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Hydrological analysis of wetland system

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Tatranská Štrba 2009

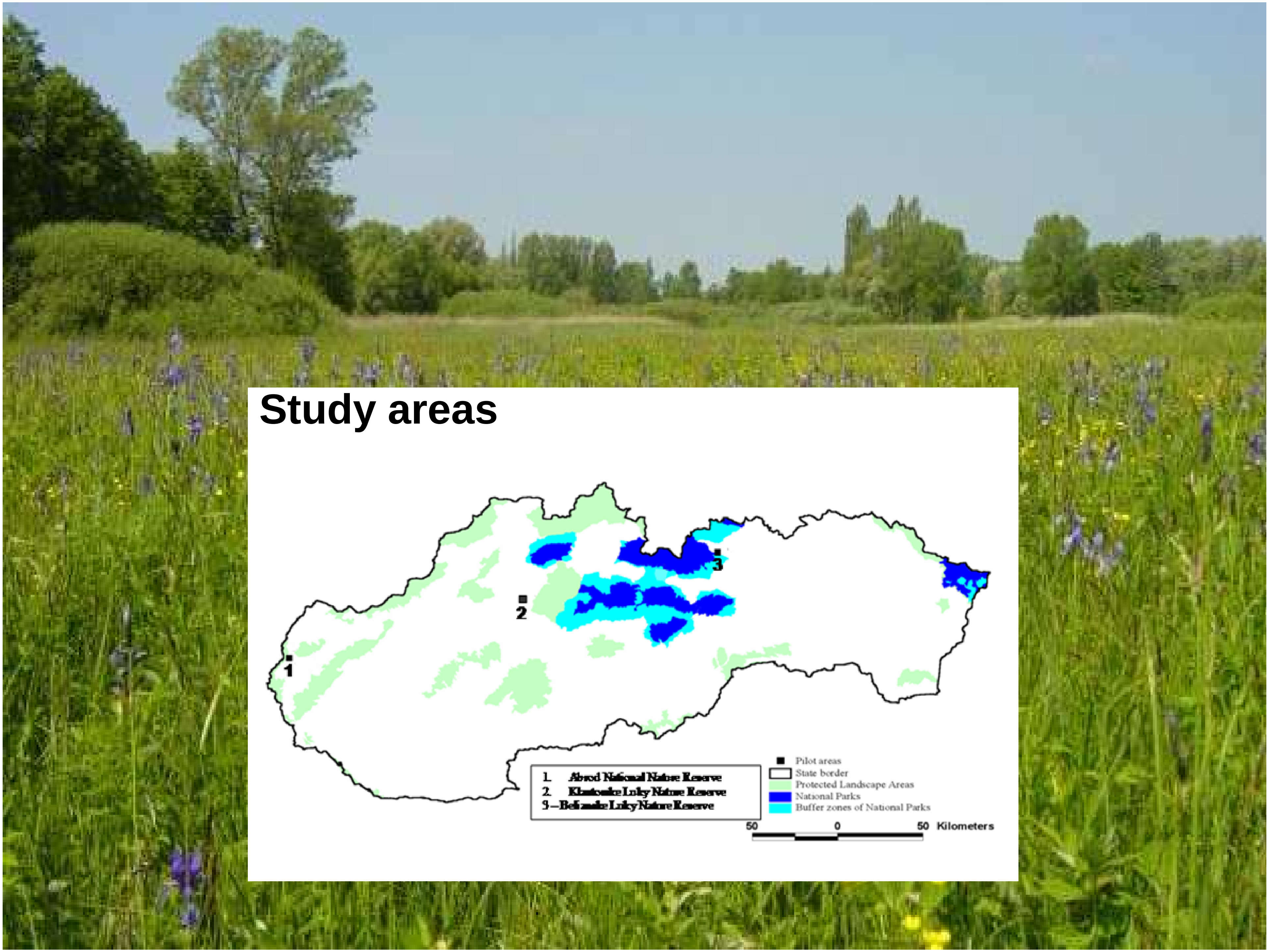
Aim of the study

- to acquire a better understanding of changes in selected wetlands in Slovakia
- to build a methodological basis for future improving of their ecological conditions, which will include recommendations for changes in land use in farm areas, as well as proposals for the creation of buffer zones and land purchases

Analysis of hydrological and climatological regime

- Discharges
- Precipitation totals
- Temperature
- Ground-water level

Time series analysis and creating of predictions models in a monthly time step



Study areas

1
2
3
1. Abrod National Nature Reserve
2. Luky Nature Reserve
3 – Luky Nature Reserve
Pilot areas
State border
Protected Landscape Areas
National Parks
Buffer zones of National Parks
50 0 50 Kilometers

Abrod wetland

Abrod - is a National Nature Reserve

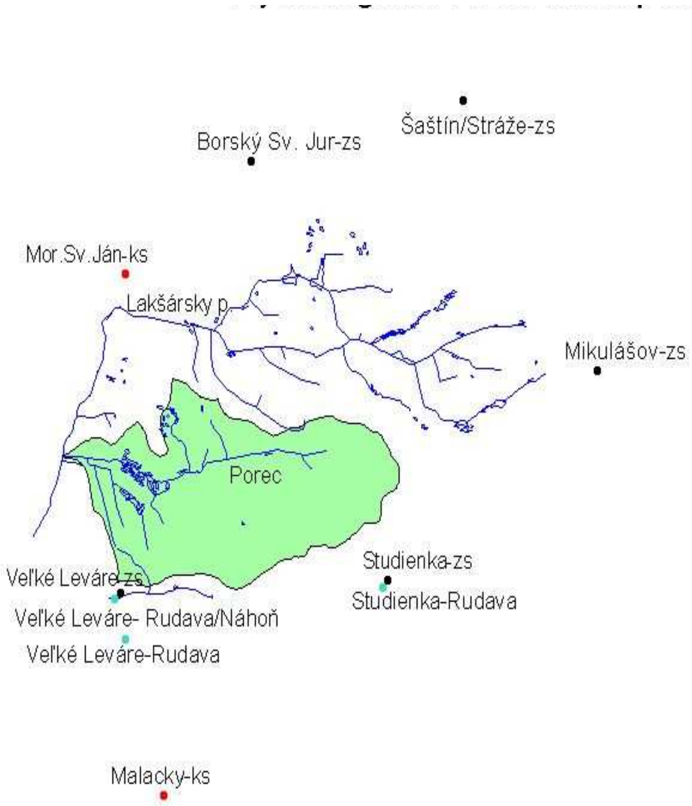
of a 92 hectares, which was designated in 1964 for rich fen protection.

Situated in the Borská lowlands, it has been recognised as a unique botanical and zoological location since 1923.

The wetland is located in natural depression in altitude 153 to 149 m a.s.l.

Currently, 480 taxa of vascular plants have been recorded, including 104 threatened species, of which 3 occur only in this area of Slovakia.

The Porec Creek is draining the Abrod wetland.



Station	Id of gauging station	Observation period	Number of years observation
Veľké Leváre/Rudava	5072	1.1.1961 - 31.12.2004	44
Studienka/Rudava	5070	1.1.1971 - 31.12.2004	34

Station	Id of gauging station	Observation period	Number of years of observation
Malackya	16160	1.1.1901 – 31.12.2004	104
Šaštín/Stráže	15200	1.1.1901 – 31.12.2004	104

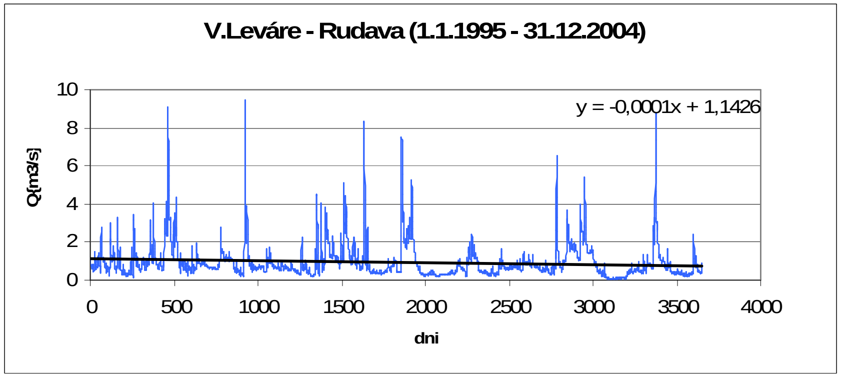
Analysis of discharges

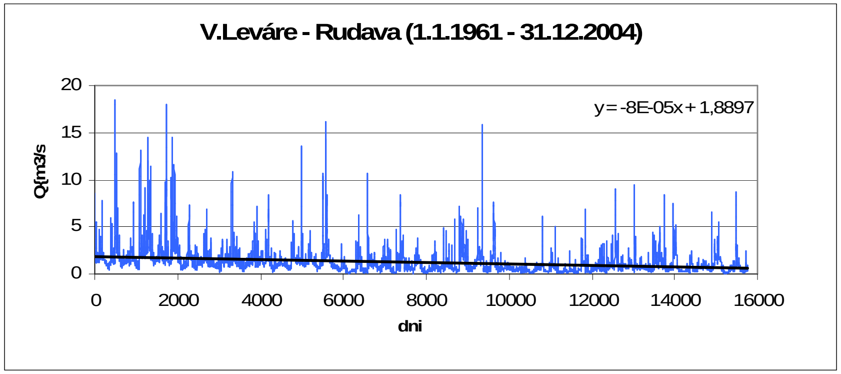
- Statistical analysis of mean annual, daily and monthly discharges
  - Basic statistical analysis
  - Homogeneity tests
  - Trend analysis
  - Analysis of seasonal and cyclical components

