Local flood warning systems and their implementation within the system of the workstation for flood monitoring and forecasting

Jakub Rak , David Sevcik, Blanka Svobodova, and Jan Strohmandl

***Abstract*—** The article describes local warning systems against floods and their possible use in protection against floods. It is focused on the installation and configuration of the system parameters and interconnection of their data outputs with other applications. These are, in particular, applications for visualization and processing of outputs from a number of gauging stations and their subsequent projection on the base map. Furthermore, the article deals with a design and implementation of the central workstation for monitoring the outputs of the local flood warning systems. This workstation is supplemented by various applications suitable for flood forecasting, monitoring and protection. The workstation is a unique modular system, which enables central monitoring of the flood and thus increases the level of protection against floods. If required, it is possible to extend the workstation by means of various modules in accordance with the given locality and nature of floods, or on the contrary, the number of modules can be reduced when dealing with less extensive issues.

***Keywords*—** Flood Protection; Flood; Natural Disaster; Emergency Management; Information Systems.

I. Introduction

THE development of society, constructions, agriculture, and industrial production leads to hazards and risks associated with it. These hazards include extraordinary events caused by humans as well as natural extraordinary events. Natural extraordinary events are natural disasters, which cause extensive damage and harm in many countries, including the Czech Republic. Floods are ones of these disasters. Not only does damage and loss affect property and districts but also the lives and health of the population. Floods, in particular, are one of the most serious problems in the Czech Republic as regards natural disasters. According to [1], the flood in 1997 in the Czech Republic caused damage of 2.25 billion Euros (based on the current conversion rate) and claimed 60 human lives. The flood affected 536 municipalities and the damage represented about 3.5 % of GDP in the respective year. Also in the following years the floods caused extensive damage to the country. Specifically, it was in 2002 when the flood claimed 17 lives and caused damage of 2.6 billion Euros (based on the current conversion rate). In total, the floods in the Czech Republic claimed 123 lives and caused damage of 6.15 billion Euros (based on the current conversion rate) between 1997 and 2010. Due to the number of fatalities and the extent of damage it is necessary to develop methods for flood protection. The prompt detection of flood is necessary for the timely deployment of protection systems.

Jakub Rak, Faculty of Applied Informatics, Tomas Bata University in Zlín, Nad Stráněmi 4511, 760 05 Zlín, Czech Republic. E-mail: jrak@fai.utb.cz.

David Sevcik, Faculty of Applied Informatics, Tomas Bata University in Zlín, Nad Stráněmi 4511, 760 05 Zlín, Czech Republic. E-mail: dsevcik@fai.utb.cz.

Blanka Svobodova, Faculty of Logistics and Crisis Management, Tomas Bata University in Zlín, Address, Studentské nám. 1532, 686 01 Uherské Hradiště, Czech Republic. E-mail: bsvobodova@flkr.utb.cz.

Jan Strohmandl, Faculty of Logistics and Crisis Management, Tomas Bata University in Zlín, Address, Studentské nám. 1532, 686 01 Uherské Hradiště, Czech Republic. E-mail: strohmandl@flkr.utb.cz.

II. Problem Formulation

Owing to the seriousness of flooding and the extent of damage and harm, the issue of flooding became a part of Czech legislation. In particular, the flood protection and related problems are provided for by the regulations: Act No. 254/2001 Coll., “the Water Act”; Act No. 239/2000 Coll., on the Integrated Rescue System, and some other regulations. Furthermore, security bodies and bodies responsible for protection of the population together with Management of water flows also gives great awareness to floods.

A. Floods

The flood can be defined as substantial temporary rise of the water surface caused by abrupt discharge flows or temporary constriction of a river bed, particularly in the event of ice formations. [5]

- winter and spring floods,
- summer floods caused by persistent regional rainfall,
- summer floods caused by short term intensive rainfall,
- winter floods caused by ice formations.

