Co-funded by the Erasmus+ Programme of the European Union

Innovative Measurement Tool towards Urban Environmental Awareness

Flooding

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This project has been funded with support from the European Commission.

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Project Partners

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1.1 Introduction

Water has always been present in human life. Unfortunately, floods and droughts are now a serious problem, especially in urbanized areas. Climate changes that we observe every day have a significant impact on changes in water management. Flood risk is related to many aspects. The most global is the observed gradual rise in the level of seas and ocean. This may result in gradual flooding of low-lying areas of the coastal. Water will remain there permanently, absorbing the space we are used to living in. It is worth remembering that our decisions influence the quality of life of future generations. Rivers and reservoirs are a more common threat, Figure 1.1 showing the frequency of floods. This shows that they most often occur not in the coastal zone, but in the middle of the continent. Weather anomalies are observed more and more often, including precipitation characteristics transform into local flash floods. Rivers and reservoirs are a more common threat. Probably everyone has seen the rainwater flowing down his/her streets. This is because the catchment area is unable to absorb the enormous amount of water that falls on it in a short time. In the first place, all depressions are flooded, rivers and reservoirs are filled, and rainwater drainage pipes are flooded. When this is not enough, water floods the basements of building, streets, and entire neighbourhoods. Therefore, nowadays water management is becoming one of the most important tasks of engineers.

Water management is an important task not only for the authorities, but also for every citizen. To be able to manage water, it is necessary to monitor the amount of water in rivers, reservoirs, urban and green areas. Measurement networks already exist in many cities to control and manage water resources. However, there are still too few of them. So, it is important that not only the authorities but also city citizens can easily monitor the water level in their cities, settlements or houses. Such actions make it possible to anticipate upcoming threats and, if possible, prevent them. And if this not possible, the allow to limit their negative effects. Then, thanks to such measurements, today each of us can protect our city, housing estate or home against the adverse effects of water.

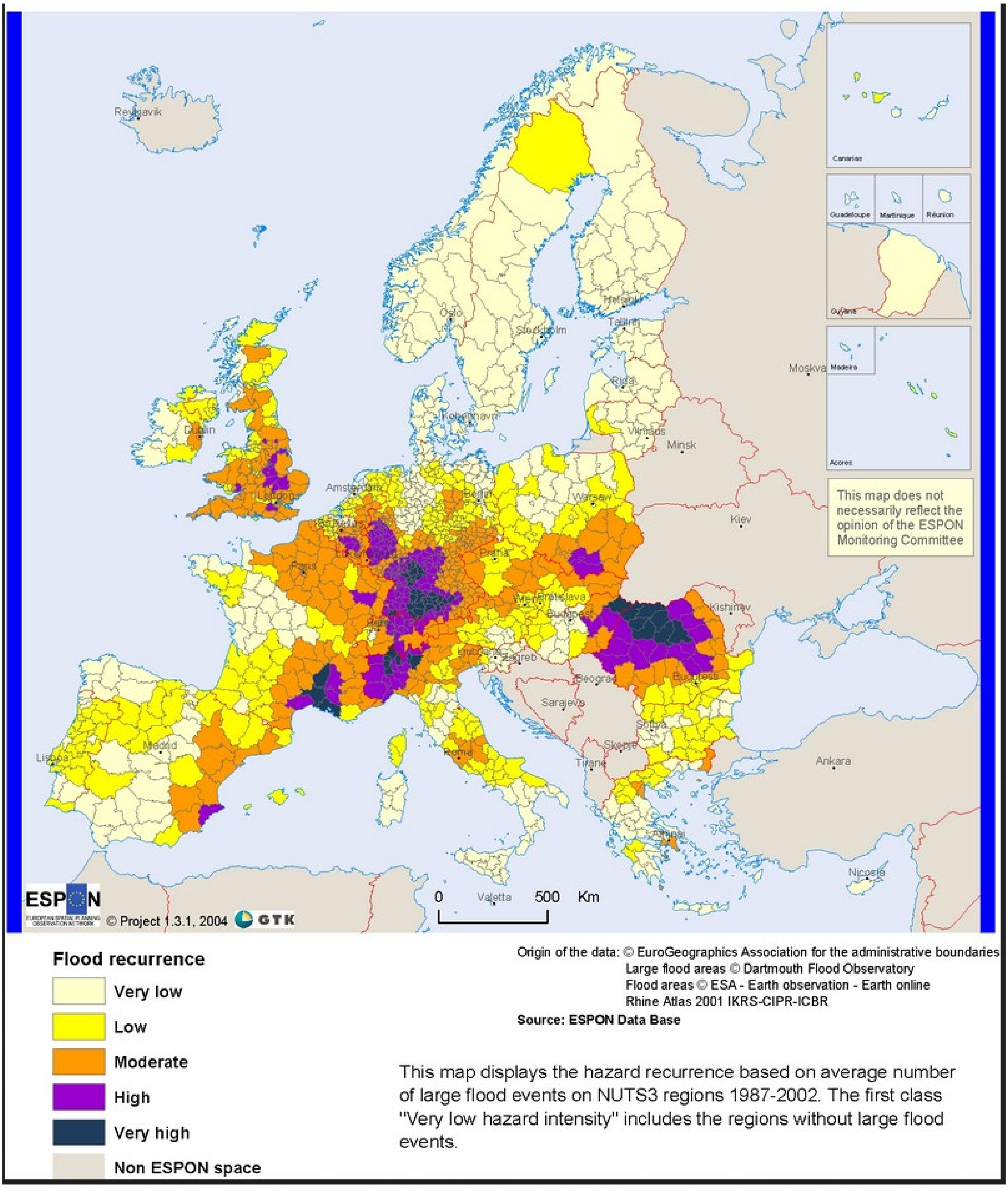


Figure 1.1. Flood frequency map (source: European Spatial Planning Observation Network (ESPON)).

1.2 Flood risk maps

Law basics

In 2006, the European Water Directors decided to establish a European exchange circle on flood mapping (EXCIMAP). European Union has adopted a European Directive on the Assessment and Management of Flood Risks [3], which aims to reduce the adverse consequences on human health, the environment, cultural heritage, and economic activity associated with floods in the Community. This Directive sets out the requirement for the Member States to develop three kinds of products:

- a preliminary flood risk assessment,
- flood mapping, with a distinction between flood hazard maps and flood risk maps,
- flood risk management plans.

According to this, flood hazard maps shall cover the geographical areas which could be flooded using at least three scenarios: low, medium, and high probability of occurrence. For each scenario the flood extent, the water depths or water level, as appropriate, and where appropriate the flow velocity, have to be represented on the maps (look at Figure 1.2 and Figure 1.3).

Rising sea levels

Rising sea level is not the most urgent problem, but it is worth visualizing its consequences. It is worth checking whether our hometown may suffer, it can be done with the „calculators" such as flood map: https://www.floodmap.net/ (Figure 1.2).

Rivers flooding

Flood risk maps can be found in European collections (for example: https://data.jrc.ec.europa.eu/collection/id-0054) as well as in local resources – Figure 1.3 (country, province, or city scale). River related floods are the most often and are caused by:

- intensive rainfall and / or snowmelt,
- ice jam, clogging,
- collapse of dikes or other protective structures.

Figure 1.2. An example of the effects of a sea level rise of 1, 5 and 10 meters (source: https://www.floodmap.net/).

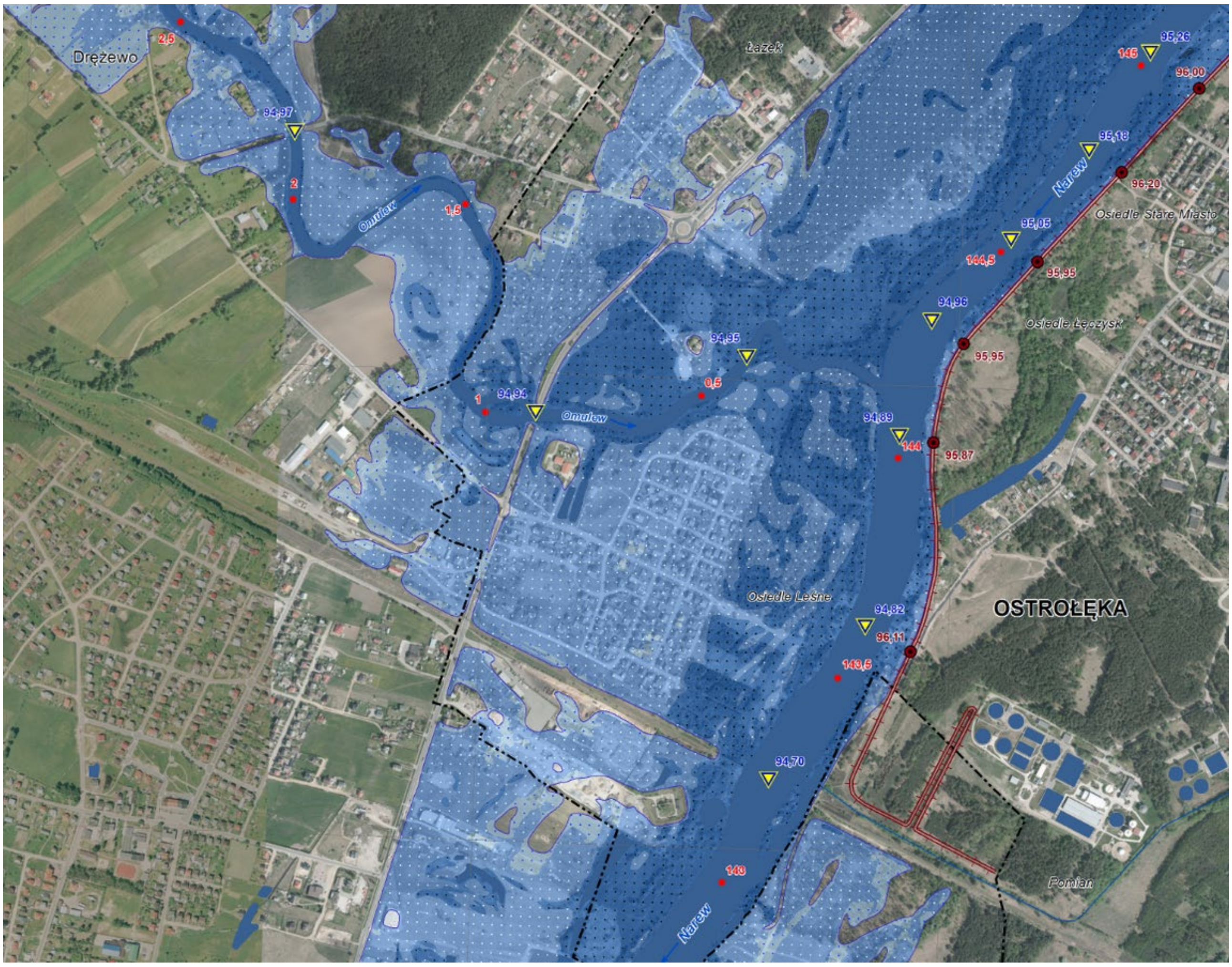


Figure 1.3. Narew river, an example of a flood risk map from Poland - the expected flood range and water depth are marked (source: https://www.kzgw.gov.pl).

