorus Gray Water Footprint Calculation

Using equation proposed by Method 2 (S. Morera et. al. 2014) :

$$GWF = Q_e * (C_{ep} - C_{maxp})/(C_{maxp} - C_{natp})$$

GWFp calculation in Dupnitsa WWTP

The GWF was calculated taking into account three possible scenarios concernig three possible solutions adopted for Dupnitsa WWTP:

- Scenario 1: Zero action - all stays as it is

- Scenario 2: Scenario 1 + adopting measures to improve the river quality (reducing the phosphorus pollution by decreasing the use of fertilizers)

- Scenario 3: assuming that the WWTP treats 100% of urban wastewater + adopting a solution for phosphorus removal in WWTP

GWFp calculation, Scenario 1
Parameters

Q_e= 16500 m^3/d C_{ep}= 0,0014 $kgTP/m^3$

Conditions/ Indicators	Dissolved oxygen mg/l	pH	N-NH4 mg/l	N-NO3 mg/l	N-NO2 mg/l	TN mg/l	P-ortho-PO4 mg/l	TP mg/l
High ecological status	9-7	-	0.1	<0.7	0.03	<0.7	<0.07	<0.15
Good ecological status	7-6	6.5-8.5	0.1-0.3	0.7-2	0.03-0.06	0.7-2.5	0.07-0.15	0.15-0.3
Moderate ecological status	6-5	-	0.3-0.6	2-4	0.06-0.09	2.5-4	0.15-0.3	0.3-0.6

C_{maxp}= 0,0003 $kgTP/m^3$ C_{natp}= 0,00017 $kgTP/m^3$

Calculation

YEAR	DATE	Q(m^3/d)	Q(l/s)	TP(kg/m^3)	Cep(P4)mg/l	Cep(P1) kg/m^3	Runoff(m^3/s)	Runoff(l/s)	Q(river)m^3/d)	River Flow (m^3/d)
2017	22/03/17	16300	189	0,0027	0,7	0,00027	2,5	2520	217700	362300
	04/04/17	16900	196	0,0015	0,7	0,00011	1,7	1790	154700	
	23/04/17	15500	180	0,0011	0,33	0,00021	2,7	2790	241000	
	04/05/17	17400	201	0,00091	0,14	0,00026	5,6	5667	489600	
	20/05/17	16600	192	0,00093	0,06	0,000011	8,2	8204	708800	
Qe(m^3/d)	**Cep(kg/m^3)**	**Cmax(river) kg/m^3**	**Cnat (kg/m^3)**							
16500	0,0014	0,0003	0,00017							

$GWFp_1 = 155.620\ m^3/d$

GWFp calculation, Scenario 2
Parameters

Q_e= 16500 m^3/d C_{ep}= 0,0014 $kgTP/m^3$

Conditions/ Indicators	Dissolved oxygen mg/l	pH	N-NH4 mg/l	N-NO3 mg/l	N-NO2 mg/l	TN mg/l	P-ortho-PO4 mg/l	TP mg/l
High ecological status	9-7	-	0.1	<0.7	0.03	<0.7	<0.07	<0.15
Good ecological status	7-6	6.5-8.5	0.1-0.3	0.7-2	0.03-0.06	0.7-2.5	0.07-0.15	0.15-0.3
Moderate ecological status	6-5	-	0.3-0.6	2-4	0.06-0.09	2.5-4	0.15-0.3	0.3-0.6

C_{maxp}= 0,00015 $kgTP/m^3$ C_{natp}= 0,00012 $kgTP/m^3$

Calculation

YEAR	DATE	Q(m^3/d)	Q(l/s)	TP(kg/m^3)	Cep(P4)mg/l	Cep(P1) kg/m^3	Runoff(m^3/s)	Runoff(l/s)	Q(river)m^3/d)	River Flow (m^3/d)
2017	22/03/17	16300	189	0,0027	0,7	0,00027	2,5	2520	217700	362300
	04/04/17	16900	196	0,0015	0,7	0,00011	1,7	1790	154700	
	23/04/17	15500	180	0,0011	0,33	0,00021	2,7	2790	241000	
	04/05/17	17400	201	0,00091	0,14	0,00026	5,6	5667	489600	
	20/05/17	16600	192	0,00093	0,06	0,000011	8,2	8204	708800	
Qe(m^3/d)	**Cep(kg/m^3)**	**Cmax(river) kg/m^3**	**Cnat (kg/m^3)**							
16500	0,0014	0,00015	0,00012							