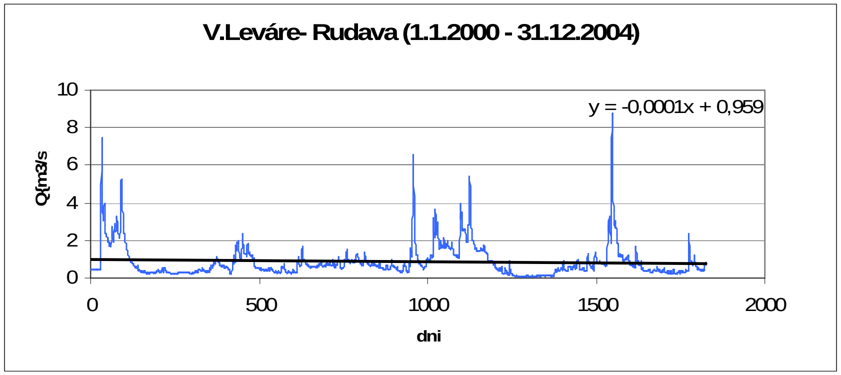
Abrod

Discharge time series - trends

Last 10 years



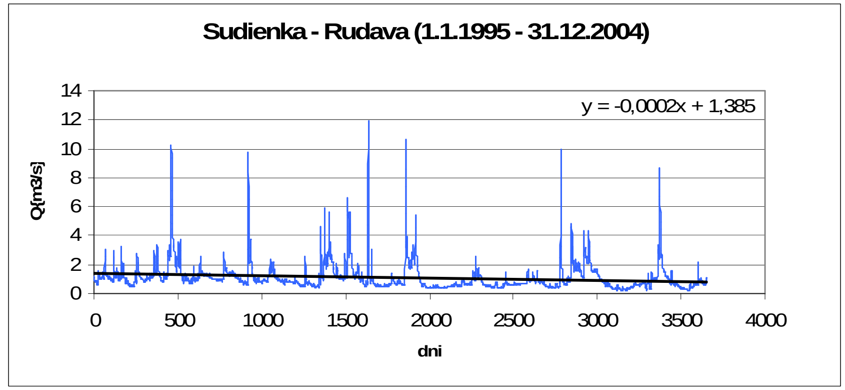


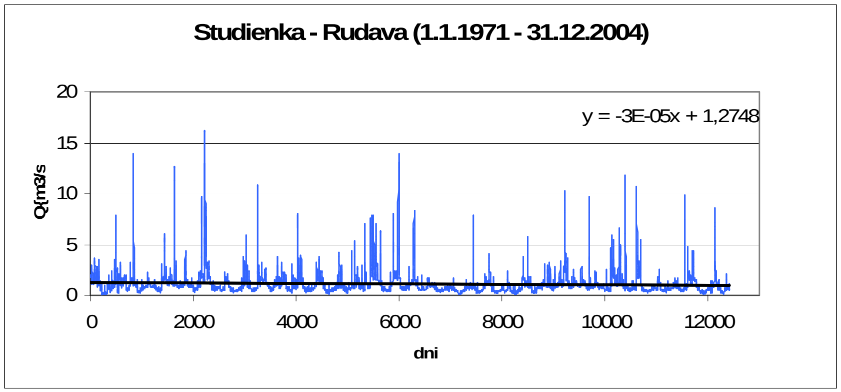


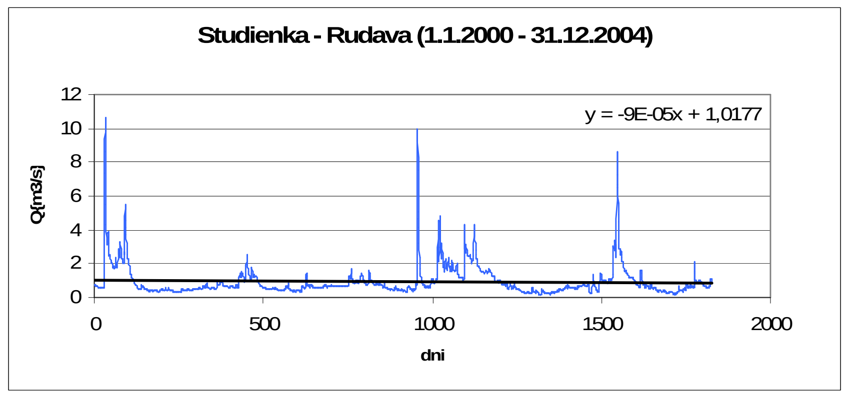
Last 5 years

Discharge time series - trends

Last 10 years

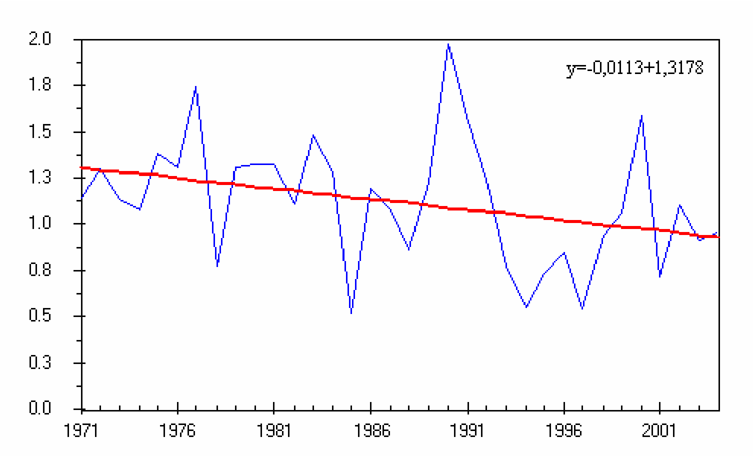


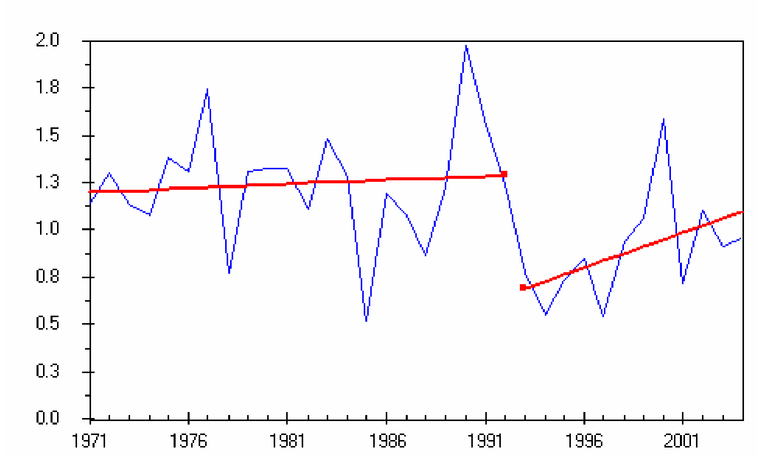




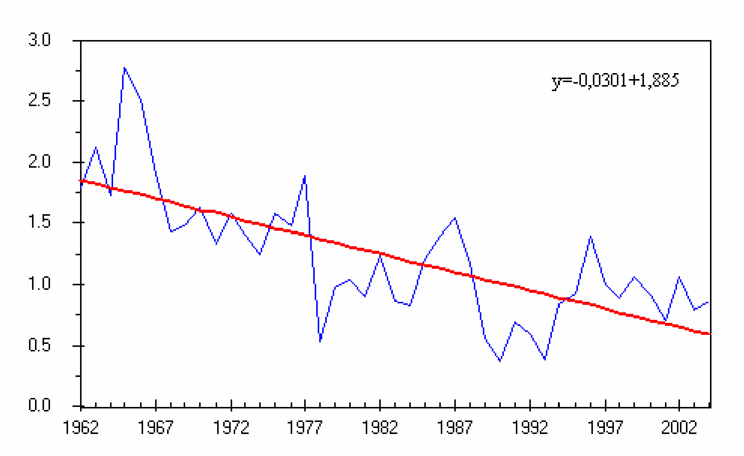
Last 5 years

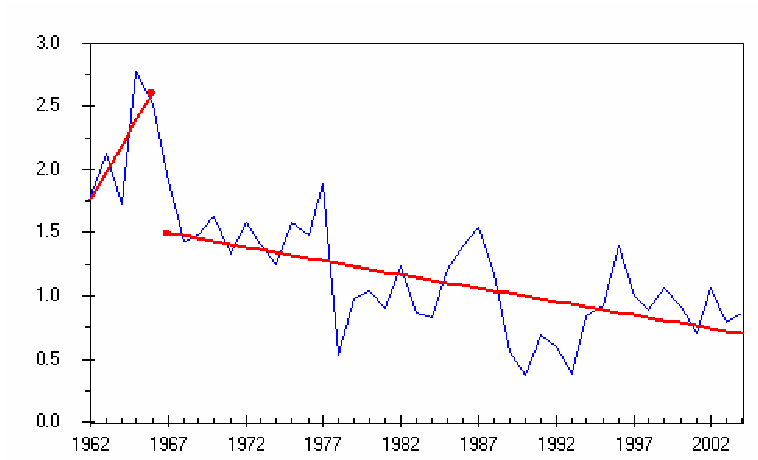
Studienka - Rudava





Veľké Leváre - Rudava





Sesonality analysis

	Veľké Leváre - Rudava		Studienka - Rudava	
Month	Qmax	Qmin	Qmax.	Qmin
I	**11**	0	1	2
II	**6**	0	3	1
III	3	0	**8**	0
IV	0	2	**4**	1
V	3	5	2	2
VI	0	**15**	**5**	0
VII	0	**8**	3	2
VIII	2	**6**	1	3
IX	2	2	2	**9**
X	**5**	3	2	**4**
XI	**7**	1	1	**7**
XII	**4**	1	2	3

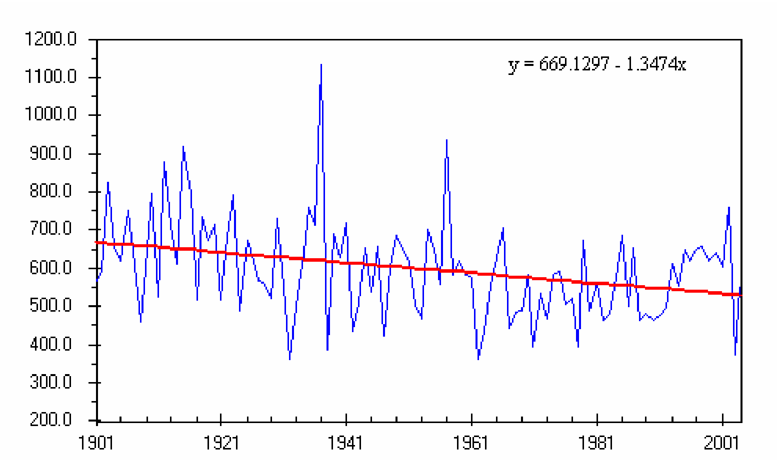
Results – discharge time series

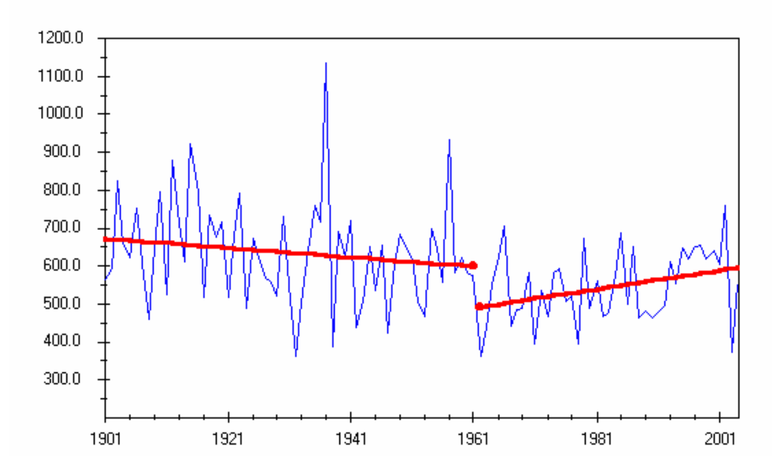
– trend of mean daily discharges is slightly decreasing for the whole period of observation
– decrease in mean daily discharges is little higher in the last period of 10 years, but not significant
– decrease in mean daily discharges is little higher in the last period of 2000-2004, than in 1984-2004
– maximum discharges – prevaling winter season
– minimum discharges – autumn and summer season

Analysis of precipitation time series

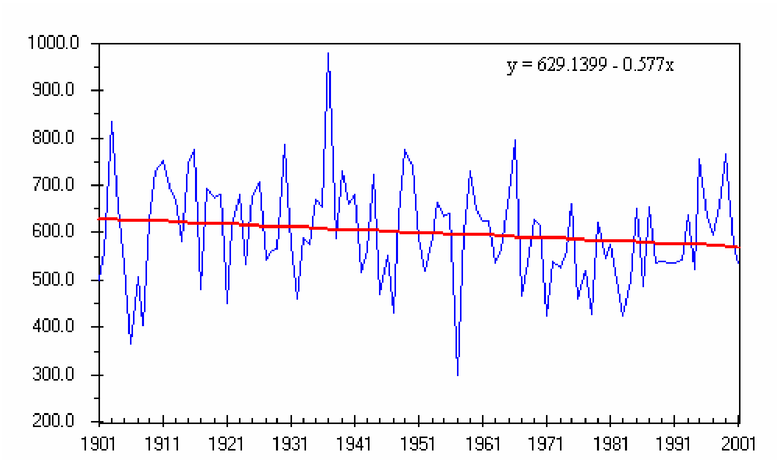
- **Analysis of mean daily, monthly and annual precipitation totals**
  - **Basic statistical analysis**
  - **Testing of homogeneity**
  - **Trend analysis**
  - **Analysis of 30-years periods**

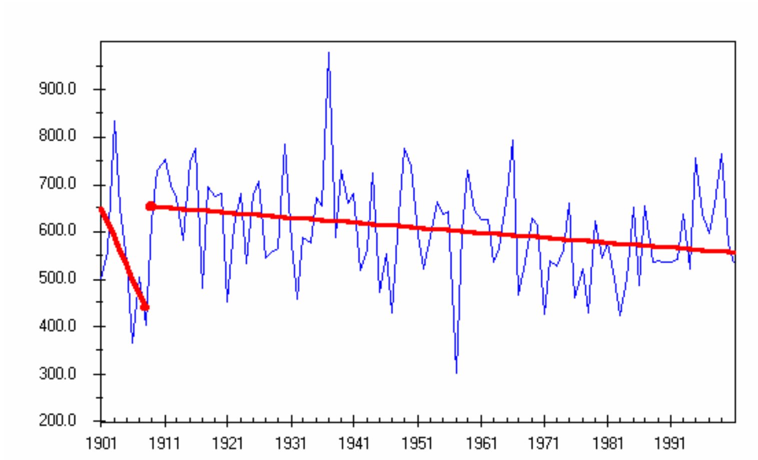
Šaštín Stráže



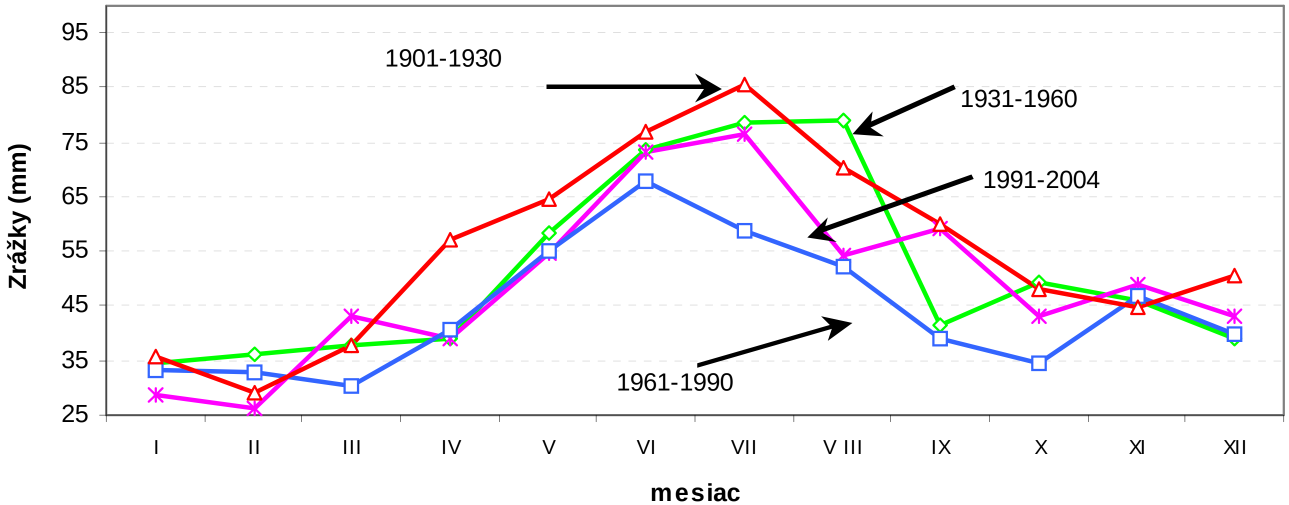


Malacky

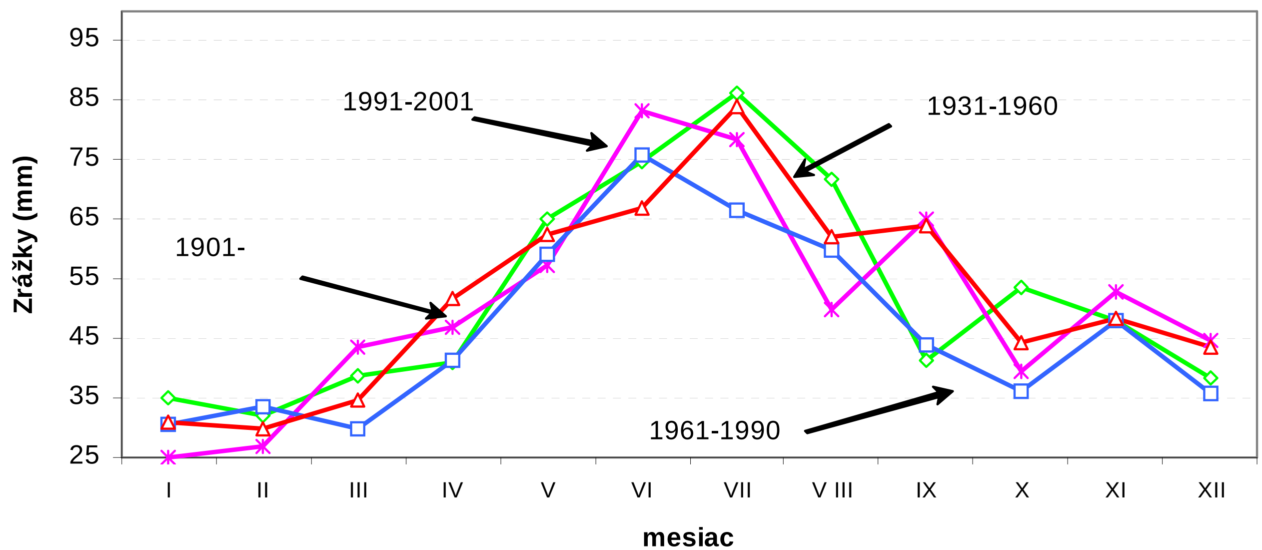




Monthly precipitation - 30 years periods



Šaštín-Stráže



Malacky

Seasonality analysis

	Šaštín /Stráže		Malacky	
Month	max	min	max	min
1	1	15	0	17
2	2	27	2	20
3	1	12	1	11
4	5	4	4	9
5	13	4	17	4
6	24	2	18	2
7	22	3	27	3
8	13	1	9	1
9	9	4	12	4
10	9	21	5	16
11	5	6	5	7
12	0	5	1	7

Results – precipitation time series

- slight decrease in annual precipitation totals in all stations
  - about 30 mm/year within 100 years period of observation
  - from 30 years period the most dry period was in 1961-1990
- maximum precipitation totals – prevailing summer season
- minimum precipitation totals – prevaling autumn and winter season

