THE EXPERIMENTAL WATERSHEDS IN SLOVENIA

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Abstract

Experimental watersheds are critical to the advancement of hydrological science. By setting up three experimental watersheds, Slovenia also obtained its grounds for further development of the science and discipline. In the Dragonja experimental watershed the studies are focused on the afforestation of the watershed in a mediterranean climate, on the Reka river the water balance in a partly karstic area is examined, and on the case of the Glinščica stream the implications of the urban environment are studied. We have obtained valuable experience and tested new measuring equipment in all three experimental watersheds.

Keywords: *experimental watershed, measurements, hydrology, afforestation, karstic area, urban area, Slovenia.*

1 INTRODUCTION

The experimental watersheds of the Dragonja, Reka and Gradaščica with Glinščica rivers are nowdays critical to the advancement of hydrological science, not only in Slovenia, but also on international level. Those watersheds have been equiped with modern measuring equipment for precise measurements of precipitation, intercepted precipitation, discharges, erosion and water quality. Thus contemporary experimental base was established used for scientific research and at the same time provided support to the teaching and studying process.

The Dragonja river basin is situated on the border between Slovenia and Croatia. Due to political and social circumstances and poorly managed agriculture in the past, the catchment area has been depopulated in the past decades, leaving the forests to develop in the abandoned agricultural fields. The changes in land use changed the hydrology of the catchment in a great deal. The Dragonja watershed was chosen as an experimental watershed, since it is interesting because of the intensive natural reforestation in the last decades, which has caused a decrease in minimal and maximal flows. At the same time no noticeable climate (precipitation and temperature) changes were observed. Precise measurements in the last few years were the basis for cooperative scientific work between the Vrije Universiteit from Amsterdam and the University of Ljubljana, which resulted in several PhD Theses, Master Theses and scientific articles. At the same time the experimental watershed provided support to the teaching and studying process. Until now, many students from Amsterdam (VUA), Ljubljana (UL) and Freiburg (UF) have performed their field work on that experimental watershed.

The Reka River is the widest known sinking stream of a classical karst area, and it has been studied since antiquity. The river sinks into the Škocijan Cave system, which was proclaimed by UNESCO as a World Heritage Site in 1986. Then the groundwater stream flows to the karst springs of the Timav, and drains into the Adriatic Sea in the Trieste Bay. Slovenian IHP Committee selected the Reka River Basin for an experimental basin. The river has a drainage area of 422 km^2 and a mean discharge of 8,26 m^3/s. In the seventies, the Reka River was one of most polluted rivers in Slovenia. During floods in 1999 and 2000, experimental measurements of velocity, water stage, suspended sediment transport, chemical parameters and toxicity tests were conducted.

In urban areas the concept of the watershed becomes more complex and difficult to define because the natural topography has been disturbed; the water may be drained through storm drains and in some cases it may be diverted by drains into other basins. Due to past regulations, urban watercourses are frequently considered only as an architectural element or as conduits for sewer and rainfall. In the area of Ljubljana watercourses Ljubljanica, Gradaščica and the Glinščica are regulated in sterile channel cross sections with high concrete banks which separate the water bodies from surrounding urban areas. The precipitation watershed area of the Glinščica comprises 17.4 km^2. The Glinščica watershed study site is equipped with weather stations, rainfall stations, two water stations with Doppler velocity meters and sample points for water quality measurement by multipurpose probe. The multipurpose probe measures dissolved oxygene and nitrates concentration, pH, specific conductivity, depth, total dissolved solids and temperature. Measurements showed how vulnerable to pollution is the Glinščica creek due to typical urban flow regime with extremely low water flows and water content especially in the summer.

2 THE DRAGONJA EXPERIMENTAL WATERSHED

The study area

The Dragonja river basin is situated in SW of Slovenia, in the northern part of the Istrian Peninsula. The basin area is hilly region, between 150 and 450 m above sea level. The area of the watershed is 90.5 km^2. In the past the area was mainly inhabited in the hilly ridge tops. In the 1960s and 1970s the region depopulated and this led to the abandonment of agricultural land use. This caused natural reforestation of the land. The forest area has increased from 25% (in 1953) to more than 60% (today). The area is geologically composed of Eocene flysch. Soil is mostly carbonate rendzina. The Dragonja watershed belongs to the submediterranean climate region with mean annual temperatures around 14 °C and the annual precipitation of 1000 mm (coast) to 1300 mm (the upper watershed area). Snow is extremely rare. The changes in land-use changed the hydrology of the catchment at great deal.

