INCOME Water Care

Improved Management of Contaminated Aquifers by Integration of Source Tracking, Monitoring Tools and Decision Strategies

A.3.3. Model of environmental pressures and impacts (Final report)

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1. Introduction

This action is strongly related to the actions A.2.1., A.2.2. and A.3.2. The aim was to develop reliable pressures-impacts numerical model. This model is developed using advanced numerical modeling tools including all relevant hydrodynamic parameters in porous media. Calibrated model is the basic tool for the cost-effectiveness analysis.

Emissions and surpluses were estimated and evaluated by existing data and knowledge for significant chemical parameters. These values were prepared as the input data layers to the numerical model to model and predict spatial distribution of expected (calculated) impacts (concentrations) of relevant parameter in groundwater. Numerical modeling will be further on used for the projection of impacts till 2027 and 2050 to develop long term vision of the objectives, measures and benefits. Long-term projection will also enable to define interim targets of water management. Interim targets would be set up as a basis for checking progress in order to ensure that action is not delayed, and will facilitate public information, participation and planning at lower administrative levels also after the project end.

The activities were performed by Geological survey of Slovenia within the project INCOME (LIFE07 ENV/SLO/000725). The main objective of the project is long-term effective management of aquifers and preservation of the quality of these water resources for future generations. The project is co-financed by European Commission, Municipality of Ljubljana and Ministry of the Environment and Spatial Planning of Republic of Slovenia.

2. Pressures and impacts model

2.1. Pressures and impacts assessment from nitrogen sources

The first pressures and impacts model was developed in the frame of the Water Framework Directive in 2005 using the Corine land cover data and improved in 2006 using the more detailed data on land use by the Ministry of agriculture. Model was based on 100 x 100 m grid GIS modeling for all the 165 aquifer systems of Slovenia. There are five aquifer systems that are also a part of the INCOME area of Ljubljansko polje and Barje.

Table 1. Pressures and impacts assessment in the frame of WFD implementation (Nacionalna baza hidrogeoloških podatkov za opredelitev teles podzemne vode Republike Slovenije, GeoZS, 2005; nitrati_korelacija2_mkgp.xls 19.5.2006)

ID Aquifer system	11712	11713	11714	11715	11716

Pressure (mean value)	Ljubljansko polje	Ljubljansko Barje	Borovniški vršaj	Iški vršaj	Želimeljski vršaj
N from agricultural land (kg/ha)	31,30	40,89	50,77	59,84	44,08
N from urbanization (kg/ha)	10,87	3,75	3,09	1,69	0,78
Share of N from urbanization (%)	25,66	8,36	5,62	2,74	1,73
N (kg/ha)	42,37	44,80	55,05	61,66	44,86
N from traffic (kg/ha)	0,06	0,05	0,02	0,03	0,01
N from waste deposits (kg/ha)	0,00	0,12	0,00	0,00	0,00
N from IPPC areas (kg/ha)	0,13	0,00	1,11	0,00	0,00
N (kg/ha)	42,37	44,80	55,05	61,66	44,86
Estimated conc. of nitrate (mg/l)	28,26	6,88	26,81	31,16	25,50
Monitoring system	13,70	0,00	0,00	0,00	0,00
Estimated concentration of nitrate (mg/l) – correlation to monitoring	19,27	9,71	18,62	20,57	18,04

The above mentioned GIS model estimated that concentration of nitrate in the groundwater of Ljubljansko polje is most probably in the range of 19 to 28 mg/l regarding the calculated pressures from nitrogen emissions. Slightly higher concentrations were assessed for nitrate concentration in groundwater of Iški vršaj. The values of surpluses were obtained from the data layer prepared by agriculture experts using the nitrogen balance assessment at the soil level (IZVRS, 2006).

It was estimated that approximately 26 % of the nitrogen content in groundwater originates from dispersed source of urbanization and almost 75 % from agriculture in Ljubljansko polje. On the areas of other aquifer systems pressured by significantly lower urbanization the relative portion from agriculture is much higher.

2.2. Nitrogen from agriculture

After 2006 no advanced detailed nitrogen surplus data layer was produced for the individual aquifer systems. Thus the same input grid data layer for the nitrogen surplus from agricultural use was used. Grid was prepared from raw data of expected surpluses from regional nitrogen balance assessment "at river basin level" (IZVRS, 2006). The input grid data layer for the nitrogen surplus from agricultural use is the input data layer to numerical model.

For an assessment of importance of different pollution sources in overall contamination various agricultural cultures in the first water protection zones for Ljubljansko polje and Barje were mapped. Described data were also prepared in GIS database.

An average land application of nitrogen was calculated on the base of values defined in Decree concerning the protection of waters against pollution caused by nitrates from agricultural sources (OJ RS, No. 113/2009). The foreseeable nitrogen requirements of the crops in kilograms per hectare were calculated and classified in four groups. Later two scenarios were prepared. The first one for land use with high nitrogen uptake crops like corn, and the second one for land use with low nitrogen uptake crops like soya. The results are presented in table below.

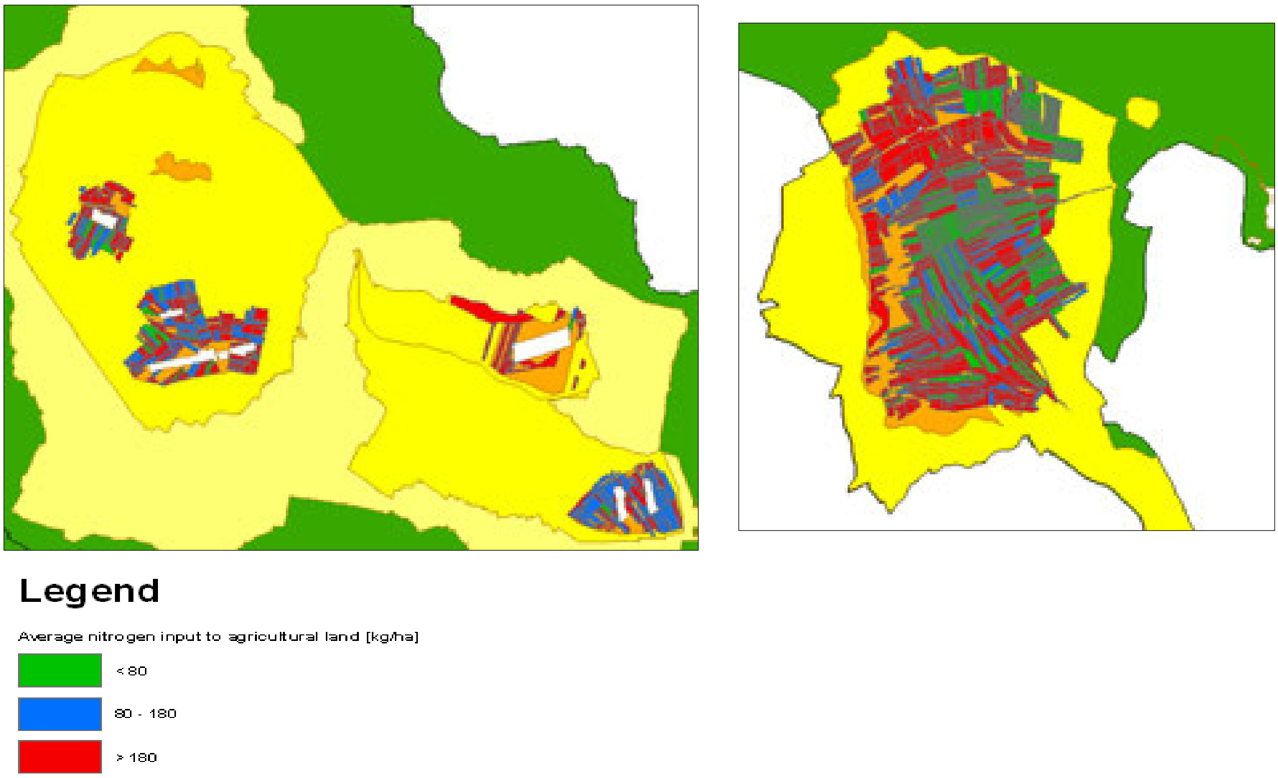


Table 2. Scenarios - nitrogen requirements of the crops.

Aquifer	State in 2011 [kg N/a]	Scenario 1 – only corn	Scenario 2 – only soya
Ljubljansko polje	46.976,95 (100 %)	65.269,94 (139 %)	19.339,24 (41 %)
Ljubljansko barje	66.911,50 (100 %)	94.769,03 (142 %)	28.079,71 (42 %)

More detailed model of pressures was in the frame of this action prepared for the sewage system.

2.3. Pressures from sewage system

2.3.1. Losses from sewage system

Within the context of losses from sewage system in the study area we analyzed the quality of channels and pipes and the year of construction to reveal the spatial distribution of the expected losses from the sewage system.

The losses from sewage systems were estimated based on literature data and empirical equations that based on laboratory experiments, field measurements by tracer tests or pressure tests, video inspection of open joints, cracks and damages and water balance assessment. The statistical and spatial distribution analyze originate from damages inspected during the regular video mains inspections on the selected areas (Table 3) where monitoring data enables us to estimate the real impacts and pressures from the sewage leakage on groundwater.

Table 3. Representativeness of the sample.

Parameter	Sample	Income area
Sewage length [km]	14,82	875,38
Material [%] - Concrete and similar - Other	 94,3 5,7	 75,0 25,0
Age of construction [%] < 1974 1975 – 1995 1996 – 2008	 59,72 39,69 0,59	 36,85 44,06 19,9

Total average exfiltration for individual discontinuity was calculated using following equation (adapted after Wolf, L. & Hötzl, H., 2004. Up scaling of laboratory results on sewer leakage and associated uncertainty):

$$q_{razpoke} = k_{sušni} * A_{razpoke} * I_{sušni} * \frac{146}{365} + k_{dežni} * A_{razpoke} * I_{dežni} * \frac{218}{365} + k_{naliv} * A_{razpoke} * I_{naliv} * \frac{1}{365} \quad (1)$$

$q_{razpoke}$ – Total average exfiltration for individual discontinuity [m^3/s];

$k_{sušni/dežni/naliv}$ – Permeability coefficient of biofilm in / dry weather / precipitation / extreme storm weather / flow conditions [m/s];

$A_{razpoke}$ – Surface of individual damage [m^2];

$I_{sušni/dežni/naliv}$ - Hydraulic gradient in / dry weather – 146 days / precipitation 218 days / extreme storm weather – 1 day / flow conditions;

b – Thickness of biofilm [m].

For calibration we used water balance method (based on data of runoff, drinking-water consumption, and sewage flow) within selected dry weather periods, preferentially in winter when the household water consumption is almost all returned to the sewage. The method was developed based upon analysis of data availability and regarding approaches from existing literature.

$$Q_{eks} = -Q_{d,CN} + Q_{d,P} + Q_{inf} - Q_1 + Q_2 \qquad (2)$$

Q_{eks}... Exfiltration from sewage system;

$Q_{d,CN}$... Daily wastewater discharge on dry winter period to Central WWTP;

$Q_{d,P}$... Daily distributed water from waterworks;

$Q_{in,TV}$... Infiltration to the sewage system;

Q_1... Daily distributed water from waterworks not returned to the sewage system (discharged to the environment – industrial use);

Q_2... Daily discharged water to the sewage system abstracted from other sources (industrial use, excavations dewatering).

Based on the water balance determinations the exfiltration from sewage was estimated on 194 l/s or 0.25 l/s/km. The results were comparable with leakage rates calculated from the other methodologies and unit rates derived from different literature.

Calibrated exfiltration rates were calculated from particular damages, known from existing CCTV records and with scaling-up on whole study area (Figure 1). The extrapolation was made based on representative sample - pipe types (concrete, PVC) and year of construction (older than 1974, between 1975 – 1995 and late). In the table below are presented the final results.

Table 4. Estimated exfiltration from sewage system.

	Exfiltration [l/s/km]	Length of pipes [km]	Exfiltration [l/d]	Exfiltration [l/s]
PVC pipes				
-1974	0.11	20.897	193.238,37	2,24
1975-1995	0.07	48.046	296.196,83	3,43
1996-2008	0.04	150.711	464.550,55	5,38
Concrete pipes				
-1974	0.34	301.709	8.952.212,14	103,61
1975-1995	0.23	337.619	6.725.487,70	77,84
1996-2008	0.12	16.401	163.358,55	1,89
Sum		875.385	**16.795.044**	**194**

The results were prepared also in GIS environment to trace the sewer water flow paths from any selected point in the area and to prepare the basis for intervention measures for the cases of accidental pollution spills and for input to numerical model, modelling pressures and impacts.

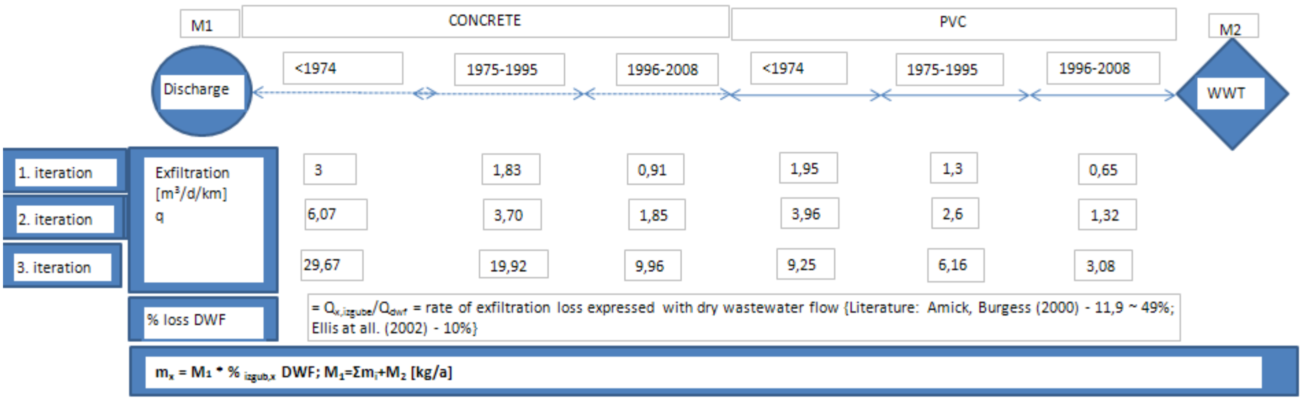


Figure 1. Model for scaling up exfiltration from sewage system.

A GIS based map data layer was prepared - a spatial distribution of expected (calculated) impacts (concentrations) of relevant parameters in groundwater in scale 1:25.000 (five maps, each for different relevant parameter).

Table 5.

	Pressure	Impact calculation	Maps
1	TCL	TCL	
2	AL		
3	NH3_4		
4	AOX		
5	Cu		
6	C6H6		
7	B		
8	Zn		
9	Cr_CE	Cr_CE	Cr_CE
10	Cr_6	Cr_6	Cr_6
11	DKM		
12	KLORI	KLORI	KLORI
13	Co		
14	Sn		

	Pressure	Impact calculation	Maps
15	KSIL		
16	Ni		
17	NNO3	NNO3	NNO3
18	NNO2	NNO2	
19	Ag		
20	SO4		
21	Pb		
22	TOC		
23	Trikl		
24	Hg		
25	As		
26	Ba		
27	N_CE	N_CE	N_CE

We also performed conceptualization of overlaying strata in order to assess impacts from the sewage system losses. Overlaying strata were categorized on following five categories: 1) medium and low permeable strata overlaying on rock basement, 2) medium and low permeable strata less than 7 m thick overlaying alluvial aquifer, 3) medium and low permeable strata more than 7 m thick overlaying alluvial aquifer, 4) intercalated continuous low to medium permeable clayey strata within highly permeable unsaturated zone (with possibility of perched groundwater level), 5) highly permeable unsaturated zone without significant continuous intercalated clayey layers.

The representativeness of monitoring points regarding the expected sources of pollution from known industrial waste water losses from sewage system was tested.

Figure 2 shows the situation of sewage system in Ljubljansko polje and Ljubljansko barje.

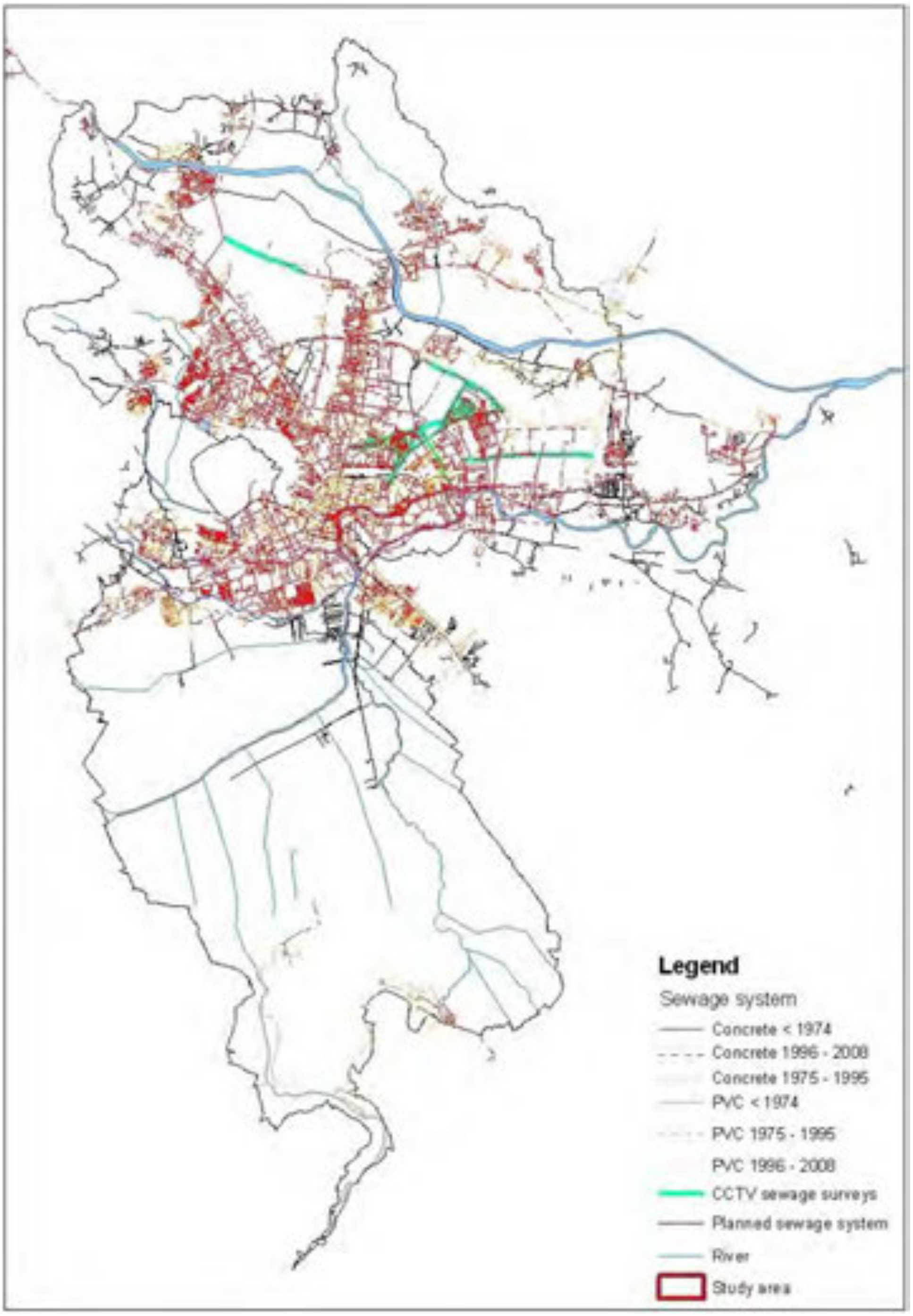


Figure 2. Sewage system in Ljubljansko polje and Ljubljansko barje.