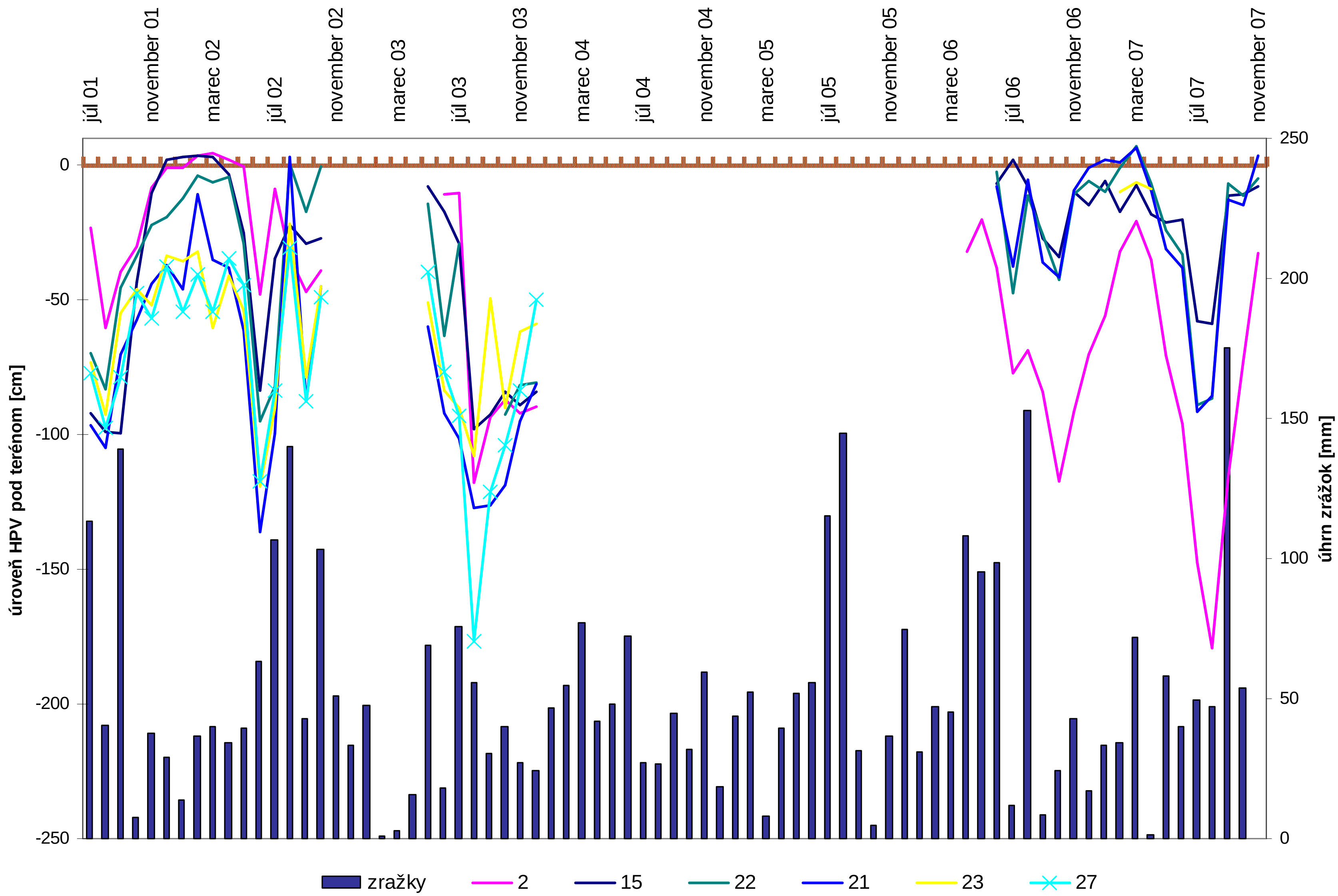
Analysis of ground-water level

- **Mean monthly values of ground-water levels**
- **Trend analysis**

Location of probes and profiles of grounwater measurements

Measurements: 1th period 8.7.2001 – 21.12.2003

2nd period from 23.4.2006



júl 01
november 01
marec 02
júl 02
november 02
marec 03
júl 03
november 03
marec 04
júl 04
november 04
marec 05
júl 05
november 05
marec 06
júl 06
november 06
marec 07
júl 07
november 07
úroveň HPV pod terénom [cm]
0
-50
-100
-150
-200
-250
úhrn zrážok [mm]
250
200
150
100
50
0
zražky
2
15
22
21
23
27

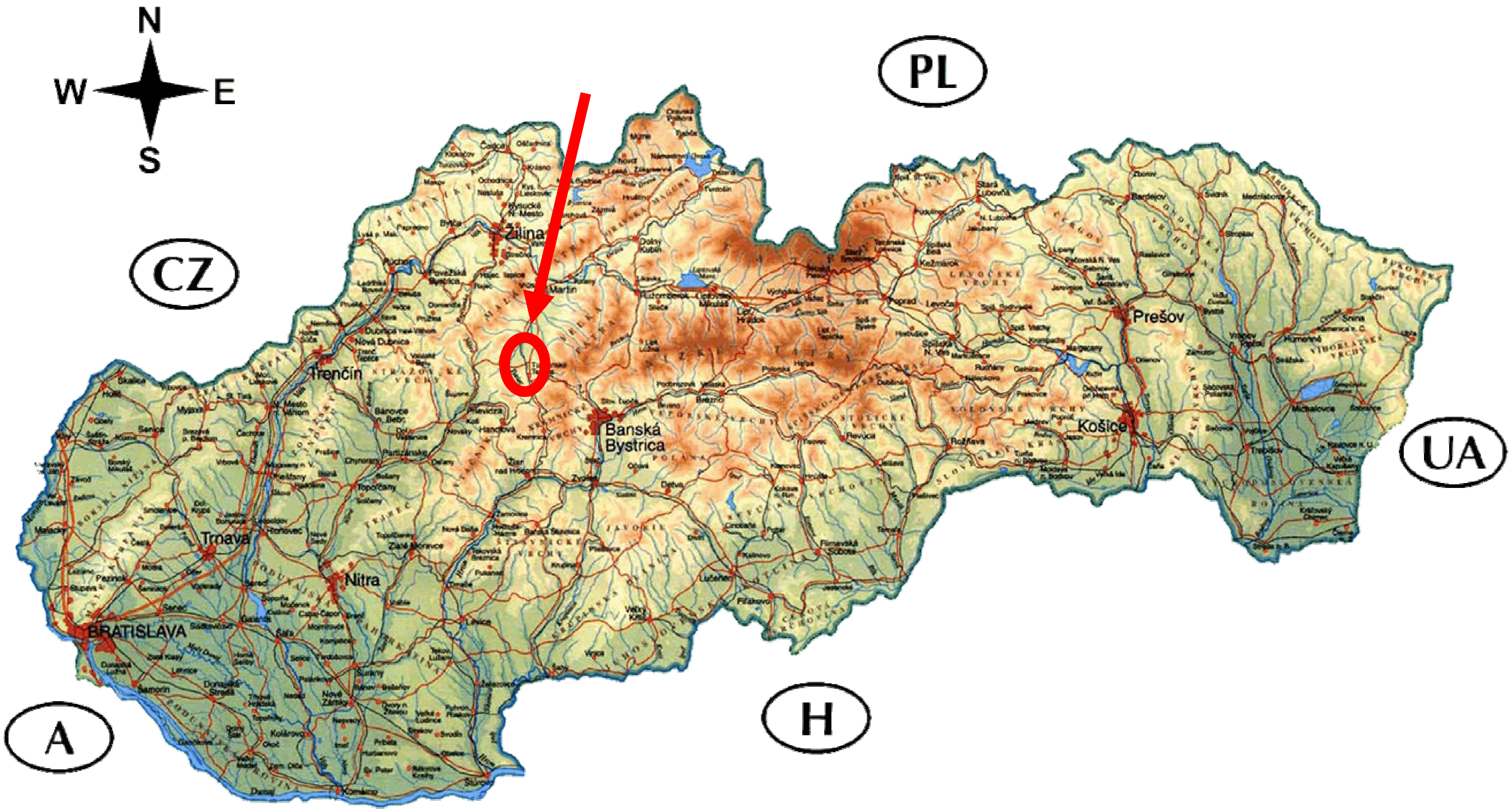
Results – ground water level

- In the winter and spring periods GWL is very close to the surface,
- Summer period GWL is sinking to 100 cm and more under the terrene, the vaporation is increasing and he precipitation

- GWL trend is influenced by precipitation totals and by surronding streams
- During the period 1961-2006 the precipitation totals are slightly increasing and the GWL trend is stable (probe of SHMU ZS 20)

- We assunme that in this region no significant decrease of GWL could be expected

Kláštorské lúky wetland



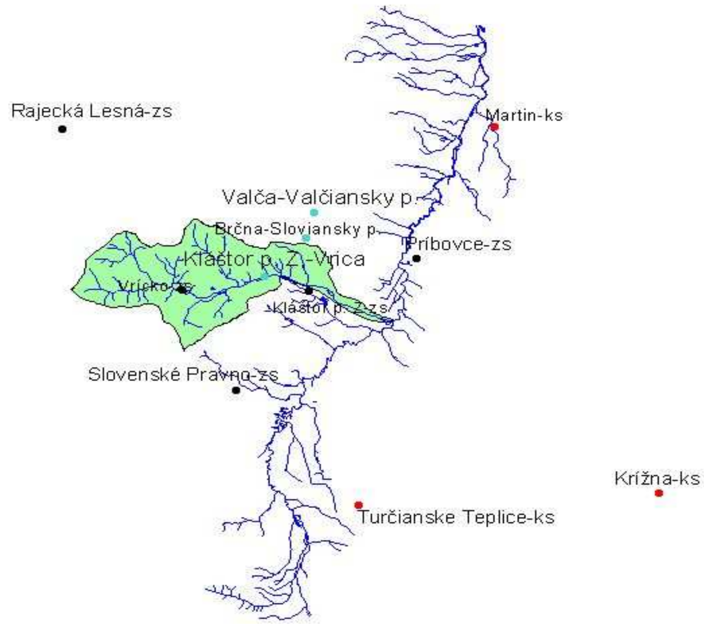
The Kláštorské lúky National Nature Reserve wetland is situated in the Strážovské Mountains.

The Kláštorské lúky wetland is a part of the Turiec wetlands, which was designated as the Ramsar site of the international importance in 1998 with a total area of 467 ha.

In 1974, 86 ha were designated as a National Nature Reserve (NNR), the category of strictest protection for national sites of special scientific interest.

Altogether 223 taxons of vascular plants were recorded within the site; of these, 28 are listed as threatened at the national scale.

A total of 90 species of spiders were identified on the site



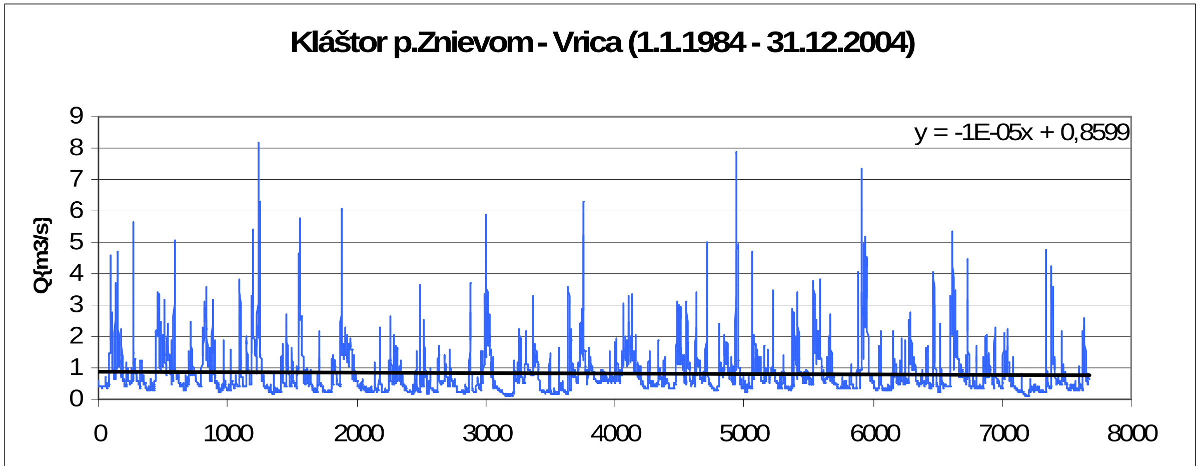
Station	Id of gauging station	Observation period	Number of years of observation
Kláštor pod Znievom/Vrica	5995	1.1. 1984 – 31.12. 2004	21
Kláštor pod Znievom/Znievsky creek	6000	1.1. 1969 – 31.12. 1986	18
Slovany/Vrica	6010	1.1. 1969 – 31.12. 1985	17

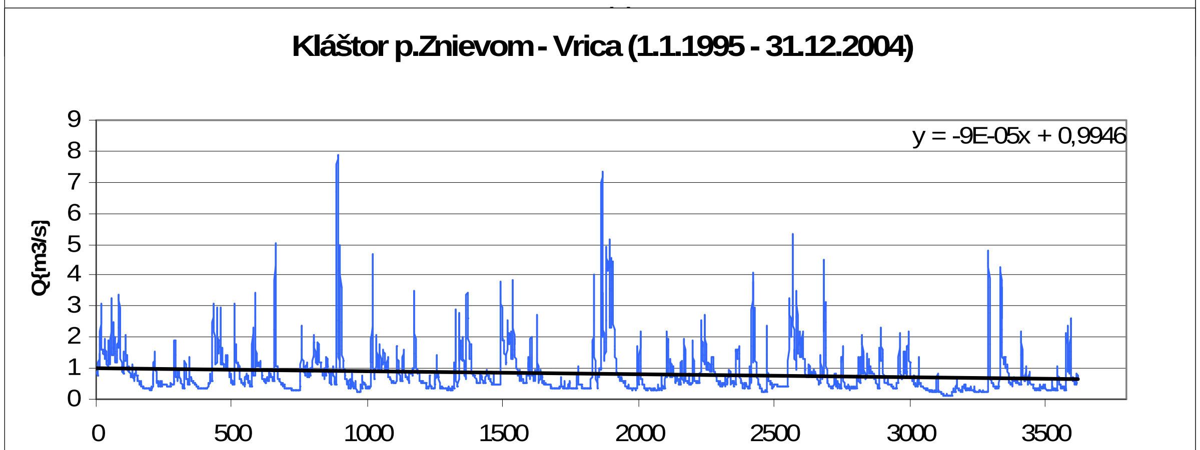
Station	Id of gauging station	Observation period	Number of years of observation
Kláštor pod Znievom	24180	1.1.1901 - 31.12.2004	104
Príbovce	24220	1.1.1901 - 31.12.2004	104

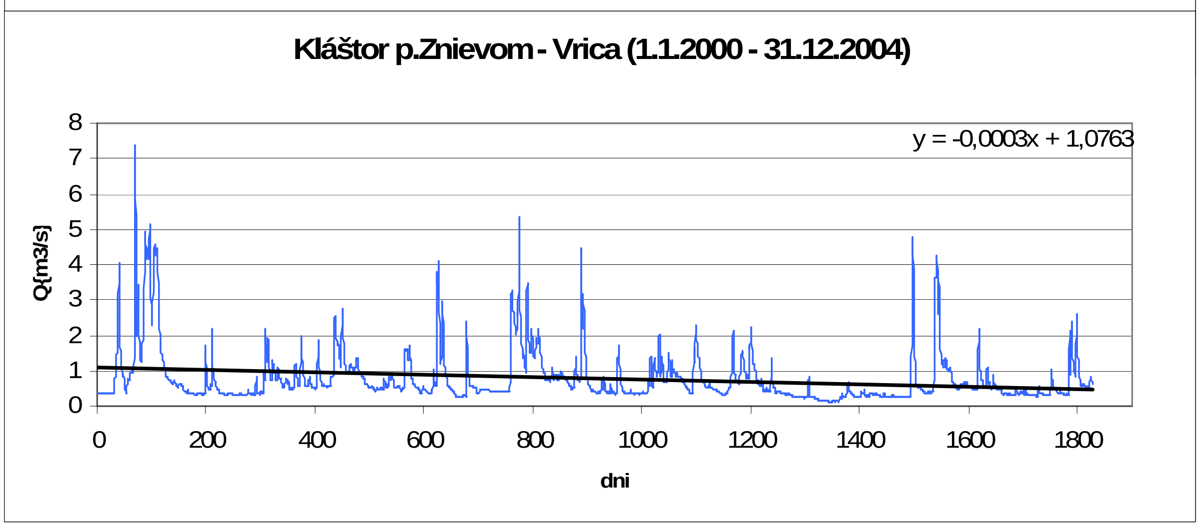
Analysis of discharges

- Statistical analysis of mean annual, daily and monthly discharges
  - Basic statistical analysis
  - Homogeneity tests
  - Trend analysis
  - Analysis of seasonal and cyclical components