The extent of flooding and resulting damages and harm are affected primarily by the following factors [6]:

- persistent rainfall, torrential rains, intensive thaw with rain causing melting of snow and releasing of ice,
- capacity and condition of the river bed,
- resistance and sufficient height of flood banks along the watercourse against surging and flowing water, and resistance of dikes against overflowing,
- influence of retention of waterworks (reservoirs, ponds, polders) and other technical protections (weirs, flood banks along watercourses, etc.),
- influence of the retention capacity of the land,
- built-up areas and the use of floodplains,
- timely notification of flood hazards;
- operative administration of water management processes during floods,
- precautions for the protection against floods.

B. Protection against floods

From the perspective of time, the protection against floods and coping with them can be described as follows. Precautions taken:

a) prior to the occurrence of floods;

These precautions include, for instance, construction changes to river beds, construction of protective elements, such as waterworks and weirs, preparation of flood protection plans, etc.

b) in the event of floods;

Evacuation of affected persons, building of improvised flood banks, water barriers, etc.

c) after the flood;

Cleaning and decontamination of affected areas, regeneration of the area, revitalization, etc.

The protection against floods is administrated by the flood protection authorities in all three periods of time.

Flood protection authorities. In the Czech Republic the protection against flood is administrated by the flood protection authorities that within their territorial scope provide services for the preparation for flood management, organization and control of all relevant actions during flooding as well as in the period immediately after the flood, including management, organization and control of other participants involved in flood protection. Activities of flood protection authorities are governed by flood protection plans. Status and activities of flood protection authorities are specified at two time levels:

a) off-flood protection authorities:

- municipal bodies and bodies of municipal districts in Prague,
- local authorities of municipalities with extended powers; authorities of municipal districts established by the Statute of the City of Prague,
- regional authorities,
- The Ministry of the Environment; provision for the preparation of rescue operations falls within the competence of the Ministry of the Interior.

b) protection authorities during the flood:

- flood commissions of municipalities; flood commissions of municipal districts in Prague,
- flood commissions of municipalities with extended powers; flood commissions of municipal districts established by the Statute of the City of Prague,
- flood commissions of regions,
- Central Flood Commission.

C. Protection against floods

In order to implement protective measures it is important to obtain information about the actual origin of the flood. This information can be acquired during the flood or within a short period prior to its origin (before the arrival of a flood wave).
As stated by [2], the acquisition of information in advance (dozens of minutes up to 2 hours) significantly lowers the probability of loss of human lives and it helps to protect their property to some extent.

Specifically, timely detection of floods is crucial for the so-called "flash floods". For these floods it is not possible to use conventional methods of a weather forecast given to a small size of the affected area and the speed of the formation. Detection by means of these methods is quite difficult and unusable in practice. The local warning systems for individual rivers installed directly in the relevant areas are one of the means of "early detection." The description of a similar system and its implementation within the municipality with extended powers in Uherské Hradiště can be found in Chapter 3

III. Problem Solution

Local systems for early warnings can efficiently be used for monitoring and giving timely notification to flood protection authorities and population within the areas at risk of flash floods. This system is a comprehensive summary of technical and software equipment that serves for detection of approaching floods. Timely detection enables acquiring some time for the implementation of protective measures. In order to make these systems widely applicable it is necessary to employ a unified system, which enables central monitoring of a large number of stations together with their visual representation.

A. Materials and methods

For testing of the system for timely warnings against floods at the territory of MEP UH, a gauging station composed of a universal registration and control unit M 4016-G3 with an integrated GSM/ GPRS modem, RS232 interface and pressure sensor of water surface PTX 7500 was used. In order to control the station the "MOST" software was used; this software enables the overall setting of all necessary parameters for the station. Apart from the "MOST" software also the "web viewer of measured data" was employed. This web interface serves for limited settings of the station and for storing and displaying outputs of measurements.

For monitoring of the given river basin the software POSIM ("POvodnovy SIMulator", in English "flood simulator") was used in order to centralize and visualize the data from individual gauging stations.