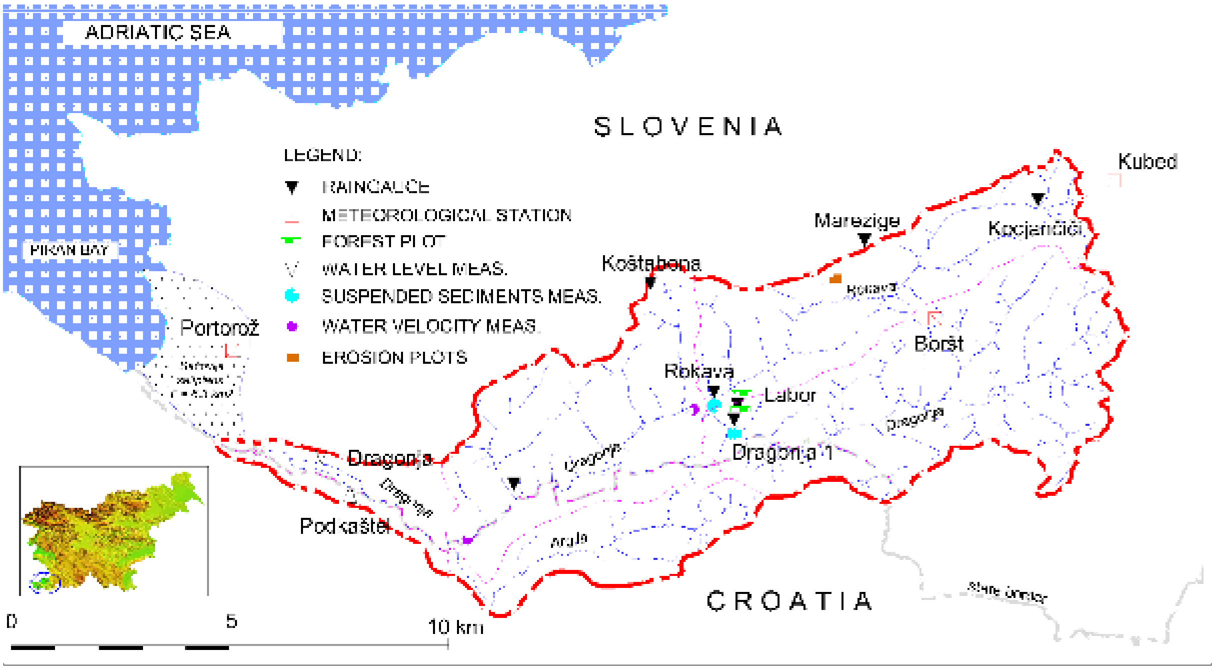

Figure 1. The Dragonja river basin with monitoring sites.

Measurements and analysis

The Dragonja river watershed was chosen as an experimental watershed in 1999 (Globevnik, 2001). The measurements on the watershed started in autumn 2000 with the aim to define the impact of the natural reforestation on the water balance of the watershed. Measurements included rainfall and meteorological measurements, discharge measurements, forest hydrological cycle components measurements and soil erosion measurements. Rainfall was measured on several locations (Labor (2x), Marezige, Kocjančiči, Sirči, Rokava, Boršt, Kubed and Stara Vala), There were also two meteorological stations in Boršt and Kubed that measured incoming and outgoing radiation, temperature, relative humidity, wind velocity, direction and precipitation. The discharges (velocity) of the Dragonja river were measured on several locations with current meter and automatically with ultrasonic Doppler instrument near the outflow of the river.

Two study plots in the forest were established in co-operation with Vrije University from Amsterdam where the forest hydrological cycle was analysed (Šraj, 2003; van der Tol et al., 2007). One is located on the north-facing slope (1419 m2) and other on the south-facing slope (615 m^2). Precipitation above the canopy, throughfall and stemflow on each plot were measured. Rainfall above the canopy was measured with a tipping bucket rain gauges and with totalisators (manual gauges) for control. Throughfall was measured with two steel gutters in combination with ten manual gauges in each plot, which were emptied and moved randomly every time. Stemflow was measured on two most typical species in each plot. Litter was collected regularly in 10 baskets for LAI (Leaf Area Index) estimation. For the same purpose and at the same points, hemispherical photographs of canopies were taken and three series of measurements of photosynthetically active radiation (PAR) were made. The specific leaf area (SLA) was estimated for the main species for need of estimating the leaf area index.

Figure 2. Precipitation measurements above the canopy (left), throughfall measurements (right, above) and stemflow measurements (right, below).

For the needs of studying the processes of soil erosion and sediment transport in the Dragonja experimental catchment discharge of the Dragonja river was measured and sediment samples (ISCO) in the Rokava catchment (the biggest tributary in the upper part of the Dragonja catchment) were taken (Petkovšek and Mikoš, 2004; Keestra et al., 2005). Also Interril soil erosion measurements were made. Eight 1 m^2 erosion plots were set up. The locations with different land use types: on bare soil in a young olive grove (2), in an overgrown meadow (2) and in the forest (4) were chosen. The erosion plots in the forest were placed on soil with two different slopes, 8° and 21°. The surface runoff from each of the erosion plots was collected in reservoirs. Measurements were performed after every erosive event. The volume of the collected surface runoff was determined first, and then samples of water and detached soil mixture from the reservoirs were taken. The samples were dried at 105°C in the laboratory, where the concentration of undissolved particles was determined.

 

Figure 3. Erosion plots in the olive grove on bare soil and the tipping bucket rain gauge (left), and the erosion plot in the forest (right).

Part of the research in the Dragonja experimental watershed deals with the development of a new synthesis method of assessing the hydromorphological status of river corridors based on state analysis of the Dragonja river. The bases of the new method were time effectiveness of data gathering and accuracy of the method. Prior to the practical research implementation, a concept of a rapid transect data gathering was designed. Additionally, an extensive hydromorphological record sheet was elaborated, including a combined list of hydromorphological variables.

Results and discussion

According to the results of one year precise measurements and analysis of individual components of the forest hydrological cycle: precipitation above the canopy, throughfall and stemflow on two forest plots facing south and north, the average values of the throughfall amounted to 67.1 and 71.5% of the associated rainfall for the south and north research plots, respectively, while the average stemflow fraction was 4.5 and 2.9%, respectively. The difference is a consequence of the different structure and characteristics of forests on both slopes. On the basis of the measurements, water balance equation and models, it was calculated that the average annual interception losses amount to 28.4 and 25.4% for the south and north slopes, respectively (Šraj, 2003; Šraj et al., 2008). The values are relatively high compared with other similar studies, which are usually between 15 and 25%. Such high loss of the deciduous forest of the Dragonja watershed is considerable and could be the reason for the reduction of surface water runoff. Regression analyses of precipitation measured on individual rain gauges showed good agreement with a correlation coefficient over 0,95. Regression analyses of the measured throughfall with fixed and roving gauges gave expected higher values of roving gauges with very high correlation coefficients.