2.3.2. Industry

During the first phase the point source discharges of industrial waste water (GIAM) are being studied and the average quantities of significant pollutants on the basis of data from the five years period (2004 - 2008) was calculated.

A map for tracing the sewer water flow paths from selected industrial discharges, all the way to the waste water treatment plant or to the surface water recipient is shown on figure Figure 3.

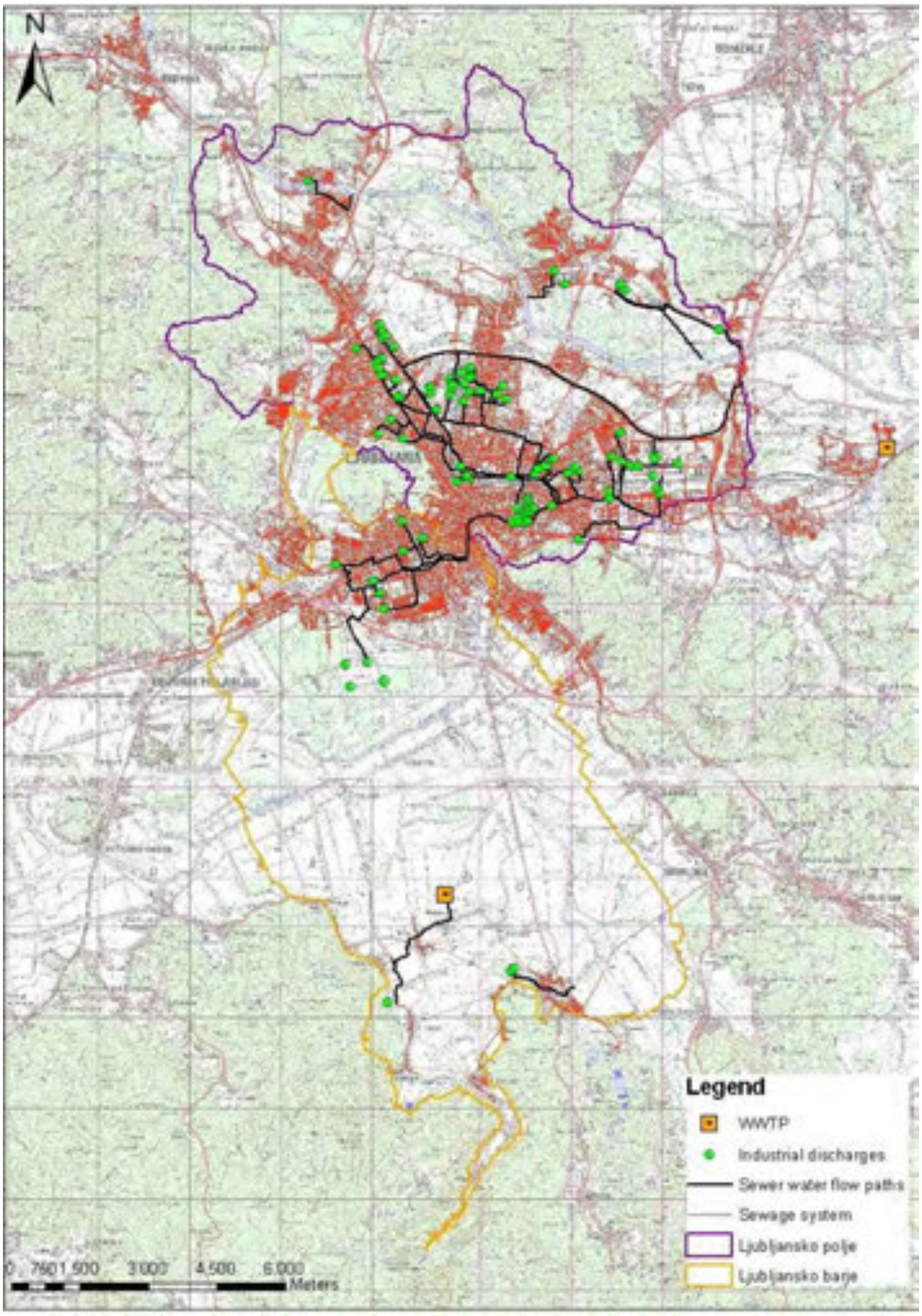


Figure 3. Sewer water flow paths from selected industrial discharges.

We improved GIS data layer of wastewater discharges into sewage system. Each of 63 discharges from 108 installations is traced separately from the input in sewage system to the output. Output is either:

1 - One of four treatment plants ČN Črnuče (1 discharge), ČN Brod (1), ČN Ig (2) or CČN Ljubljana (46),

2 – Direct discharge to the surface streams Bezlanov graben (2), Curnovec and Ljubljanica (2),

3 – Sewage system without treatment plant (6) and

4 – Combined (3) with more than one possible output.

This "industrial waste water sewage paths layer" is set for data layer to numerical model and is one of the most important data layer in the DSS system of eventual pollution sources identification.

Further we calculated what would be the concentration of individual pollutant lost from sewage system in the groundwater. We took into consideration the rate of exfiltration 194 l/s and yearly renewable amount of groundwater 500 mm/y.

In the table below are presented the calculated concentrations compared to monitoring results in observation wells. The first preliminary assessment showed quite good match prior the numerical modeling.

Table 6. Calculated concentrations.

Calculated concentration [mg/l]:	Exfiltration	Monitoring		
		Average	Min	Max
Total nitrogen	9.75	3.50	0.77	8.37
Total phosphorus	1.52	0.018	0.008	0.11
Chloride	29.32	13.45	0.30	64.65
Sulphate	6.79	14.01	0.60	37.25
Cu	0.0036	0.0010	<0.001	0.0020
Zn	0.0187	0.0154	<0.01	0.0760
AOX	0.0217	0.0027	<0.001	0.0086
Cr	0.0011			
Cr6+		0.0049	0.001	0.0430

2.3.3. A share of individual pollutants from different sources

A share of individual pollutants from different sources from urbanization compare to the total load at waste water treatment plant was quantified.

For each group of emission sources was estimated (households and other polluters) or calculated (industry and traffic) from existing emission monitoring data the loads that contribute to groundwater pollution.

Table 7. Share of individual pollutants from different sources.

Parameter	Industry	Other polluters	Households	Traffic	Flow at WWTP
Total nitrogen	4%	79%	17%	0%	100%
Total phosphorus	10%	54%	37%	0%	100%
Chloride	5%	82%	11%	1%	100%
Sulphate	7%	60%	33%	0%	100%
As	4%	96%	0%	0%	100%
Cu	11%	86%	0%	3%	100%
TOC	17%	83%	0%	0%	100%
Zn	11%	83%	0%	6%	100%
Fluorides	1%	99%	0%	0%	100%
AOX	16%	84%	0%	0%	100%
Cd	0%	51%	0%	48%	100%
Cr	31%	67%	0%	2%	100%
Ni	11%	65%	0%	23%	100%
Pb	22%	45%	0%	34%	100%
Hg	1%	99%	0%	0%	100%
Ammonium nitrogen	11%	89%	0%	0%	100%
BTX	2%	98%	0%	0%	100%
LKCH	19%	81%	0%	0%	100%

From this analyze we concluded that the largest part of emissions is contributed by others polluters, that are not liable to implement the monitoring.

Very important portion of metals in groundwater originates from traffic while the dominating source of chromium is industry.

3. Pressures and impacts analysis – results

3.1. Mass balance assessment and nitrate concentration of groundwater body

- Mass of nitrogen surplus from agriculture: M_K
- Mass of nitrogen losses from households:
  - nitrogen losses from sewage system (194 l/s) (line source pressures along sewage pipes): $M_{GO} = M_G$
  - nitrogen losses from residential buildings (point sources 1,17 kgN/a/PU): $M_{GP} = M_G$
- Mass of yearly renewed groundwater body: Q_{ren} = 3 m^3/s (= 94,608,000 m^3/a)
- Mass of groundwater body within aquifer (m_{ef} = 15 %): M_{GWB} = 383,362,341 m^3.
- M_{GWB} / Q_{ren} = 4.05

	M [kgN/a]	c [mg/l] - Q_{ren}	c [mg/l] - M_{GWB}
M_K	468,779	21.95	5.42
M_{GO}	179,993	8.39	2.08
M_{GP}	238,482	11.17	2.76

Concentration of nitrate c [mg/l] from total N surplus from agriculture would be 21.95 mg/l diluted in yearly renewable quantity of water.

Concentration of nitrate c [mg/l] from sewage system losses of nitrogen from households would be 8.39 mg/l (taking into account line sources assessment) or 11.7 mg/l (taking into account point sources from residential buildings (30 % loss of 4.7/kg/a/Population Unit)).

3.2. Nitrate concentration in groundwater body – spatial distribution assessment

Nitrate concentration in Ljubljansko polje alluvial groundwater body (mg/l) – Impacts of pressures from nitrogen losses from sewage system and nitrogen surplus from agriculture

	MIN	MAX	**MEAN**	STD
Impacts assessment 1: Spatial distribution average (Inverse distance weighting interpolation of monitoring points)	7.40	37.26	**18.59**	3.27
Impacts assessment 2: Simple average of	5.95	38.00	**18.83**	7.38

	MIN	MAX	**MEAN**	STD
monitoring points				
Impacts assessment 3: Numerical modeling (Pressures: N losses from sewage system + N surplus from agriculture)	0.00	364.00	**17.61**	30.93
(Pressures: Only losses from sewage system	*0.00*	*327.42*	***7.03***	*17.65*
(Pressures: Only N surplus from agriculture)	*0.00*	*303.27*	***10.58***	*25.36*

The mass of nitrogen diluted in groundwater body from agriculture is very probably two times higher than the mass of nitrogen from sewage system. The impact of nitrogen from agriculture on groundwater body is globally 11 mg/l and 7mg/l from sewage system. The overall impact is 18 mg/l of nitrate in the groundwater body of Ljubljansko polje.

3.3. Nitrate distribution in groundwater body

First figure (Figure 4) is presenting distribution of nitrate revealed by monitoring sites values and results of its IDW (inverse distance weighting) interpolation. The most significant path of nitrate pollution is evident from Dravlje on the west side, passing area of Navje / Bežigrad and continuing through Savlje, Hrastje towards Zadobrova.

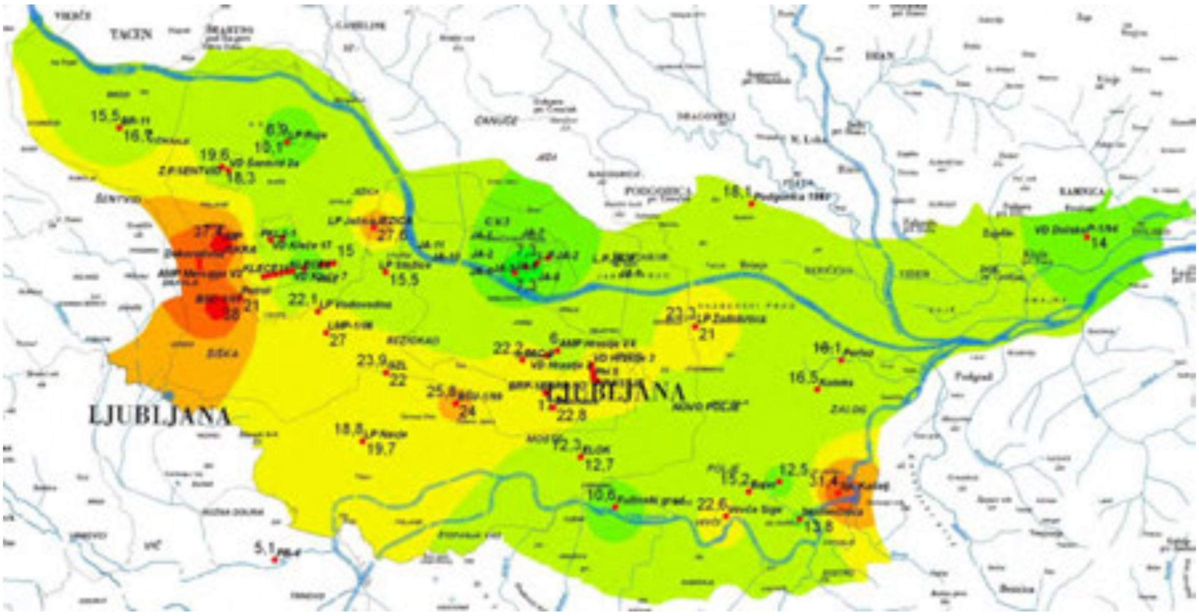


Figure 4. Inverse distance weighting interpolation of nitrate form monitoring points.

A comparison with results of dynamic model for sewage exfiltration (based on cracks and damages – line sources) on Figure 5 indicate a good correlation of contaminant dispersion. Losses from sewage reveals a significant impact in the area of Dravlje, further on to Navje / Bežigrad, BŠV-1/99 and then Hrastje waterworks towards the Novo Polje and then towards Koteks and Perlez near Zalog.

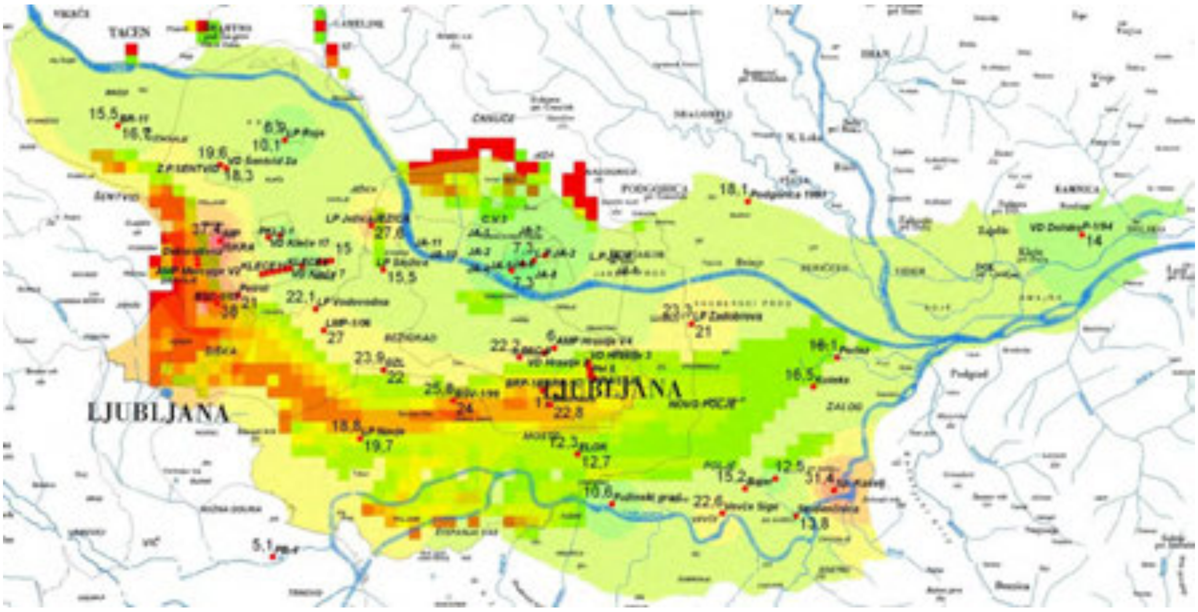


Figure 5. Expected nitrate distribution originated from sewage system (presented in grid from numerical model) overlaying the spatial distribution of nitrate from monitoring points interpolation.

Figure 6 shows the comparison with total (agricultural and sewage pressure of nitrogene) spatial distributed results of nitrate distribution. Regarding Figure 6 it can be seen significant added impact of agriculture between Ježica and Kleče, over Vodovodna / Stožice, passing Hrastje and continuing towards Zadobrova, Perlez.

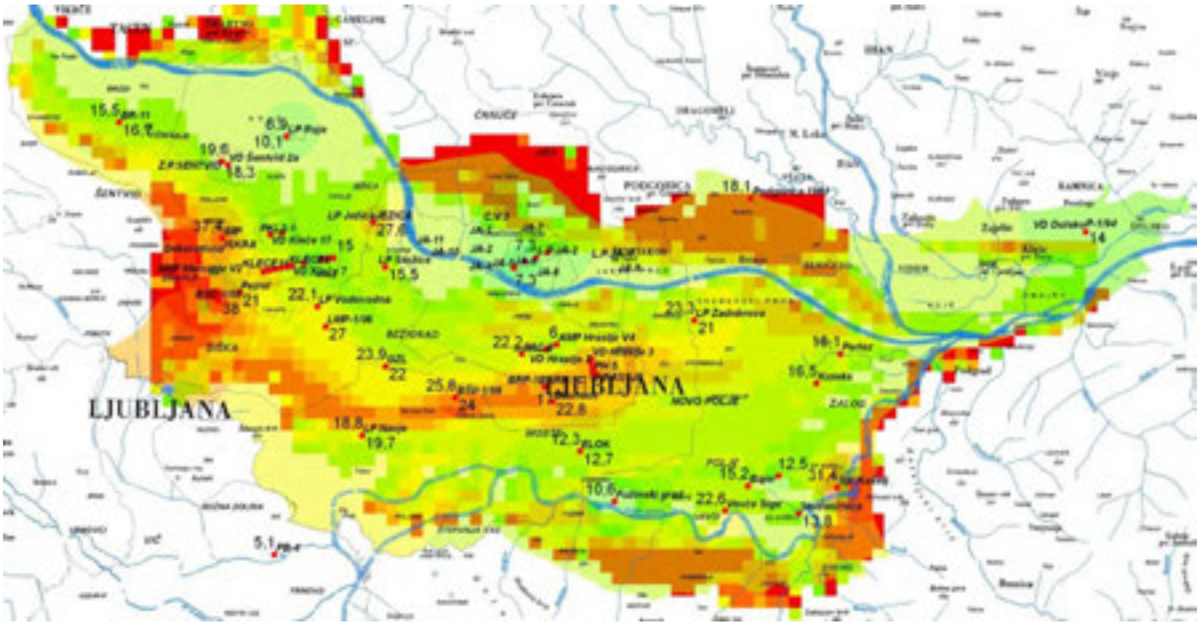


Figure 6. Expected nitrate distribution originated from sewage system and agriculture (presented in grid from numerical model) overlaying the spatial distribution of nitrate from monitoring points interpolation.

Impacts of sum of pressures from agriculture and sewage system together are seen in the line of observation wells between Vodovodna, LMP-1/06, GZL, PAC-9, Hrastje (multiple wells), LP Zadobrova and Perlez. Concentrations of nitrate along this line are significantly over 20 mg/l. South of this line the impacts from sewage system is strongly predominated.

Nitrate in Kleče well field is predominantly of agriculture origin, while nitrate in Hrastje well field is of agriculture and sewage system origin, roughly in equivalent portions.

Comparison of spatial distribution of nitrate concentrations obtained from monitoring data and from numerical modeling shows overall good representatives of monitoring networks. This is also confirmed by rather good matching of nitrate concentration levels. Nevertheless, it is evident that there is a lack of monitoring data on the area between Šišenski hrib, Grad, Tabor, Štepanja vas, Moste and Navje to reveal the exact spatial distributions of impacts from sewage system.