By means of all connected gauging stations this application is capable of monitoring, displaying and the simulation of stages of floods and their impact.

In the experimental part of the research the float and device for manual measuring of time were used in order to measure the flow rate of the river.

For the purpose of creating the workstation for monitoring outputs of the 65” High-Performance LED Backlit Commercial-Grade Display and other data sources the following devices were used: computer PC mini Lenovo IdeaCentre Q190 connected to a display device NXT, VISO 2002–the warning and information system which forms a comprehensive lower level workstation; web application www.chmu.cz run by the Czech Hydrometeorological Institute where meteorological data can be accessed; AR Drone–the unmanned aerial device with a HD camera and Axis camera system for direct monitoring of flood stages and condition of equipment.

The system of timely warning is based on the method of continuous measurements of water surface and the wireless transmission to the server, or mobile station (mobile phones) and their processing for monitoring and warning.

Implementation and engagement of the system within the processes of flood protection is quite difficult. The implementation of the system in the territory of the MEP Uherské Hradiště and its testing was accomplished as follows.

B. Local systems for early warnings

The local system for early warning is a set of interconnected elements used for monitoring the water surface. Implementation of the local system for early warnings consists of following steps.

- Gauging profile.
- Installation of individual parts of the system and their interconnection.
- Configuration of the basic parameters of the station by means of “MOST” SW and the Web viewer of measured data.
- Implementation of outputs of the system.

Gauging profile.

The first step of installation is the choice of an appropriate gauging profile, in other words finding a suitable place for installation.

The suitable profile must comply with the basic requirements, which are in particular:

- distance from the area at risk,
- power supply,
- firm attachment,
- GSM network coverage.

On selection of the suitable profile the actual installation of individual parts of the system was accomplished.

A suitable place for the installation of the tested system was chosen in town Uherské Hradiště. Specifically, the system was mounted on the bridge pillar in compliance with all conditions of the safe installation. The gauging profile is depicted in Fig. 1 while Fig. 2 shows a detail of the installed station.

Fig. 1. The area of gauging profile. [12]


Fig. 2. The gauging profile with the gauging station.

Installation of individual parts of the system and their interconnection.

The main parts, which included the registration and control unit M 4016-G3 together with the pressure sensor of water surface PTX 7500, were mounted on the fixed part of the bridge structure. The sensor was placed below the water surface at a height of 0.5 m above the bottom of the river (this height protects the sensor from fouling). The registration and control unit was mounted on a lighting column at a height of 2 m above the top edge of the bridge in a metal protective casing. Mounting it on a lighting column enabled connection to the source of electrical energy and thus ensured a permanent power supply (12 V). In the event of a power outage the station is equipped with a rechargeable battery. The battery allows operating up to 48 hours. In order to connect the station with the sensor a RS232 bus was used.

For the actual application of the system, the station was connected to the server by means of the GSM network (through data SMS messages). Individual parts of the system and their interconnection are very apparent in Fig. 3.

Scanning the water surface of the watercourse. Scanning of the water surface is provided by a pressure sensor PTX 7500, which operates on the principle of scanning the pressure of the water column above the sensor. The sensing part is thus located under water surface in a place that reduces the likelihood of fouling. Communication between the sensor and registration or control unit is provided by means of metallic cables. The gauging profile also includes a staff gauge for quick checking of the actual water level.

used, namely the water level.

The following section of the article describes the process of detection of regular discharge flow.