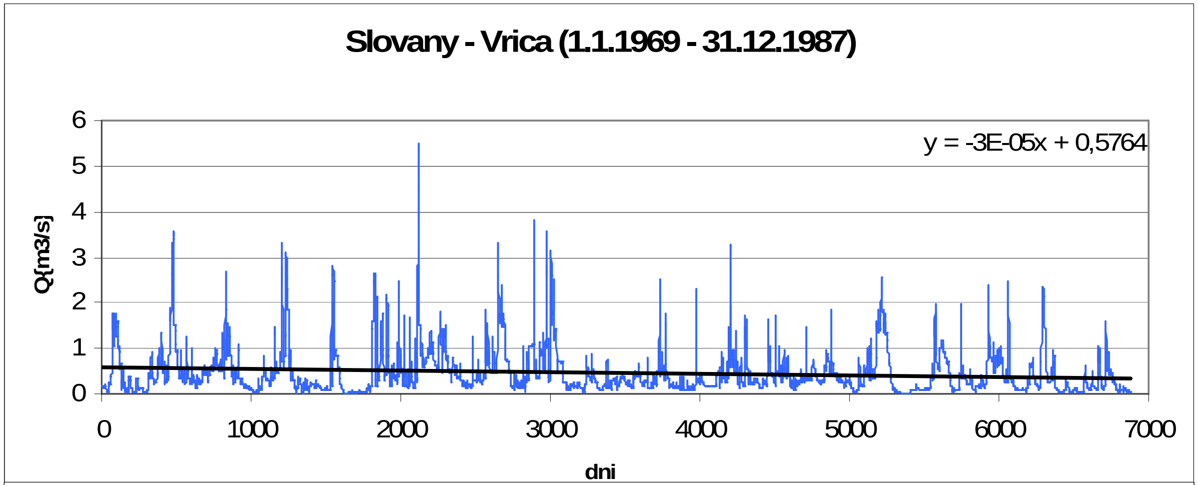
Kláštor pod Znievom – Vrica- discharges

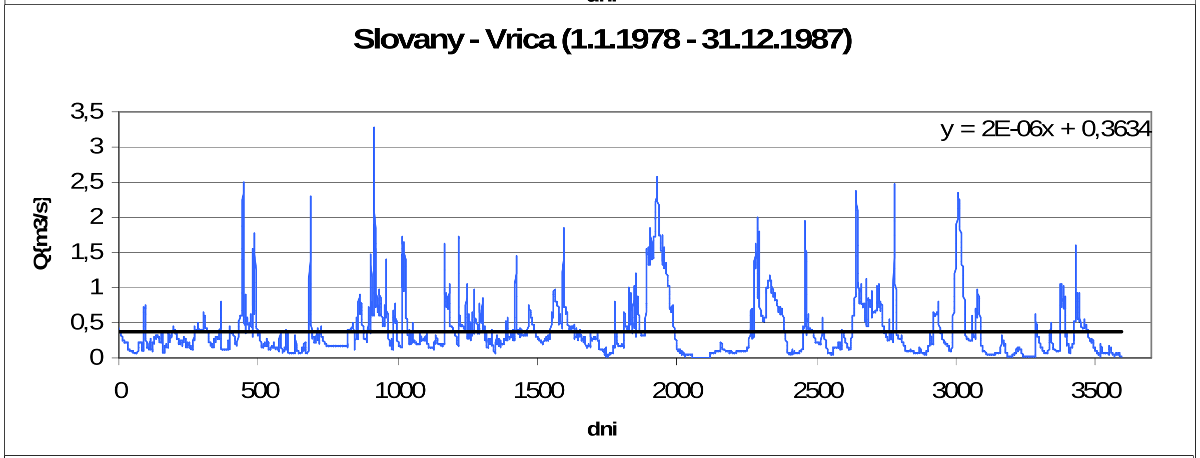


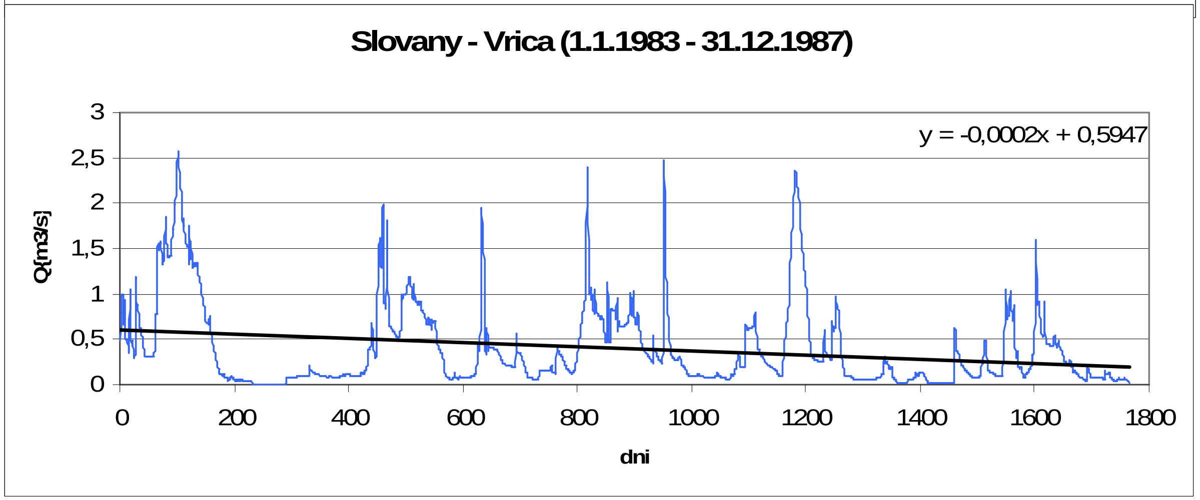




Slovany - Vrica discharges







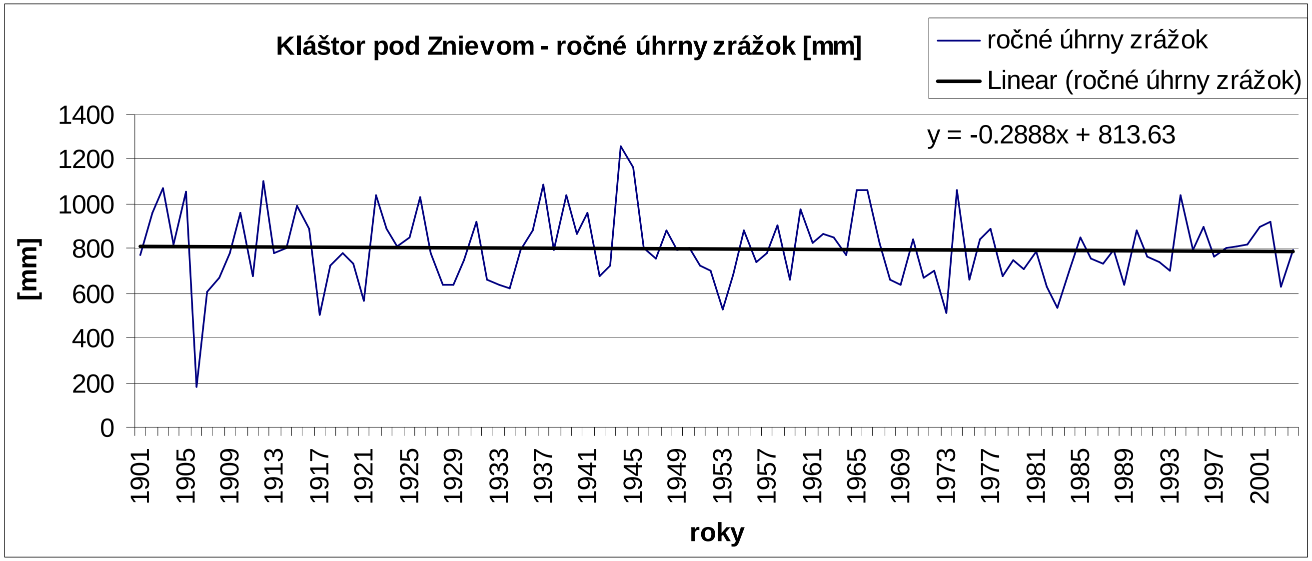
Results – discharges

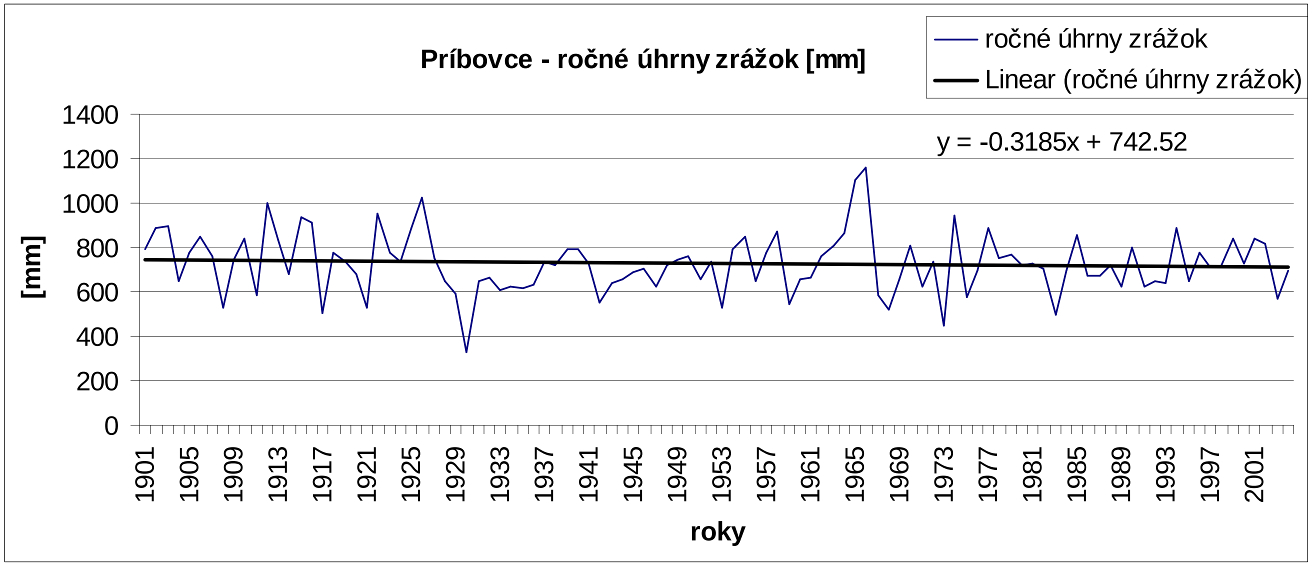
- Kláštor pod Znievom - Vríca
  - trend of mean daily discharges is slightly decreasing for the whole period of observation
  - decrease in mean daily discharges is little higher in the last period of 2000-2004 (mean daily discharge = 0,732 m3/s, max. daily discharge = 0,783 m3/s), in 1984-2004 mean daily discharge = 0,808 m3/s, max. daily discharge = 0,819 m3/s)
- Slovany – Vríca
  - trend of mean daily discharges is slightly decreasing
- Time series of discharges in both stations were homogenous

Analysis of precipitation time series

- **Analysis of mean daily, monthly and annual precipitation totals**
  - **Basic statistical analysis**
  - **Testing of homogeneity**
  - **Trend analysis**
  - **Analysis of 30-years periods**