3.4. Chromium-6 concentrations in groundwater body – spatial distribution assessment

The result of IDW interpolation shows a shape of plume starting southeast of industrial site Litostroj (LP Vodovodna) passing Bežigrad (GZL), Savlje (BŠV-1/99) and towards Moste (Figure 7).

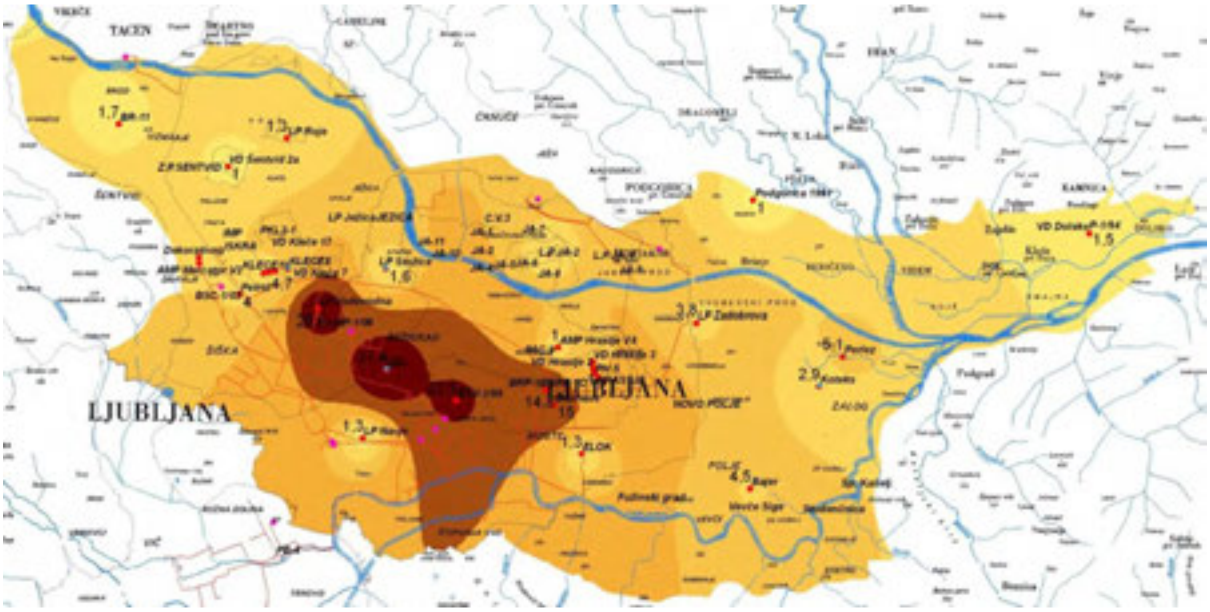


Figure 7. Inverse distance weighting interpolation of chromium-6 form monitoring points.

The most significant impacts of chromium-6 exfiltration from sewage system (where industrial discharges of important chromium loads are known) are expected spreading dominantly along flow path from Dravlje, passing north of Navje, Zelena jama and towards Moste. In the northern part of the aquifer an area of important impact along Tomačevo towards Šentjakob could be probably present (Figure 8).

Calculated impacts have much lower values than values from monitoring results. Also, the main calculated flow path is shifted significantly to the south from the apparent flow path revealed by monitoring sites. It could be concluded that other sources of chromium 6, like old burdens or higher unknown losses (Figure 8). It is again evident that there is a lack of monitoring data on the area between Šišenski hrib, Grad, Tabor, Štepanja vas, Moste and Navje to reveal the exact spatial distribution.

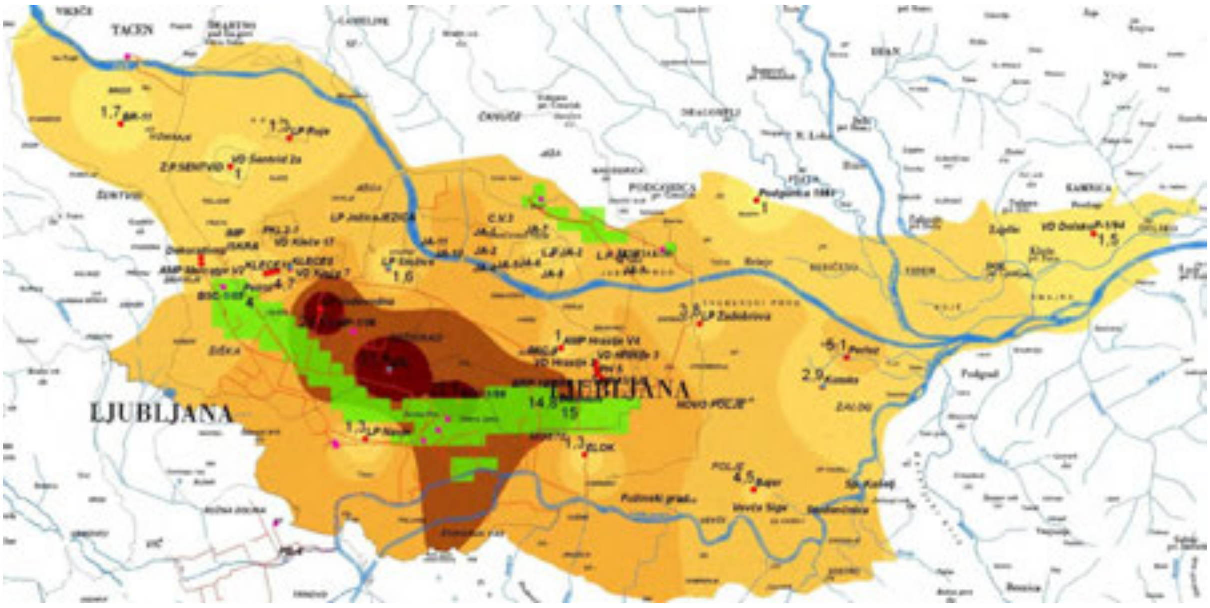


Figure 8. Expected chromium-6 distribution originated from sewage system (presented in grid from numerical model) overlaying the spatial distribution of chromium-6 from monitoring points interpolation.

The largest probability of the presence of chromium 6 is from Vodovodna south to Poljane towards Koteks. Significant trends at the area (like Koteks and GZL) are downward. An exception is the Hrastje waterworks were chromium 6 concentrations have significant upward trends.

3.5. Chromium concentrations in groundwater body – spatial distribution assessment

The result of IDW interpolation shows a significant impact on the areas of Bežigrad (GZL) / Savlje (BŠV-1/99) and Hrastje (Figure 9).

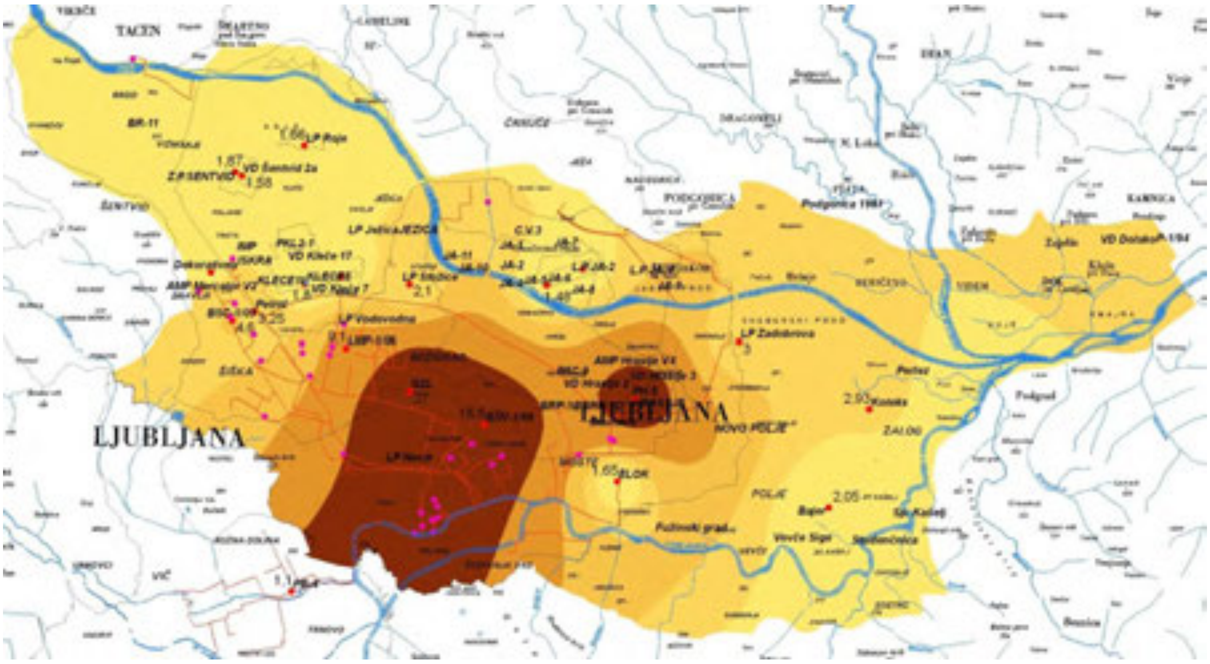


Figure 9. Inverse distance weighting interpolation of chromium-tot form monitoring points.

Calculated pollution dispersion from loss of chromium from sewage system (mass of chromium from known industrial discharges) matches very good to monitoring results (spatial distribution of discharge sites is shown by purple dots on Figure 10. Nevertheless, it is again evident a lack of monitoring points on wider area of Navje, Tabor, Poljane.

Due to high deviation of results of monitoring and calculated values of concentrations there are probably also some other sources of chromium 6, like old burdens or higher losses for which we do not know.

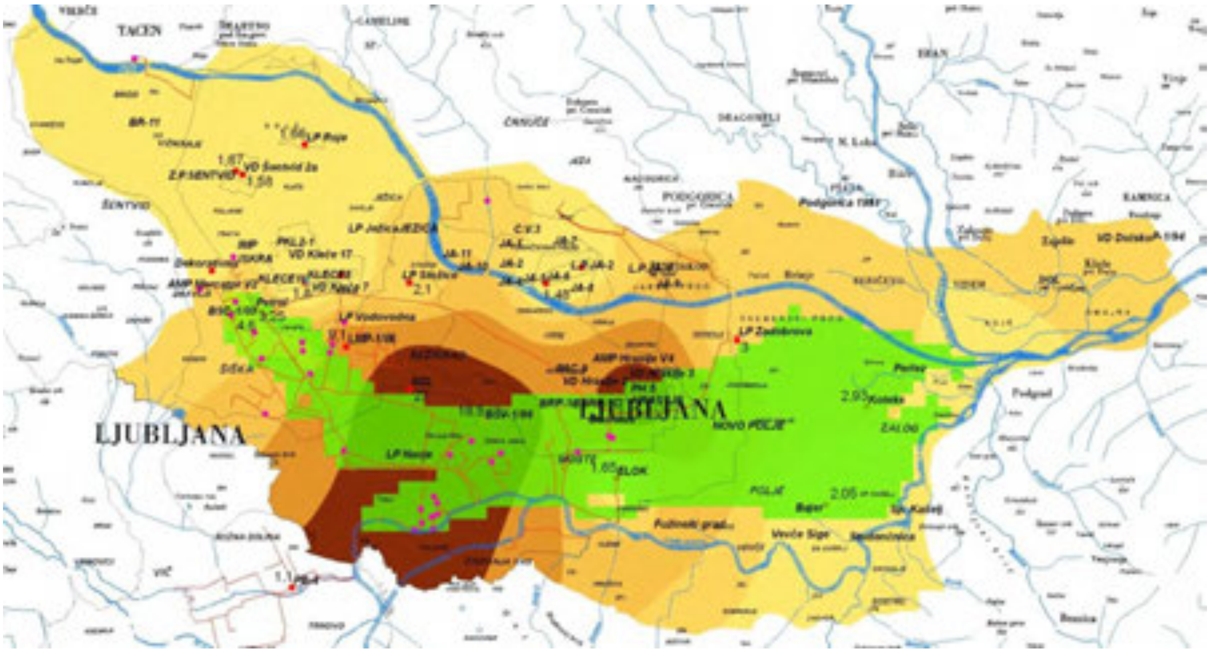


Figure 10. Expected chromium-tot distribution originated from sewage system (presented in grid from numerical model) overlaying the spatial distribution of chromium-tot from monitoring points interpolation.

Monitoring point BŠV-1/99 is very probably one the most important sites to monitor the spatial spread of the contamination from sewage system, not only of chromium but also nitrate and all other pollutants from sewage system (households and industrial origin).

It is very evident that Hrastje well filed could be very susceptible to eventual pollution from industrial waste water discharges sites to sewage system.

4. Effectiveness of basic measures

Analysis of trends was performed using all available time series data and all parameters in the INCOME chemical database. We used all-time series with at least 4 measurements of individual parameter.

Significance of trend was determined statistically.

Linear regression equation:

$y = \alpha + \beta x + \varepsilon,$

x... time,

y... measured value,

ε... error.

Least square method →.

$$b=\frac{\frac{1}{n}\sum_{i=1}^{n}Y_iX_i-\frac{1}{n}(\sum_{i=1}^{n}Y_i)\frac{1}{n}(\sum_{i=1}^{n}X_i)}{\frac{1}{n}\sum_{i=1}^{n}X_i^2-\frac{1}{n^2}(\sum_{i=1}^{n}X_i)^2}=\frac{\frac{1}{n}\sum_{i=1}^{n}Y_iX_i-YX}{\frac{1}{n}\sum_{i=1}^{n}X_i{}^2-X^2}=\frac{S_{xy}}{S_x^2}$$

$$a=\frac{1}{n}\sum_{i=1}^{n}Y_i-\frac{1}{n}\sum_{i=1}^{n}X_ib=Y-Xb=Y-\frac{S_{xy}}{S_x^2}X$$

Standard deviation:

$$\sigma^2=\frac{1}{n-2}\sum_{i=1}^{n}\varepsilon_i^2=\frac{1}{n-2}\sum_{i=1}^{n}(Y_i-a-bX_i)^2=\frac{n}{n-2}S_Y^2(1-R_{XY}^2)$$

T vaklue:

$$T=\frac{R_{xy}\sqrt{n-2}}{\sqrt{1-R_{xy}^2}}$$

Y, X... [average],

S_xS_y...[stdev],

S_x^2, S_Y^2..[var],

S_{xy}... [covar],

R_{XY}... [correl].

$$\rho_{XY}=R_{XY}=\frac{S_{xy}}{S_xS_y}=\frac{\sum_{i=1}^{n}(X_i-X)(Y_i-Y)}{\sqrt{\sum_{i=1}^{n}(X_i-X)^2\sum_{i=1}^{n}(Y_i-Y)^2}}$$

All points with significant trends were shown in figures in the appendix 1.

Nitrogen concentrations have significant upward trends only on few monitoring sites in Ljubljansko polje and Ljubljansko barje areas. The majority of observation sites have either no significant trend or they have significant downward trend.

Analysis of trends reveals the favorable efficiency of basic measures, both in agriculture activity as well as in the urbanization. Nevertheless, the few unfavorable local trends, especially in the pumping sites areas, call the attention the need to improve the basic measures to control the whole water body and to reveal the local losses and surpluses.

The spatial distribution of significant upwards does not expose any of two the most important sources, agriculture and urbanization. Further improvement of measures should be addressed to both sectors.

Pesticides concentrations have significant upward trends also only on few monitoring sites in Ljubljansko polje and Ljubljansko barje areas. The important warning from trend analysis is that significant upward trends were locally detected on the areas of pumping sites. This fact shows that the use of pesticides in the direct recharge zone of wells is highly riskful. Especially the pollution in the Brest area shows that the lack of awareness or neglecting of this risk can seriously endanger all the so far made efforts and investments in water supply system.

The dominating majority of monitoring sites does not show any significant upward trend of PCE and TCE. There are few monitoring sites in Ljubljansko polje and Ljubljansko barje areas that show significant upward trend. In Ljubljansko polje these trends are significantly distributed in the main groundwater direction from Stožice towards Hrastje and further on the east. Nevertheless, this is probably not the plume like contamination but rather the local sporadic contaminations.

Significant upward trends of metals are not present on the Ljubljansko Barje, but there are several sites in Ljubljansko polje. Similar to PCE and TCE spatial distribution of trends they are aligned from Stožice towards Hrastje and further on the east. There are also two significant upward trends in the highly urbanized area southwest of Hrastje in the area of dense sewage system dewatering the major waste water emission points.

The most represented significant upwards trends are chlorides and also sporadically hydrogen carbonates, potassium, sodium and electric conductivity. These trends could originate from sewage system, traffic and could also be of climatic origin. Certainly they could not be of unique origin as it is proved by the pressure and impact analysis. It is obvious that these effects should be diminished by the amelioration of sewage system and improvement of measures for waste water emissions from industry, urbanization and traffic.

The most represented significant downward trends are sulphates. They are significantly more presented in Ljubljansko polje than in Ljubljansko Barje. Their spatial distribution seems not to be dependent of pressures from urbanization. Does the reason could be the diminished air pollution in last decades, it was not assessed.

5. Projection of impacts and objectives to 2027 and 2050

At the first stage of work we gathered and studied the existing long-term projections of Ljubljana Community development in order to determinate the expected pressures on water environment. The basic reference documents were Strategic physical plan and Operational physical plan for the period till

2017 and long-term Vision of Ljubljana Community area till 2027. The strongest impacts are expected from the planned 4 hydropower plants on the Sava River (2027), increasing of sealed surfaces (2027), implementation of Action plan for urban waste water treatment and sewing (2017) and increasing of traffic and migration (2027).

The most significant management issue in projection of impacts is the risk of contamination from sewage system. The quality of water could be worsened if the renovation of old sewage would not follow the ageing. The risk of pollution would increase significantly and in that case endanger mostly Hrastje water filed.

The objectives to 2027 and 2050 are recommended to reach the nitrate concentration bellow 25 mg/l in any observation point and bellow 15 mg/l for groundwater body (2027). In next long term period the concentration of nitrate significantly bellow 20 mg/l in any observation point and around 10 mg/l for groundwater body (2050).

Any new active substances of plant protection product should not be occured in the water abstraction wells for public supply (2027).

The mass of all contaminants from industrial waste water traffic discharges to sewage system should be diminished (2015 - 2027).