The measurements were extended in 2005 when eight 1 m^2 erosion plots for interrill soil erosion measurements were set up on locations with different land use types: on bare soil in a young olive grove, in an overgrown meadow and in the forest. In 2006, 33 erosive events were registered, contributing 875 mm of rainfall, while 43 events in

2007 contributed 939 mm of rainfall. The total annual rainfall erosivity factor R in 2006 amounted to 2090 MJ/ha mm/h generating 8.43 kg/m2 of soil loss on the bare soil. The total R factor for 2007 was approximately 75% higher than in 2006, while the annual soil loss on bare soil was higher by only 25%. Few major erosive events were responsible for the greater part of the washed soil: the 3 most intensive erosive events in 2006 meant 55% of the annual R factor, while for the same portion of the annual R factor in 2007 5 erosive events were needed. The interrill soil erosion in the forest is strongly connected to the vegetation period when the most intensive erosive events occur: the portion of the forest soil loss in the summer period, when the vegetation cover is nicely developed, is much lower than the soil loss on the bare soil (Petan et al., 2008).

3 THE REKA EXPERIMENTAL WATERSHED

The study area

The Reka river has a drainage area of 422 km^2 and a mean discharge of 8,26 m^3/s. It is the widest known sinking stream of a classical karst area, and it has been studied since antiquity. The river sinks into the Škocijan Cave system, which was proclaimed by UNESCO as a World Heritage Site in 1986. Then the groundwater stream flows to the karst springs of the Timav, and drains into the Adriatic Sea in the Trieste Bay. The stream density is about 1.696 km/km^2. Slovenian IHP Committee selected the Reka River Basin for an experimental basin. In the seventies, the Reka River was one of most polluted rivers in Slovenia. The Reka River Basin is situated on the Brkini syncline Eocene flysch rocks surrounded by a large karstic region (Brilly et al., 2002).

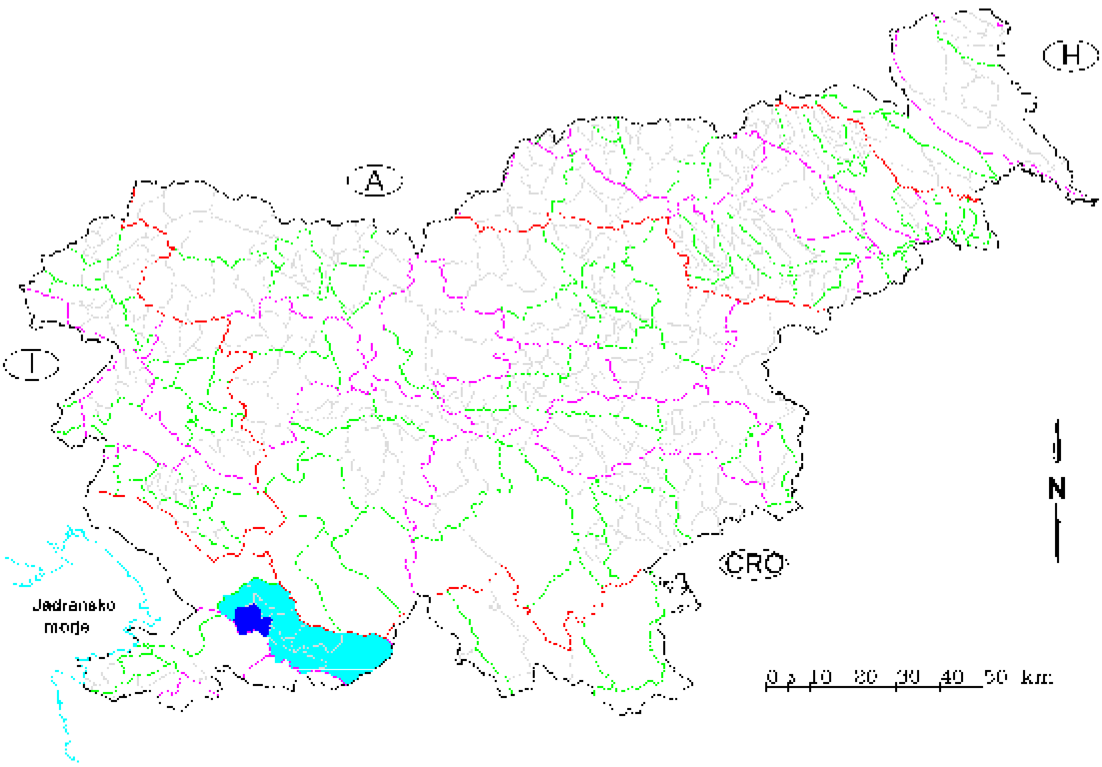

Figure 4. The Reka river and Padež watershed.

Measurements and results

There is a town Ilirska Bistrica, plus a lot of small villages, along the valley. The chemical and woodwork industry heavily polluted the river, which was one of most polluted streams in Slovenia. The main polluters were the fiberboard factory and the organic acids factory in Ilirska Bistrica. The BOD_5 was between 100 and 200 mg/l during the mean flows in 1969 and 1979. Industrial water treatment was unsuccessful, and the Reka River valley was an unpleasant place with a specific smell caused by the anaerobic processes in the river body, especially during the low flows, with only few hundred liters per second of discharge. Pollution prevention work started in the seventies. A wastewater treatment plant and two reservoirs for low flow recharge were constructed. In the nineties, the industrial production decreased and the pollution diminished.

There were three hydrological gauging stations in the basin. Two of them, Cerkvenikov mlin and Trnovo, are equipped with a recorder. The others are only staff gauges, and some of them have been abandoned. The Cerkvenikov mlin hydrological station was established in 1951. A large fluctuation in discharges can be observed there. The lowest discharges are in the summer time, when the natural discharge is below 200 l/s.

During floods in 1999 and 2000, experimental measurements of velocity, water stage, suspended sediment transport, chemical parameters and toxicity tests were conducted.