Kláštor pod Znievom - precipitation

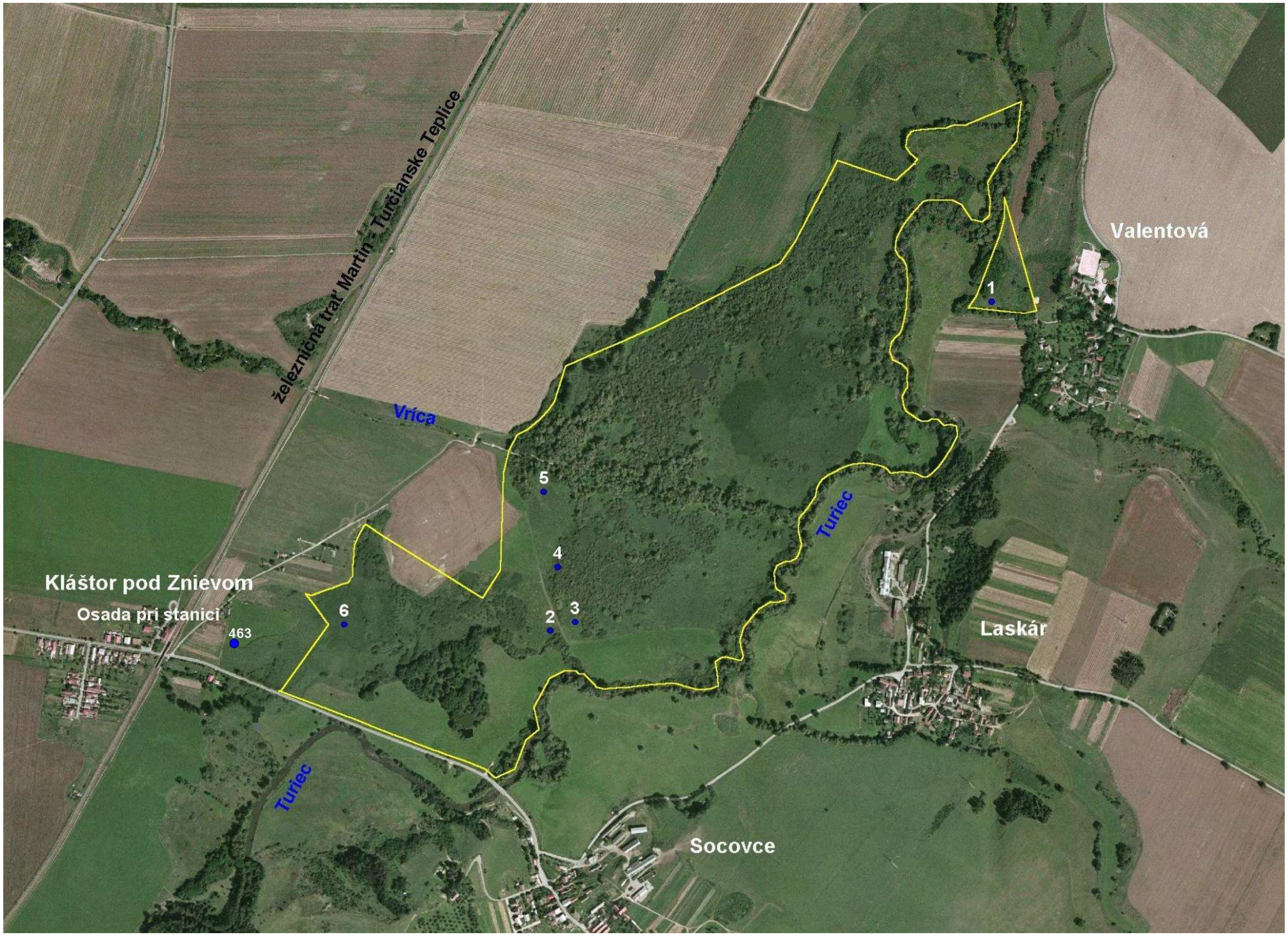




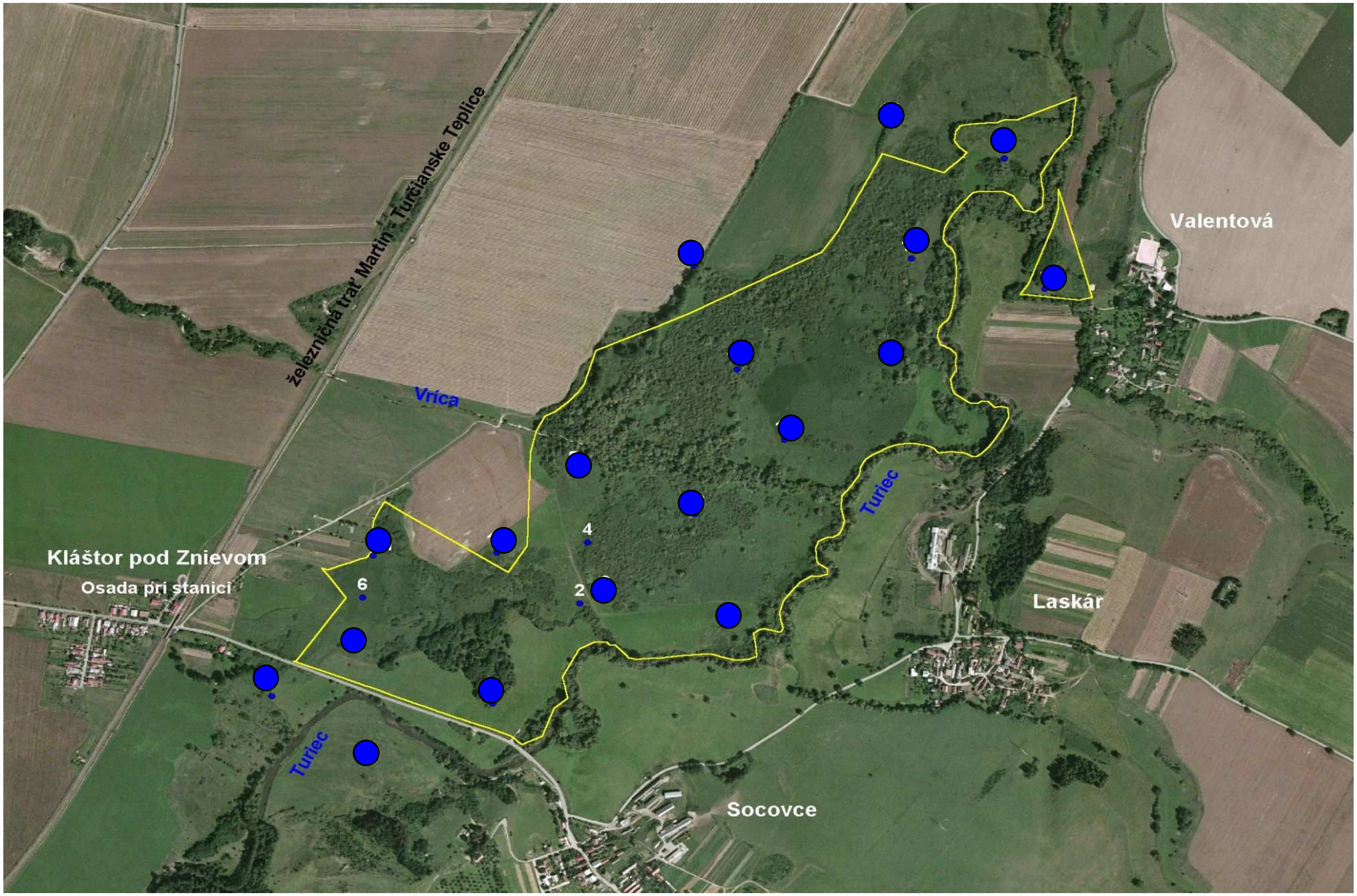
Observation network of ground-water level

- 1 observation object provided by SHMI (Kláštor pod Znievom č. 463, observation from 1958)
- 1996 – 2004 – 6 observation objects in the wetland region (some of them were stolen, observation finished)
- From 2005 – observation in 18 objects, new location was proposed

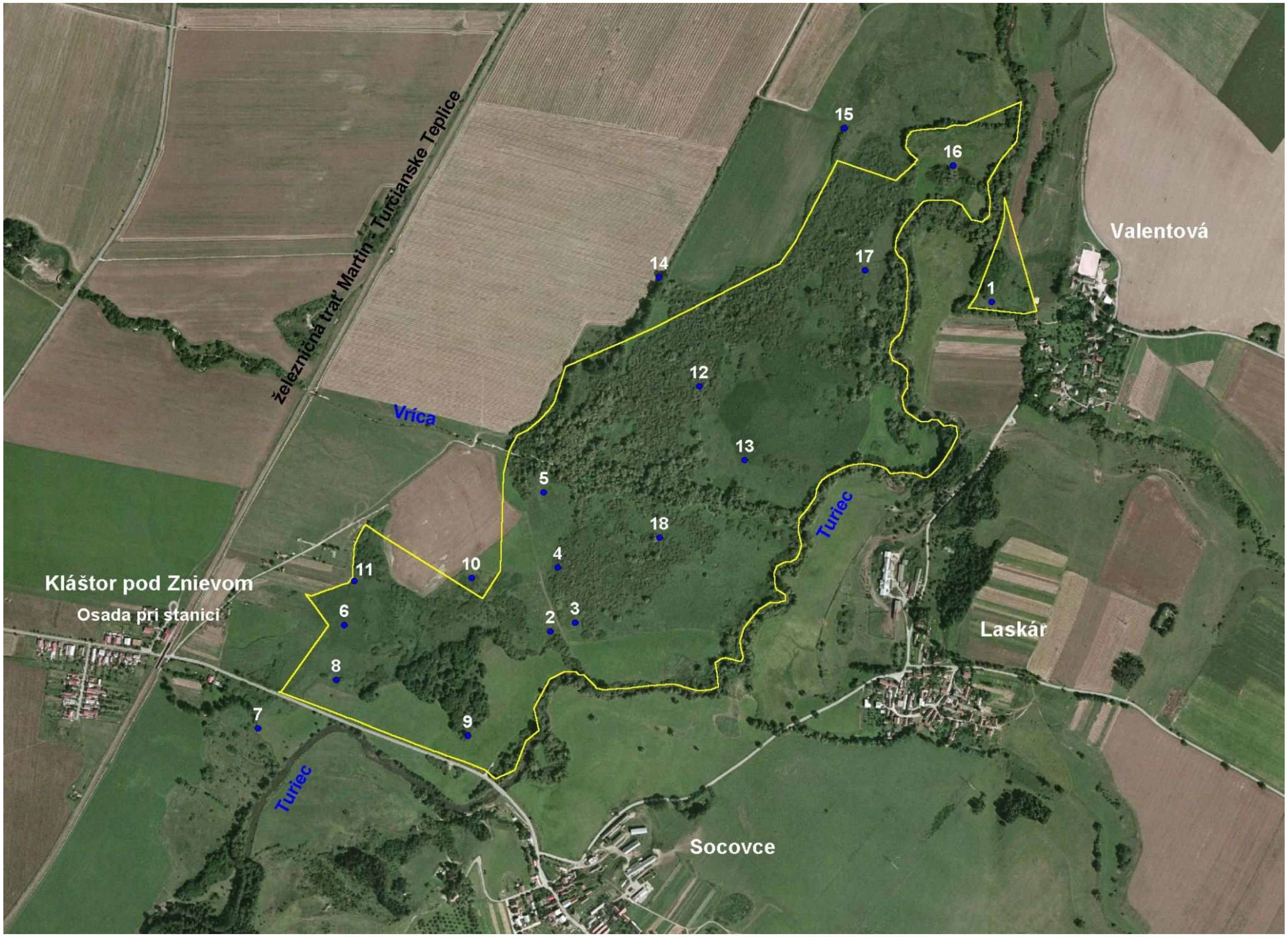
Observation in 1996-2004



Proposal a new observation system



New network of ground-water observation (1-18) from 2005



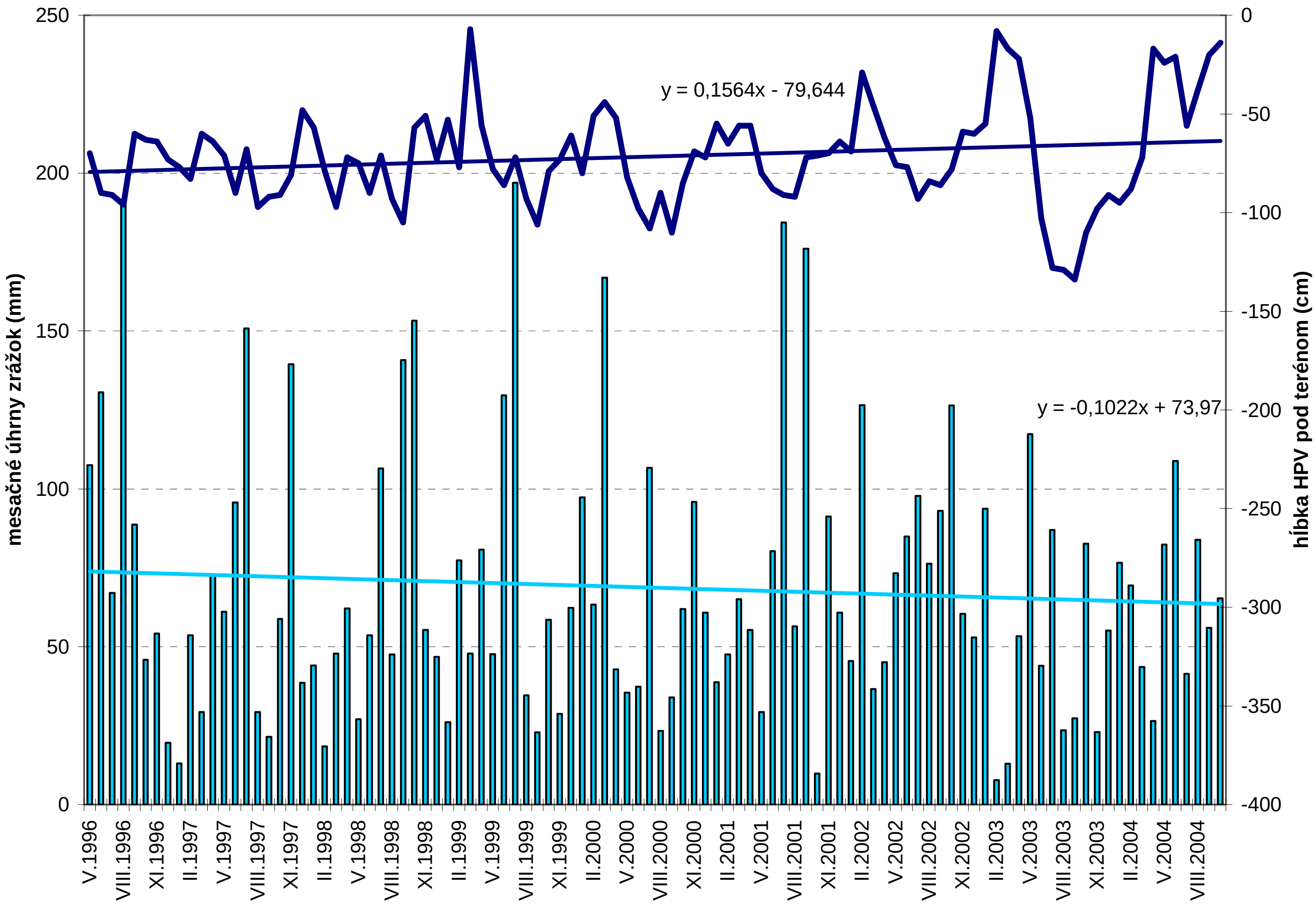
Analysis of ground-water level

- Object of SHMI No. 463: 1958 - 2004
- Objects 1, 2, 3, 4, 6: 1996 – 2004

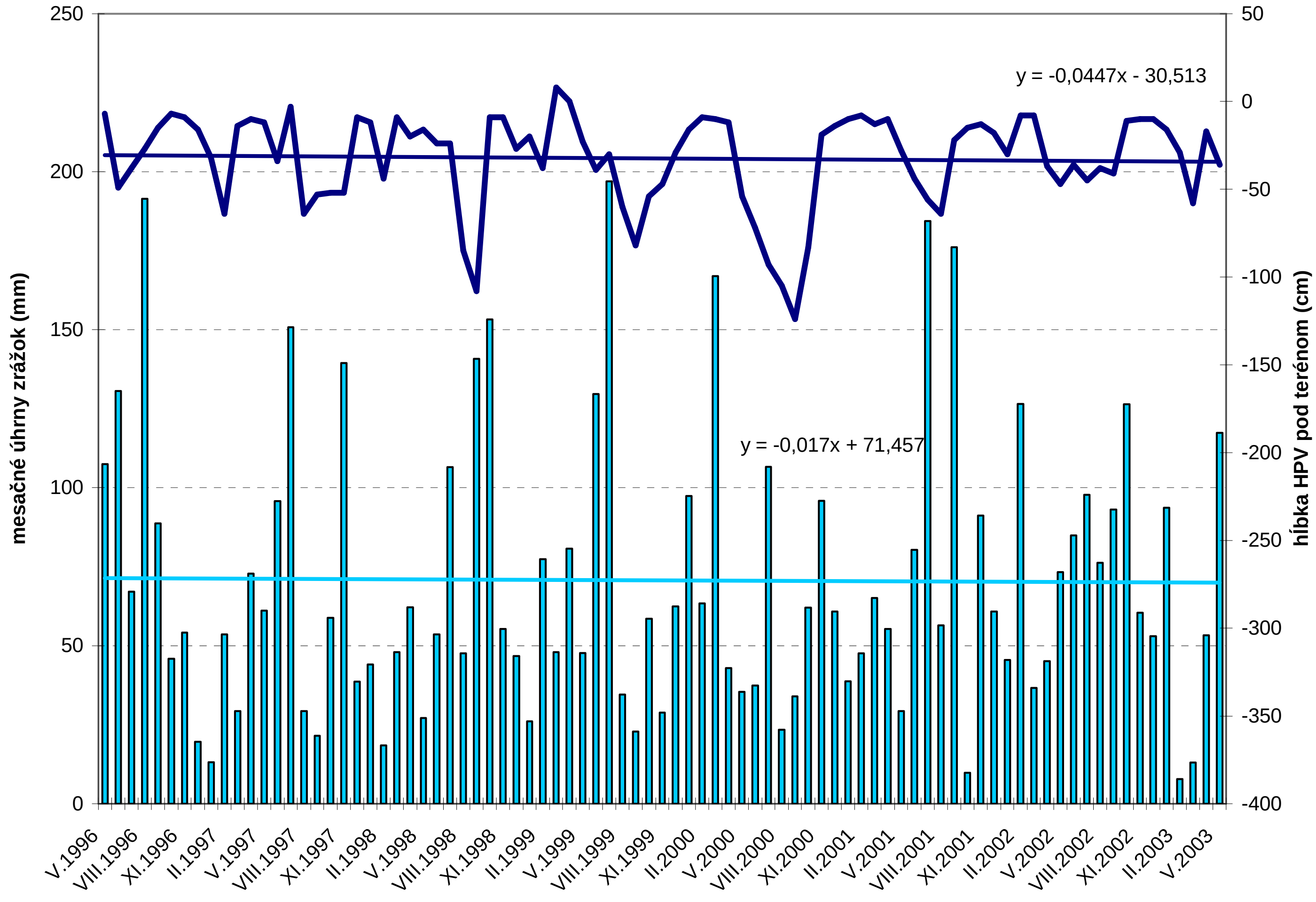
- Mean monthly values of ground-water levels

