Geodetic monitoring of suspended particles in rivers

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Abstract. There is a trend in modern approach to the management of space of collecting the spatial data, in order to obtain useful information. In this paper a research of suspended particles in the river Drava and Mura will be introduced. The goal is to connect different fields of water management in countries where the rivers Drava and Mura flows in purpose of water management sustainability. The methods such as GNSS for mapping cross sections of the river, the use of ADCP (Acoustic Doppler Current Profiler) measurement system and water sampling to monitor sediment in the water will be presented.

1. Introduction
The goal of today’s water management is to predict the water currents and suspended material to be able of sustainable development along rivers. Two of the largest rivers in Slovenia (Drava and Mura), shared also by Austria are of the great interest. In this paper the supervision of sediments by running the monitoring of transport of suspended parts in the selected profile river are investigated. All used methods for this research works such as, geodetic methods, hydrological methods, methods of measuring the concentration of suspended parts and forecasts of transport of suspended parts are described. The results of geodetic measurements from GNSS (Global Navigation Satellite System) method for accurate profile positioning, hydrological measurements of watercourses with the use of acoustic Doppler meter ADCP (size and direction of the velocity vector of the water, the surface of cross-sections of the channel, flow, temperature and the bottom configuration) and simultaneous water sampling (10 liters) for laboratory measurement of concentration and determination of the suspended parts in some areas and depths of the selected profile on the river Drava (at the Šturm’s stream inflow) are studied.

2. The objective of suspended particles monitoring
The main objective of monitoring of the suspended parts is to improve our knowledge of the sediments transport and calibration of existing or establishment of new models of suspended sediment in both the river. Activities are divided into two major parts, where the first applied to the extraction of data about the flow, geometry of the channels and the amount and type of floods and in the second part a detailed hydro-dynamic analysis, where streamlines of the treated parts of the river in connection with the planned transport of suspended sediments is simulated.

Expected immediate impact of particulate matter monitoring are as follows: network of measuring places of suspended sediments, balance of suspended sediment transport in the period of 3-4 years and the simulation of the size of the suspended sediments
3. Working methods

3.1 General

Geodetic measurement methods based on GNSS, where the exact position of the current profiles is defined using a satellite signal.

Hydrological data of the river are obtained using the Acoustic Doppler Current Profiler (ADCP). With ADCP accurate information about the size and direction of the velocity vector, the cross-sectional surface, flow, configuration of the bottom and water temperature can be measured.

For such cases ADCP is widely used at sea (Firing, Hummon, 2010), rivers (Woodward, 2007) and lakes. ADCP can be used in navigation (Firing, 1991, King, 1995). At the time of hydrologic measurements water is sampled for the purposes of monitoring the concentration and type of the suspended parts of the streams, from which in the laboratory hard substances are excreted. The amount and also on selected representative samples the size of the parts, and mineral and chemical structure are analyzed. On selected river sections, the water samples are taken in three locations: on the left, in the middle and on the right side of the river and from the surface from 1.5 m depth and 3m depth.

3.2 Geodetic methods

The Topcon GNSS equipment (Hyper Pro receiver and FC 200 data collector) is used. It is a GNSS system which as given point in space takes satellite locations in time of the measurement. With this equipment the American GPS satellites and Russian Glonass satellites can be tracked which improves the accuracy of the results. Surveying method is a base-rover system, where the base receiver in every survey epoch is stabilized on the same (known) point that at the first time epoch was determined and in general lies on the profile under investigation. Satellite signal receives base receiver and rover on the boat and communicate with one another via radio frequency links. Rover is on the boat attached to the computer with the cable, to which also ADCP is connected. This enables to the WinRiver software to write the measured data from the GNSS rover and ADCP (Figure 1, Figure 2).