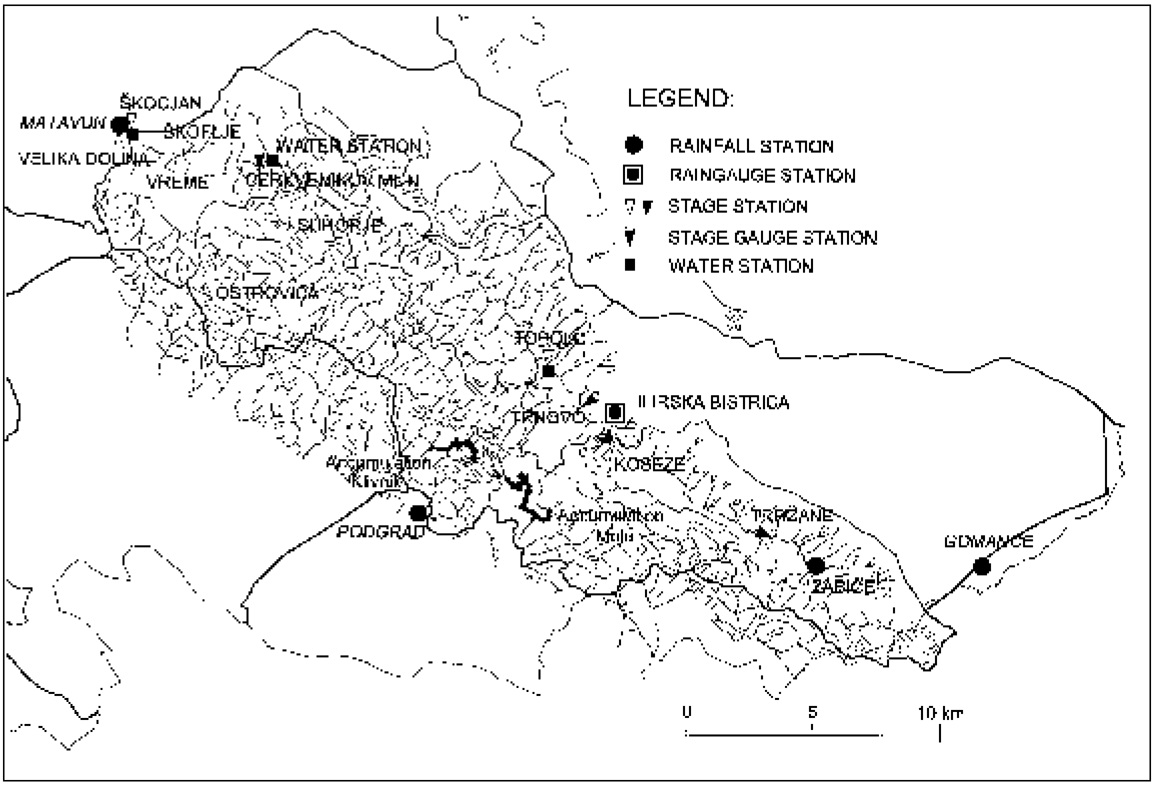

Figure 5. The Reka river gauging stations and measuring sites.

The measurement of velocity and discharge took place at the Cerkvenikov mlin state gauge station. Three instruments were used to measure the stream velocity: Valeport self recording current meter, Starflow ultrasonic velocity meter and ISCO 6700 compatible area-velocity module.

Figure 6. Valeport self recording current meter and Starflow ultrasonic velocity meter (left), and ISCO 6700 compatible area-velocity module (right).

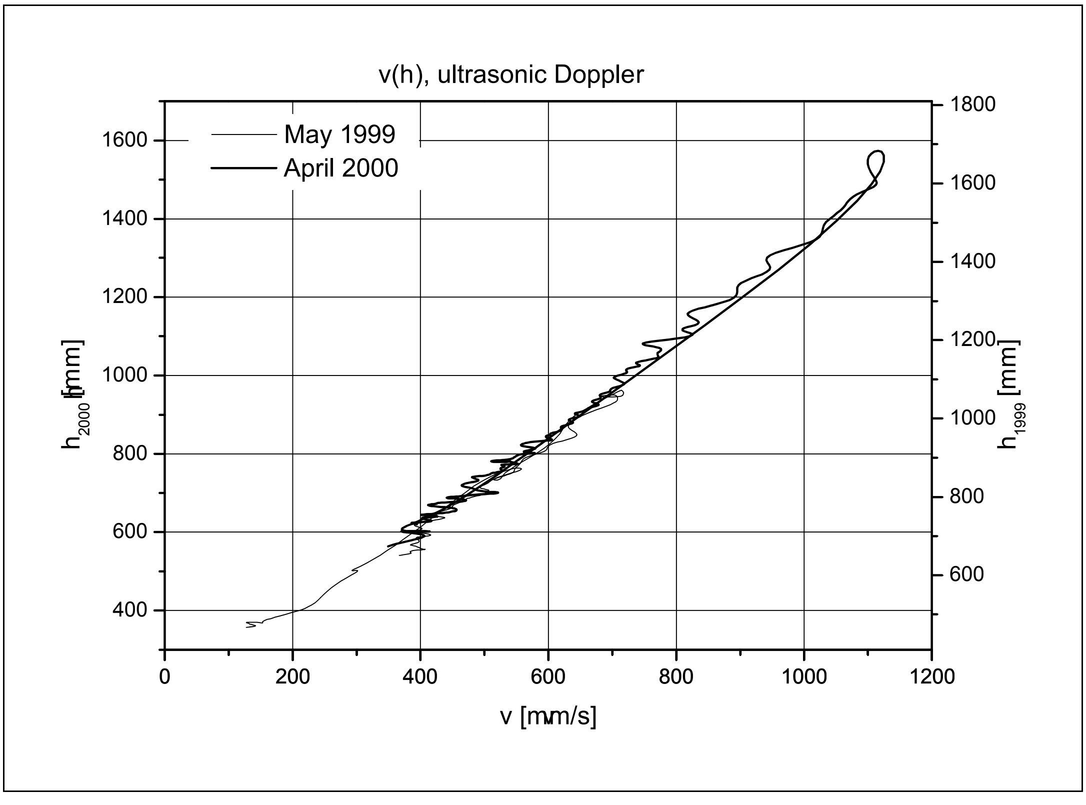

Figure 7. Stage - velocity curve for two events.