- Trend analysis

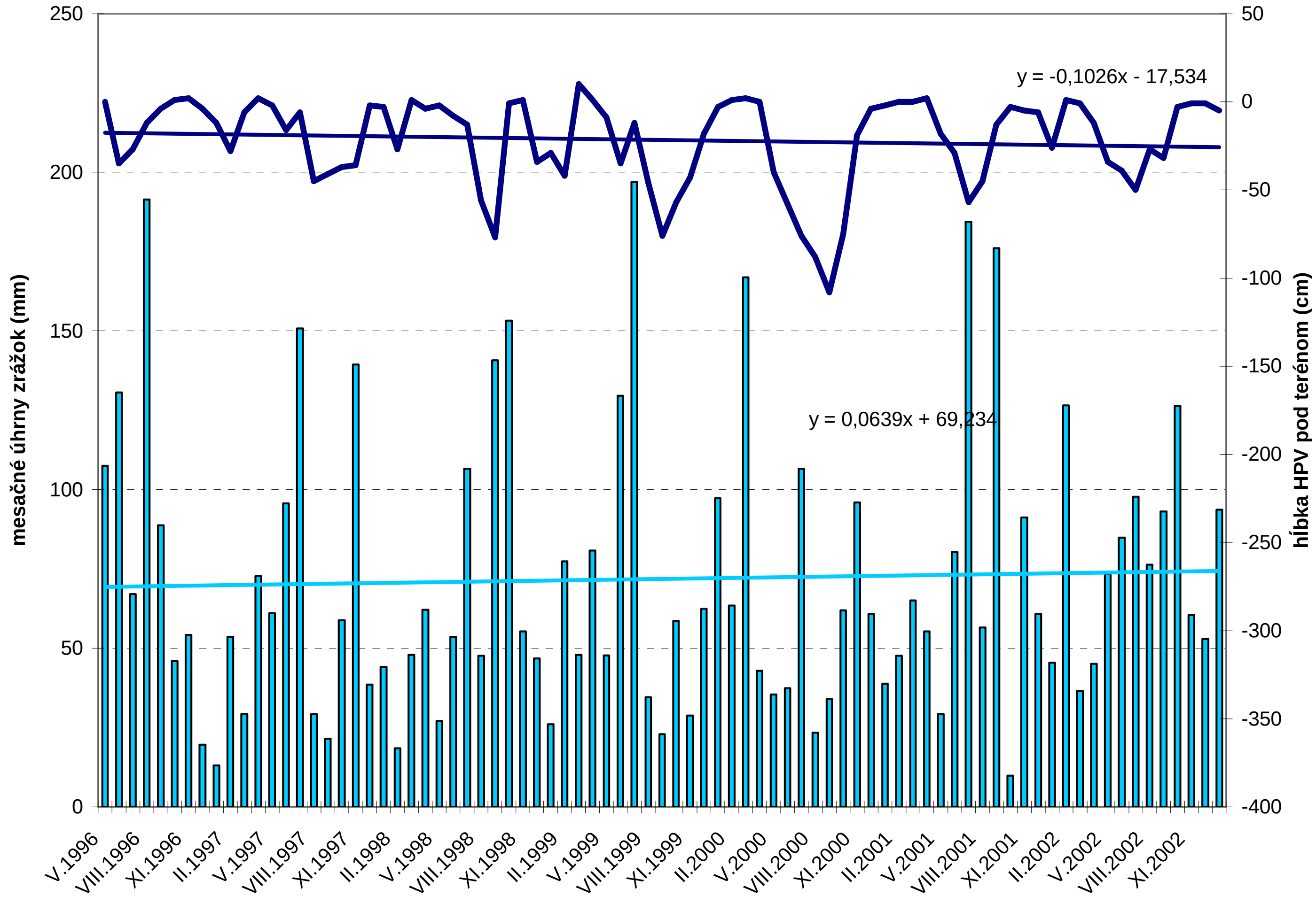
Object 1: 1996-2004



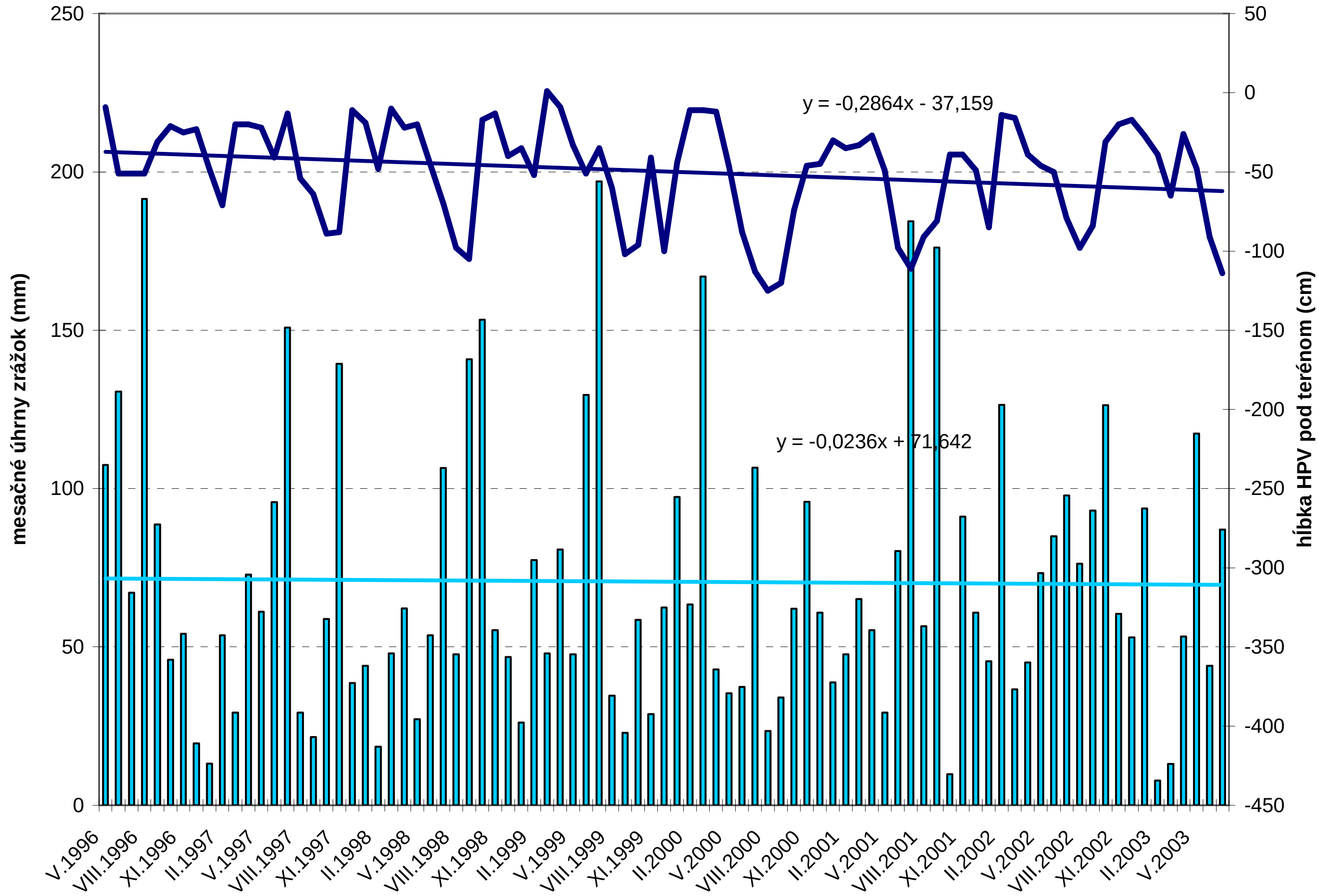
Object 2: 1996-2004



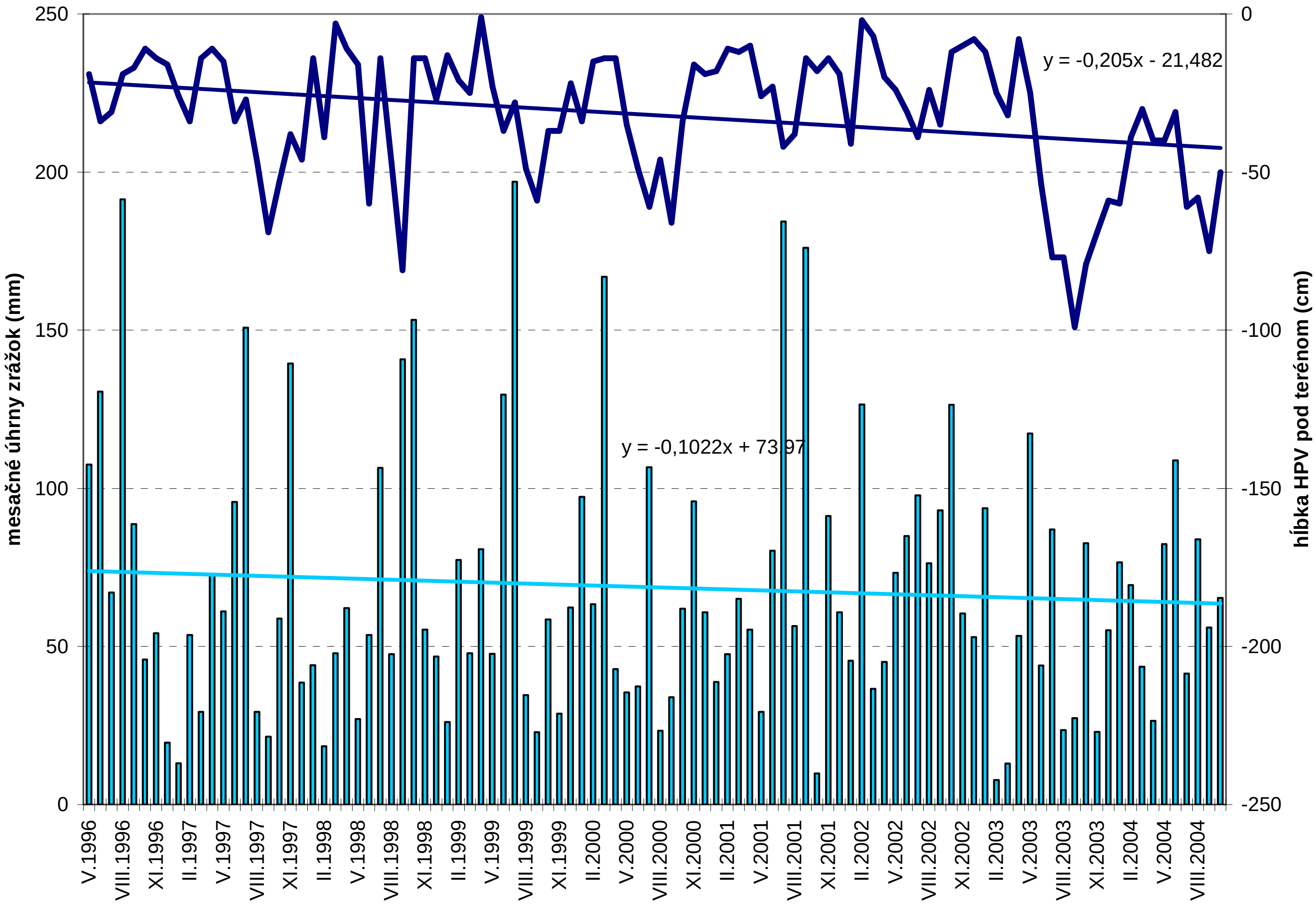
Object 3: 1996-2004



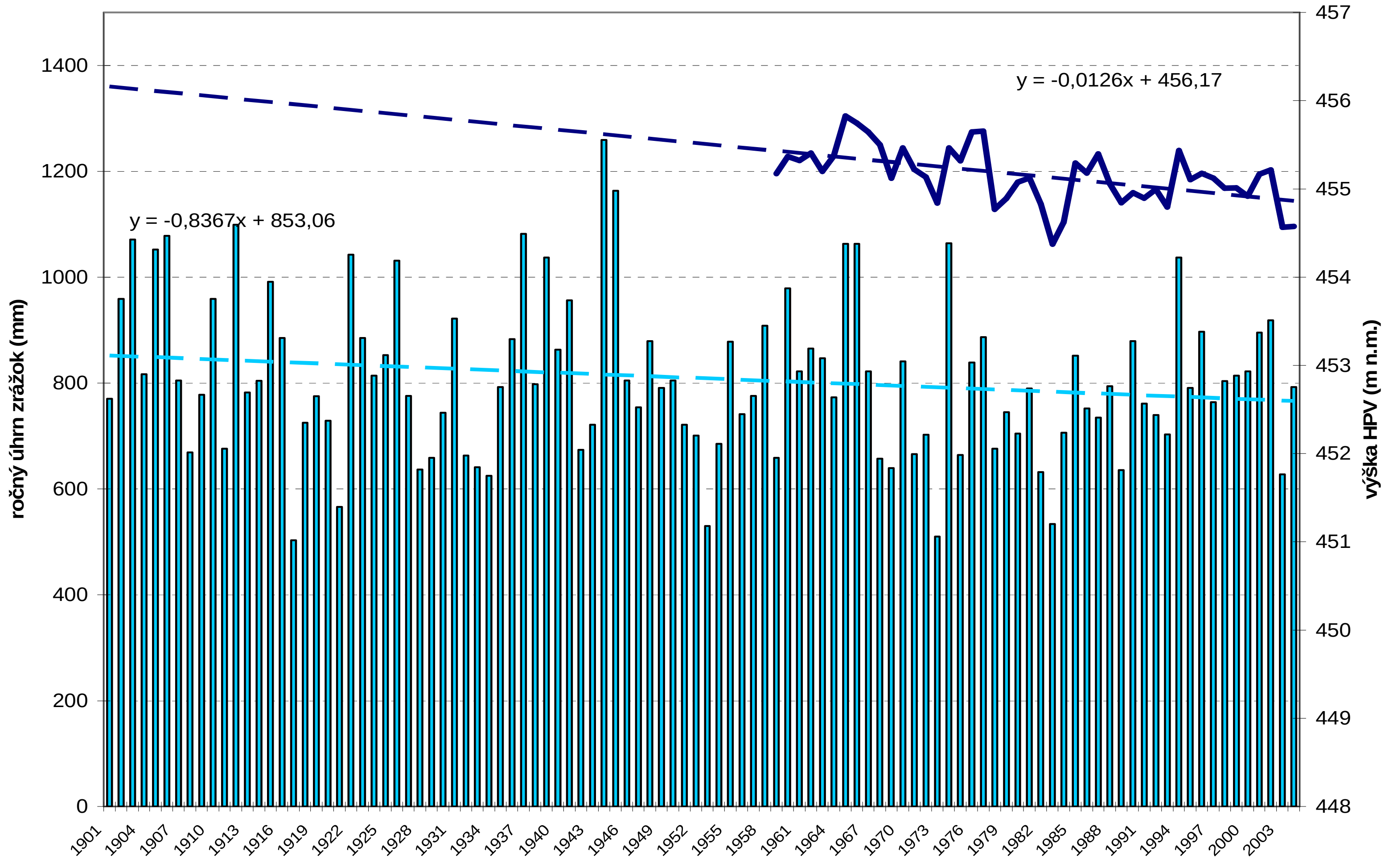
Object 4: 1996-2004



Object 6: 1996-2004



Ground-water level in 463: 1959-2004
and annual precipitatoion totals: 1901 -2004



Results – ground water level

- In all probes and guging objects the minimum of GWL was observed during August till October and maximum in February till April
- Precipitation totals have slightly decreasing trend during the period 1901-2004 influencing the GWL,
- In the future slight decreasing trend of the GWL can be presupposed

Belianske lúky

The National Park - wetland Belianske lúky (892 500 m2) is situated in the north – east part of Slovakia, near villages Spišská Belá, Strážky and Ždiar in the basin of the Biela River.

The area forms the biggest spring-fed fen system in Slovakia with an extraordinarily high value of biodiversity.

51 different threatened taxa of higher plants have been recorded from a total number of 220 species in the locality thus far.