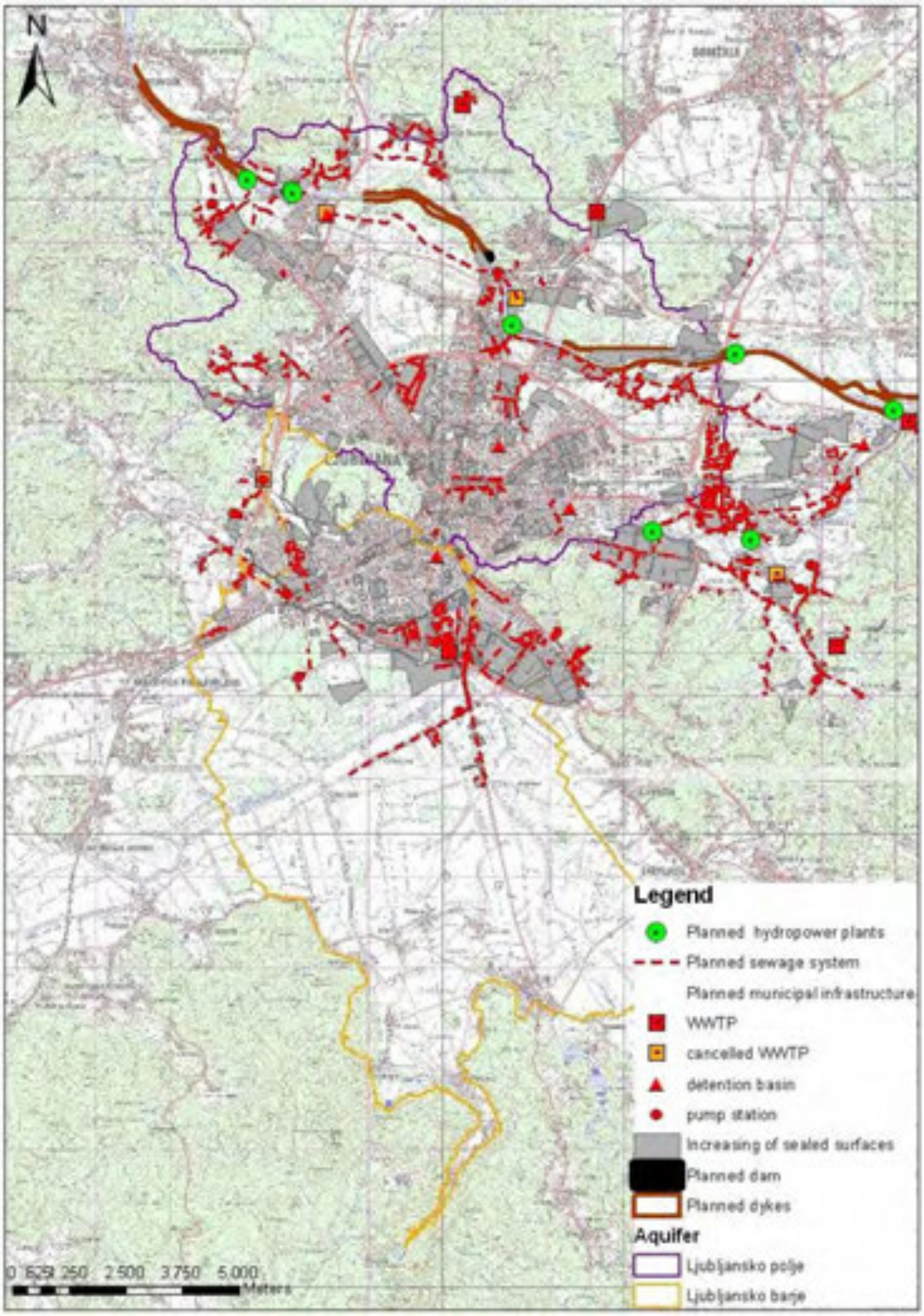


Figure 11. Development from an actual spatial plan.

6. Setting up priorities for measures in program of activities

The first priority measures is implementing the prevent and limit objectives:

To prevent an input into groundwater means: There should be no significant increase in concentration of pollutants in the groundwater, even at a local scale. All measures deemed necessary and reasonable to avoid the entry of hazardous substances into groundwater, should be taken.

Limit applies to all non-hazardous pollutants. All measures necessary to limit inputs into groundwater should be taken so as to ensure that such inputs do not cause deterioration in status or significant and sustained upward trends in the concentration of pollutants in groundwater.

- Point sources

Decreasing emissions of substances by waste water:

All the emissions of waste water that are under obligation of emission monitoring (industry, landfill) should provide the measures/plan for reduction of mass of pollutants entering the sewage system or ground.

All other activities that produce wastewater (except households) should report to the sewage manager the list of substances that will be emitted and the estimation of yearly mass of substances that will be used in the work process.

Sewage system manager should precisely monitor the mass balance of emitted quantity of substances and amount of all substances coming to the treatment plant.

Sanitation and reconstruction works on sewage system should follow the priority: 1) age of construction, 2) material of construction, 3) water protection areas VVO I and VVO II a, 4) branches along the main emissions flows from industry.

In the every spatial planning cycle, the community should provide the plan of decreasing the overall mass of substances entering into the ground from traffic and manipulation surfaces.

Any exemption from preventing input into ground can be made under certain conditions inputs. This could be performed for inputs which are considered by the competent authorities to be of a quantity and concentration so small as to obviate any present or future danger of deterioration in the quality of the receiving groundwater. The consideration has to be made by risk analysis methodology required by the

Rules on criteria for the designation of a water protection zone (OJ RS, No. 64/2004). The risk analysis has to assess the quality of receiving water not only at the discharge point but also directly below the input in the groundwater (POC 1). Prevent and limit monitoring have to be provided for those exemptions where there could be significant uncertainties in prediction of site specific impacts and designing additional measures.

In the community's Ordinances on spatial planning conditions for planning zones the part regulating the waste water emissions: Roofed surfaces should be recommended instead of open manipulation surfaces to diminish the waste water quantities and reusing the clean water from the roof to recharge the aquifer. All the wastewater from surfaces that could contain hazardous substances should be preferentially emitted in the sewage system.

The most important is to perform the thorough inspection of sewage system in the wider area of Dravlje and further on the area of the considered highest risk of contamination from sewage (Figures 4, 5).

The plan for renovation of sewage system has to include the area of the highest risk of pollution from sewage system between Dravlje and Savlje (BŠV-1/99) as a priority area.

All the discharges of industrial waste water (especially containing chromium) should be thoroughly inspected, controls of real content of contaminants in discharge sites should be regularly measured in the mentioned area.

In the line of observation wells between Dekorativna, Mercator, Vodovodna, LMP-1/06, Navje, GZL, PAC-9, Hrastje (multiple wells), BŠV-1/99, LP Zadobrova and Perlez analysis of nitrate, chromium-tot, chromium-6 should be analysed twice a year and results regularly free accessible on the internet.

The mass of chlorides, for icing prevention, discharging into the ground and sewage should not be increasing.

- <u>Dispersed sources</u>

Regular exchange of data between waterworks and agriculture sectors should be established: 1) quality of water in all monitoring points, 2) actual trends of nitrogen and pesticides concentrations in groundwater, 3) measurements of nutrients and pesticides in the soil, performed by agriculture monitoring and control activities, 4) actual list of active substances in plant protection products in the actual agriculture practice, 5) manure plans and actual distribution of plant cultivation.

Specialized experts should be nominated to communicate between agriculture and waterworks sectors. They should prepare: 1) the plan to select and stimulate the agriculture measures, the most efficient for groundwater quality, from the list of basic agriculture environmental programme, 2) the plan for optimization of nutrients and plant protection products use and decreasing the surpluses, 3) proposal for adequate incentives and subsidies diminishing the nitrogen surplus. This should be performed in regular 6 years cycles, following water management plans and spatial planning.

All the efforts should be made to prevent the use of organic active substances for plant protection in the narrowest water protection area VVO I and to limit as much as possible in the direct recharge zone VVO II a.

Agricultural land should be in any case retained as non-built up – green areas in the water protection areas VVO I and VVO II a.

7. Definition of important points of compliance

Four different points of compliance (POC) are defined:

• POC 0: is located at the base of the source in the unsaturated zone-just below the ground surface.
The purpose is to control limit values;

• POC 1: is located at the point of input into the groundwater; (for a direct input, POC 0 would be the same as POC 1), At POC 1 the actual concentration in the groundwater itself is primarily taken into account;

• POC 2: is located hydraulically down gradient from the input in between POC 1 and a spring or a well. The purpose of this compliance point is to provide an early warning that the spring or well might be impacted and for predicting the potential impact of the input.

• POC 3: This POC is used to assess whether the desired groundwater quality is reached and to monitor the impact at the spring or well. If a risk assessment shows that the pollutant will exceed the compliance value at this POC, then pollution is likely to occur as a result of the input. Measures/controls will need to be put in place to remove this impact, or the activity should not be permitted.

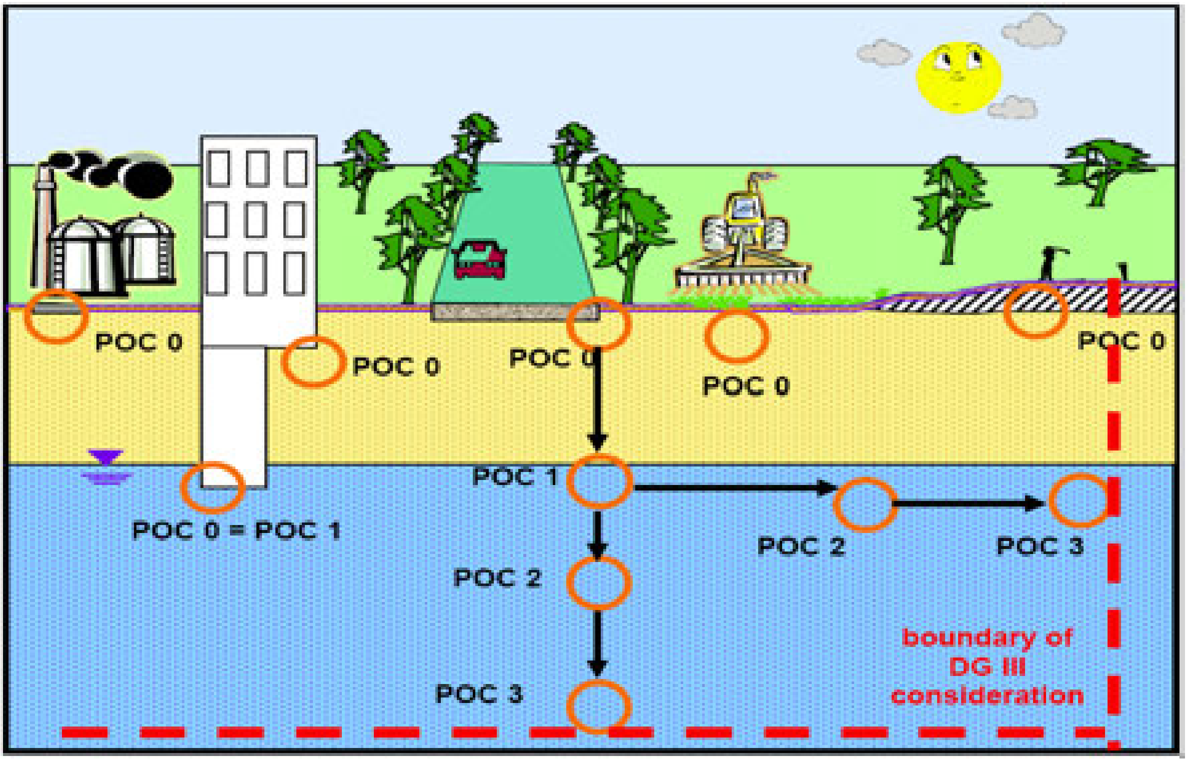


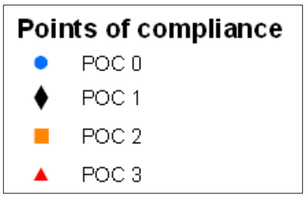
Figure 12. Points of compliance - GUIDANCE ON PREVENTING OR LIMITING DIRECT AND INDIRECT INPUTS IN THE CONTEXT OF THE GROUNDWATER DIRECTIVE 2006/118/EC.

A "Compliance Value" for a substance is the concentration and associated compliance regime that, when not exceeded at the compliance point, will prevent pollution. This is measured at the "prevent/limit" monitoring point (POC 1, 2, or 3).

A compliance value thus prevents an environmental standard being exceeded at a receptor. Compliance values typically relate to protecting water uses such as drinking supplies or surface water environments. However, values from other legislative regimes (Drinking Water Standards or Environmental Quality Standards (EQS)) should not be used automatically without further consideration of their relevance, particularly where the compliance regime is different. Misuse of such standards can lead to over or under protection of the groundwater resource.

Compliance values differ to "Limit Values" in terms of where they are set and applied. A "Limit Value" for a substance is the concentration and associated compliance regime that, when not exceeded at the source, will prevent an unacceptable release to groundwater. This is measured at the source, i.e. the point of release (POC 0). Limit values can be expressed as a concentration or acceptable loading. They can be included in a permit as a condition, or specified as a remedial target for soils on contaminated land sites.

Legend:



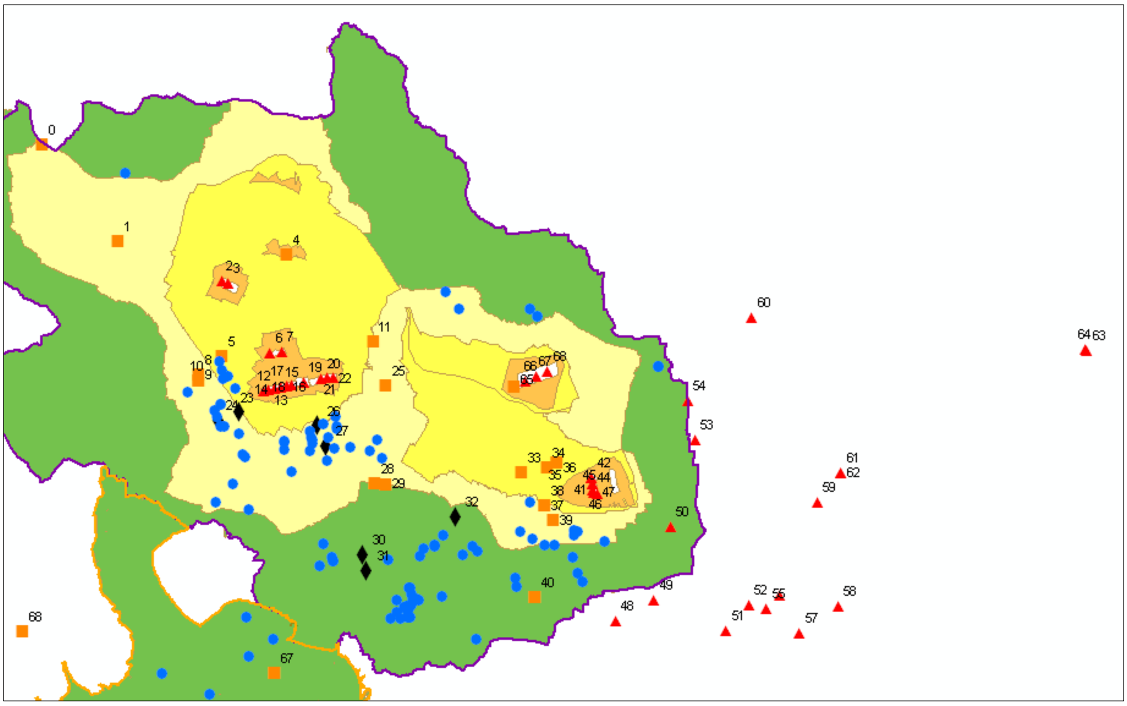


Figure 13. Points of compliance (POC) – Ljubljansko polje.

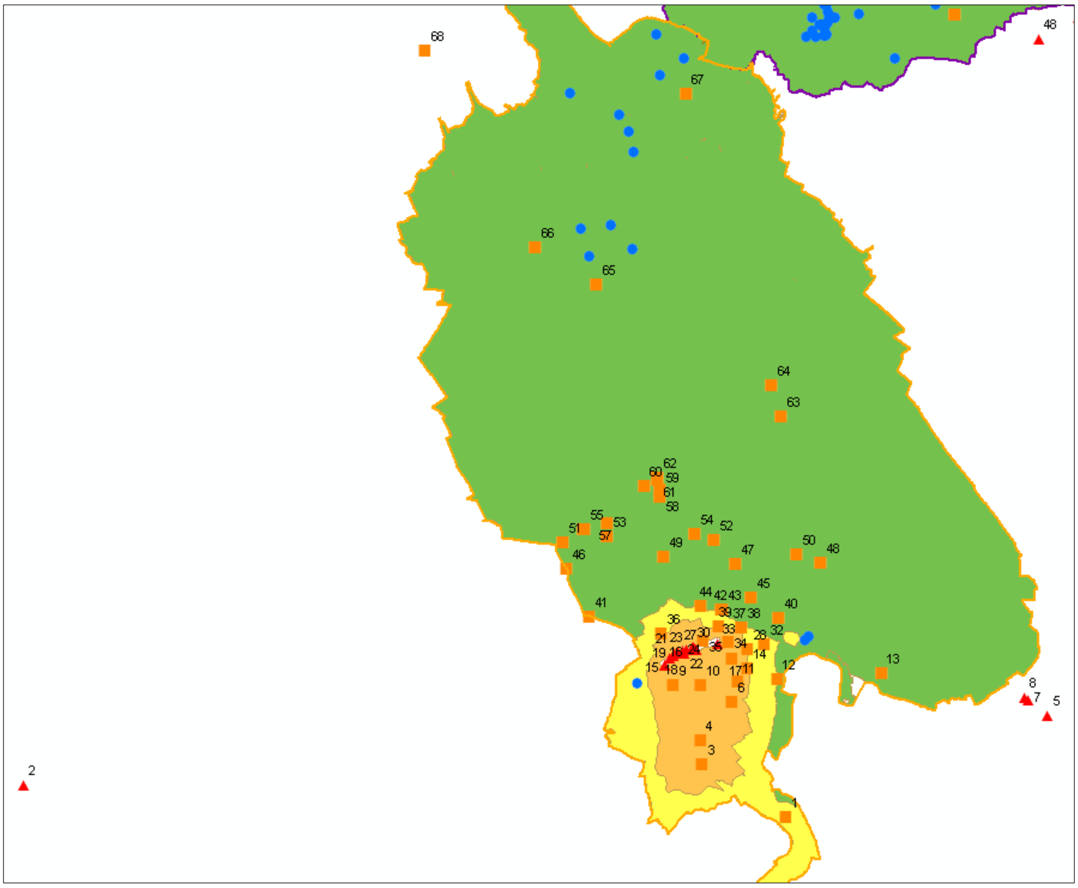


Figure 14. Points of compliance (POC) – Ljubljansko Barje.