$GWFp_2$ = 912.690 m^3/d

GWFp calculation, Scenario 3
Parameters

Q_e= 21500 m^3/d C_{ep}= 0,00044 $kgTP/m^3$

Conditions/ Indicators	Dissolved oxygen mg/l	pH	N-NH4 mg/l	N-NO3 mg/l	N-NO2 mg/l	TN mg/l	P-ortho-PO4 mg/l	TP mg/l
High ecological status	9-7	-	0.1	<0.7	0.03	<0.7	<0.07	<0.15
Good ecological status	7-6	6.5-8.5	0.1-0.3	0.7-2	0.03-0.06	0.7-2.5	0.07-0.15	0.15-0.3
Moderate ecological status	6-5	-	0.3-0.6	2-4	0.06-0.09	2.5-4	0.15-0.3	0.3-0.6

C_{maxp}= 0,00015 $kgTP/m^3$ C_{natp}= 0,00012 $kgTP/m^3$

Calculation

YEAR	DATE	Q(m^3/d)	Q(l/s)	TP(kg/m^3)	Cep(P4)mg/l	Cep(P1) kg/m^3	Runoff(m^3/s)	Runoff(l/s)	Q(river)m^3/d)	River Flow (m^3/d)
2017	22/03/17	16300	189	0,0027	0,7	0,00027	2,5	2520	217700	362300
	04/04/17	16900	196	0,0015	0,7	0,00011	1,7	1790	154700	
	23/04/17	15500	180	0,0011	0,33	0,00021	2,7	2790	241000	
	04/05/17	17400	201	0,00091	0,14	0,00026	5,6	5667	489600	
	20/05/17	16600	192	0,00093	0,06	0,000011	8,2	8204	708800	
Qe(m^3/d)	**Cep(kg/m^3)**	**Cmax(river) kg/m^3**	**Cnat (kg/m^3)**							
21500	0,00044	0,00015	0,00012							

$$GWFp_3 = 261.797\ m^3/d$$

GWFp calculation in Sorrento WWTP

Parameters

Q_e= 5000 m^3/d C_{ep}= 0,0014 kgTP/m^3

Nutrients	Maximum allowable concentration (µg/l)	Referenced guideline (EU, CCME, US-EPA)
Nitrate (NO_3)	13000	CCME
Nitrite (NO_2)	60	CCME
Phosphorus (total)	Ultra-oligotrophic 4 Oligotrophic 10 Mesotrophic 20 Meso-eutrophic 35 Eutrophic 100	CCME

C_{maxp}= 0,00001 kgTP/m^3 C_{natp}= neglectable (Italian regulation)

Calculation

YEAR	DATE	Q(m^3/d)	Q(m^3/month)	TP(kg/m^3)
2014	11/02/14	5995	179850	0,0017
	09/04/14	6388	191640	0,0009
	12/05/14	4662	139860	0,00037
	19/05/14	4879	146370	0,0012
	03/06/14	4536	136080	0,0021
	11/06/14	5055	151650	0,0016
	07/07/14	6692	200760	0,0001
	07/10/14	4925	147750	0,0003
	11/11/14	4839	145170	0,0014
	09/12/14	3718	111540	0,0016
2015	12/01/15	7316	219480	0,0026
	03/03/15	3735	112050	0,0019
2016	10/02/16	4683	140490	0,0019
	20/04/16	2839	85170	0,0027
	13/09/16	5480	164400	0,0003

$GWFp = 702.953\ m^3/d$

6. Suggested technology for Phosphorus Removal in WWTPs

Suggested technology for phosphorus removal in WWTPs of Dupnitsa

Open Raceway Pond

- Increase Phosphorus Removal capacity of the WWTP till 81%
- Suitable for agricultural area
- Economically and energetically sustainable.

Suggested technology for phosphorus removal in WWTP of Marina Grande di Sorrento

OMEGA System

- Increase Phosphorus Removal capacity of the WWTP
- Suitable for Coastal Cities
- Economically and energetically sustainable.

7. Conclusions

Data collection and analyses to calculate the GWF in two different WWTPs

- **The data scarcity forced the team to do own sampling and chemical analyses**
- **The data collected show that river Djerman in Bulgaria is in “good ecological status”**

The calculated GWFs for these three scenarios shows that:

- **Scenario 1 has the best GWF, but it is not the most favourable one**
- **Scenario 2 is the worst one, it requires more water to dilute the pollution than it is available in the river.**
- **Scenario 3 is the best one, where all wastewater will be treated, measures to remove phosphorus will be taken and the river ecological status will be enhanced to “High”.**
- **The GWF for Sorrento WWTP has higher value but there is sufficient water to dilute the pollution, coming with the effluent.**

Thanks for your attention