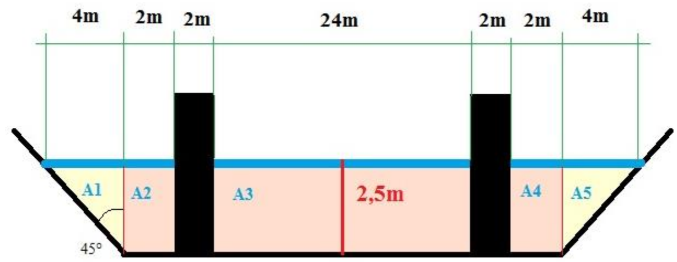

Fig. 4. The gauging profile model

The regular discharge flow was calculated based on equation No. 1, where Q is the resulting discharge flow in [m^3*s^{-1}], F is the surface of the cross sectional area of the water surface in [m^2] and V_S is the velocity of the discharge flow in [$m*s^{-1}$]. The resulting discharge flow is 43.2 [m^3*s^{-1}]. In order to reduce the influence of measurement errors, the velocity of the discharge flow was measured 10 times and subsequently the average value VS was calculated (see the equation No. 2). These values are specified in Tab. 1.

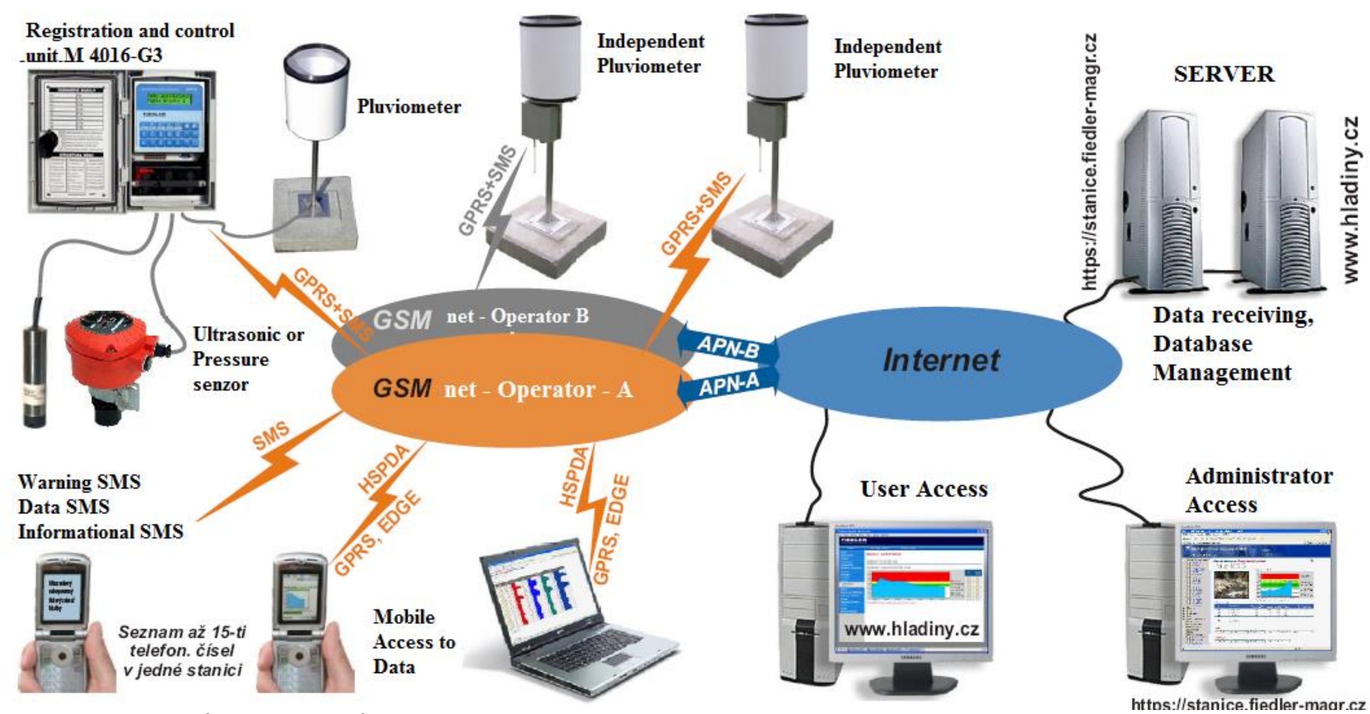

Fig. 3. The scheme of Local systems for early warnings [4]