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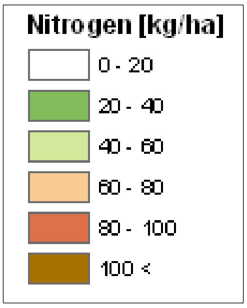
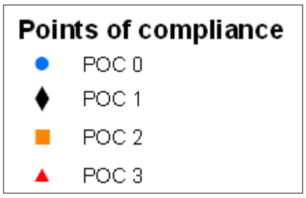
APPENDIX 1

Legend:





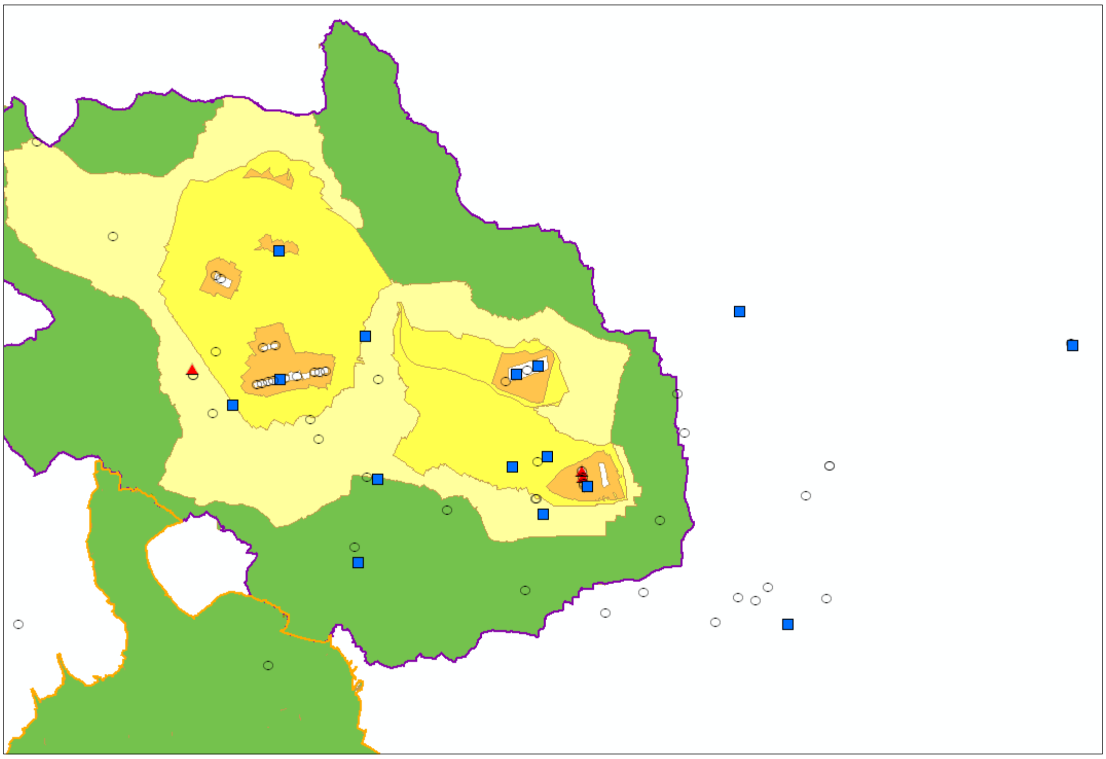


Figure 1. Significant trends of nitrogen.

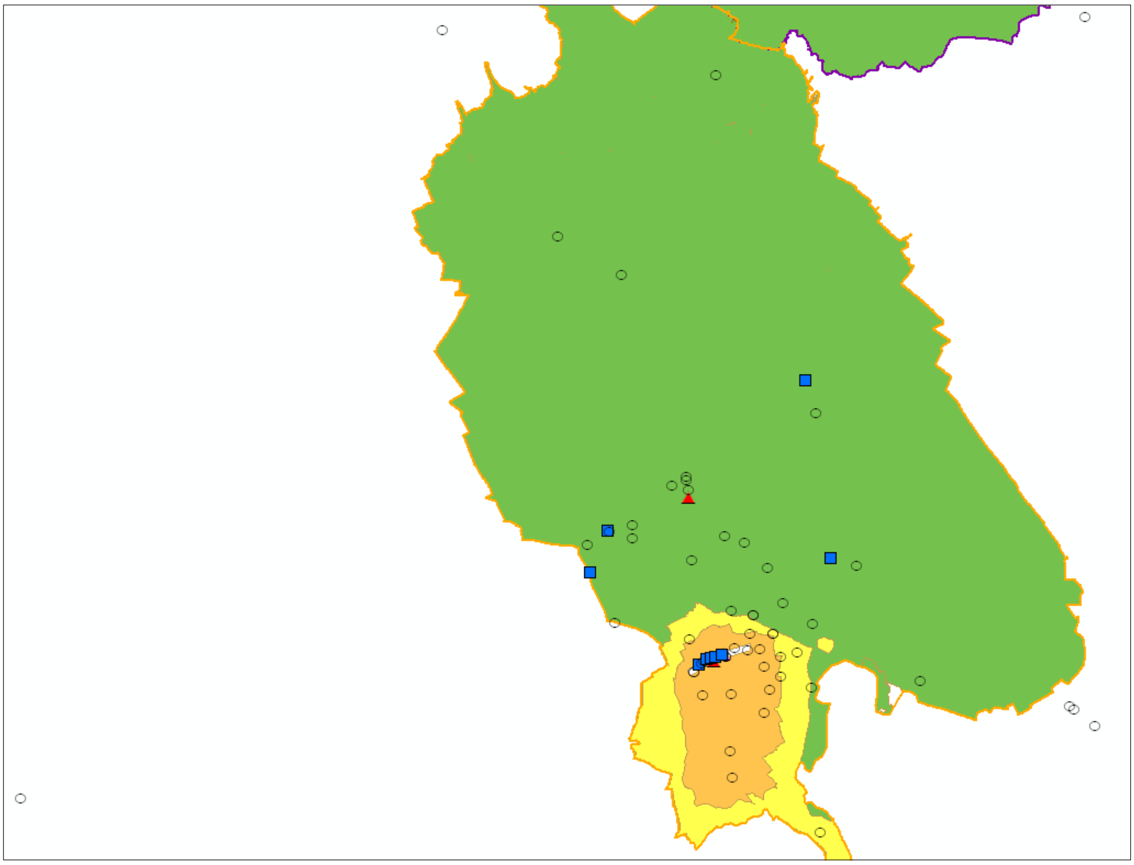


Figure 2. Significant trends of nitrogen.

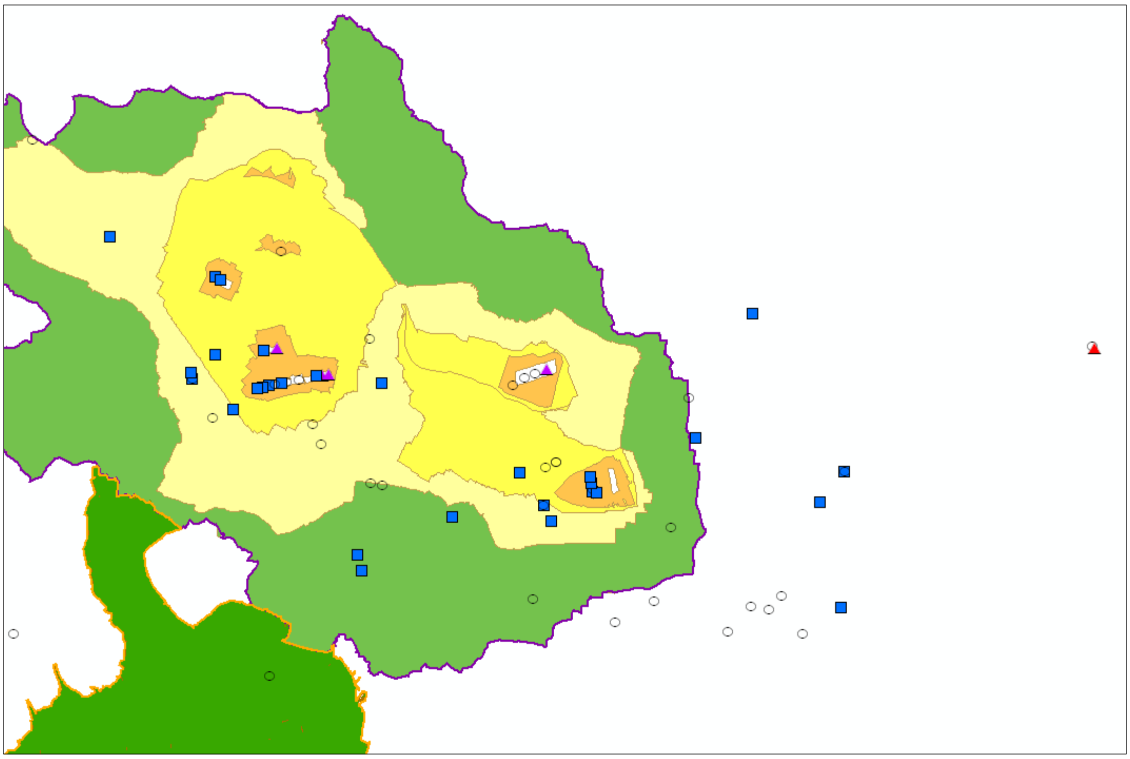


Figure 3. Significant trends of pesticide.

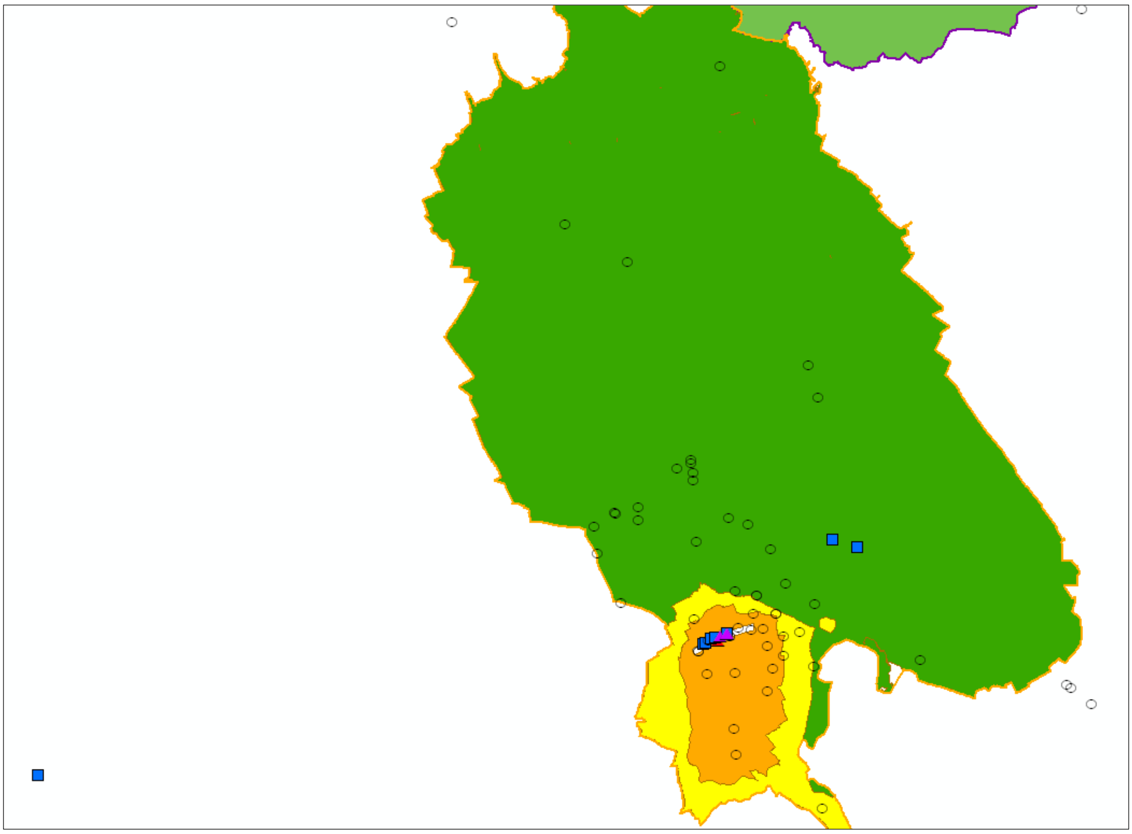


Figure 4. Significant trends of pesticide.

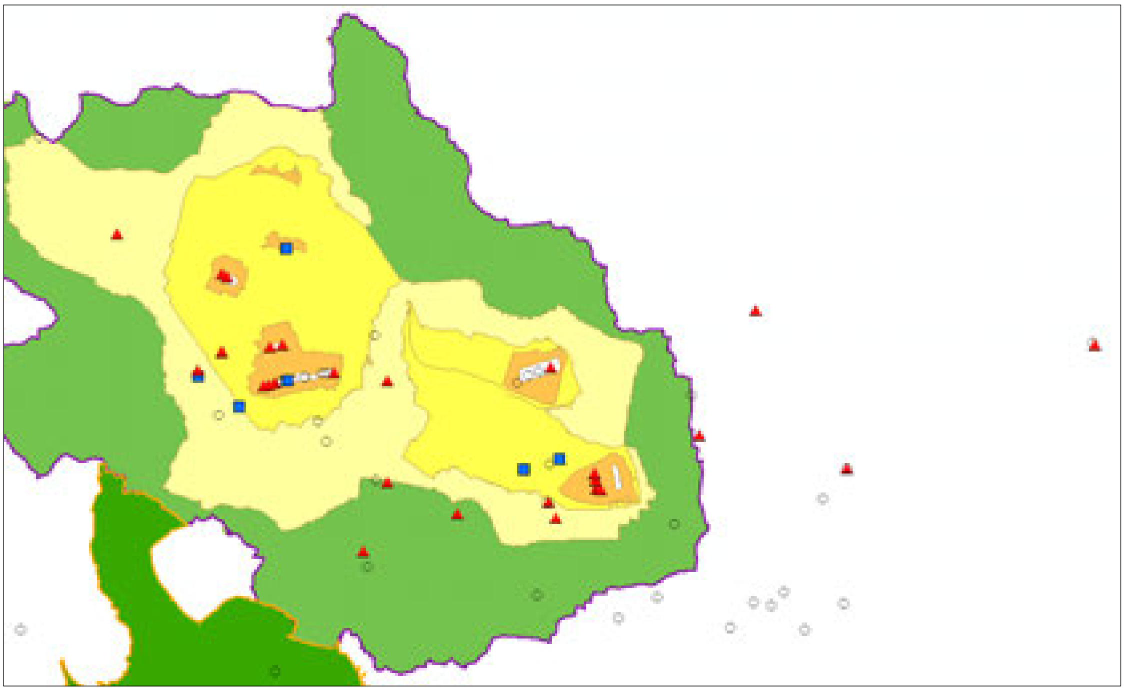


Figure 5. Significant trends of chloride.

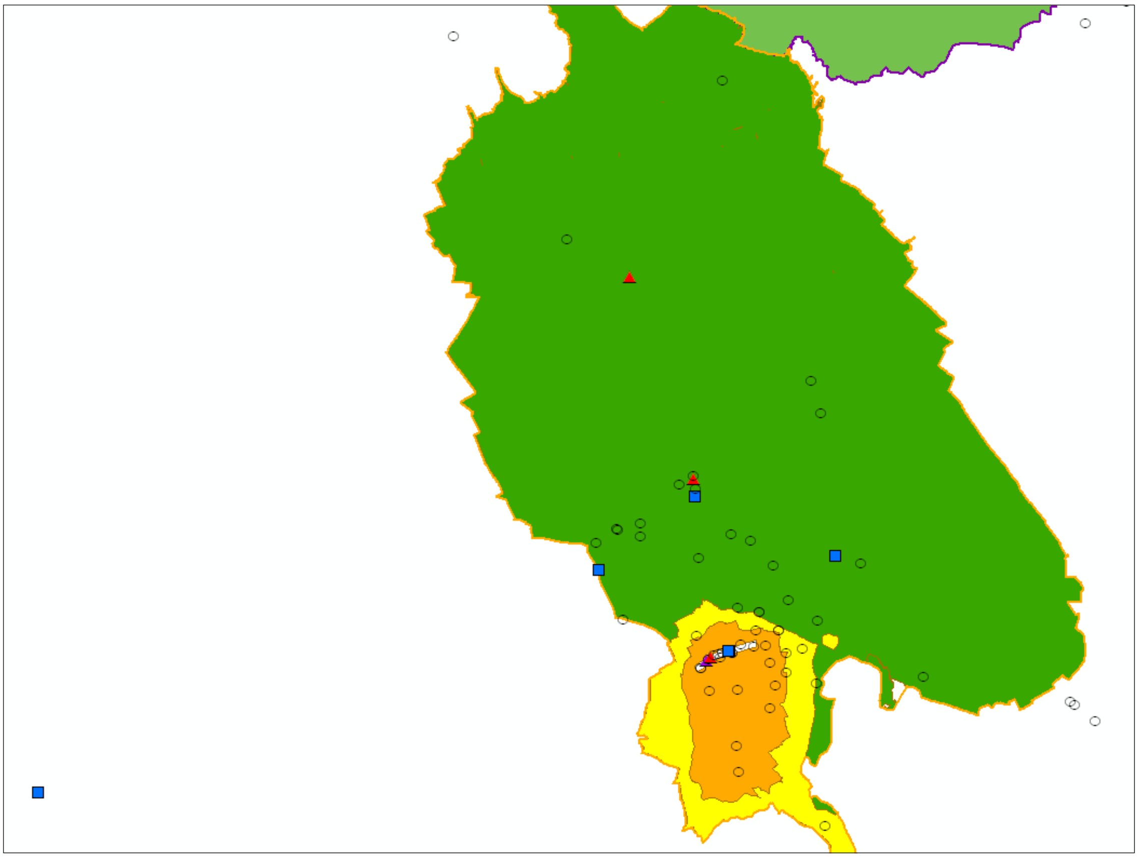


Figure 6. Significant trends of chloride.

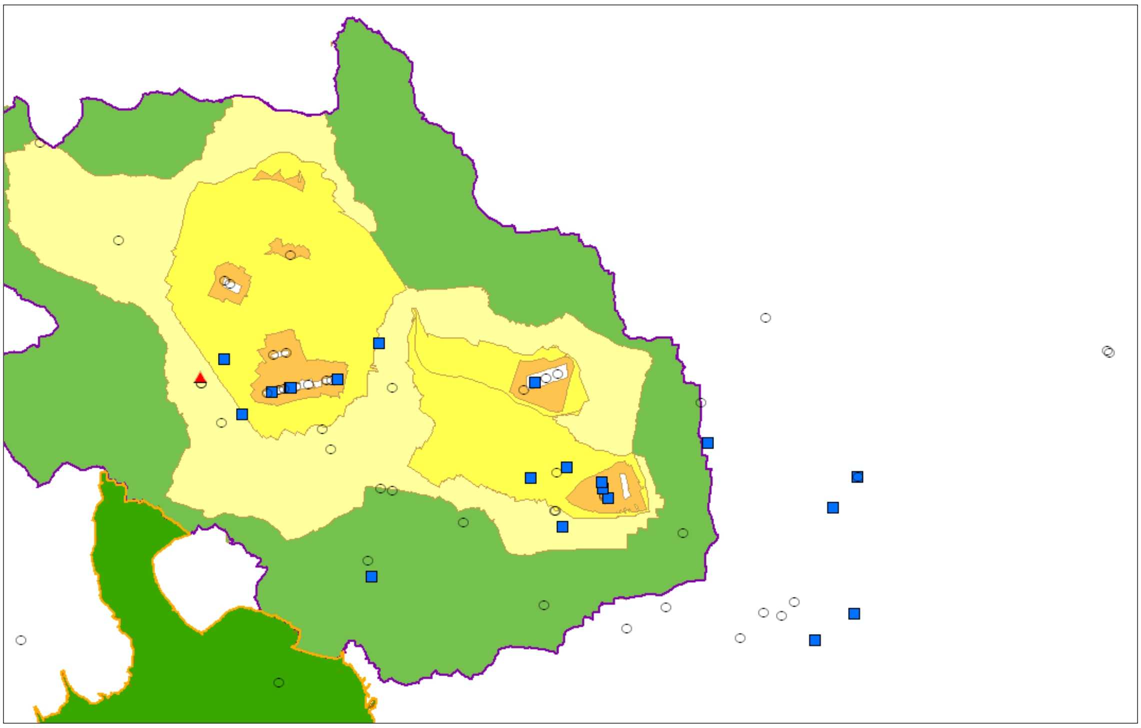


Figure 7. Significant trends of sulphate.