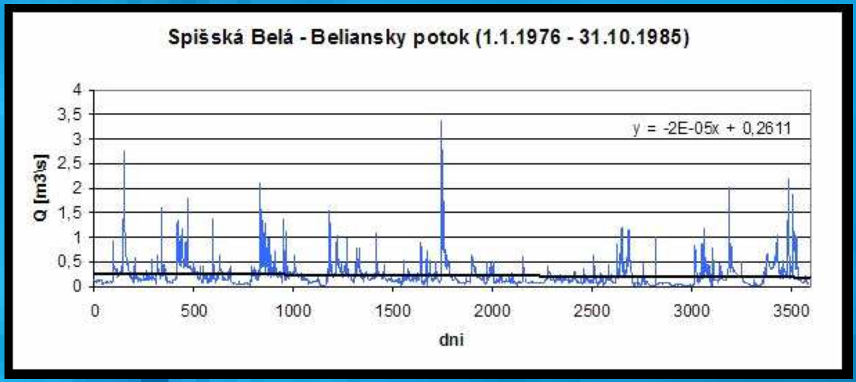
Station	Id of gauging station	Observation period	Number of years of observation
Spišská Belá-Strážky/ Čierna voda	8200	1.1.1976 - 31.10.1985	10
Spišská Belá/ Beliansky potok	8210	1.1.1976 - 31.10.1985	10

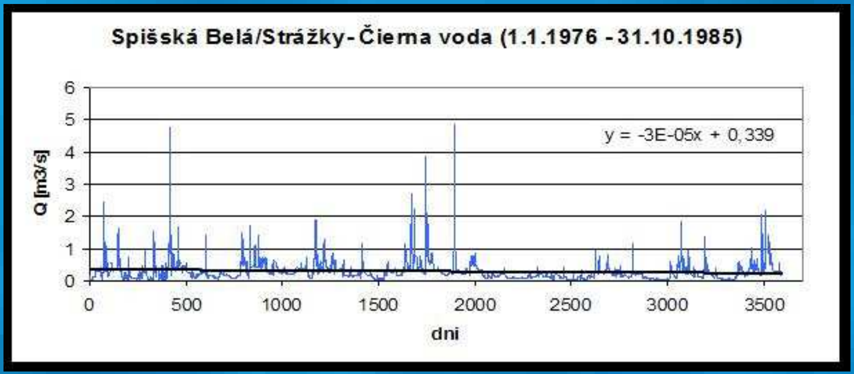
Station	Id of gauging station	Observation period	Number of years of observation
Tatranská Lomnica	12140	1.1.1901- 31.12.2004	104
Kežmarok	12180	1.1.1901- 31.12.2004	104

Analysis of discharges

- Statistical analysis of mean annual, daily and monthly discharges
  - Basic statistical analysis
  - Homogeneity tests
  - Trend analysis
  - Analysis of seasonal and cyclical components

Results – discharge time series



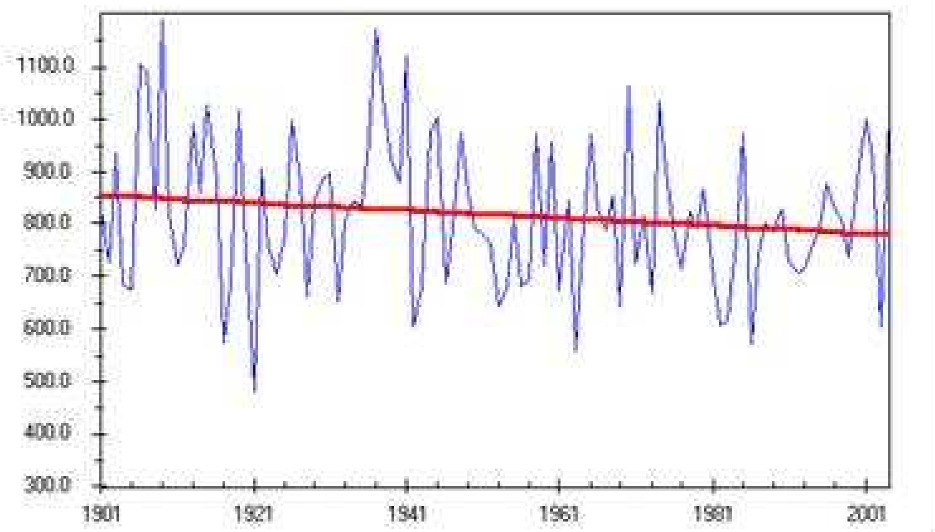


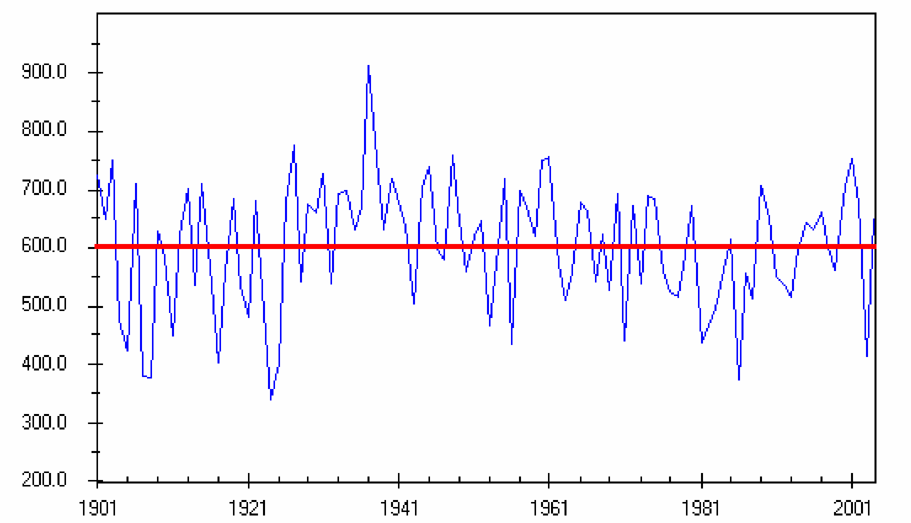
- trend of mean daily discharges is slightly decreasing for the whole period of observation
- maximum discharges – prevaling spring
- minimum discharges – autumn and summer season

Analysis of precipitation time series

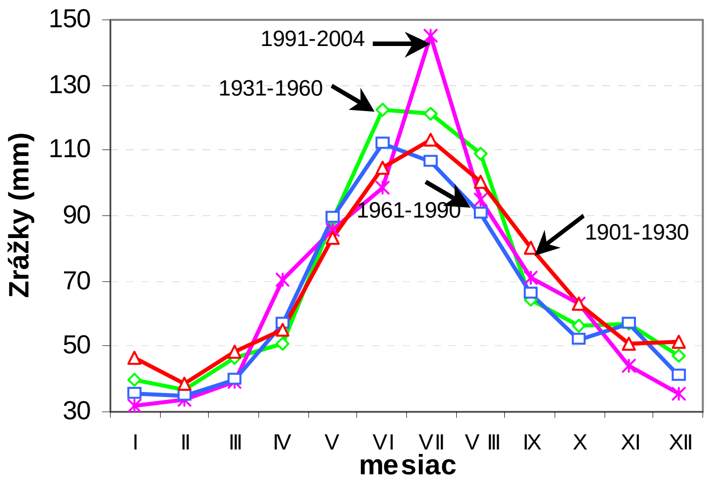
- Analysis of mean daily, monthly and annual precipitation totals
  - Basic statistical analysis
  - Testing of homogeneity
  - Trend analysis
  - Analysis of 30-years periods

Tatranská Lomnica and Kežmarok – trend of mean annual precipitation





Kežmarok



Results – precipitation time series

- slight decrease in annual precipitation totals in all stations
  - from 30 years period the most dry period was in 1961-1990
  - the wettest period was 1991-2004
- maximum precipitation totals – prevailing summer season
- minimum precipitation totals – prevaling winter season

Analysis of ground-water level

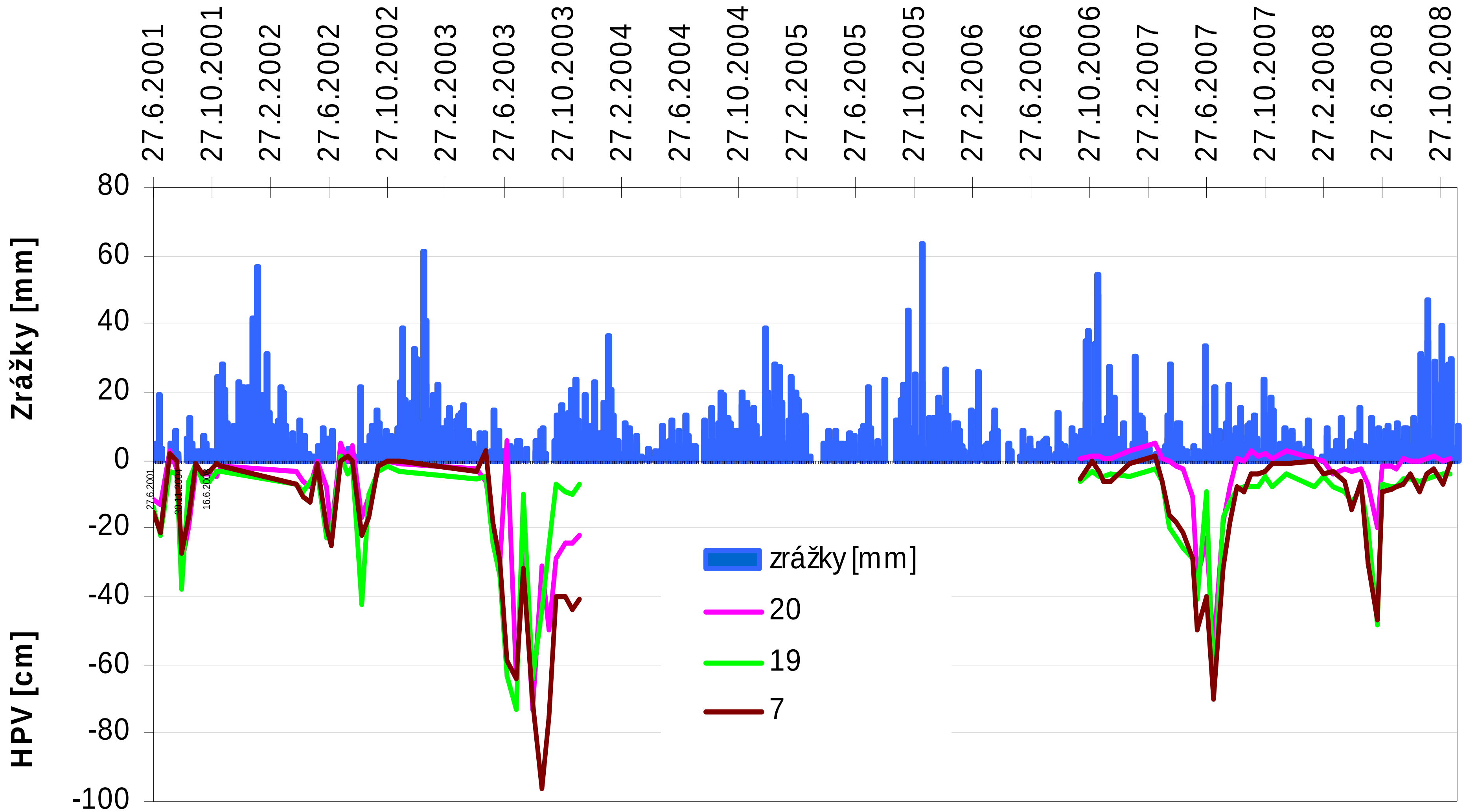
- Mean monthly values of ground-water levels
- Trend analysis

Measurements:

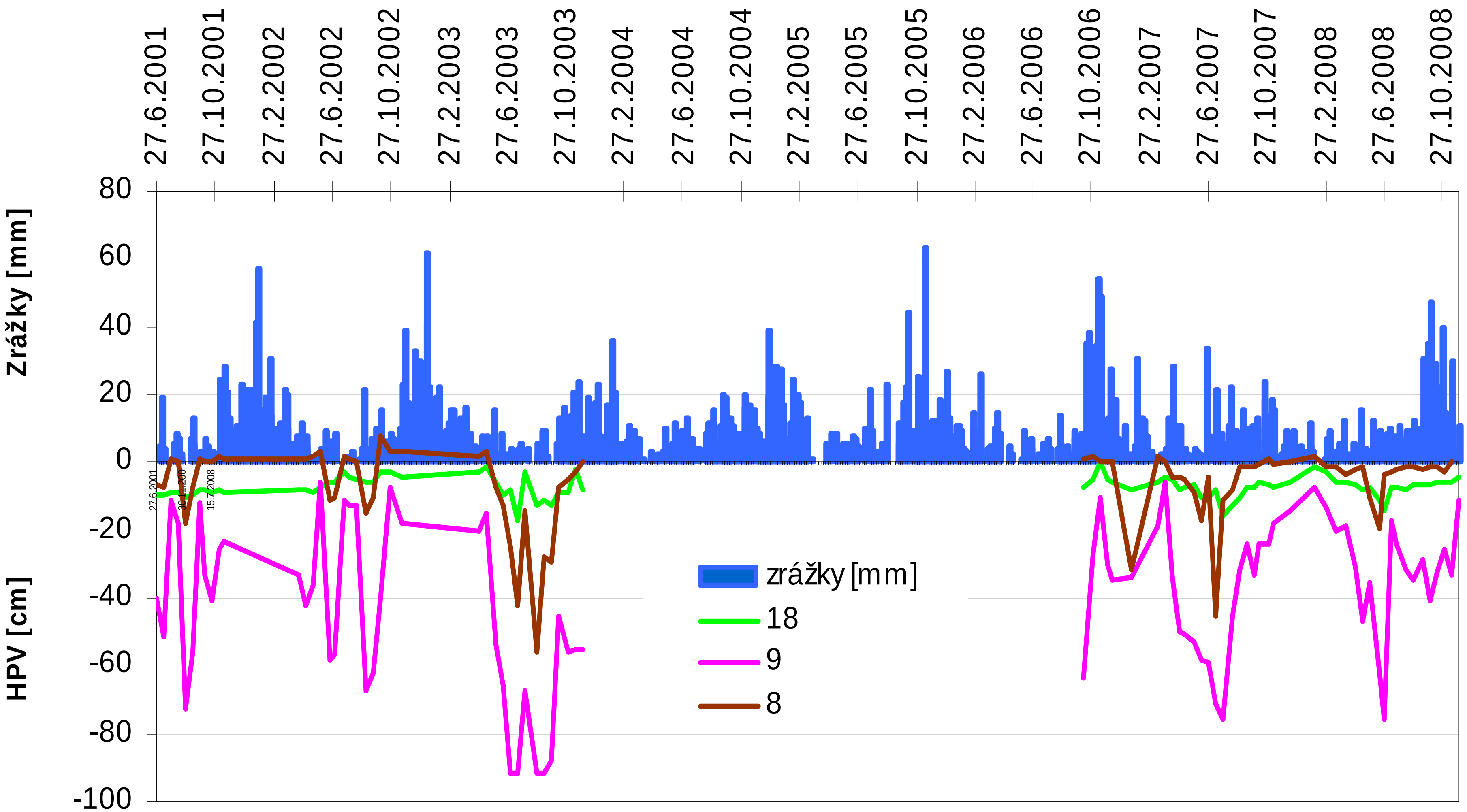
1th period 27.6.2001 – 27.9.2003

2nd period from 6.10.2006

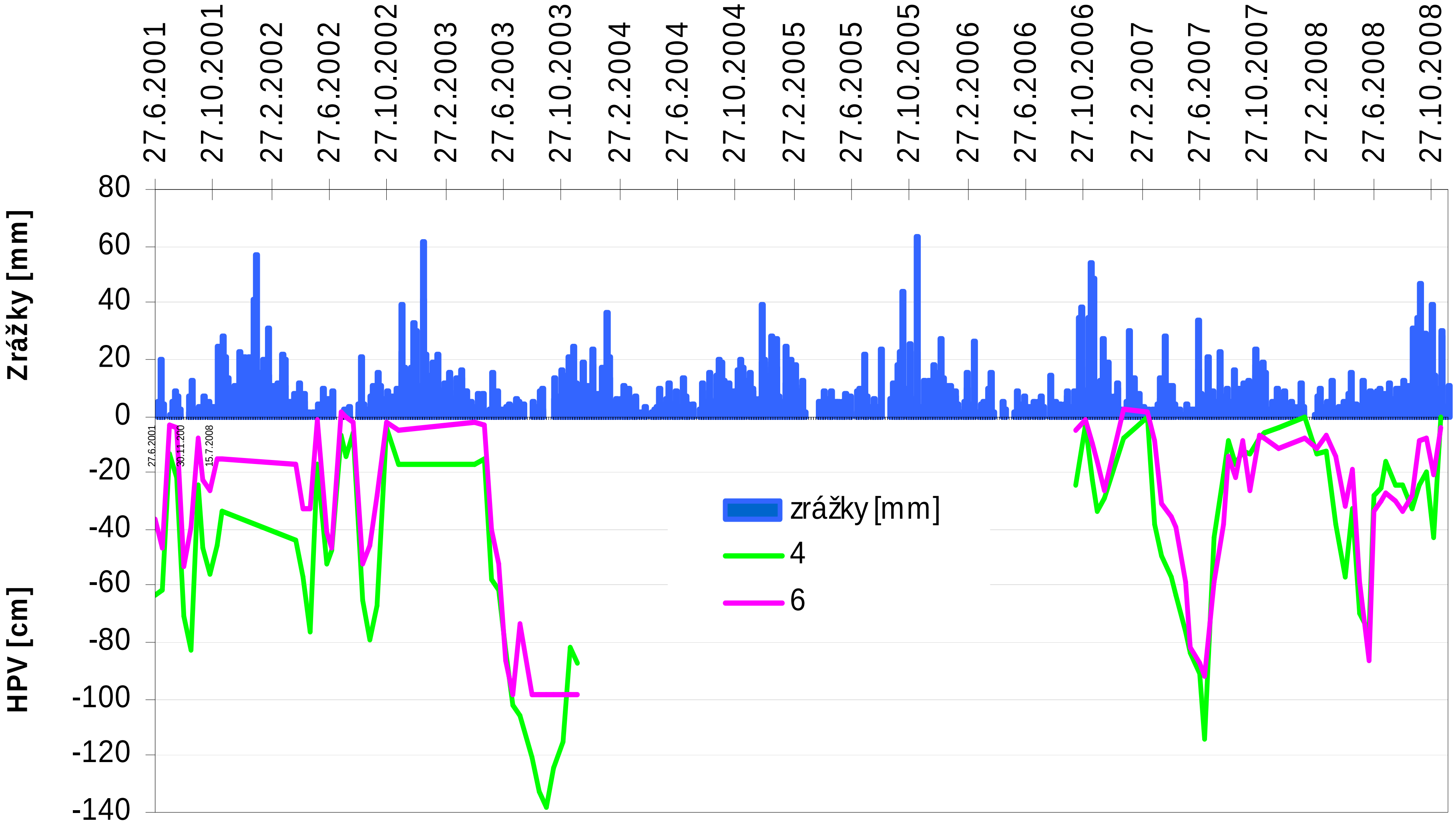
Ground-water levels HPV in probes 7 – 19 and 20 in the Belianske lúky and precipitation totals at the station Tatranská kotlina during 2001-2008



Ground-water levels HPV in probes 8 – 9 and 18 in the Belianske lúky and precipitation totals at the station Tatranská kotlina during 2001-2008



Ground-water levels HPV in probes 4 and 6 in the Belianske lúky and precipitation totals at the station Tatranská kotlina during 2001-2008



Results – ground water level

- In all probes and guging objects the minimum of GWL was observed during summer months and maximum in the spring season
- Precipitation totals have slightly decreasing trend during the period 1966-2006 and are influencing the GWL
- The GWL in the station Spišská Belá (1966-2006) has observed increasing trend
- In the future no significant change of the GWL can be presupposed

Time series modeling and creating of monthly forecating models

Time series modeling

Decomposition of time series:

- Testing of trend T,
- Sesonal component S,
- Cyclical component C,
- Residual component e

additiv way of decomposition

$$X_t = T_t + S_t + C_t + e_t$$

Tested models

Linear models – AR [p] (AutoRegressive model), **MA [q]** (Mooving Average model), **ARMA[p,q]**

Models with long memory – ARFIMA
(AutoRegressive Fractional Integrated Moving Average)

Nonlinear models

TAR	(Threshold Autoregressive)
SETAR	(Self-Exciting Threshold Autoregressive)
STAR	(Smooth Transition Autoregressive)
LSTAR	(Logistic Smooth Transition Autoregressive)

Comparison of derived models

RMSE (Root Mean Squared Error)

$$RMSE = \sqrt{\frac{1}{N}\sum_{t=1}^{N}\left(y_t - \hat{y}_t\right)^2}$$

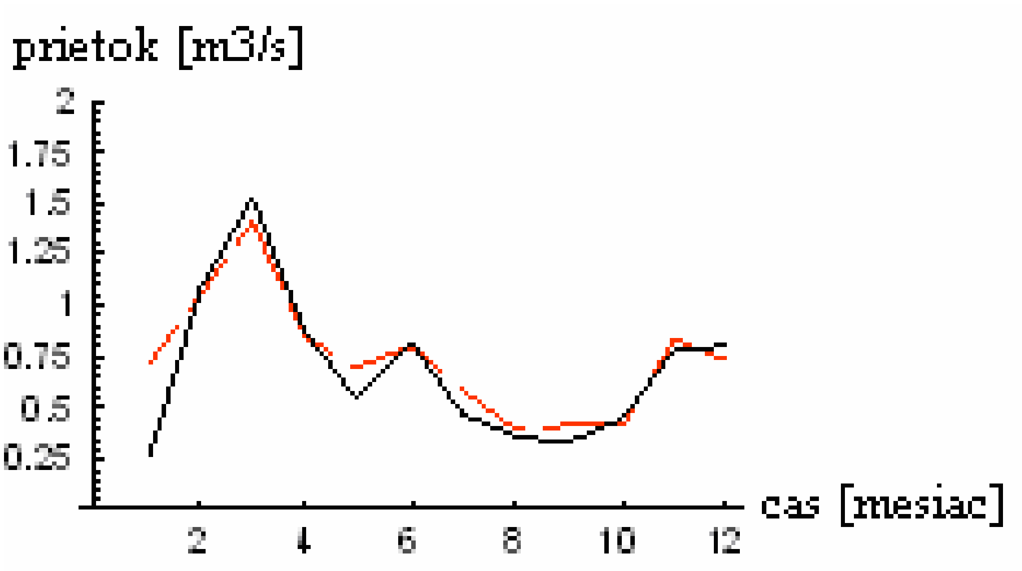
MAE (Mean Absolute Error)

$$MAE = \frac{1}{N}\sum_{t=1}^{N}\left|y_t - \hat{y}_t\right|$$

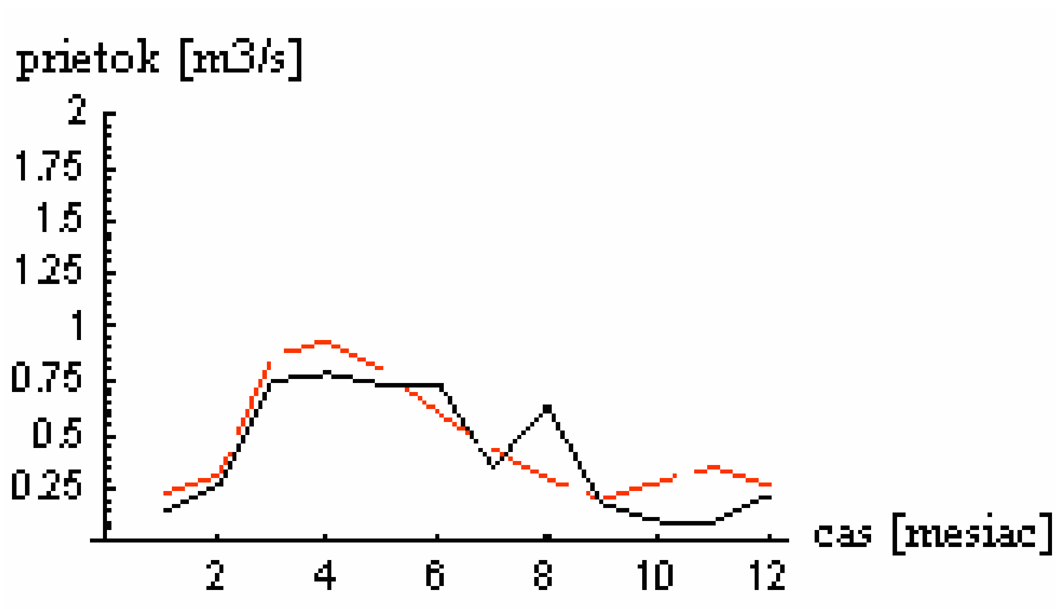
Comparison of modeling results RMSE and MAE errors
Example – Kláštorké lúky

Station / Model	Kláštor pod Znievom	Príbovce	Kláštor pod Znievom/ Vrica	Kláštor pod Znievom/ Znievsky potok	Slovany/ Vrica
ARMA model	**19.241** **23.096**	**22.251** **18.844**	0.216 0.154	**0.202** **0.128**	0.19 0.161
	AR[1]	**AR[1]**	AR[1]	**MA[1]**	AR[1]
(LM)	Short memory	Short memory	0.102 0.154	Short memory	0.129 0.159
			AR[1]		ARMA[1,1]
TAR	lin	lin	0.788 0.736	lin	lin
			SETAR [1,1]d=1		
TAR_LM			**0.107** **0.086**		**0.113** **0.087**
			SETAR [1,1] d=1		**SETAR [1,1] d=1**

Models with long memory

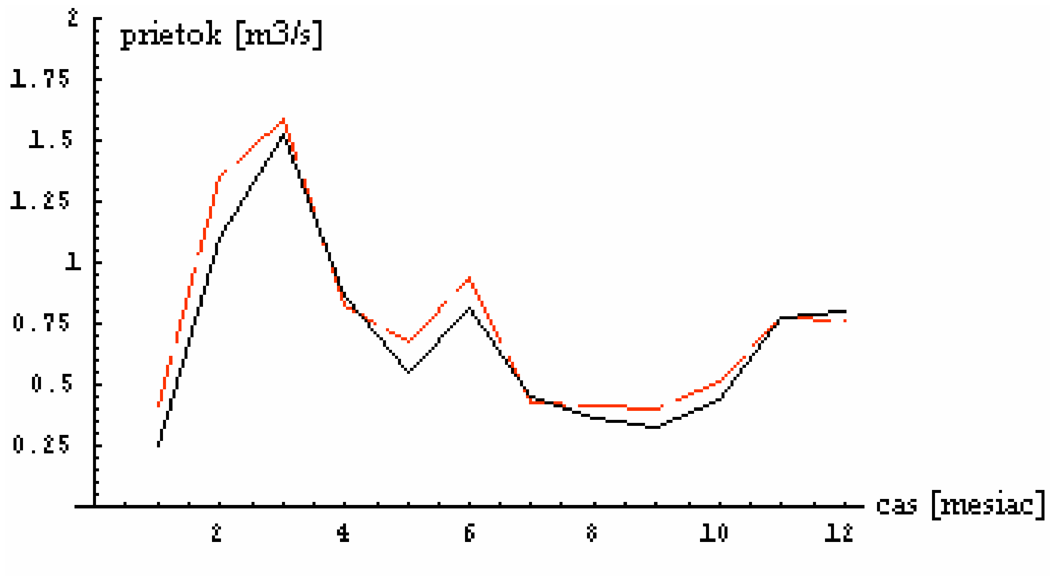


Kláštor pod Znievom/ Vríca; ARFIMA (AR[1])

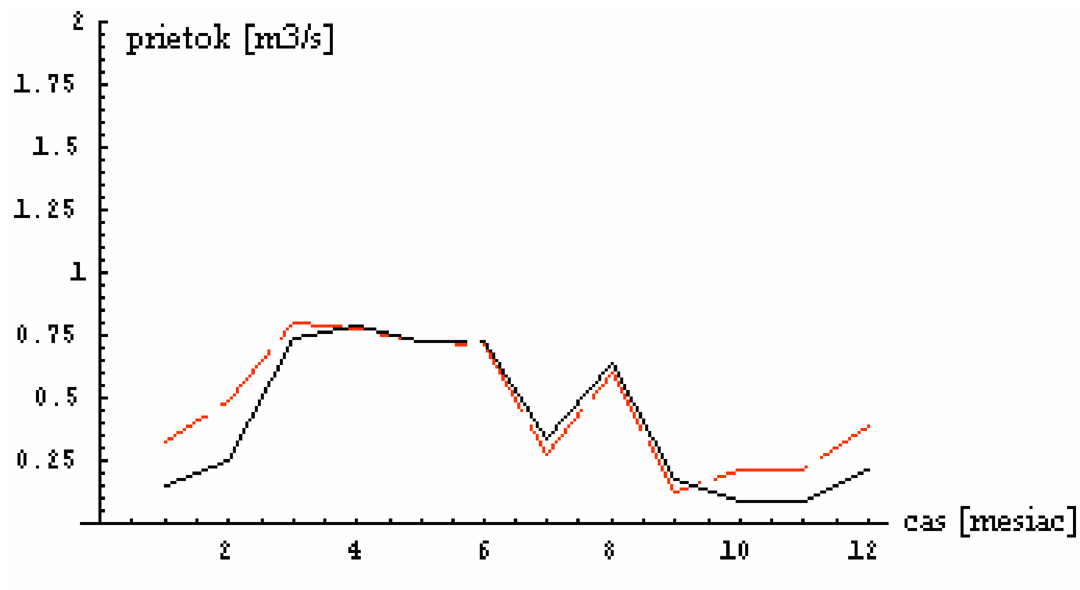


Slovany/ Vríca; ARFIMA (ARMA[1,1])

Nonlinear TAR models with long memory



Kláštor pod Znievom/ Vríca; TAR_LM (SETAR [1,1] d=1)



Slovany/Vríca; TAR_LM (LM_SETAR [1,1] d=1)

Prediction errors MAE and RMSE and selected best models for analysed gauging stations

Wetland Kláštorské Lúky			
Station	Best model	MAE	RMSE
Kláštor pod Znievom/Vríca	TAR_LM SETAR (1,1) d=1	0.086	0.107
Kláštor pod Znievom/Znievsky Creek	MA(1)	0.128	0.202
Slovany/ Vríca	TAR_LM SETAR (1,1) d=1	0.087	0.113
Kláštor pod Znievom	AR(1)	23.123	19.272
Príbovce	AR(1)	22.309	18.973
Wetland Belianske Lúky			
Spišská Belá/ Beliansky Creek	AR(1)	0.074	0.092
Spišská Belá Strážky/ Čierna voda	ARFIMA(1,1) d=1	0.120	0.139
Tatranská Lomnica	AR(1)	22.158	18.985
Kežmarok	AR(1)	16.458	14.532
Wetland Abrod			
Studienka/ Rudava	AR(1)	0.452	0.555
Veľké Leváre	ARFIMA(1,2) d=1	0.242	0.339
Šaštín Stráže	AR(1)	25.265	30.584
Malacky	AR(1)	22.704	28.972

Conclusions – modeling discharge time series

- The models tested were the linear ARMA, ARFIMA models with a long memory, the nonlinear TAR models and the TAR models combined with the long memory model.

- For discharge predicting the most suitable models were the linear AR models, long memory models or combined model TAR and long memory model, which provided the best results.

Conclusions – modeling discharge time series

- Linear ARMA models were suitable for the time series of the mean monthly precipitation totals.
- Modeling and forecasting the mean monthly precipitation totals was not satisfying, therefore for future studies the use of models like ARCH (Autoregressive Conditional Heteroscedasticity) and GARCH (Generalized ARCH) or MSW (Markov-Switching) can be recommended for testing.

- The derived predicting models could help ecologists
  in decision-making concerning wetland management,
  in improving the ecological conditions in the wetlands and
  in planning future eco-technical measures in the analysed wetlands.


Thank you for your attention