If we look at maps and European flood risk analyses, we see that mainly the largest watercourses are analysed (Figure 1.4). Of course, main rivers generate the most terrible threats and cause the biggest material losses on the country scale. However, from the point of view of the rivers in our neighbourhood, the most important thing is what happens behind the fence and has a direct impact on his health and property. Those with a better or worse effect are handled by the local administration.

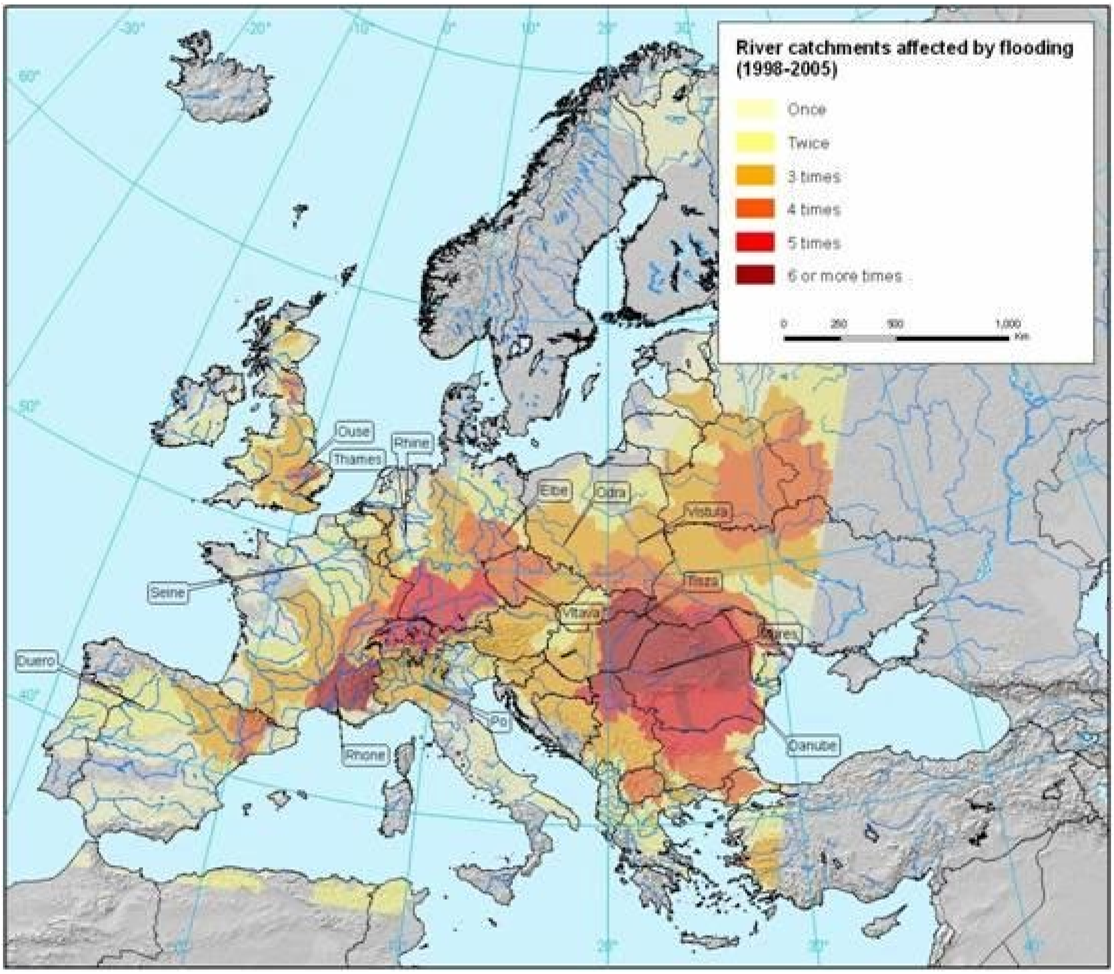


Figure 1.4. Recurrence of flood events in Europe between 1998 and 2005 (source EEA).

Every year, the awareness and commitment of members of local communities are growing. Contrary to appearances, estimating the flood risk in our area does not have to be difficult. We can all help to monitor flood risk index, regardless of our engineering and technical advancement level.

1.3 The channel capacity

When we want to determine the state of flood risk in our place of residence, we need certain parameters describing the water level in places that are characteristic and important from the point of view of flooding. Such parameters include, for example:

- the water level in the river / reservoir,
- type of land cover around the river / reservoir (green areas, forest, city centre, asphalt parking etc.),
- the percent of green areas,
- the amount of water that falls during rainfall (from the closest rain gage),
- amount of water infiltrating into the ground etc.

All these parameters are needed to determine the channel capacity. Because the maximum capacity for these characteristic places gives engineers information about the amount of water that can flow in these places. Such information allows us to determine the degree of flood risk and, if necessary, start actions aimed at limiting the negative effects of floods. To illustrate the most important parameters allowing to determine the amount of water in the city and to determine the capacity, the measurements carried out by students in Gdańsk during their internships are described below. The below-described measurements were made using measuring devices under the supervision of a teacher. However, it is also possible to obtain estimates of river flow and capacity by performing the measurements described in chapter 4.2.4. Such measurements can be performed by anyone without the need for measuring equipment. Performing such measurements is an important element in creating a local measurement network that protects our homes, housing estates and cities.

Manning formula

The Manning formula is an empirical formula, which can be used to calculate cross-sectional average velocity flow in open channels. The Manning equation is a widely used and very versatile formula in water resources. It can be also used to compute the flow in an open channel, compute the friction losses in a channel, derive the capacity of a pipe, check the performance of an area-velocity flow meter, and many more. The Manning formula uses water surface slope, cross-sectional area, and wetted perimeter of a length of uniform channel to determine the flow rate. There are many ways to express the Manning equation. The equation was derived to describe the velocity in a conduit, but for hydraulic computations, it is often desirable to express the equation in the form of a flow. The basic version of the equation will be discussed:

$$V = \frac{1}{n} \cdot R_h^{\frac{2}{3}} \cdot S^{\frac{1}{2}}, \tag{1}$$

where:

V – cross-sectional mean velocity [m/s],

n – Manning coefficient of roughness [s/m$^{(1/3)}$] – in general rougher conduits with higher friction have a higher value, and smoother conduits with lower friction have a lower value, depending on the type of material and the channel condition, select a value from the table (it can be found on the internet).

R_h – hydraulic radius [m] – this is the variable in the equation that accounts for the channel geometry. Hydraulic radius is computed from the area divided by the wetted perimeter of the flow. The wetted perimeter is literally just like it sounds – it is the length of the conduit around the perimeter that is wet. (Figure 1.5).

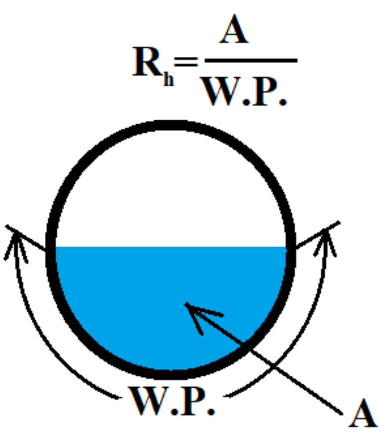


Figure 1.5. Hydraulic radius.

S – slope of the energy gradient [m/m] – often calculated as channel bottom slope (Figure 1.6).

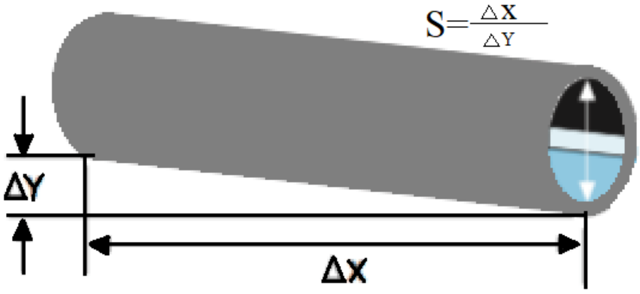


Figure 1.6. Hydraulic radius.

Based on the above formula, it is possible to determine the average flow velocity in the watercourse cross-section. However, to determine the throughput, we use the flow rate. Therefore, to calculate the flow rate, it is necessary to use additionally the continuity equation:

$$Q = V \cdot A = constans, \tag{2}$$

where:

Q – flow rate [m^3/s],

V – cross-sectional mean velocity [m/s],

A – cross-section area [m^2].

Case study Gdańsk

Students performed measurements to determine the capacity of the river in different sections of the analyzed stream. The measurements took place on June 25, 2020 in Gdańsk in the Jelitkowo district at the mouth of the Gdańsk Bay. In the area of measurements were located the "Jelitkowska" reservoir and the "Oliwski" stream (Figure 1.7).