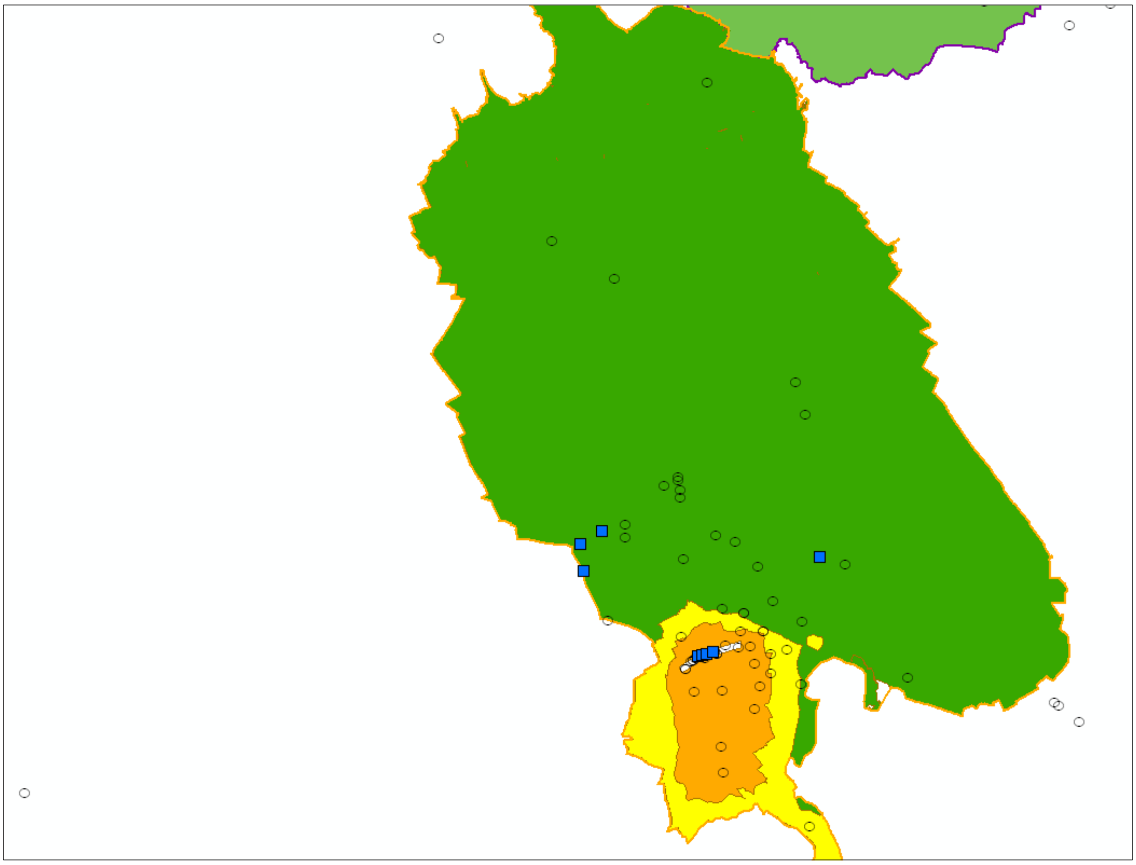


Figure 8. Significant trends of sulphate.

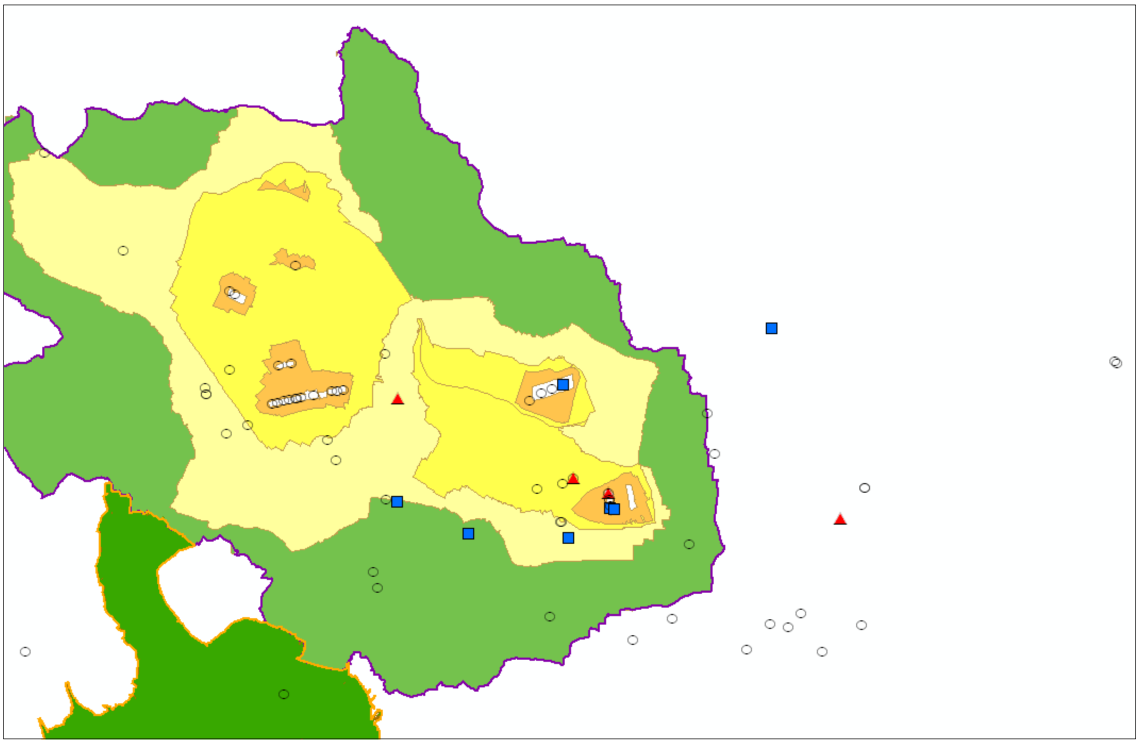


Figure 9. Significant trends of PCE.

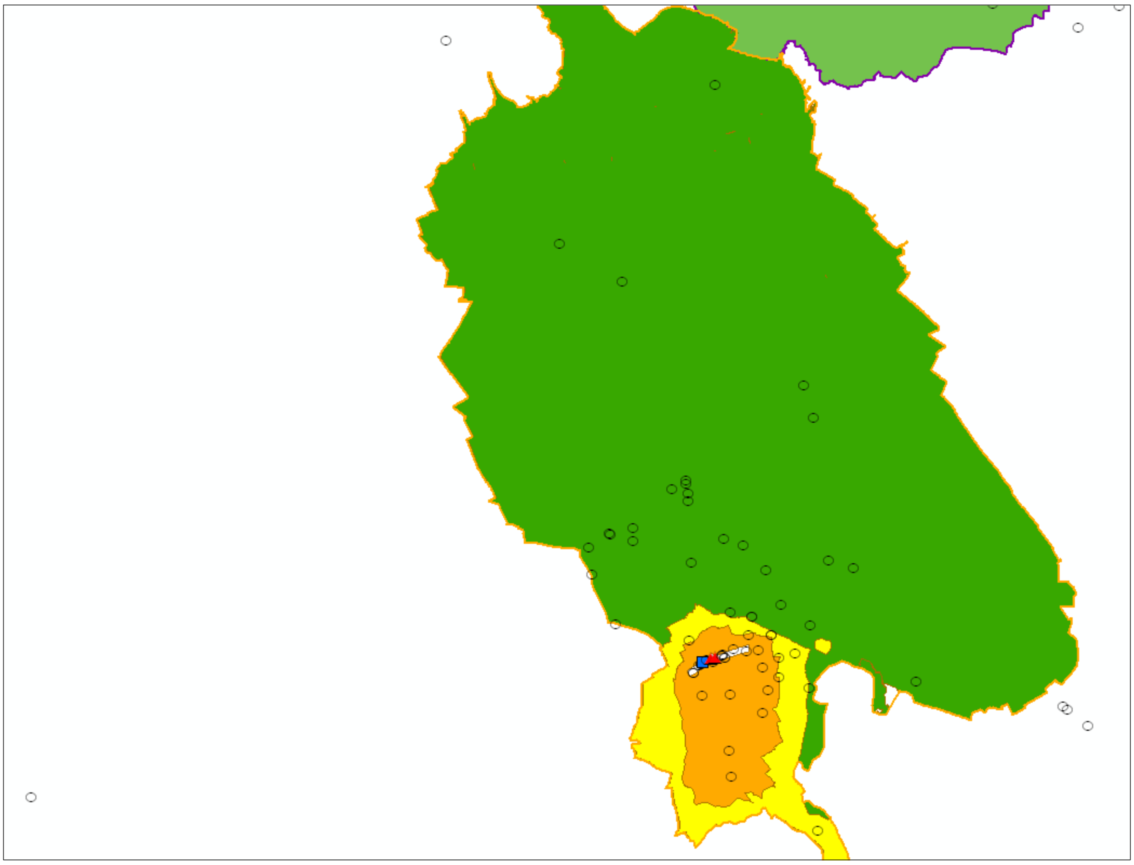


Figure 10. Significant trends of PCE.

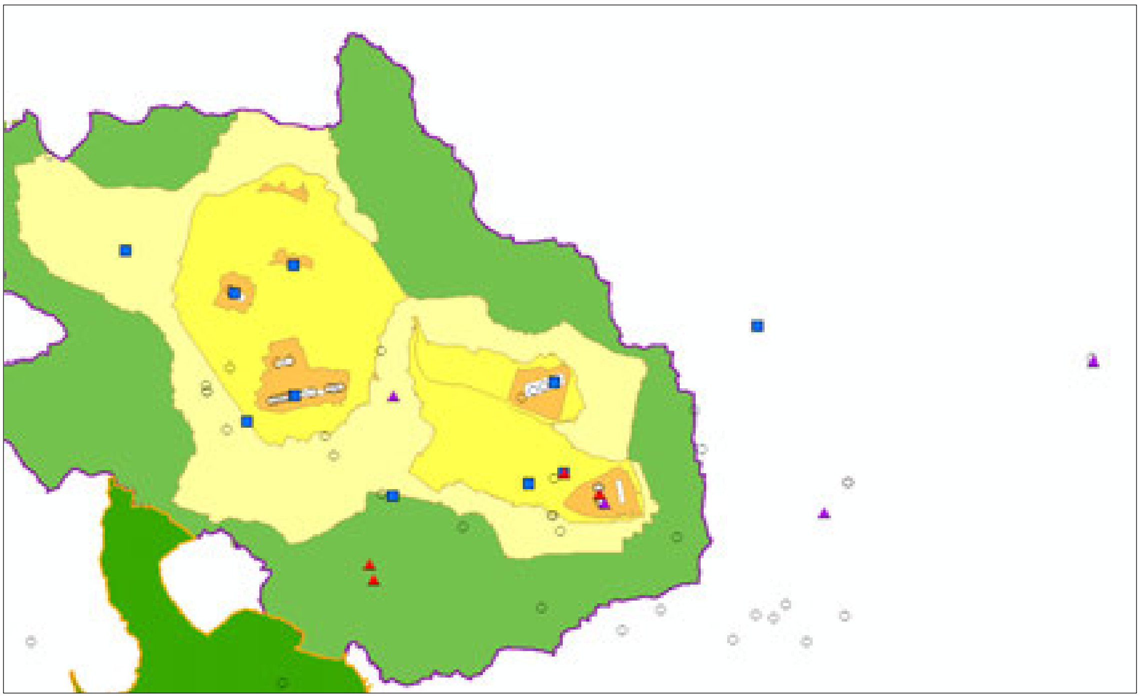


Figure 11. Significant trends of metals.

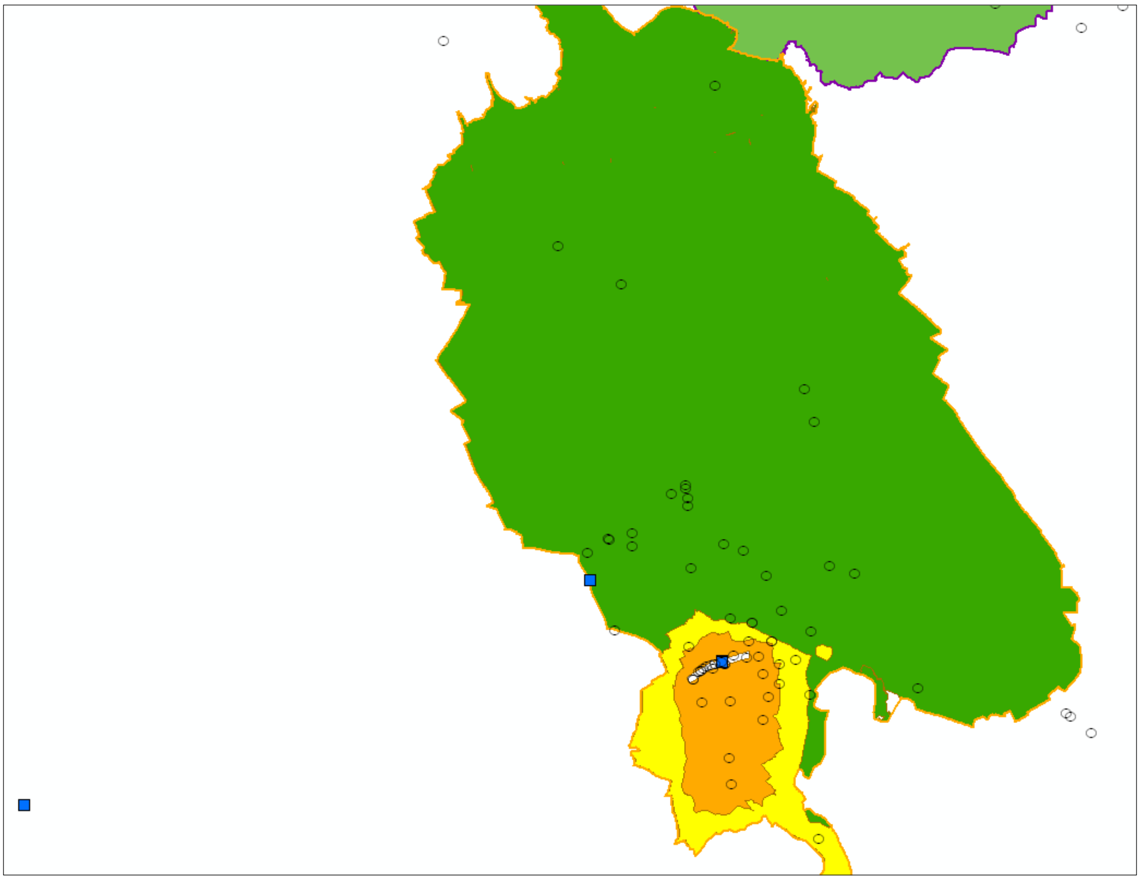


Figure 12. Significant trends of metals.

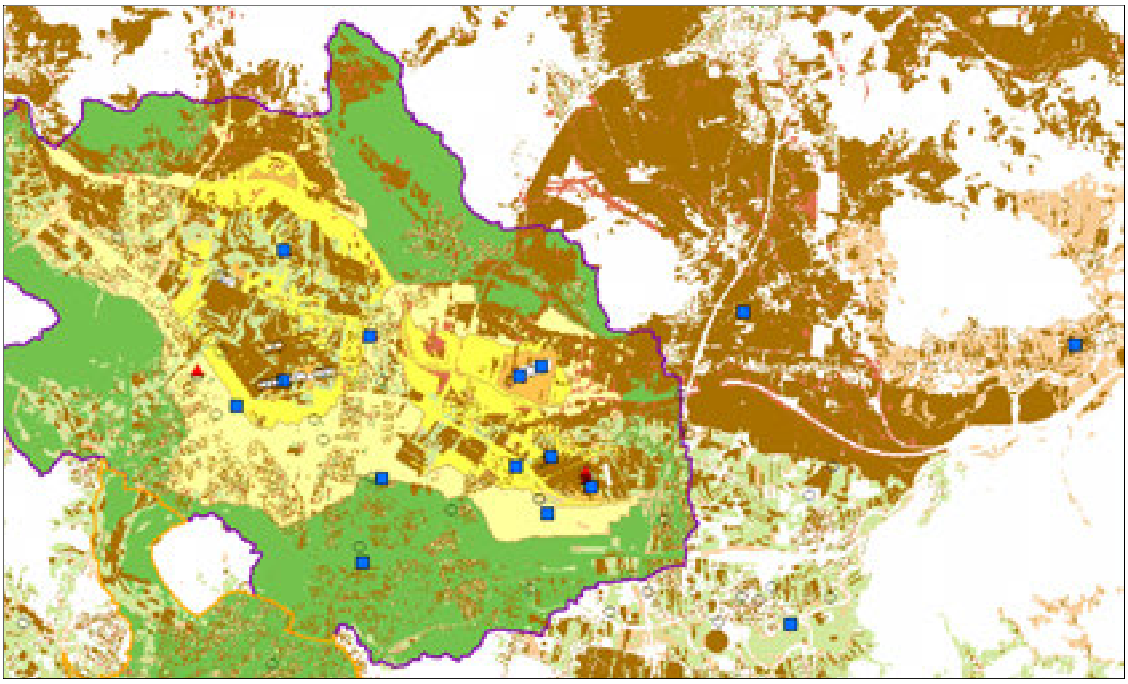


Figure 13. Nitrogen loads and significant trends of nitrogen in ground water.

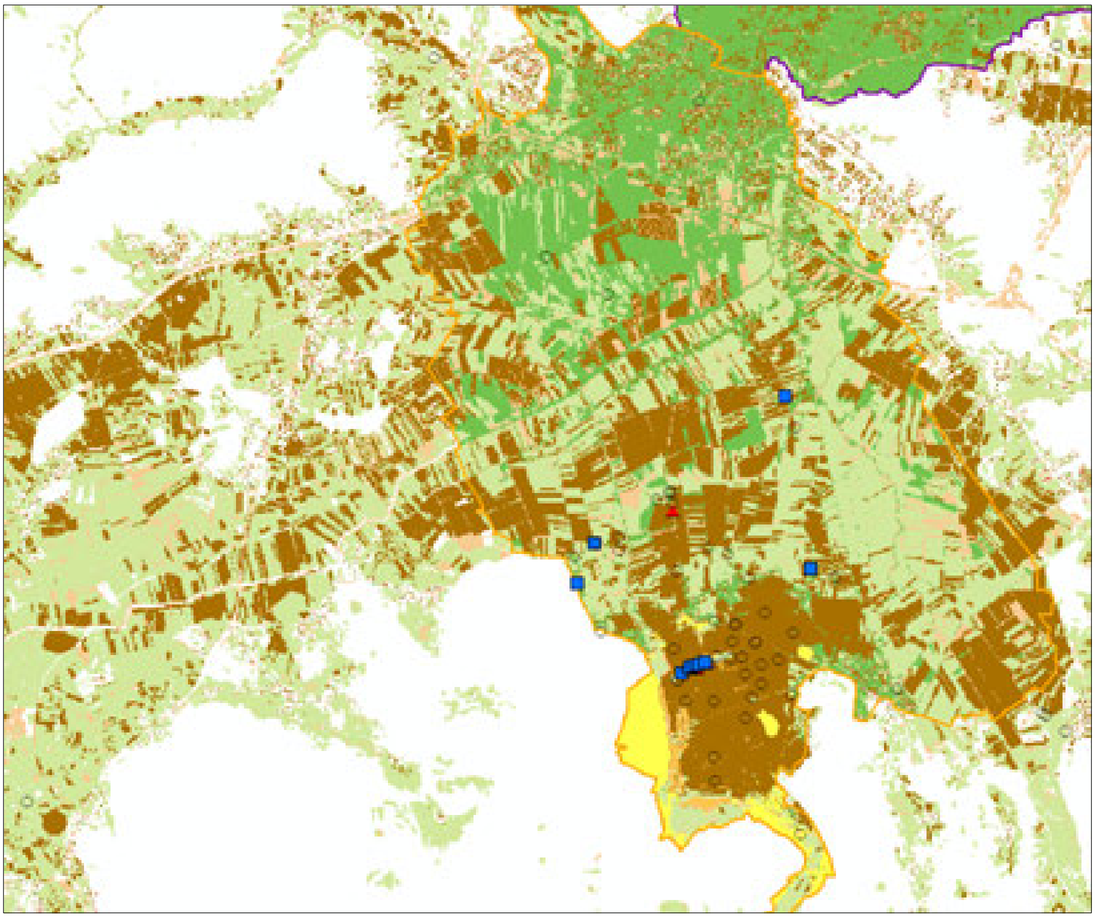


Figure 14. Nitrogen loads and significant trends of nitrogen in ground water.