The suspended solids concentration were measured with following instruments: Hach SS6 turbidimeter, Partech IR40 infrared sensor and ISCO 3700 sampler. The turbidimeter was not operating all the time, due to problems with pumping.

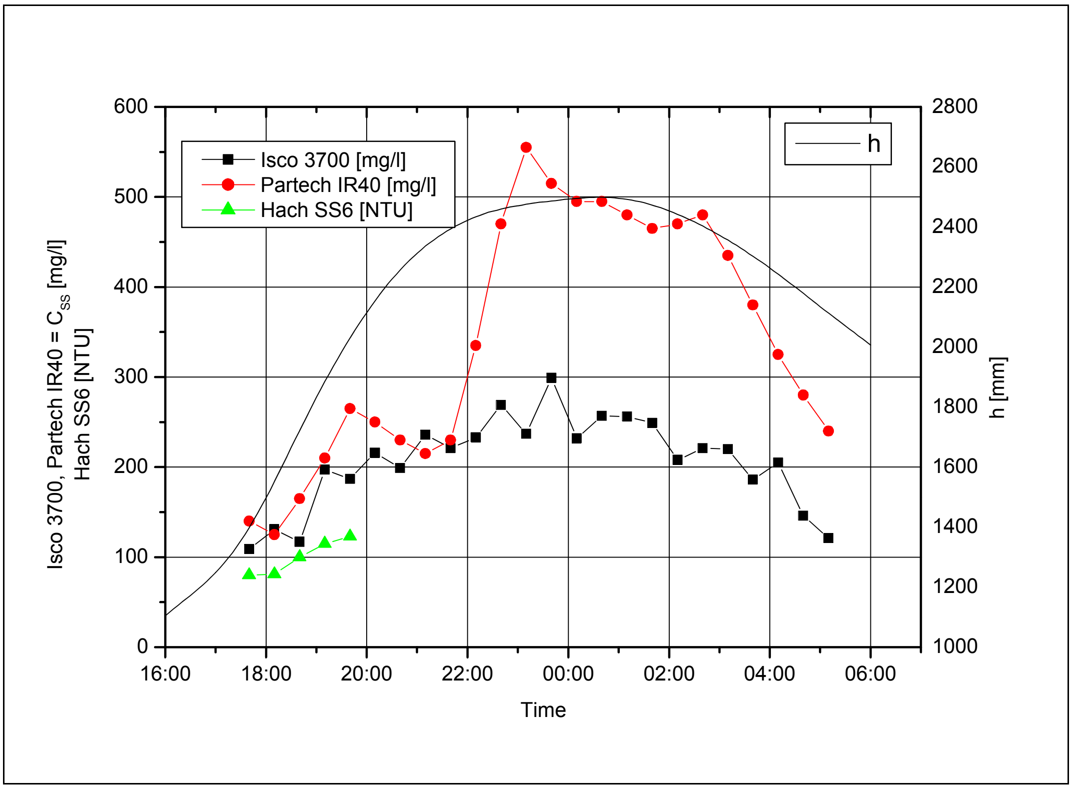

Figure 8. Measured suspended sediment on 29-30 March 2000.

Water quality parameters: temperature, pH, conductivity (SEC) and dissolved oxygen (DO) of the Reka River were measured at different hydrological conditions with a Sound YSI 600 and the portable ISCO 6700 auto-sampler.

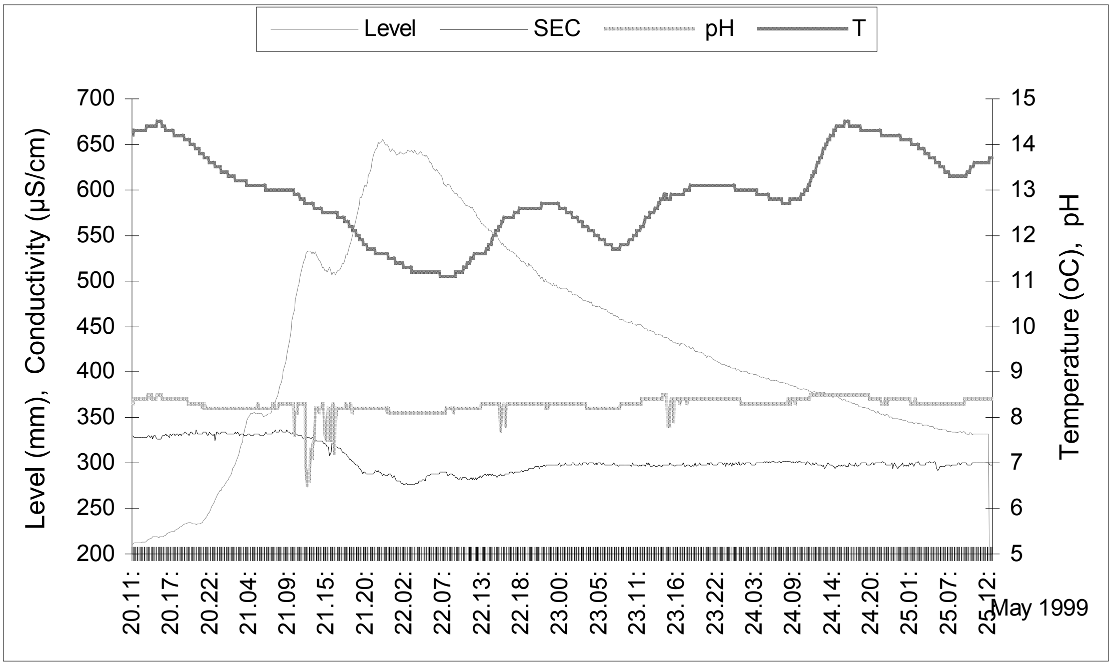

Figure 9. Water quality measurement in May 1999.