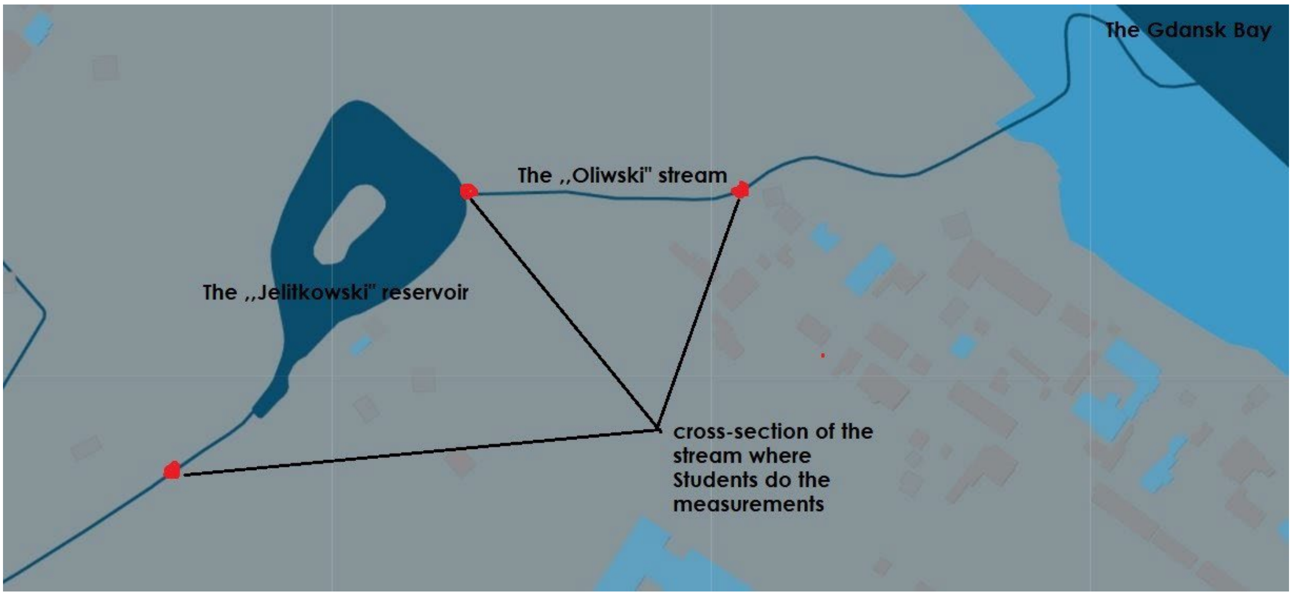


Figure 1.7. The area of the measurements.

The measurements were carried out as part of student internships, where under the supervision of a teacher, the students could take the necessary measurements using the available measuring devices. During the measurement's students performed:

- bottom sounding in two cross-sections of the stream,
- measurement of the flow velocity with the use of hydrometric mills in these cross-sections (Figure 1.8),
- measurement of surface velocity using floats and a stopwatch.

Moreover, in order to determine the longitudinal slope of the water level, height measurements were made with a technical level. In addition, in one of the cross-sections located at the outflow from the reservoir, measurements of the load of the overflow with a sharp edge (weir) were made (Figure 1.9).

Figure 1.8. The cross-section where students did measurements.

Figure 1.9. The cross-section shown on Figure 1.7 where students measured the load of the overflow with a sharp edge (weir).

Thanks to the performed measurements, it was possible to precisely determine the maximum capacity of the channel in places important from the perspective of flood risk. Such measurements allow not only to control the current flow conditions, but also to determine the limits, the exceeding of which means the occurrence of a flood risk. Therefore, it is important to make such measurements cyclically over a long period of time.

As can be seen in the figures above, two river cross-sections with bridge structures and a sharp-edge overflow cross-section were selected for measurements. This choice was not accidental, because during a flood it is possible that in these cross-sections the river will overflow onto nearby areas, such as a tram terminus, a street with a roundabout. It is important, therefore, to determine the maximum capacity of the channel in these places and periodically control the water level in order to limit losses in the event of danger. Students on the basis of measurements performed diagrams illustrating the dimensions of the channel and the bridge as well as the depth of water on the day of measurement (Figure 1.10, Figure 1.11). On the basis of these data, it is possible to determine the maximum capacity of the channel (Table 1.1 and Table 1.2). For this, Manning's formula (1) and continuity equation (2) should be used.

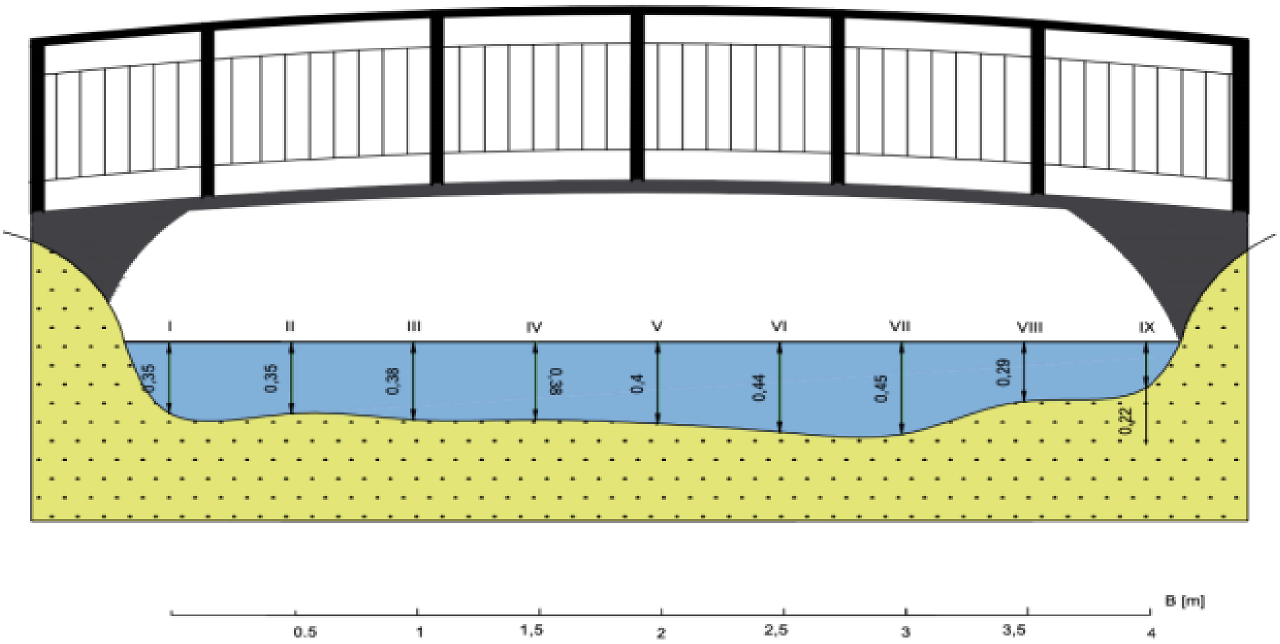


Figure 1.10. The cross-section of the stream at a section before the reservoir, B - cross-section width.

Table 1.1. The parameters needed to determine capacity for cross-section of the stream at a section before the reservoir under different flow conditions.

parameters	during measurements	taking into account the bridge when flowing with a free surface	taking into account the bridge when flowing under pressure
cross-sectional area A [m²]	1.567	4.578	4.578
hydraulic radius R_h [m]	0.332	0.733	0.555
slope of the energy gradient S [‰]	0.895	0.895	0.895
Manning coefficient of roughness n [$m^{-1/3}$ s]	0.028	0.026	0.024
flow rate Q [m³/s]	0.803	4.282	3.854

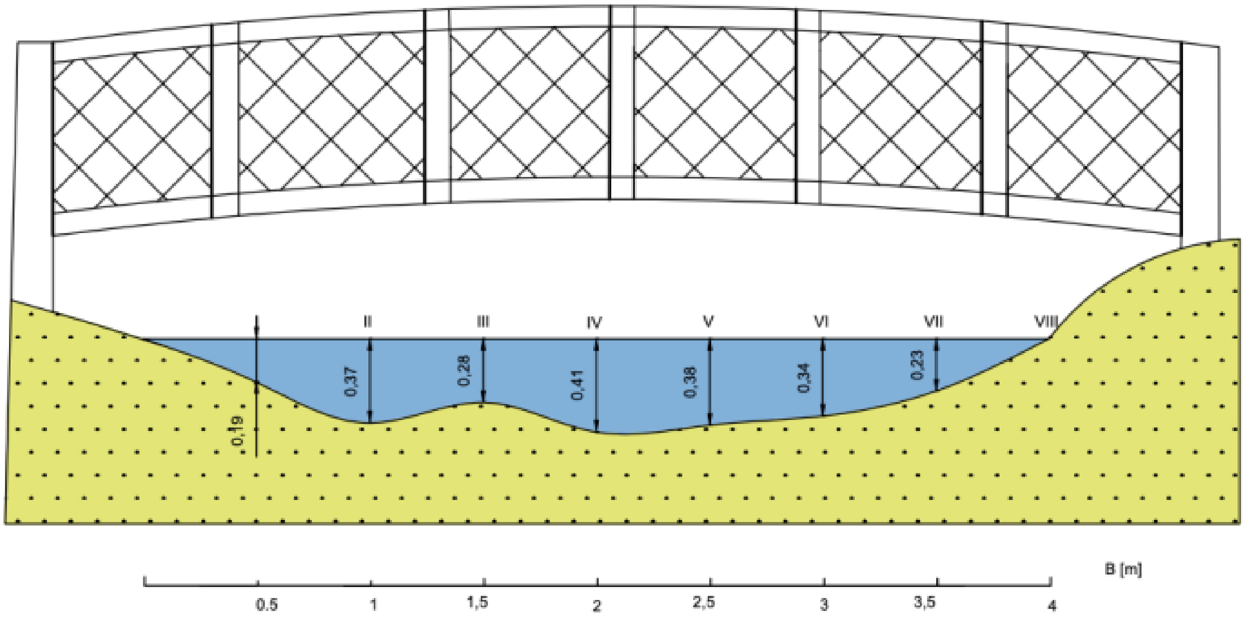


Figure 1.11. The cross-section of the stream at a section behind the reservoir and overflow with sharp edge (weir), B – cross-section width; I, II, ..., VIII – hydrometric verticals.

Table 1.2. The parameters needed to determine capacity for cross-section of the stream at a section behind the reservoir and overflow with sharp edge under different flow conditions.

parameters	during measurements	taking into account the bridge when flowing with a free surface	taking into account the bridge when flowing under pressure
cross-sectional area A [m²]	1.118	3.890	3.890
hydraulic radius R_h [m]	0.268	0.650	0.487
slope of the energy gradient S [‰]	0.895	0.895	0.895
Manning coefficient of roughness n [$m^{-1/3}$ s]	0.030	0.028	0.026
flow rate Q [m^3/s]	0.463	4.282	3.854

To determine the flow rate and the overflow capacity, it is necessary to determine the values of the parameters described in the figure below – Figure 1.10.