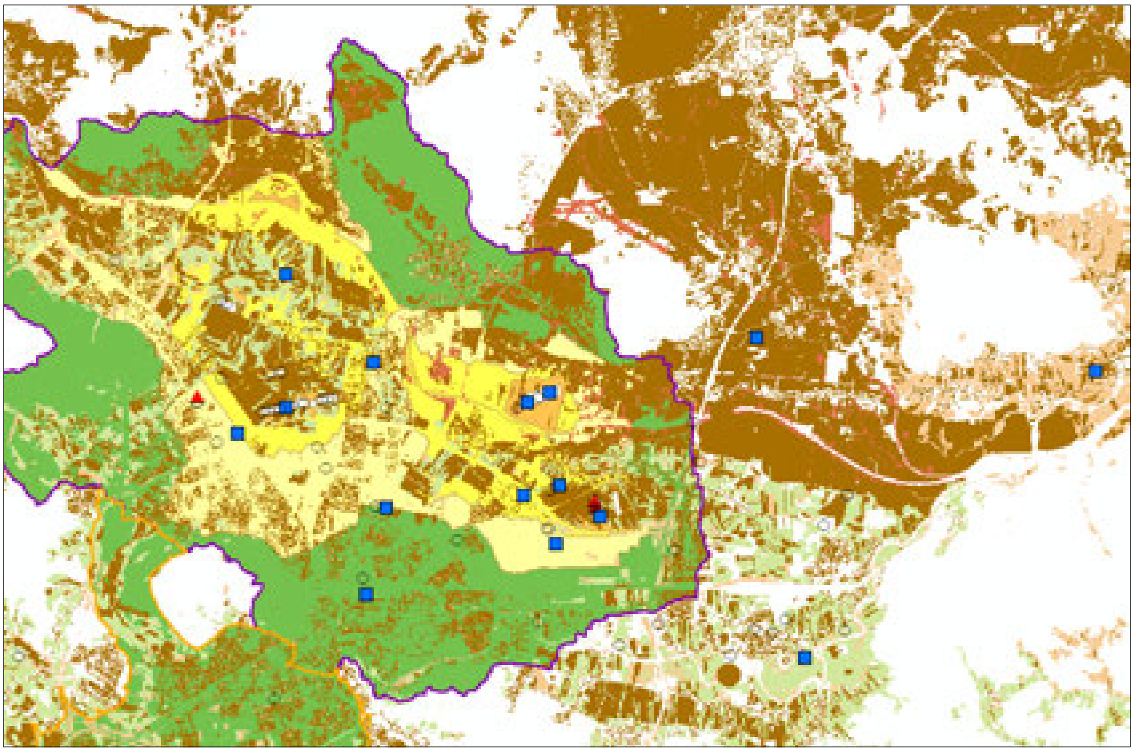


Figure 15. Nitrogen loads (including sewage) and significant trends of nitrogen in ground water.

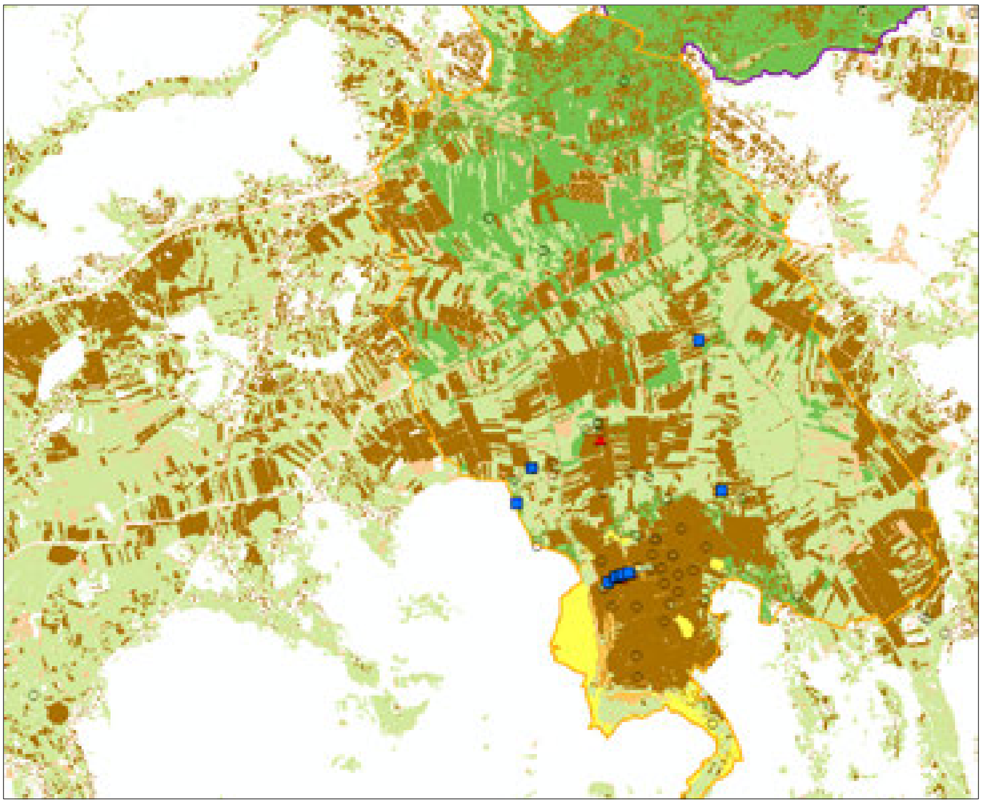
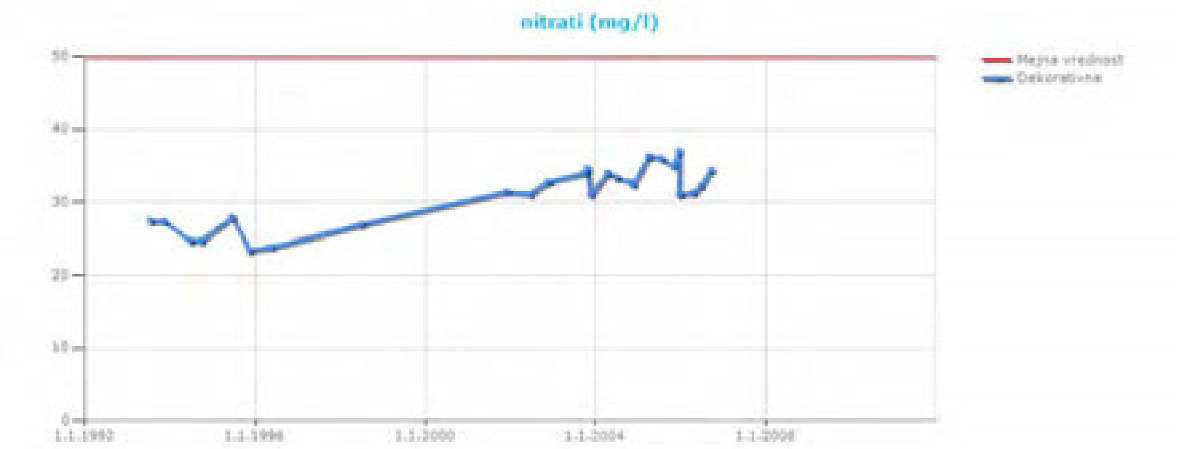
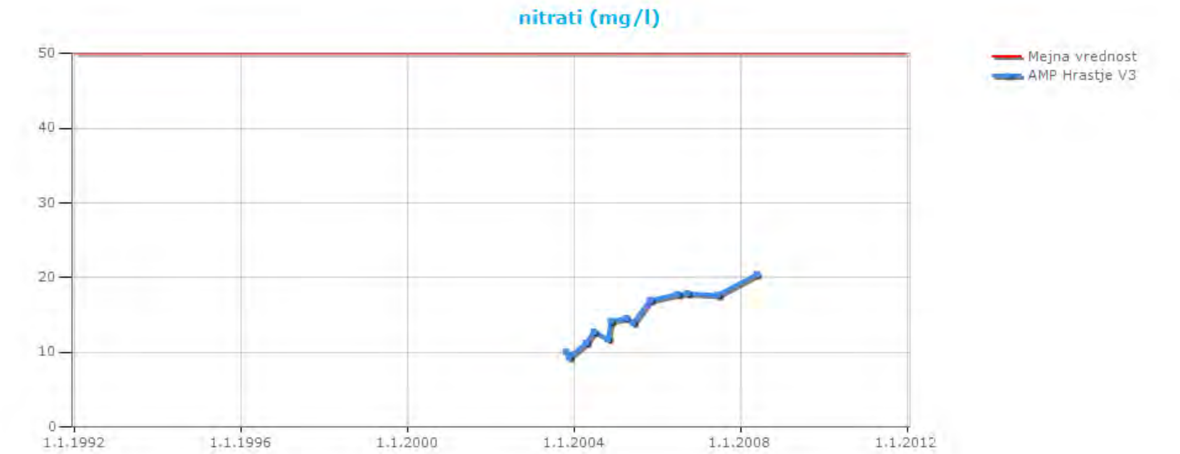
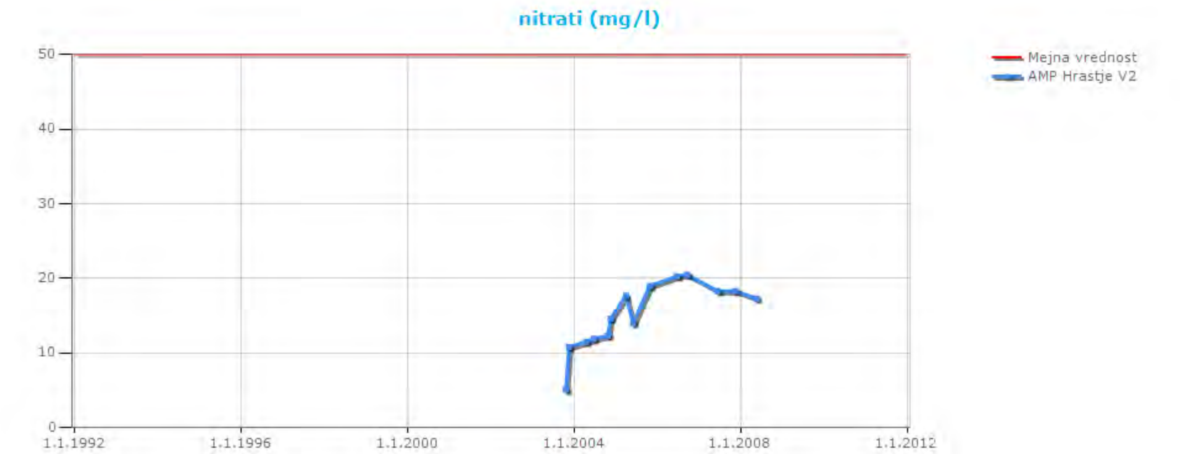


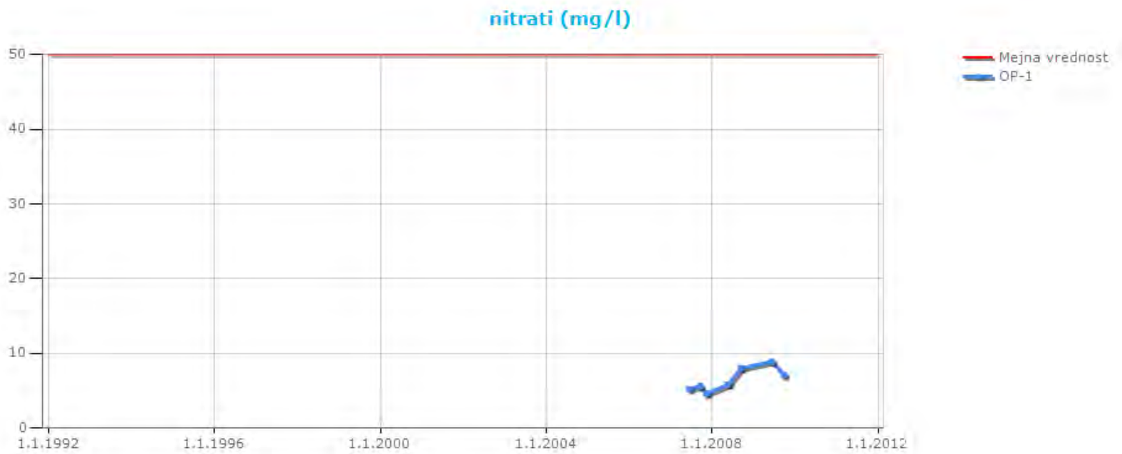
Figure 16. Nitrogen loads (including sewage) and significant trends of nitrogen in ground water.

Significant upward trends on Ljubljansko polje in Barje:





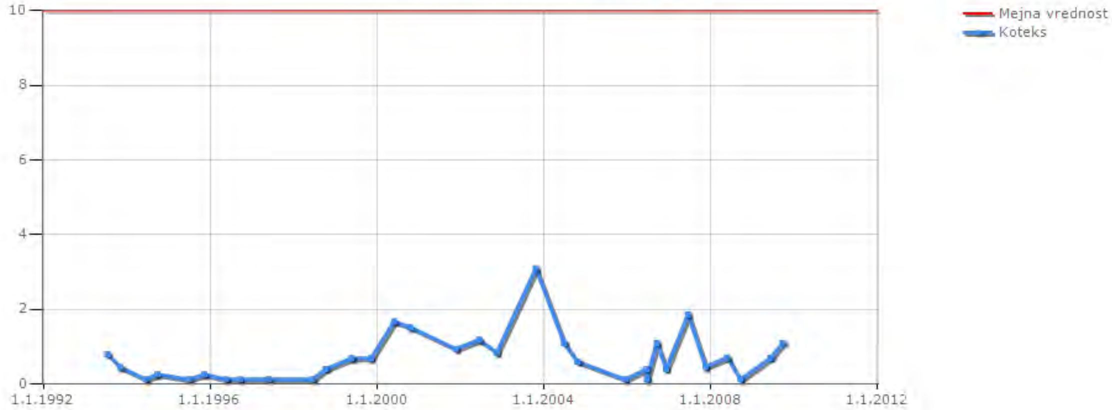



nitrati (mg/l)
50
40
30
20
10
0
1.1.1992
1.1.1996
1.1.2000
1.1.2004
1.1.2008
1.1.2012
Mejna vrednost
OP-1

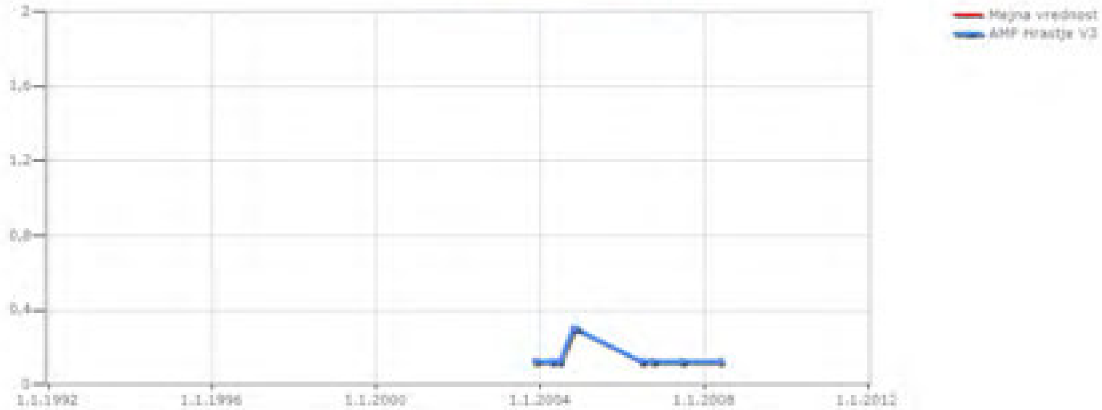

nitrati (mg/l)
50
40
30
20
10
0
1.1.1992
1.1.1996
1.1.2000
1.1.2004
1.1.2008
1.1.2012
Mejna vrednost
VD Brest 1a
VD Brest 2a


1,1,2,2-tetrakloroeten (µg/l)
10
8
6
4
2
0
1.1.1992
1.1.1996
1.1.2000
1.1.2004
1.1.2008
1.1.2012
Mejna vrednost
LP Stožice

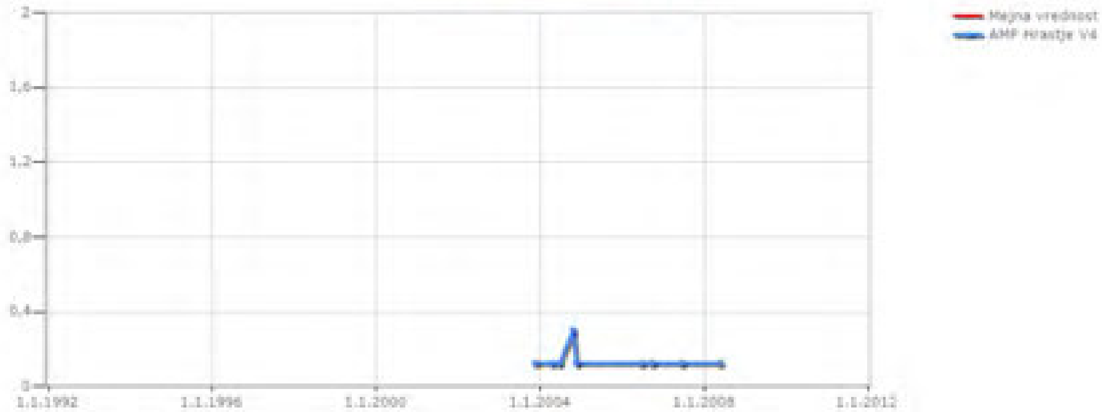
1,1,2,2-tetrakloroeten (µg/l)



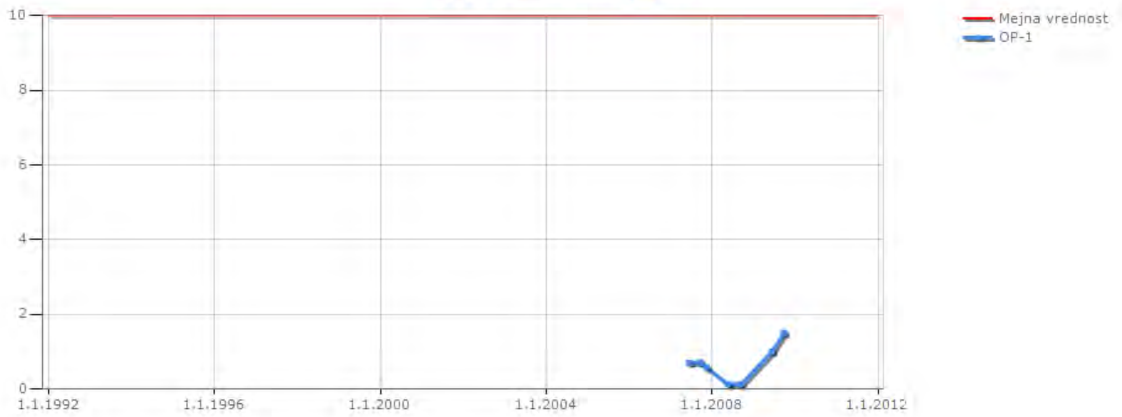
1,1,2,2-tetrakloroeten (µg/l)