The aim of selecting three microbiotests was to find out if there were any differences in their sensitivity. Namely, the conventional *Daphnia* toxicity test is legally adopted for testing the toxicity of samples from rivers during the regular annual biomonitoring of surface water quality (Brilly et al., 2001).

4 THE GRADAŠČICA – GLINŠČICA EXPERIMENTAL WATERSHED

The study area

The Gradascica River basin spreads in the transitional area from the Dinaric into Alpine region in the central part of Slovenia. The headwater section flows through the varied mountain relief of the Dolomites, and is carved with numerous ravines and valleys. The Gradaščica river watershed comprises an area of 154.4 km^2, which reaches far into the Polhov Gradec mountains.

Steep slopes, fairly high altitudes and abundance of precipitation (average yearly quantity from 1600 to 1700 mm) result in a quick rise in the water level of the Gradascica. The plain area of the Ljubljana basin widens on the eastern part of the watershed. At the Bokalce dam, the Gradascica splits into two water bodies, the Mestna Gradascica and the Mali Graben, which flow into the Ljubljanica River. The Bokalce dam controls the discharge to Mestna Gradascica stream and only about 10 % of discharge of the Gradascica River diverts to the Mestna Gradascica stream. The Mali Graben carries in total about 90 % of discharge of the Gradascica River.

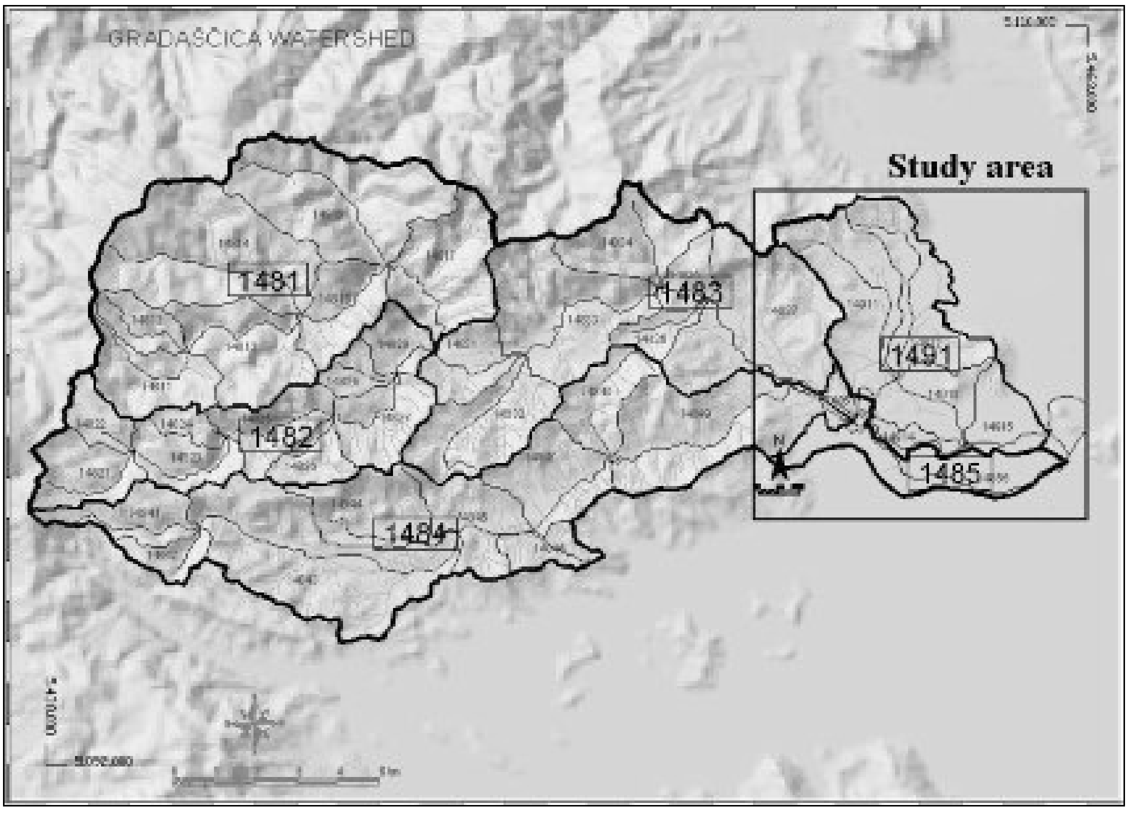

Figure 10. The Gradaščica river experimental watershed.

Glinscica (1491) is the tributary of the Mestna Gradascica stream. The area is close to the city centre and is heavily urbanised. The stream was heavily modified and regulated by concrete blocks (Rusjan et al., 2003). The Mestna Gradascica also divides into the upper and lower part related to confluence with the Glinscica. The Glinščica watercourse has its source under the north-eastern slopes of Toško čelo (590 m altitude) and passes into the plain area of the Ljubljana Plain, which is of poor permeability and flows into the Gradaščica (293 m altitude), presenting the southernmost point of the basin. The topography of the basin is comprised of a hilly area to the east and to the west and a plain area that spreads out in the southern part. Vast urban areas extend mostly in the eastern and southern parts of the catchment. The precipitation watershed area of the Glinščica comprises 17.4 km^2. The position of the runoff within the urban area is determined by the removal of rainfall water by way of a sewage system, therefore the orographic barrier fails to coincide with the Glinščica drainage. The total drainage area of the Glinščica up to its outlet into the Gradaščica is somewhat bigger and comprises 19.3 km^2 of the catchment area.