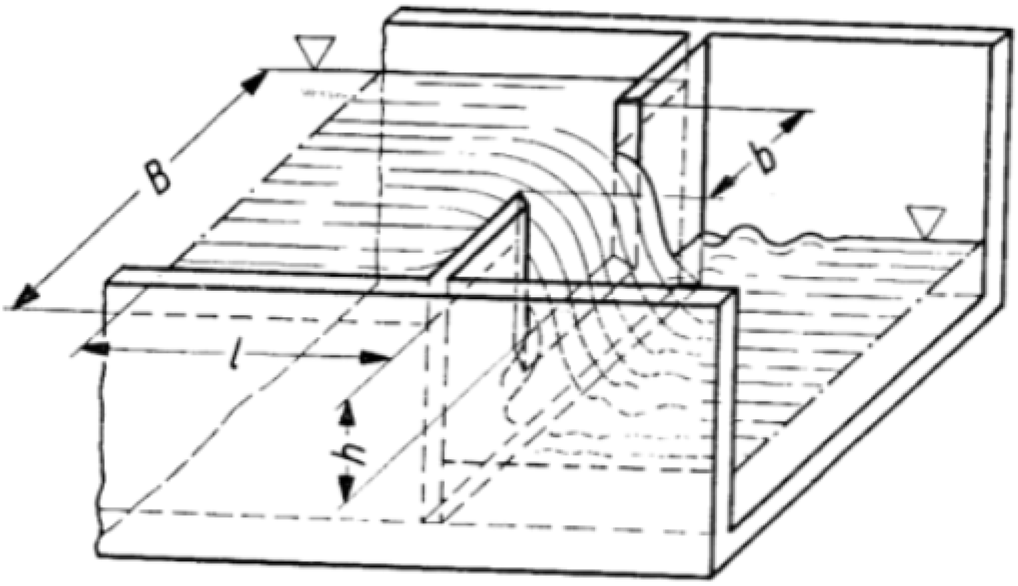


Figure 1.12. Sharp edge overflow with rectangular cut-out (www.prz.rzeszow.pl) where: B – width of the flowing water stream; b – width of the overflow edge; h – damming over the overflow edge (overflow load); l – distance of measured damming.

During the measurements, the students dealt with an overflow that had two spans, the structure as shown in Figure 1.12 and Figure 1.9, based on the measurements, they determined such parameters as:

- the ordinate of the overflow for span I: 2.652 m above sea level,
- the ordinate of the overflow for span II: 2.721 m above sea level,
- the ordinate of the water table behind the overflow: 2.633 m above sea level,
- the ordinate of the road: 4.400 m above sea level,
- overflow width for span I: B_I = 1.59 m,
- overflow width for span II: B_{II} = 1.56 m.

Based on these parameters, it is possible to determine the overflow load:

- for span I: h_I = 0.019 m and $h_{I\,max}$ = 1.748 m,
- for span II: h_{II} = 0.088 m and $h_{II\,max}$ = 1.679 m.

Knowing these parameters, it is possible to determine the flow rate and the wire maximum capacity on the basis of the formula:

$$Q = \frac{2}{3} \cdot \mu \cdot b \cdot \sqrt{2g} \cdot h^{\frac{2}{3}} \left[\frac{m^3}{s}\right], \quad (3)$$

where:

Q – flow rate [m^3/s],

μ - discharge coefficient [-] can be determined experimentally or from literature data,

b – overflow width [m] (Figure 1.12),

g – acceleration of gravity [m/s^2],

h – overflow load [m]

Flow rate for measurements:

$$Q_I = \frac{2}{3} \cdot 0.675 \cdot 1.59 \cdot \sqrt{2 \cdot 9.81} \cdot 0.019^{\frac{2}{3}} = 0.226 \left[\frac{m^3}{s}\right],$$

$$Q_{II} = \frac{2}{3} \cdot 0.675 \cdot 1.56 \cdot \sqrt{2 \cdot 9.81} \cdot 0.088^{\frac{2}{3}} = 0.615 \left[\frac{m^3}{s}\right],$$

$$Q = Q_I + Q_{II} = 0.226 + 0.615 = 0.841 \left[\frac{m^3}{s}\right],$$

The maximum capacity:

$$Q_I = \frac{2}{3} \cdot 0.81 \cdot 1.59 \cdot \sqrt{2 \cdot 9.81} \cdot 1.748^{\frac{2}{3}} = 5.519 \left[\frac{m^3}{s}\right],$$

$$Q_{II} = \frac{2}{3} \cdot 0.81 \cdot 1.56 \cdot \sqrt{2 \cdot 9.81} \cdot 1.679^{\frac{2}{3}} = 5.271 \left[\frac{m^3}{s}\right],$$

$$Q = Q_I + Q_{II} = 5.519 + 5.271 = 10.79 \left[\frac{m^3}{s}\right],$$

Tools

In the calculations presented in chapter 4.2.3.2, the parameters determined during field measurements were used. However, we do not always have the opportunity to go out and measure everything in the field, especially with the use of specialized (usually expensive) measuring equipment. Parameters such as depth and water velocity (and thus the discharge) can be measured in a simplified way (details in chapter 4.2.4), after all, even very estimated information is better than none. Even if we cannot estimate these parameters visually, we can perform calculations for various variants. Assuming a set of values, like water depth or velocity, we are able to determine the parameters determining the threat, as well as the characteristic values of these parameters.

The channel and cross-section geometries are the most difficult parameters to estimate. Fortunately, almost all of us have access to a computer and the Internet (even in public libraries), and as we know, the Internet is a powerful data resource. In this case, a digital elevation model (DEM) can be used. DEM is a 3D computer graphics representation of elevation data to represent terrain. Based on it, we can quite accurately determine, among others, height above sea level, as well as the terrain. profile – e.g. a floodplain. Files with the numerical terrain model can be found in the European database (https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem). However, as with flood hazard maps, it is also worth checking local sources, sources of altitude data for individual locations can be found, inter alia, via the website: https://www.opendem.info/opendemsearcher.html or on government portals (Figure 1.13 – an example from Poland).

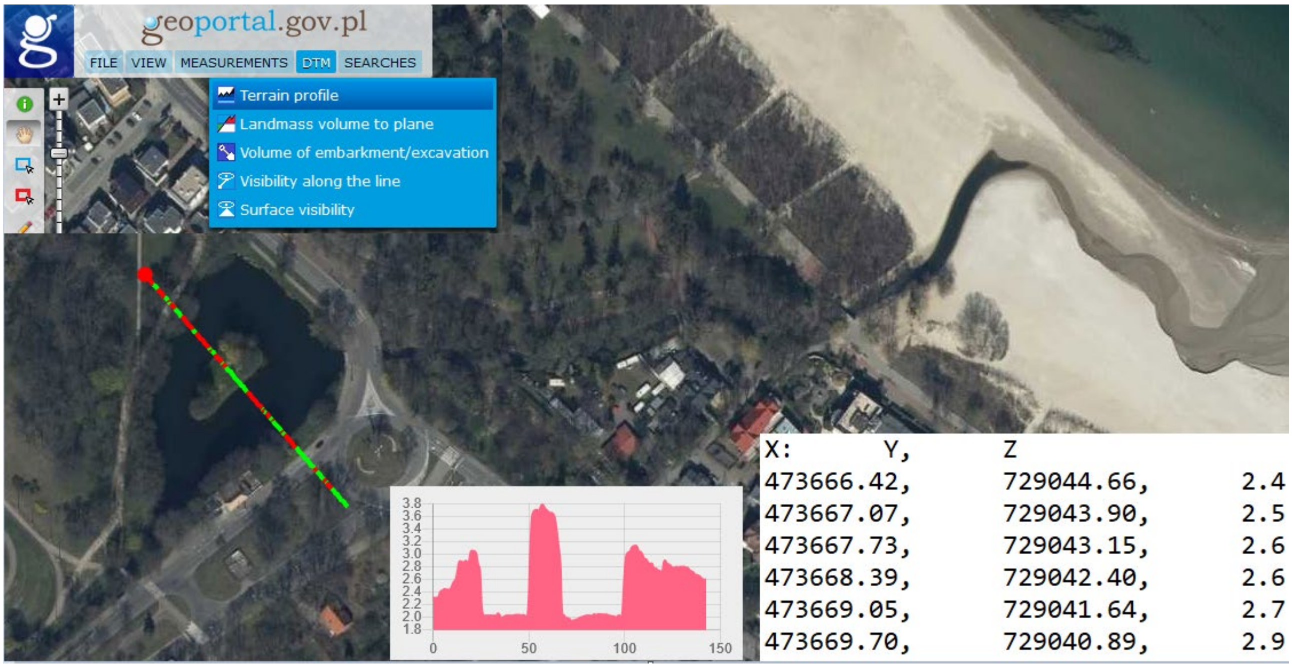


Figure 1.13. The example of cross-section geometry, based on DEM (sources: geoportal.gov.pl).

Linking a measurement point to an existing observation network

It is not always possible to make measurements (or even observations) during heavy rain, in an unmeasured area with flood risk. In such situations, local observation networks can be used. But what if there is a local measurement network in the area, but the point of our choice is not there? If you decide to set up your observation point, it is a good idea to "link" your cross-section to the nearest professional measuring point. This can be done even if we are separated from it by a large distance or if the point is located on a neighboring watercourse (a more difficult task requiring a longer series of observation data). It is enough to find a statistical connection between observed parameters and measurements at the closest, already existing, measuring station. It should be remembered that, as in the case of empirical formulas, a full correspondence will not be obtained in this way, as the results will be estimated but sufficient to determine the risk of flooding.

How to find the relation between measuring points P1 and P2 (Figure 1.14). Hydrology like creativity, there is plenty of options e.g.:

- measure the discharge at P2, with different water levels at point P1, then determine the relation $Q_{P2}(H_{P1})$,
- measure water levels at P1 and P2, and find the relation $H_{P2}(H_{P1})$, then base on Manning formula calculate $Q_{P2}(H_{P2})$ for set of water levels,
- find relation between the QP1 and QP2 base on the hydrological atlas
- mix up methods... etc.