**Figure 1. GNSS measurement system**

**Figure 2. The boat with the measurement equipment**

Each measurement profile is defined by two geodetic points (in the local coordinate system) to the points on each river bank. Geodetic points at the beginning and at the end of the profile are stabilized with a wooden stick. In Fig. 3 an example of the profile of the Drava river near a tributary stream of Sturm is shown. The measurement section is shown with the red line.
3.3 Hydrologic methods

ADCP boat (Figure 4) is the RioGrande ZedHed 1200 kHz type (Teledyne RD Instruments). It enables measurement of river flow in riverbeds of depths more than 0.4 m. Due to the specifics of broadband measurement procedure can be done to a depth of 15 m and current velocity up to 10 m/s. ADCP current speed on the assumption equates to the speed in the water dissolved or suspended parts. To determine the speed it uses Doppler phenomenon (measures the change between the emitted and received frequencies). Water speed is measured indirectly, through in the water dissolved particles, air bubbles and other parts. At the same time ADCP measures the depth of the river as a time of signal travel to the bottom of the channel and back. For all measurements the frequency between 500 and 2000 kHz is used. This method is used world widely used at the rivers and on the sea for speed analysis, sedimentation, sediment transport and hydrodynamics (Kinze 2010, Kim, 2012, Kostaschuk, 2005).

The depth and the speed measurements are performed simultaneously with a single pass of the channel. With WinRiver software and radio connections (also wireless connection) between ADCP and portable computer all data can be monitored online and in real time. Final results are the flow, surface of the cross-section, medium speed, etc. – known immediately after crossing of the river.

Figure 3. Digital-ortho photo, Šturm stream and the measurement profile

Figure 4. ADCP attached to the boat and to the computer
Because of the draft of the ADCP and the fact that each of the four transmitter and receiver are at the surface there remains a small section near the surface that ADCP cannot measure. The thickness of this layer is between 20 and 30 cm. Also there is an unmeasurable area at the bottom of the riverbed, as a result of interference diffraction of the sound beam. The thickness of this area is approximately up to 6% of the water depth. Unmeasurable is also small part at both edges of the channel, so we need to assess the length of the ACDP to the river banks. The inflow through unmeasured parts are added to the measured flow rate using interpolation or extrapolation methods. Unmetered parts of the channel are shown in Figure 5.

![Unmeasured stream at river banks](image1)

**Figure 5.** Unmeasured and measured parts of the profile of the river using ADCP

WinRiver Software Enables on-line checking of measured results. On the upper left side of the Fig. 6 a cross section showing the velocity vector is presented; at lower left is cross-section of the channel; the red line shows the path of the ADCP with respect to the direction of north - south, the blue shows the average velocity vectors (direction and magnitude) of individual verticals. On the right side the collection of the most important measurements with numbers are showed.

![Example of WinRiver measurement screen and numerical results](image2)

**Figure 6.** Example of WinRiver measurement screen and numerical results

### 3.4 The methods for concentration suspended particles measurements

For the purposes of determining the concentration of suspended parts of the waters of Drava and Mura on different segments of the watercourse and in the different depths water samples are taken. Each sample contains at least 10 liters of water, which is more than the application of standardized methods
for determining the concentration of suspended material. Due to the large quantities of water when sampling the results of suspended material are more reliably. Larger amounts of extracted material also allows us to do some further research such as sizing and structuring the parts. The combination of the use of ADCP and determination of sediments is represented in the work of the author (Mol, 2003), comparison the ADCP and the transmission-meters in the work of the author (Holdaway, 1999).

Taken the samples are also carried out at the time of the hydrological measurements at selected sections of rivers with boats (Drava - Šturm, Figure 7), from the ferry on Mura (Mura - Vranji vrh) or the bridge (Drava – at Ptuj city).