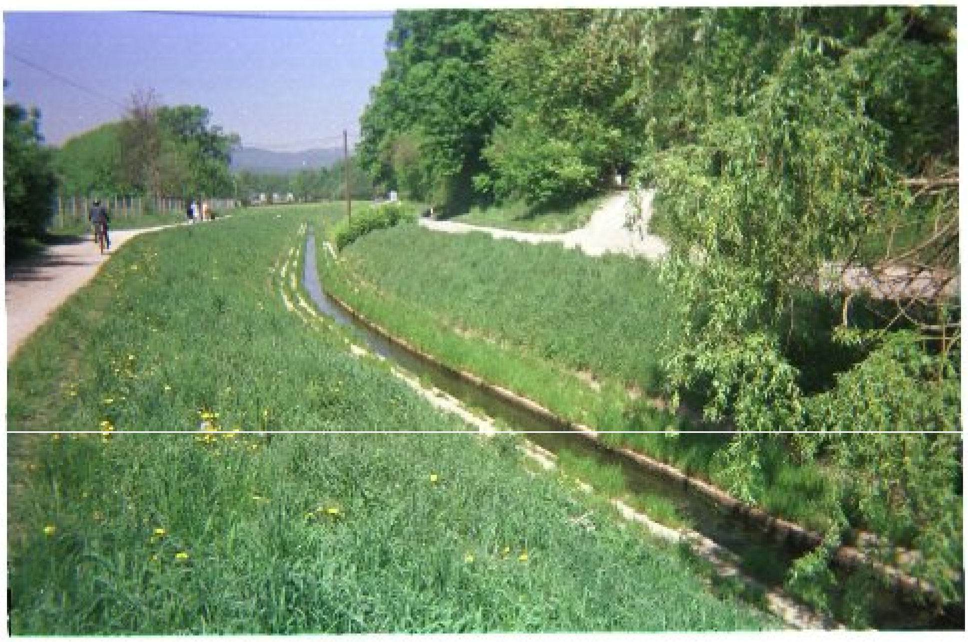

Figure 11. The Glinščica watercourse channel in Ljubljana.

Measurements and analysis

The measuring equipment includes a one-dimensional ultrasonic Doppler instrument, 2D/3D handheld Doppler velocimeter and water quality multiprobe. One-dimensional Doppler instruments, which are placed at the bottom of streams, continuously record the water level, measure water velocity and temperature. The multi-purpose instrument, designed for in-situ and flow-through applications, measures parameters simultaneously. It can be used for remote or attended monitoring of fresh, salt, or polluted water; in both, surface and groundwater. The multiple parameters include: nitrate, temperature, conductivity, depth, dissolved oxygen, Oxidation Reduction Potential (ORP) and pH. Measurements by multi-purpose probe were carried out in different seasons in approximately 40 measuring cross sections along the streams

Glinsica, Mestna Gradascica, Mali Graben and Przanec from July 2003 to July 2004. The continuous measurements of fluctuations of parameters in streams were also derived by the probe for 24 hours at 15-minute sampling rate in 3 cross sections equipped by the Doppler instruments. Six rain gauge stations were used for rainfall measurement. Measurements showed how vulnerable to pollution is the Glinščica creek due to typical urban flow regime with extremely low water flows and water content especially in the summer. The measurements have been conducted from July 2003 (Brilly et al., 2006).

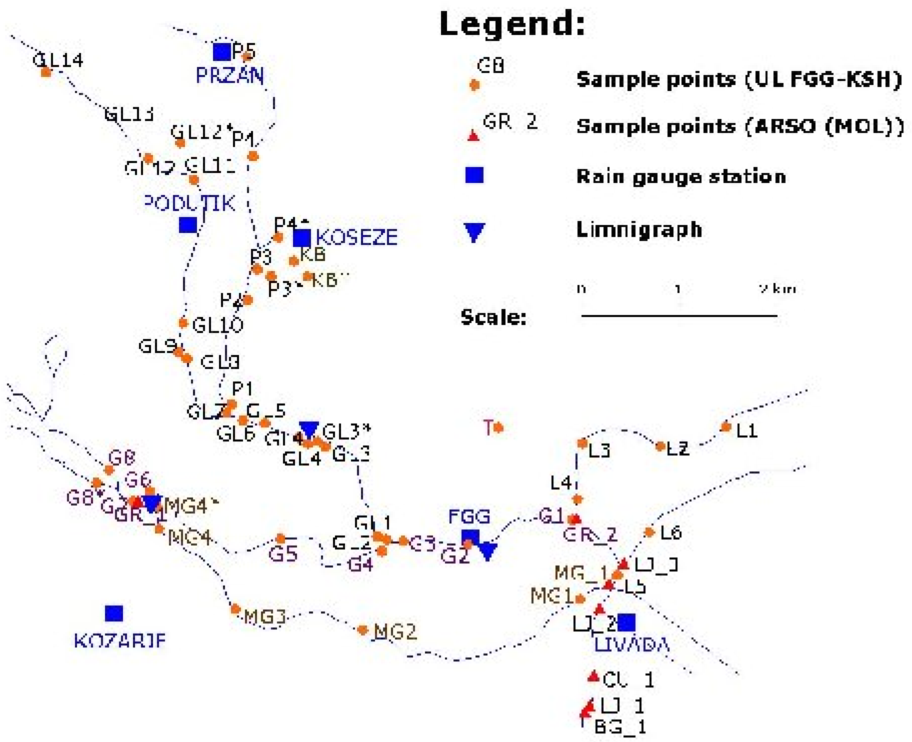

Figure 12. Measuring sites in the study area.