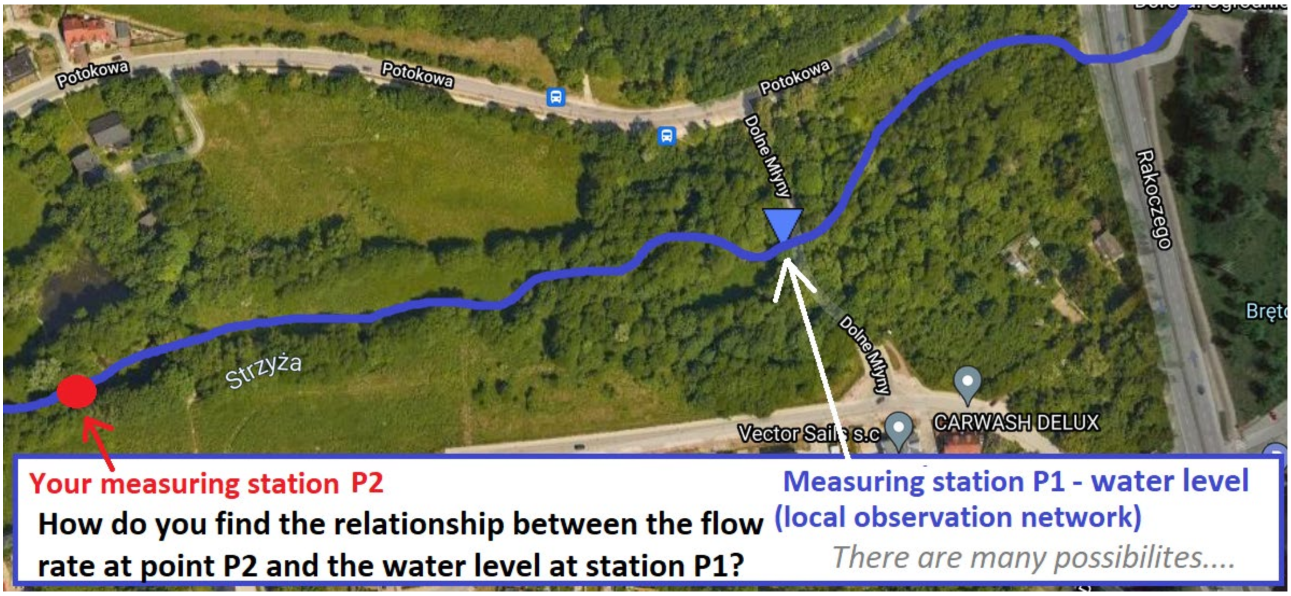


Figure 1.14. Linking a measurement point to an existing observation network.

The most important conclusions

- Due to modern technology, you can define the basic parameters determining the risk of flooding without leaving your home. Everyone has an impact on reducing the effects of flooding (early threat detection), it is worth knowing your area well.
- If our nearby canal is not included in the flood risk maps, you can define safe conditions yourself. It is also worth monitoring other parameters such as retention capacity, weather conditions, and standard relationships between rainfall and surface run-off / flow in watercourses (for basic methods look at 4.2.4).

1.4 Simple methods for measuring parameters affecting the flood index

Water surrounds us everywhere, even if it is not obviously visible. We must remember that water-related risks are not only determined by the rivers, seas, and water reservoirs. Monitoring of parameters related to the water can be and should be performed in any location. All you need to do is select the appropriate module. Measurements can be carried out in places such as: ***river*** (a place where water flows), ***reservoir*** (a place where water collects), ***green area*** (an area where water filters into the ground) and an ***urban area*** (an area where water flows over a built-up area). All measurements can be made independently, without the help of a teacher and without the use of specialized devices. These measurements make it possible to determine the parameters of water and its quantity. When choosing a place to take measurements, it is good to look around in the vicinity for such places. In cities, you can find places where several such areas are next to each other, e.g. a park through which a river flows. In such a place, measurements can be made from the river module, green area module and urban area module. The Table 1.3 presents a list of possible measurements depending on the current location.

Table 1.3. List of possible measurements in different locations.

Name	Location			
	Green area	**Urban area**	**Stagnant water**	**Flowing water**
Questionnaire				
Precipitation	x	x	x	x
Infiltration	x	x	x	x
Surface runoff	x	x	x	x
Basin description	x	x	x	x
Nature-based solution	x	x	x	x
Sewage system		x		
Water level (reservoir)			x	
Water level (river)				x
Measurement				
Precipitation	x	x	x	x
Infiltration	x	x		
Surface runoff	x	x		
Water level (reservoir)			x	
Water level (river)				x
Velocity (river)				x
Discharge (river)				x
Velocity (surface runoff)	x	x		
Retention	x	x		
Temperature	x	x	x	x

Would you like to take care of your surroundings and be more aware of the changes that occur there (from the point of view of water management and flood risk)? You can make regular hydrometric measurements, or collect information by filling out periodic questionnaires that monitor environmental changes related to increasing or decreasing flood risk. By analyzing the results collected over months and years, it is possible to determine probable trends concerning retention capacities, frequency of precipitation (and its volume), water levels in rivers and water reservoirs in the analyzed area, etc. It is clear that if the amount of precipitation is increasing and the catchment is subject to progressive urbanization, with no anticipation of sites that allow for local retention, the flood risk index is increasing and the risk is becoming greater. So try to find as many relationships as possible for your area to predict the flood risk index especially in places where you know that local flooding and flooding already occur or in places that are of particular concern to you. For the field characteristic description use file Flooding Questionnaire.doc and create your set of tables according to Table 1.3.

Green area

Table 1.4. List of possible measurements in green area (check list).

Green area	Precipitation	Infiltration	Surface runoff	Basin description	Nature-based solution	Velocity (surface runoff)	Retention	Temperature
Questionnaire	x	x	x	x	x			
Measurement	x	x	x			x	x	x

Retention – Field easy {output: location – text, area – numbers [m^2], volume – numbers [m^3], description – text, photo}

Is there small retention in your area? These are places where water can accumulate rather than go directly to the rainwater drainage system. Small retention can take the form of depression (water will collect and evaporate there), a green area (rainwater will settle on plants, infiltrate into the ground), rain gardens, green roofs, etc. Try to find several places in your area that will allow you to locally keep the water or restore it to its natural circulation. For each site, take a picture, describe how the water is stored, and also try to estimate how much water can be collected there (volume, area, etc.) – measurement can be made with any device, even with a piece of stick or a shoe (something that you can later dimension).

Infiltration – Field easy {output: location – text, infiltration time – numbers [s], water volume – numbers [ml], base area – numbers [cm^2]}

Measuring device:

- prepare a cylinder-shaped container (bucket, plastic bottle, etc.),
- cut off the bases, and if this is impossible, make a hole as large as possible in both bases,
- measure the volume of the cylinder and the area of the base / hole in the base,
- prepare several portions of water, about 1 liter of water each – water may be more or less depending on the capacity of the prepared device,
- prepare a stopwatch.

Find several different types of land cover in your area (pavement, lawn, bare earth, asphalt), these will be measuring points. At each point, place an empty measuring device. At the same time, pour the prepared portion (0.5-1 liter) of water and start the stopwatch, measure the time needed for the whole poured water to infiltrate. Due to the very low infiltration velocity in impervious areas a safe place should be selected, you cannot block the passage, or expose yourself to unexpected interruption of the measurement.

Precipitation – Field easy {output: container inlet area – number [cm^2], volume – number [ml], time – number [s], daily sum of precipitation – number [dm^3 / day]}

A rain gauge can be any container in which we can collect water: a bowl, a jar, a bottle with cut-off neck (any shape of the inlet). The volume of water that will be collected in the container and the time it took for this water to collect should be measured. The measurement can be performed in two variants measurement of: the daily sum of precipitation, and the instantaneous intensity of the rainfall episode.

Measurement of the precipitation intensity. During the rain, at the same time, set the container to catch rainwater and start the timer. We check how long it took to fill the entire container (if it did) and how long all the rain was. In the case of a long rainfall episode, the measurement can be stopped when you notice a significant reduction in the strength of the precipitation (e.g. transition to a drizzle). Then we measure the volume of the collected water.

Measurement of the daily sum of precipitation. The rain gauge should be put in a safe place that allows it to be left for several days or even months. Every day at the same time the volume of collected water should be measured. The rain gauge should be emptied and put back in the same place after the measurement. If you notice any "rubbish" such as leaves or other debris, remove it immediately (taking care not to take away the collected water).

Temperature – Field easy {output: location – text, air temperature – number [°C], water temperature – number [°C]}

An outdoor thermometer should be used to measure the temperature. Measurements should be performed at the beginning and at the end of field research. In the case of measurements are longer than 2 hours or noticeable temperature changes during the exercise will be noticed, the temperature should be measured several times – the frequency of measurements should be selected to capture the dynamics of temperature changes.

The air temperature is measured in the same way as checking the temperature on a windows thermometer. During the first measurement (after removing the thermometer), wait a few minutes for the exact value to stabilize.

Urban area

Table 1.5. List of possible measurements in urban area (check list).

Urban area	Precipitation	Infiltration	Surface runoff	Basin description	Nature-based solution	Sewage system	Velocity (surface runoff)	Retention	Temperature
Questionnaire	x	x	x	x	x	x			
Measurement	x	x	x				x	x	x

Surface runoff – Field easy {output: water depth – number [cm], stream width – number [m], description – text, photo}

The surface runoff can be measured in two variants – during / just after the rain or in the dry period.

Measurement in the "wet" period *– choose a place in the area that turns into a periodic stream after rain (e.g. on the street or pavement). Take a photo, measure the water depth and the width of the "stream" and then calculate the cross-sectional area.*

Measurement in the "dry" period *is limited to locating and dimensioning the places where surface run-off is potentially to be observed. Take a picture of the streets (or other places) where water flows after heavy rain. Let us assume that these places become periodic streams. Measure them and try to determine the maximum capacity, e.g. in the case of street, check the maximum cross-section that water can flow (street width and height of the curb).*

Velocity (surface runoff) – Field easy {output: cross-section length – number [m], flow time – number [s], description – text and photo}

Measure the velocity of the surface runoff:

- find a straight section of the street – a place where surface runoff is pronounced, mark the beginning and the end, measure the length (L [m]),
- prepare a "float" – something that will float on the water surface, it can be a piece of wood, a paper ship, etc.
- throw in the float at least one meter before the beginning of the marked section, measure the time needed for the float to swim between the marked points (t [s])
- calculate the surface speed v = L / t [m / s]

Take photos and make notes – how the surface runoff looks like (grass, sand, sidewalk, concrete, asphalt etc.). If you have measured both: surface runoff velocity and surface runoff cross-section area then you can calculate the discharge, according to the continuity equation (2).