![Figure 7. Equipment for water sampling](image)

The procedure for execution of the suspended particles of the water is as follows:
- The samples shall be suspended for several days or such time, to suspended material can thicken on the bottom,
- the clean water, which must not contain any parts, is poured away
- these two actions are repeated several times, and samples are put into smaller and smaller containers (Figure 8),
- In the last phase the water is eliminated by evaporation,
- On the basis of the mass of the extracted components and the quantity of subtracted water the concentration of suspended material in the water is calculated.

![Figure 8. Elimination of suspended material from water by evaporation.](image)

4. Results
In the case of Sturm's stream measurement there are three profiles on approx. 20 m. On Fig. 9 those three measured and drawn profiles can be seen. Three profiles close one to another allows us to make a 3D model of that section of the river bed. (Figure 10).
Figure 9. Measured and drawn cross sections on the Drava river near Sturm stream

Figure 10. 3D model of the river bed

There were seven measurements on the Sturm’s stream. Hydrological results are shown in Table 1.

Table 1. Hydrologic results of seven measurements

| Date       | 14.10.2009 | 14.01.2010 | 20.04.2010 | 17.6.2010 | 16.9.2010 | 31.1.2011 | 22.3.2011 |
|------------|------------|------------|------------|-----------|-----------|-----------|-----------|
| Q (m³/s)   | 441.347    | 314.285    | 188.319    | 555.801   | 428.936   | 312.399   | 168.726   |
| T (°C)     | 12.8       | 3.36       | 10.89      | 16.71     | 15.18     | 3.55      | 7.77      |
| Max. depth (m) | 6.47   | 6.04       | 5.74       | 6.52      | 6.00      | 5.75      | 6.33      |
| River speed (m/s) | 0.794 | 0.615      | 0.406      | 0.946     | 0.779     | 0.524     | 0.662     |
| Area of the profile (m²) | 586.36 | 534.58     | 519.51     | 626.14    | 566.33    | 579.23    | 562.01    |

Figure 11. Velocity vectors in a cross section

Concentrations of the suspended material were defined in samples from three profiles which were taken away in the depths of 2 and 4 meters and from the surface of the river (Figure 12). The results are shown in Table 2.
Table 2. The results of concentration of suspended material measurements

| Location | Concentration of suspended material (g/l) |
|----------|-----------------------------------------|
| Date     | 14.10.2009   | 14.01.2010   | 20.04.2010 | 17.6.2010 | 16.9.2010 | 31.1.2011 | 22.3.2011 |
| P-1, 2m  | 0.012        | 0.004        | 0.004      | 0.054     | 0.017     | 0.005     | 0.006     |
| P-1, 0m  | 0.012        | 0.003        | 0.003      | 0.040     | 0.013     | 0.001     | 0.005     |
| P-1, 1m  | 0.014        | 0.004        | 0.004      | 0.053     | 0.016     | 0.003     | 0.005     |
| P-2, 2m  | 0.012        | 0.004        | 0.004      | 0.054     | 0.015     | 0.001     | 0.005     |
| P-2, 0m  | 0.011        | 0.004        | 0.003      | 0.050     | 0.015     | 0.001     | 0.005     |
| P-3, 2m  | 0.014        | 0.005        | 0.004      | 0.049     | 0.015     | 0.003     | 0.007     |
| P-3, 1m  |              |              |            |           |           |           |           |

Figure 12. Places where the water examples were taken

5. Conclusion
The article presents the results of measurements of suspended material from the area of the Drava River. Water samples are treated taken at the site of the influx of Šturm’s stream. At the time of sampling flow of the Drava River was also measured. From the collected data it is possible to base the following conclusions: The amount of suspended material increases with the flow of water, but not linearly. In this area it is eliminates part of the suspended material due to the channel geometry. The quantity of sediment particles depends primarily on the water flow. The mineral composition of suspended materials is a reflection of the environment in which flows the river Drava and its tributaries. Further investigation, including measurement of concentrations of suspended materials, river flow and channel configuration using ADCP and GNSS, will be the basis for hydrodynamic analysis and prognosis of sedimentation.

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