Results and discussion

The measurements of parameters by the multi-purpose instrument were performed in four two-day campaigns in July, October 2003, and January, March 2004. The number of measuring points was reduced during each campaign because of the rather small scale of the studied area. Among the parameters measured, the measurements of dissolved oxygen and pH value are discussed in detail.

Dissolved oxygen is a basic requirement for healthy aquatic ecosystems. The water in the streams was saturated with dissolved oxygen for more than 70 % of the time. The water was over-saturated in the summer time. The over-saturation with dissolved oxygen was higher in heavily modified concrete channels of the Mestna Gradascica and Glinscica streams than in the rehabilitated channel of the Mali Graben River. The concrete bottom and banks of the Mestna Gradascica and Glinscica streams are intensively overgrown by algae. As the concrete channel is mainly unshaded, the photosynthetic activity is very intense. This is reflected on the high concentration of dissolved oxygen, which is oversaturated during the daytime in the summer.

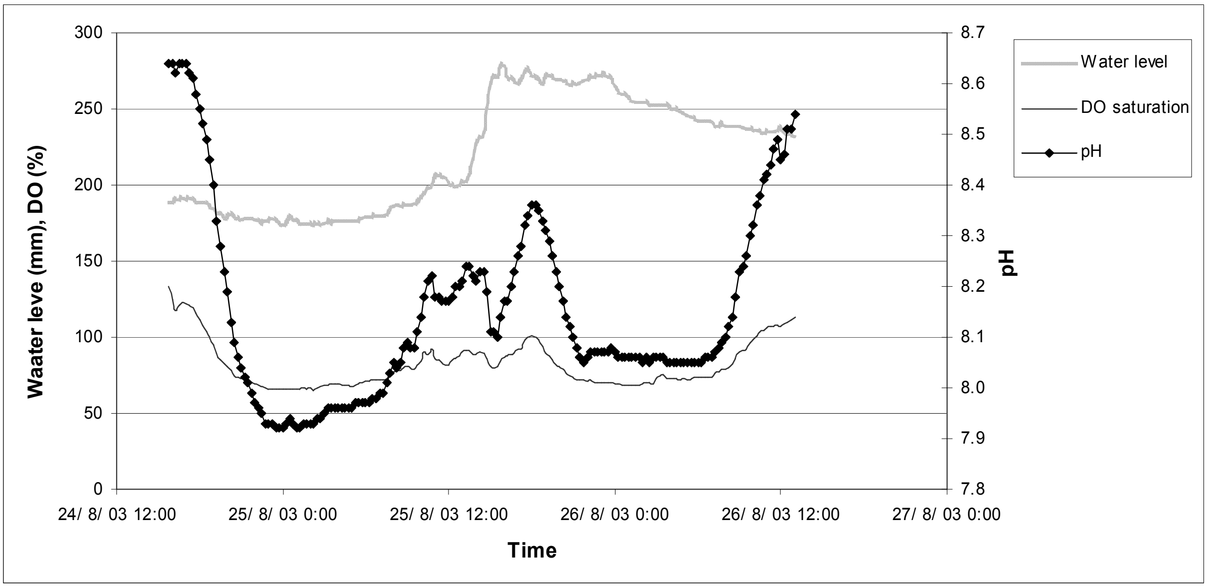

Figure 13. Continuous measurements of water level, pH and dissolved oxygen saturation in the Mestna Gradascica River.

The pH of the stream water reflects the chemical characteristics of precipitation and land surface. Levels of dissolved carbon dioxide in stream water reflect the balance between uptake of carbon dioxide by aquatic organisms (for photosynthesis) and release of carbon dioxide (by respiration). On the other hand, the concentration of dissolved oxygen is increased by the photosynthetic activity during the daytime and the dissolved oxygen can be depleted during the night by the respiration of water organisms.

The measurements were logged automatically at 15-minute intervals. The relation between the variations of pH and dissolved oxygen saturation is evident. Increased values of pH and dissolved oxygen saturation during the daytime are result of diurnal photosynthetic activity in the water body. The temporal fluctuations of pH and dissolved oxygen saturation are also related to the increased water discharge during a small flood wave produced by 11 mm rainfall.

5 CONCLUSIONS

The measurements on the Dragonja river basin started in autumn 2000 with the aim to define the impact of the natural reforestation on the water balance of the watershed. According to the result of one-year measurements, the average value of the precipitation throughfall amounted to 67.1 and 71.5% of the associated rainfall for the south and north research plots, respectively, while the average stemflow fraction was 4.5 and 2.9%, respectively. The difference is a consequence of the different structure and characteristics of forests on both slopes. The average annual interception losses amount to 28.4 and 25.4% for the south and north slopes, respectively. The values are relatively high compared with other similar studies. Such high loss of the deciduous forest of the Dragonja watershed is considerable and could be the reason for the reduction of surface water runoff. The conclusions of the research will improve the current understanding of hydrological processes, conditions and interaction between water, soil, deciduous forest and climate in the representative watershed of the Dragonja river.

The process of urbanisation has been accompanied by intensive changes of hydrological characteristics of watersheds. The concept of the watershed in urban areas has become more complex and difficult to define because the natural topography is disturbed in the process. The results of the monitoring on the Glinščica watershed demonstrate a wide range of information that can be gained from continuous measurements of basic water quality parameters in connection with analysis of hydrological regime of the urban environment. One of the major advantages of this type of monitoring is the possibility to quantify water quality extremes that cannot be detected by traditional spot measurements or sampling. This leads to a better understanding of dynamic short term variability in stream water quality and a new insight concerning watershed and in-river processes. The understanding of the processes calls for many field measurements, modelling, data mining and analyses. The use of monitoring is the first step of research, which would help understand the system and identify the key factors for modelling.

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