Precipitation – Field easy {output: container inlet area – number [cm^2], volume – number [ml], time – number [s], daily sum of precipitation – number [dm^3 / day]}

A rain gauge can be any container in which we can collect water: a bowl, a jar, a bottle with cut-off neck (any shape of the inlet). The volume of water that will be collected in the container and the time it took for this water to collect should be measured. The measurement can be performed in two variants measurement of: the daily sum of precipitation, and the instantaneous intensity of the rainfall episode.

Measurement of the precipitation intensity. During the rain, at the same time, set the container to catch rainwater and start the timer. We measure the time remaining until the rainfall ends or until the container (rain gauge) is completely full. In the case of a long rainfall episode, the measurement can be stopped when you notice a significant reduction in the strength of the precipitation (e.g. transition to a drizzle). The we measure the volume of the collected water.

Measurement of the daily sum of precipitation. The rain gauge should be put in a safe place that allows it to be left for several days or even months. Every day at the same time the volume of collected water should be measured. The rain gauge should be emptied and put back in the same place after the measurement. If you notice any "rubbish" such as leaves or other debris, remove it immediately (taking care not to take away the collected water).

Temperature – Field easy {output: location – text, air temperature – number [°C], water temperature – number [°C]}

Water temperature is measured in a similar way to air temperature measurement. Approximately 1 minute must elapse between the insertion of the thermometer in the water and the value reading (liquid inertia in the thermometer). Read the temperature carefully, do not remove the thermometer from the water while taking the measurement.

Stagnant water – reservoir

Table 1.6. List of possible measurements in reservoir (check list).

Stagnant water	Precipitation	Infiltration	Surface runoff	Basin description	Nature-based solution	Water level (reservoir)	Temperature
Questionnaire	x	x	x	x	x	x	
Measurement	x					x	x

Water level (reservoir) – Filed easy {output: location – text, water level – number [m], measurement location sign – text}

The water level in the reservoir is measured with a metal or wooden rod. It can be made from the bridge, on the edge if it is safe to do, or from a platform on the tank if available. Observe all safety rules during the measurement. If the reservoir is monitored, you can read the water level in a water gauge.

Temperature – Field easy {output: location – text, air temperature – number [°C], water temperature – number [°C]}

Water temperature is measured in a similar way to air temperature measurement. Approximately 1 minute must elapse between the insertion of the thermometer in the water and the value reading (liquid inertia in the thermometer). Read the temperature carefully, do not remove the thermometer from the water while taking the measurements.

Flowing water – river

Table 1.7. List of possible measurement in river (check list).

Flowing water	Precipitation	Infiltration	Surface runoff	Basin description	Nature-based solution	Water level (river)	Velocity (river)	Discharge (river)	Temperature
Questionnaire	x	x	x	x	x	x			
Measurement	x					x	x	x	x

Water level (river) – Field easy {output: location – text, measurement location sign – text, measuring point number – number [-], water level – number [m]}

The water level in the river can be measured with a metal or wooden rod. The water level in the river should be measured in several places (cross-section perpendicular to the shore). Measurement should be taken from the bridge or the edge. If it is safe to do so, the measurement can be made by entering the river. Observe all safety rules during the measurement, especially when someone is in the water.

Velocity (river) – Field easy {output: location – text, distance – number [m], time – [s]}

The flow velocity in the river can be measured with a piece of wood. To perform the measurement, you need to find a straight part of the river, then select the starting and ending points and measure the distance between them. The next step is to throw a wooden piece into the river before the starting point – it should be placed in the center of the cross-section. As soon as the piece of wood passes the starting point, start the timer and measure the flow time of the wooden piece to the endpoint. By knowing the time and distance traveled by the piece of wood, you can calculate the velocity. This is the surface velocity of water in the river.

Temperature – Field easy {output: location – text, air temperature – number [°C], water temperature – number [°C]}

Water temperature is measured in a similar way to air temperature measurement. Approximately 1 minute must elapse between the insertion of the thermometer in the water and the value reading (liquid inertia in the thermometer). Read the temperature carefully, do not remove the thermometer from the water while taking the measurement.

Data collection protocol & methodology

The collection of measurement data will be done through a spreadsheet. The measurement results from the selected place should be saved in one file with name of this place and date. In this file each of the tabs with the names of modules will contain the measurement results from this module. If no measurements have been made in the selected place, just skip it. Questionnaire measurements are completed in google forms (look at chapter 1.6).

1.5 Difficult methods for measuring parameters affecting the flood index

Difficult methods require the use of professional measurement equipment such as a flow meter. Therefore, the measurement procedure and the type of results obtained will vary depending on the devices used. Remember! Some measurements, such as those relating to the sewage system, must be performed with special care. Difficult measurements should be made alternately (or additionally) with the selected easy measurements selected for a given location – Table 1.3.

Rivers and reservoirs

Water level (river) – Field difficult

The measurement of the water surface level in the river can be done using a metal or wooden rod. It can be made from a bridge or shore if safe to do so. If the river is small, the measurements of the water surface level can be done by entering the river. The measurement of the water surface level in the river should be made in the selected cross-section in several places by making the so-called probing. This allows to determine the shape of the measurement cross-section and its characteristic parameters, such as the cross-sectional area, wetted circumference, or the width of the river at the water surface level.

Water level (reservoir) – Field difficult

Measurement of the water surface level in the reservoir can be made with the use of a marked metal rod or the ordinate of the water level with the use of staff and a leveller. The measurement can also be taken from the gauge if the reservoir is monitored. Measurement can be taken from the bridge, on the shore if it is safe to do so, or from a platform on the tank if available. Warning! Observe all safety rules during the measurement.

Local velocity (river) – Field difficult

The local velocity in the river is measured using a current meter or other velocity measuring device. To perform the measurement first, it is necessary to probe the cross-section of the river bed. After the probing is completed, the number and position of the measurement verticals are determined (Table 1.8, Table 1.9). In each of them, velocity measurements are made at appropriate depths. Spot velocity measurements can be divided into:

- complete – measurements are made in many points for many verticals,
- surface – in verticals at the water surface, this is to determine the maximum velocity because, based on the velocity curves, can be known that there is a maximum speed under the water surface level,
- shortened – at selected points and verticals:

- single-point – at a depth of 0.4h or 0.6h from the bottom, where h is the water depth in the hydrometric verticals:

$$v_m = v_{0,4h} \text{ or } v_m = v_{0,6h},$$

- two-point – at a depth of 0.2h and 0.8h from the bottom:

$$v_m = 0{,}5 \cdot (v_{0,2h} + v_{0,8h}) \text{ or } v_m = 0{,}25 \cdot (v_{0,2h} + 2 \cdot v_{0,4h} + v_{0,8h})$$

Table 1.8. Rules for the selection of hydrometric verticals.

river width [m]	pilot distribution [m] not less than	number of hydrometric verticals
to 2	0.2	not less than 3
3 – 10	0.5	4 – 5
11 – 30	1.0	7 – 8
31 – 80	2.0	9 – 10
81 – 200	5.0	11 – 12
over 200	10.0	over 15

Table 1.9. Distribution of measurement points in hydrometric verticals.

depth h [m]	free surface flow		ice cover or an overgrown riverbed	
	distribution of measurement points	number of measurement points	distribution of measurement points	number of measurement points
< 0.2	0.4 h	1	0.5 h	1
0.2 – 0.6	0.2 h, 0.4 h and 0.8 h	3	0.15 h, 0.5 h and 0.85 h	3
> 0.2	at the bottom, 0.2 h, 0.4 h, 0.8 h and near the surface	5	at the bottom, 0.2 h, 0.4 h, 0.6 h, 0.8 h and near the surface	5

Discharge (river) – Field difficult

The measurement of the flow rate is indirectly acquired by measuring the flow velocity. The velocity is measured at selected points in the cross-section, called the hydrometric cross-section. Such a cross-section must meet the following conditions: it should be located on a straight section of the river, it should be single, compact, and regular. In such a selected cross-section, first, the depth sounding from the bottom to the water surface level is carried out, and then at selected points located on the hydrometric vertical (at different depths) of this cross-section, the velocity is measured. The velocity measurements can be made using e.g. a current meter. Based on the measurements with a current meter, the flow velocity is calculated using the formula:

$$V = \alpha + \beta \cdot n$$

where:

V – flow velocity [m/s],

α, β – current meter constants,

n – number of current meter revolutions per second [rev./s].

Using velocity measurements for individual hydrometric verticals, velocity curves can be plotted (Figure 1.14). Making use of velocity measurements for individual hydrometric verticals, velocity curves can be plotted. On their basis, the average velocity for the hydrometric verticals is determined. It is calculated by dividing the area under velocity curves by the vertical water depth.

Based on these measurements, the flow rate can be calculated by the following methods:

I. Harlacher's method – computational and graphic,

Calculation according to this method is performed as follows:

1) Sketch of a cross-section with marked hydrometric verticals (Figure 1.15).

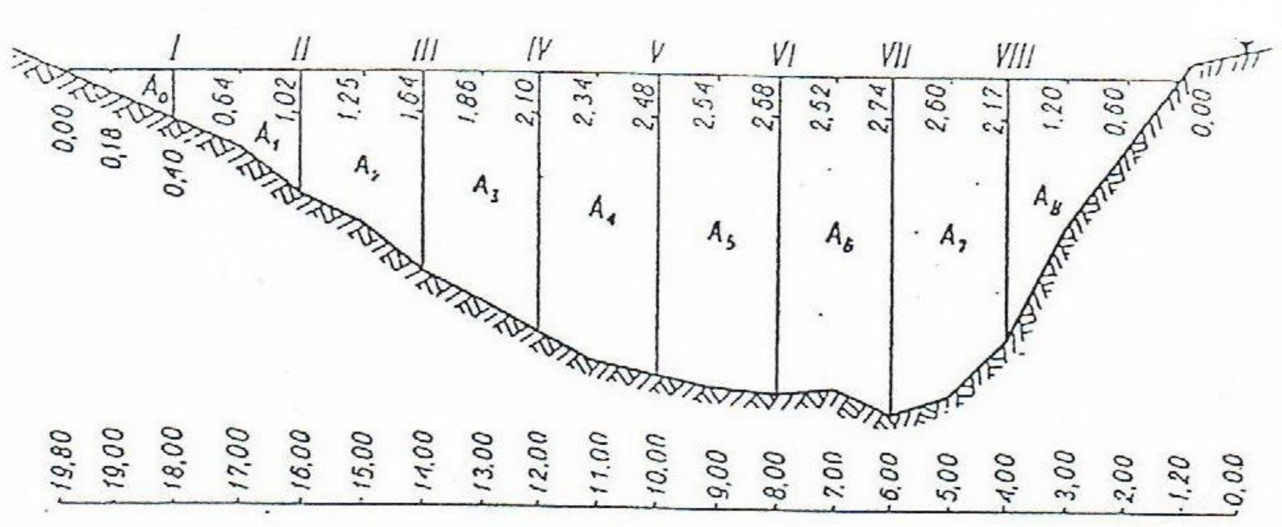


Figure 1.15. Sketch of the cross-section with marked hydrometric verticals.