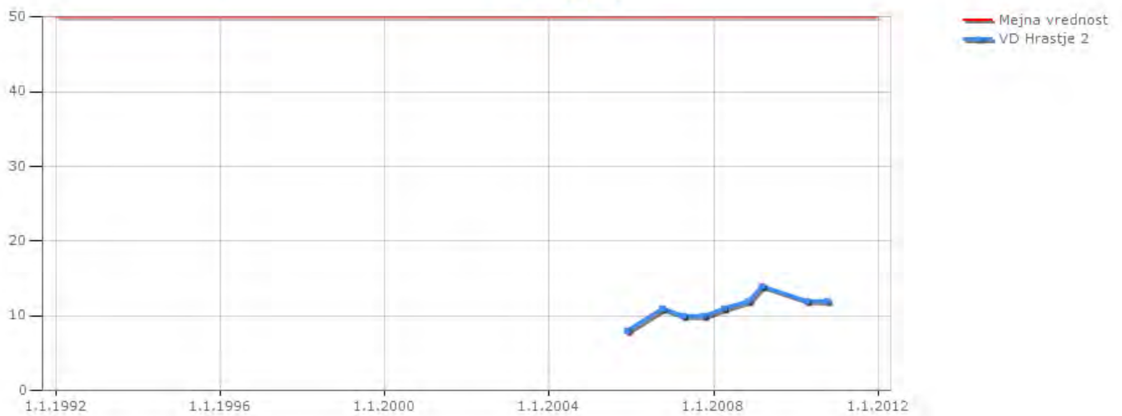
1,1,2,2-tetrakloroeten (µg/l)



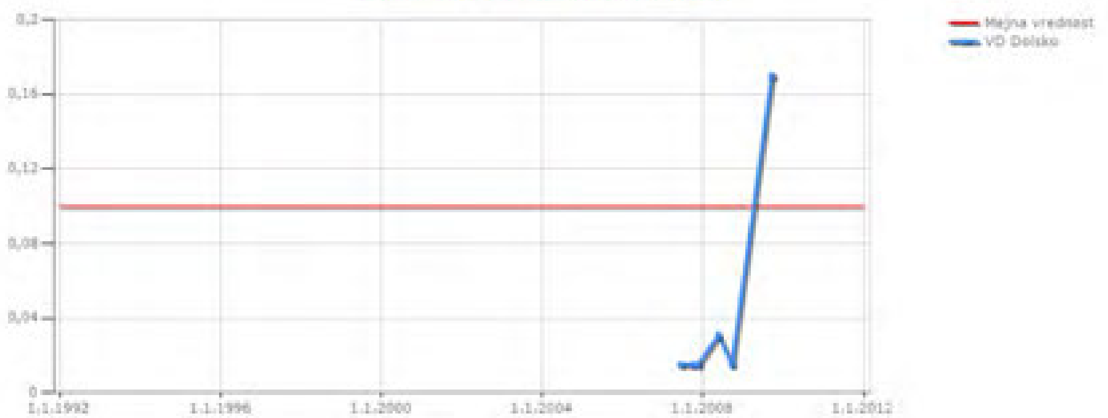
1,1,2-trikloroeten (µg/l)

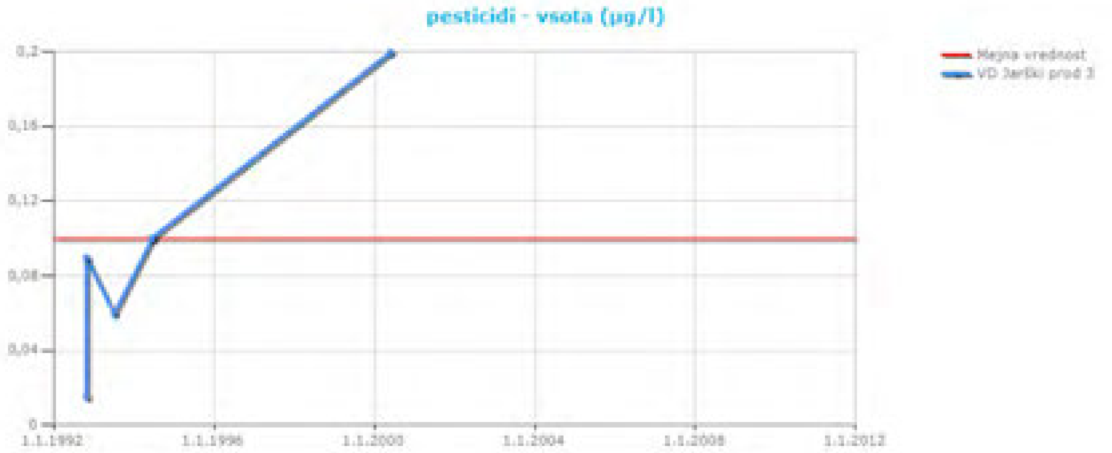


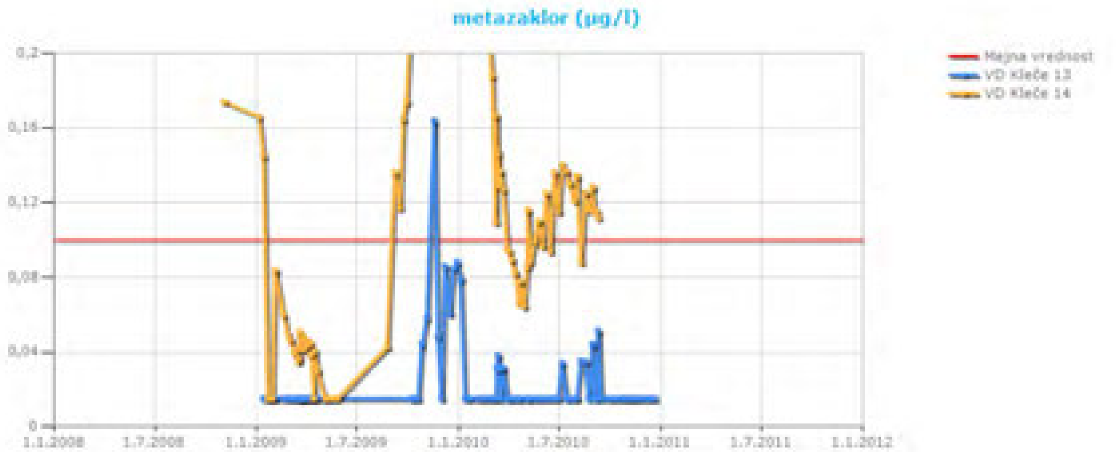
Cr 6+ (µg/l)



metabolit S-metolaklora ESA (µg/l)




pesticidi - vsota (µg/l)
Mejna vrednost
VD Jarški prod 3
0,2
0,16
0,12
0,08
0,04
0
1.1.1992
1.1.1996
1.1.2000
1.1.2004
1.1.2008
1.1.2012


metazaklor (µg/l)
Mejna vrednost
VD Kleče 13
VD Kleče 14
0,2
0,16
0,12
0,08
0,04
0
1.1.2008
1.7.2008
1.1.2009
1.7.2009
1.1.2010
1.7.2010
1.1.2011
1.7.2011
1.1.2012


desetilatrazin (µg/l)
Mejna vrednost
VD Brest 2a
0,2
0,16
0,12
0,08
0,04
0
1.1.2008
1.7.2008
1.1.2009
1.7.2009
1.1.2010
1.7.2010
1.1.2011
1.7.2011
1.1.2012


desetilatrazin (µg/l)
Mejna vrednost
VD Brest 1a
1
0,8
0,6
0,4
0,2
0
1.1.2008
1.7.2008
1.1.2009
1.7.2009
1.1.2010
1.7.2010
1.1.2011
1.7.2011

Table 1. Increasing trends in Ljubljansko polje

Monitoring point	tetrachloroethane	Al	AOX	AT	Cu	Ca	Cr 6+	Cr-filt.	Fe- filt.	fluoride	HCO3	K	Cl	conductivity(20 oC)	conductivity(25 oC)	KPK byKMnO4	ESA	metazachlor	Mg	Na	N	NO3-N	oglj. ksl. Prosta	orthophosphate	pesticides - total	strontium	SO4	TOC
1												•	•	•	•													
2						•																						
3					•								•		•					•			•					
4										•																		
5																				•								
6						•					•		•							•								
7				•									•							•								
8													•		•					•	•						•	
12													•															
13													•															
14													•															
16																							•					
21																		•										
22												•						•		•								
25	•								•			•	•		•					•			•					
29						•					•		•						•	•								
30																			•									
31									•					•														
32						•					•		•						•									
35															•					•				•				
36	•	•												•		•												•
37													•							•								
39													•							•								
41	•												•	•	•						•							
42						•							•						•	•								
43			•										•	•	•				•	•	•					•		
44						•	•						•						•	•								
46						•							•															
47							•	•					•		•					•			•					
48						•																•						
53													•							•								
59	•	•							•																			
60													•	•									•					
62																				•								
63																	•			•						•		
68											•		•		•										•			

Table 2. Increasing trends in Ljubljansko barje

Monitoring point	trichloroethane	trichloroethane	AT	Ca	desetilatrazine	desetilterbutilazine	HCO3	K	Cl	conductivity(20 oC)	conductivity(25 oC)	KPK byKMnO4	Mg	nitrate	orthophosphate	pesticides - total
7									•							
18							•	•			•					
21				•							•		•			
22			•		•									•		
24	•															
27	•					•										
29					•						•			•		•
30						•										
58		•		•	•							•		•	•	
61									•							
65										•						

Table 3. Decreasing trends in Ljubljansko polje

Monitoring point	trichloroethane	tetrachloroethane	trichloroethane	dichlorobenzamide	Al	AOX	AT	Cu	Ba	benzene	B	bromacil	bromide	Zn	Cr (total)	Cr 3+	Cr 6+	Cr-filt.	desetilatrazine	desetilterbutilazine	diuron	fluoride	HCO3	K	Cl	chloroform	metazachlor	metolachlor	Na	Ni-filt.	nitrate	NO3-N	pesticides - total	prometrine	propazine	simazine	SO4	Pb	terbutilazine	terbutryn	TOC	trichloromethane
1						●	●				●								●																						●	
2																			●																						●	
3							●				●			●					●																							
4									●		●														●						●										●	
5							●												●																		●					
6							●												●								●										●					
7																											●															
8							●												●																							
9																					●																					
10																								●																		
11																																●					●					
12							●												●																							
14																			●																							
16							●				●				●	●	●	●	●										●		●						●				●	
17																																					●				●	
20																			●																							
21							●												●																						●	
22							●												●																		●					
23							●						●						●													●					●					
25							●		●								●		●									●												●		
26										●																																
29	●																●															●										
30							●																																			
31							●		●		●								●			●									●						●	●				
32	●																																	●								
33													●						●													●					●					
35											●																										●					
36																									●				●		●						●					
37							●																																			
39	●						●												●				●									●					●				●	
42				●															●																		●					
43							●												●																		●					
44				●															●									●							●		●					
46	●						●												●																●							
47	●			●			●				●	●		●		●			●							●		●			●		●	●		●	●					●
53																																					●					
53				●																														●			●					
57																																●					●					
58							●												●	●																	●					
59							●		●		●						●		●									●			●						●				●	
60	●	●			●		●	●			●			●				●	●											●	●		●					●			●	
62							●												●									●									●		●			
63											●																				●											
65						●																																				
66													●																			●					●				●	
68	●		●				●		●		●						●		●											●	●										●	

Table 4. Decreasing trends in Ljubljansko barje

Monitoring point	trichloroethane	AOX	AT	Zn	desetilatrazine	HCO3	Cl	conductivity(20 oC)	conductivity(25 oC, field)	Mg	Na	NO3-N	propazine	SO4	Pb	terbutilazine	TOC
2			•	•	•					•							
18					•		•		•		•	•					•
19					•				•								
21	•																
23					•				•			•		•			•
24			•		•				•			•		•			
27			•		•				•			•		•			•
29		•	•				•	•			•	•	•		•		•
30			•		•	•	•					•		•			•
31			•	•	•												
46							•				•	•		•			
48			•		•												
50			•		•		•					•		•		•	
51														•			
55														•			
56												•					
58								•									
64												•					
69					•							•		•			

Legend
Expected distribution of Nitrate (mg/l) from numerical model - Pressure: N total surplus (from agriculture and exfiltration from sewage system - households)
< 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
> 50
Alluvial Aquifer boundary
Drinking Water Protection area
Monitoring points
M = 1 : 25 000
0
0.5
1
2 km
N
Geological Survey of Slovenia
GeoZS
INCOME Water Care
Life
Data source:
GURS (2008), ARSO (2012), MOL (2012), VO-KA (2012), GeoZS (2012)
Digital cartography:
Meglič P, Pestotnik S, Janža M, Prestor J.

Appendix 2


Legend
Expected distribution of Nitrate (mg/l) from numerical model - Partial Pressure: N loss from sewage system - households
< 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
> 50
Alluvial Aquifer boundary
Drinking Water Protection area
Monitoring points
M = 1 : 25 000
0 0.5 1 2 km
N
Geological Survey of Slovenia
GeoZS
INCOME Water Care
Life
Data source:
GURS (2008), ARSO (2012), MOL (2012), VO-KA (2012), GeoZS (2012)
Digital cartography:
Meglič P, Pestotnik S, Janža M, Prestor J.
Appendix 3
LJUBLJANA
SAVA
LP Roje
VD Šentvid 1a
VD Šentvid 2a
LP Ježica
LP Stožice
LP Vodovodna
LMP-1/06
PINCOME 1/10
GZL
BSC-1/03
Petrol
Dekorativna
AMP Mercator V1
AMP Mercator V2
IMP
BR-11
VD Kleče 17
VD Kleče 16
VD Kleče-1
VD Kleče 14
VD Kleče 9
VD Kleče 8
VD Kleče 8a
VD Jarški prod 2
VD Jarški prod 3
VD Jarški prod 1
JA-6
PAC 9
LP Obrije
VD Hrastje 3
VD Hrastje 2
AMP Hrastje V3
AMP Hrastje V2
PH 5
VD Hrastje 1
BRP-1B
BRP-1C
Bauhaus
BSV-1/99
LP Navje
ELOK
NOVO POLJE
LP Zadobrova
Studenčnica-Perles - (Zalog Zadobrova)
Perlez
Koteks
Petrol Zalog PVd
Studenčnica-v Slapah (Fužine)
Bajer
Studenčnica-Bajer - (Polje, Na Griču)
Sp. Kašelj
Studenčnica-Zg. Kašelj
Fužinski grad
Vevče Sige
Podgorica 1991
VD Dolsko
P-1/94
PB-4


Legend
Expected distribution of Nitrate (mg/l) from numerical model -
Partial Pressure: N surplus from agriculture
< 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
> 50
Alluvial Aquifer boundary
Drinking Water Protection area
Monitoring points
M = 1 : 25 000
0
0.5
1
2 km
N
Geological Survey of Slovenia
GeoZS
INCOME
Water Care
Life
Data source:
GURS (2008), ARSO (2012), MOL (2012), VO-KA (2012), GeoZS (2012)
Digital cartography:
Meglič P, Pestotnik S, Janža M, Prestor J.
Appendix 4
LJUBLJANA
BR-11
LP Roje
VD Šentvid 1a
VD Šentvid 2a
IMP
Dekorativna
AMP Mercator V1
AMP Mercator V2
Petrol
BSC-1/03
LP Vodovodna
LMP-1/06
PINCOME 1/10
GZL
LP Ježica
LP Stožice
BSV-1/99
LP Navje
ELOK
PB-4
VD Jarški prod 2
VD Jarški prod 3
VD Jarški prod 1
JA-2
LP Obrije
PAC 9
VD Hrastje 3
AMP Hrastje V3
PH 5
VD Hrastje 1
AMP Hrastje V2
BRP-1B
BRP-1C
Bauhaus
NOVO POLJE
LP Zadobrova
Podgorica 1991
VD Dolsko
P-1/94
Studenčnica-Perles - (Zalog,Zadobrova)
Perlez
Koteks
Petrol Zalog PVd
Bajer
Studenčnica-v Slapah (Fužine)
Studenčnica-Bajer - (Polje, Na Gričku)
Sp. Kašelj
Fužinski grad
Vevče Sige
Studenčnica-Zg. Kašelj


Legend
Expected distribution of Cromium (µg/l) from numerical model - Partial Pressure: Cr loss from sewage system (industrial waste water)
0
< 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 5.1
Alluvial Aquifer boundary
Drinking Water Protection area
Monitoring points
M = 1 : 25 000
0
0.5
1
2 km
N
Geological Survey of Slovenia
GeoZS
INCOME Water Care
Life
Data source:
GURS (2008), ARSO (2012), MOL (2012), VO-KA (2012), GeoZS (2012)
Digital cartography:
Meglič P, Pestotnik S, Janža M, Prestor J.
Appendix 5
LJUBLJANA
SAVA


Legend
Expected distribution of Cromium 6+ (µg/l) from numerical model -
Partial Pressure: Cr 6+ loss from sewage system (industrial waste water)
0
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1
1 - 1.2
Alluvial Aquifer boundary
Drinking Water Protection area
Monitoring points
M = 1 : 25 000
0
0.5
1
2 km
N
Geological Survey of Slovenia
GeoZS
INCOME Water Care
Life
Data source:
GURS (2008), ARSO (2012), MOL (2012), VO-KA (2012), GeoZS (2012)
Digital cartography:
Meglič P, Pestotnik S, Janža M, Prestor J.
Appendix 6
LJUBLJANA
BR-11
LP Roje
VD Šentvid 1a
VD Šentvid 2a
IMP
VD Kleče 17
VD Kleče 16
Dekorativna
AMP Mercator V1
AMP Mercator V2
VD Kleče-1
VD Kleče 14
VD Kleče 9
VD Kleče 8
VD Kleče 8a
Petrol
BSC-1/03
LP Vodovodna
LMP-1/06
LP Ježica
LP Stožice
PINCOME 1/10
GZL
BŠV-1/99
LP Navje
ELOK
PB-4
VD Jarški prod 3
VD Jarški prod 2
VD Jarški prod 1
JA-6
LP Obrije
PAC 9
VD Hrastje 3
VD Hrastje 2
AMP Hrastje V3
AMP Hrastje V2
PH 5
VD Hrastje 1
BRP-1B
BRP-1C
Bauhaus
NOVO POLJE
LP Zadobrova
Studenčnica-Perles - (Zalog,Zadobrova)
Perlez
Koteks
Podgorica 1991
VD Dolsko
P-1/94
Petrol Zalog PVd
Bajer
Studenčnica-Bajer - (Polje, Na Gričku)
Sp. Kašelj
Studenčnica-v Slapah (Fužine)
Fužinski grad
Vevče Sige
Studenčnica-Zg. Kašelj