2) Calculation of the subsections of the cross-sectional areas of trapezoidal or triangular shapes (outermost areas). The average depth for each subsection of the cross-section is determined as the arithmetic mean of the depths of the hydrometric vertical limiting the field. Based on the width of each subsection and the average depth, the area of each subsection is calculated.

3) Determination of the average velocity for each of the hydrometric vertical using the velocity curve (Figure 1.16).

4) Calculation of the middling value of average velocity as the arithmetic average of the average velocity for the perpendiculars of a given subsection or for the extreme (triangular) subsections as 2/3 of the average value for the perimeter perpendicular.

5) Determination of partial flows as the product of the subsection values by the average velocity values. Summing up the calculated partial flows, the value of the flow rate for the analysed cross-section is obtained (Harlacher's computational method) (Table 1.10).

6) Drawing of the average velocity curve by putting vertically upwards the average velocity value in individual hydrometric verticals. This curve makes it possible to determine the value of the average velocity for any vertical in the cross-section (Figure 1.16).

7) The product of the depth in a given hydrometric vertical by the average velocity in this hydrometric vertical $x = h \cdot v$ [m²/s] are calculated and the lengths x are placed vertically downwards. This creates a flow curve. Warning! The scale of this curve must be selected so that it fully fits in the cross-section (Figure 1.17).

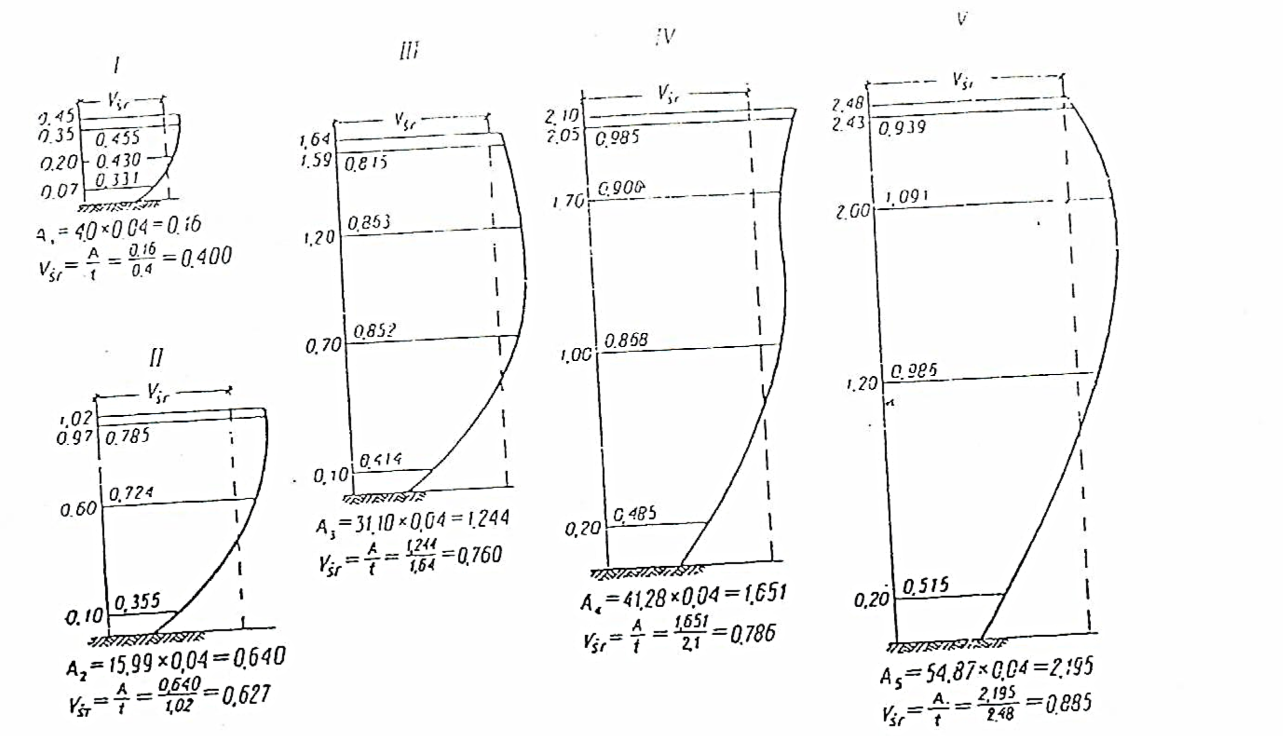


Figure 1.16. Sample sketches of the velocity curve with calculations of the average velocity for the hydrometric vertical.

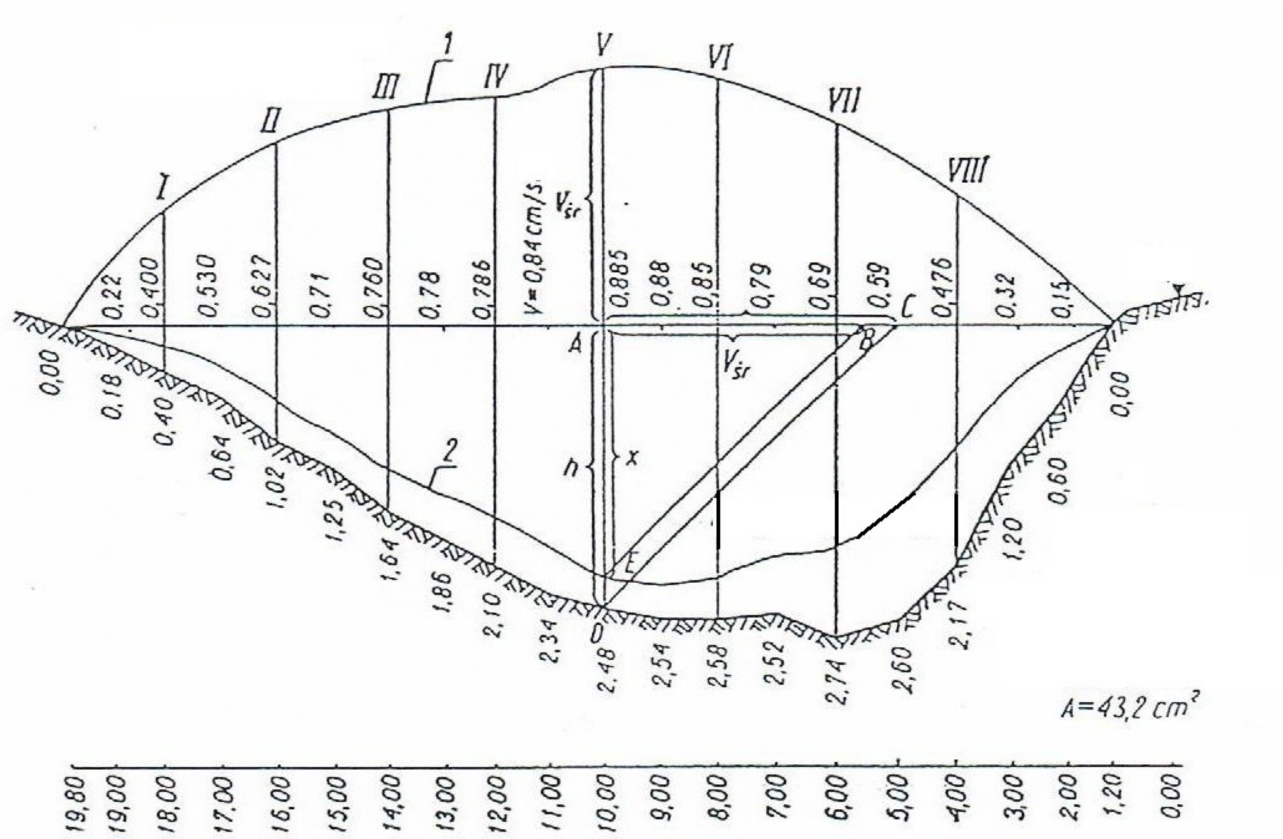


Figure 1.17. Sketch of the cross-section with marked hydrometric verticals with the average velocity curve (1) and the flow curve (2).

Table 1.10. Summary of calculation results of flow rates for Figure 1.17.

Hydrometric vertical number	The depth of the river at the vertical point [m]	Width of the subsections [m]	Areas of subsections of the cross-section between verticals [m²]	Average velocity in verticals [m/s]	Middling value of average velocity for fields [m/s]	Partial flows [m³/s]
I	0.40	1.80	0.36	0.400	0.267	0.096
		2.00	1.42		0.513	0.728
II	1.02	2.00	2.66	0.627	0.693	1.843
III	1.64	2.00	3.74	0.760	0.773	2.891
IV	2.10	2.00	4.58	0.786	0.835	3.824
V	2.48	2.00	5.06	0.885	0.867	4.387
VI	2.58	2.00	5.32	0.850	0.770	4.096
VII	2.74	2.00	4.01	0.690	0.583	2.862
VIII	2.17	2.80	3.04	0.476	0.317	0.964
			Sum: $A = 31.09\ m^2$		$Q = 21.691\ m^3/s$	

8) On the basis of the resulting flow curve, the total flow rate is calculated by determining the value of the area bounded by the flow curve (graphical Harlacher's method) (Figure 1.15).

II. Culmann's method

This method consists in determining the lines of equal velocities, i.e. isovel, in the cross-section. Isovels are determined on the basis of the measured velocity values in individual hydrometric vertical. To determine the flow rate with this method, perform the following steps:

1) Draw a sketch of the cross-section with the hydrometric verticals and velocity values at individual points of the verticals (Figure 1.18).

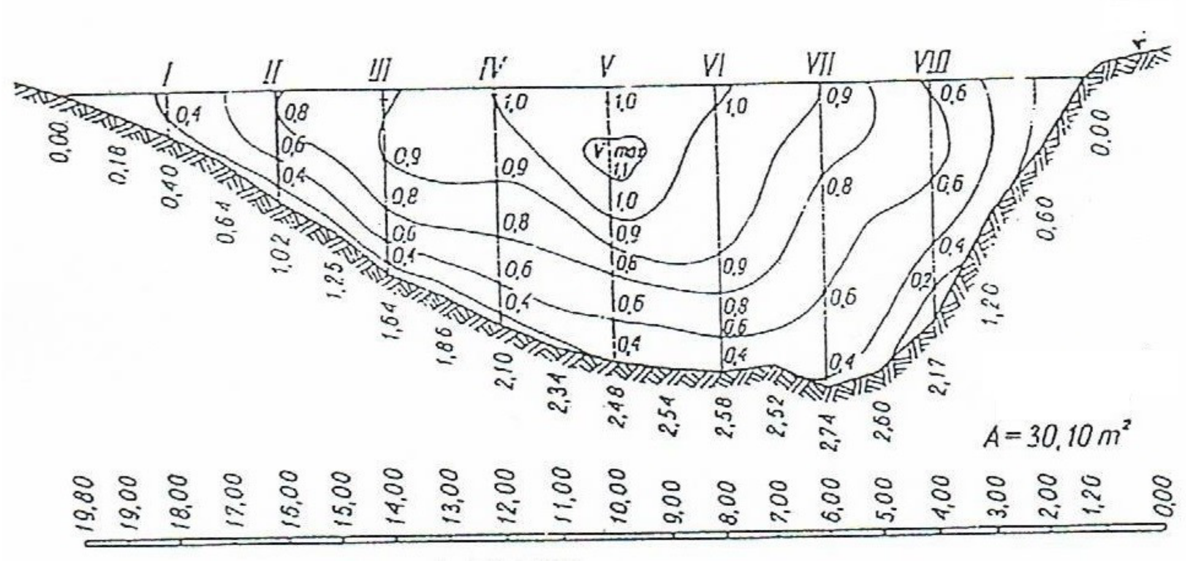


Figure 1.18. Sketch of the cross-section with marked hydrometric verticals with isovels.

2) On the basis of known values of point velocities, determine isovels by interpolation between points.
3) On the basis of the drawing, determine the values of the surface area between the designated isovels.

4) Calculate the average velocity between isovels. In the case of extreme values, the average velocity value is determined as follows:

$$V_A(\min) = 0.5 \cdot V_{min}$$

$$V_A(\max) = V_{max}$$

where:

V_A – average velocity between isovels [m/s],
V_{min} – minimal velocity on isovel [m/s],
V_{max} – maximal velocity in isovel [m/s].

5) Knowing the values of the average velocities between isovels and the surface area between them, it is possible to determine the partial flow rates by multiplying these values for individual component fields. By summing up the values of the partial flow rates, the flow rate for the entire cross-section is obtained (Table 1.11).

Table 1.11. Summary of calculation results of flow rates for Figure 1.18.

Hydrometric vertial number	Subsections of the cross-section between verticals [m/s]	Areas of subsections [m²]	Average velocity of subsections [m/s]	Partial flows of subsections [m³/s]
I	0.2 – 0.0	0.60	0.10	0.060
II	0.4 – 0.2	2.55	0.30	0.765
III	0.6 – 0.4	6.10	0.50	5.050
IV	0.8 – 0.6	6.60	0.70	4.620
V	0.9 – 0.8	5.20	0.85	4.420
VI	1.0 – 0.9	5.80	0.95	5.510
VII	1.1 – 1.0	2.93	1.05	3.080
VIII	1.1	0.32	1.10	0.350
			Sum: A = 30.10 m²	Q = 21.86 m³/s

Geometry (river cross-section) – Field difficult

The geometry is measured for the selected river cross-section. The needed parameters are the shape of this cross-section, and its dimensions, such as the cross-sectional area, the maximum cross-sectional area and the width at the water surface level, as well as for the maximum filling. Measurements are made by probing the bottom of the channel, and measuring the width with a metal ruler. The cross-section measurements should be selected so that it is easily accessible. It can be located near the bridge or in any section of the watercourse.

Geometry (reservoir cross-section) – Field difficult

The geometry of the reservoir is measured by measuring (if possible) its dimensions and water depth. In addition, the geometry of the river that flows in and out of the reservoir should be measured. The dimensions of the riverbed / reservoir are determined by the so-called probing the bottom in several longitudinal and transverse sections and levelling of slopes and dry parts (if any). It is necessary to perform as many measurements to accurately reproduce the river/reservoir geometry. It can be done from bridges, structures going deep into the reservoir, a pontoon, and if it is not possible from the shore, but in several (several dozen) places. The reference point for all measurements (so as to combine the measurement of the bottom with the measurement of slopes) can be the water surface level.

Sewage system

Measurement of the flow rate in the rainwater sewage system must be supervised (teacher, technician, or employee of the municipal company), **never do this measurement alone**. Due to many unpredictable factors, such as e.g. heavy water pollution, strong current, sharp objects in the sewage, be especially careful during the measurement. Measurements in collectors of combined sewage systems should be performed carefully, with gloves, trying to limit contact with water to a minimum.

Water level (sewage system) – Field difficult

The first step of the measurement is the visual inspection and description of the cross-section, the following information should be recorded:

- the type of rainwater collector (a pipe, an open channel, etc.),
- type of medium (rainwater drainage, combined sewage system),
- condition of the collector at the measurement location (observations regarding the fragments before and after the cross-section),
- the state of flowing water (color, amount of suspended solids, type of suspension, sediment, smooth or rushing flow, etc.),
- the shape of the collector and the material it is made of,
- characteristic dimensions (collected dimensions must enable drawing with the collector cross-section in the place where the measurement is performed),
- collector slope – if it is possible.

The water level in the analysed cross-section should be measured. The measurement should be performed in such a way that it will be possible to draw a line representing the water table level on the drawing of the channel cross-section. The method of measuring the water level must be appropriate to the technical possibilities given by the characteristics of the measurement location. The measurement can be made with a level, levelling rod, any rod or pole, tape measure, ruler, piece of wood, etc. All methods are allowed, but remember that the priority is the safety of the performed measurement.

Discharge (sewage system) – Field difficult

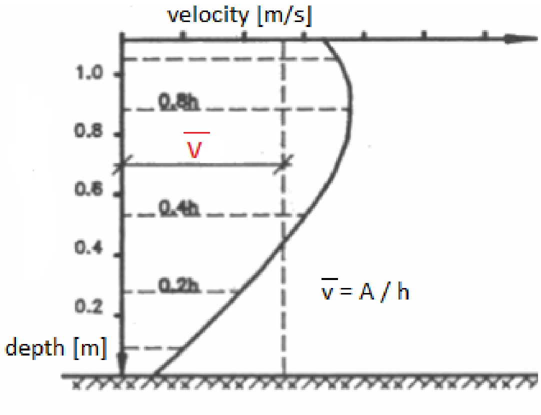
Before measuring the rainwater velocity, make a sketch of the collector and measure the current water level (see previous instructions). The flow meter used for the measurement must be suitable for use in polluted water.

Measurement procedure:

1. Designate the hydrometric vertical points and define the depths of water level and the depths at which the measurements will be made. The number and distribution of measuring points depend on the characteristics of the observed flow (spatial variability) and the dimensions of the collector. Mark the measurement points on the sketch. Before starting the measurement, consult the location of the measurement points with the teacher.
2. At each point, measure the local velocity three times. The measurement is performed following the instructions attached to the flow meter.

Elaboration of the results:

1. For each measurement point, determine velocity value (reject unrealistic values considered as the measurement error, and calculate the average from the remaining values) and estimate the average measurement error.
2. For each hydrometric vertical line, draw depth – velocity curves in each vertical and calculate the average velocity (Figure 1.19).
3. Determine the average velocity over the entire subsection (more information in the „Discharge (river)" instruction).
4. Calculate the discharge, based on the continuity equation or methods described in „Discharge (river)" instruction.
5. Description of the drained area (size, land development, hydrological characteristics, map).



where:

v – the velocity [m/s]

h – the water depth [m]

A – the area under the depth-velocity curves

Figure 1.19. Velocity in hydrometric vertical line.

6. Description of the last rainfall episode observed in the area drained by the analysed collector (if it is possible to find them, e.g. on the websites of municipal companies, environmental monitoring, weather forecasts etc.):
   - location of the rain gauge,
   - when was the last large rainfall,
   - duration and intensity of the last rainfall,
   - weather conditions in the period between the occurrence of the described rainfall episode.
7. Description of measurement procedure (adopted methods and assumptions), conclusion.

1.6 Final results description

For the presentation of the methodology to your students, you can use Flooding presentation.pptx. For the field characteristic description use file Flooding Questionnaire to print.doc to create your set of tables according to Table 1.3 or Flooding Questionnaire set.doc and during measurements, the results are collected via application and send to the database Climate Scan. Students should prepare a full report of data collection and data analysis, including photo documentation of sampling and measurements conduction. Report should include analysis of flooding parameters and terrain conditions as well as weather conditions including photos. The last step should include conclusions and summing. For the knowledge income verification use the Flooding pre-post test to print.doc.

1.7 External materials

See: https://impetus.aau.at/outputs/

Folder: Flooding

- Flooding instruction.pdf
- Flooding Questionnaire to print.doc
- Flooding Questionnaire set.doc
- Flooding pre-post test to print.doc
- Flooding pre-post test key.doc
- Flooding presentation.pptx

1.8 Definitions

Catchment area (*synonym* basin) – the area of land from which water flows into a river, lake, or reservoir.

Reservoir – a natural or artificial lake for storing and supplying water for an area.

Flood risk index – the parameter showing the level of the flood risk, is determined by the summed probability of flood hazards.

Water level – the level of the water surface, in relation to the bottom of this reservoir/river or in relation to the ordinate above sea level.

Channel capacity *(synonym* river capacity, and in general, rain water system capacity) – the maximum amount of water that can pass through a river (including culverts, bridges, changes of channel shape etc.) without causing damage and without flowing over the banks.

River flow *(synonyms* river discharge, flow rate) is the volume of water flowing through a river channel, measured at any given point in cubic meters per second.

1.9 Literature

[1] Mays Larry W., 2010, *Water Resources Engineering,* Arizona State University, USA, Wiley

[2] EXCIMAP, 2007, „Handbook of good practices for flood mapping in Europe" – ebook https://ec.europa.eu/environment/water/flood_risk/flood_atlas/pdf/handbook_goodpractice.pdf

[3] Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32007L0060

[4] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32000L0060