Discharge flow calculation – the water level. In order to calculate the discharge flow a graphical-numerical method [15] consisting of the manual measurement of water flow rates by means of floats was employed [5]. Based on the examination of the bottom of a suitable gauging profile, a model of this profile was created (see Fig. 4). Furthermore, bridge pillars were integrated into the model and subsequently, a cross sectional area of the water surface was calculated. To calculate the surface, the data from the gauging station was

$$Q = F * VS \tag{1}$$

$$V_S = \frac{\sum_{k=1}^{10} V_x}{10} \tag{2}$$

By means of the calculation, the value of the average discharge flow of water in the place of the gauging profile was acquired. Consequently, based on the average discharge flow it is possible to derive an equation for determining the standard flow, namely on the basis of changes in water surface and velocity of discharge flow (equation No 3), where the Q is the resulting discharge flow in [m^3*s^{-1}], x is the actual water level and Vs is the actual speed of flow.

$$Q = (32 * x) * Vs \quad (3)$$

Tab. 1. The table of the velocity of the flow for equation 2

Experiment	1	2	3	4	5	6	7	8	9	10	V_S
Vx [$m*s^{-1}$]	0.6	0.55	0.5	0.55	0.5	0.55	0.5	0.6	0.55	0.5	0.54

$$V_S = 0{,}54\ [m*s^{-1}]$$
$$Q = 80*0{,}54 \quad (4)$$
$$Q = 43.2\ [m^3*s^{-1}]$$

Configuration of the basic parameters of the station by means of "MOST" SW and the Web viewer of measured data.

For the basic settings of the station the "MOST" SW was used. This included, in particular, setting of parameters of individual channels. In the case tested the channels were "water surface, flow rate and voltage". These channels make it possible to monitor the surface of the river in the given profile, calculate volume discharge flow and check the voltage on the backup battery of the control unit (see Fig. 5). The software also enables setting up to 20 relays, which can be used for the control of various devices. For the said test case no other device with direct input was used. For this reason the configuration of the relay of the control unit was not applied. Furthermore, the parameters for the GSM transmission network, period of communication and the format of individual SMS messages were set up. The messages were divided into two groups–operational and alarm messages. In order to enable the possibility of direct notification via the SMS messages, the groups of users with individual phone numbers and assigned roles were established within the setting of data transmission. Upon setting up the basic parameters of the station the individual data SMS messages were assigned to individual levels of water surface. In this case three basic parameters for the given profile were used, namely "flood stage 1, 2, and 3" which were acquired from the Morava river basin authority. In the Czech Republic, the previously mentioned terms and their values are defined by legislation. Based on individual stages of flood the emergency services are mobilized; the level of actions ranges from increased vigilance to state of emergency and rescue interventions. For configuration of this particular station the values were as follows:

- 1. Flood stage – Flood watch.
- 2. Flood stage – Flood warning.
- 3. Flood stage – Flooding
- Flood stage – Extreme flooding

By using these limit values the individual alarm messages were set. For the purposes of testing the gradient setting of alarm messages for changing the water level dependent on time was not used.

Successful installation and setting of all parts of the system were verified by testing the operation during which the measured data related to the current state of water surface was compared to data obtained by manually measuring by means of the staff gage.

Implementation of outputs of the system.

The actual installation of the local system for early warnings is only one of the basic steps in protection against floods. Nevertheless, the following steps included in the implementation of the station's outputs are also significant. The outputs can be connected to a desktop software application. However, in order to ensure a quick response, the connection to the web application and particularly to the mobile GSM stations (mobile phones) is more convenient. Owing to this connection it is possible to report on the imminent hazard within one minute. In particular, notification by means of the GSM gateway is the main advantage of this system. Communication is based on the GSM module (gateway) employing a user's SIM card (the station then works as a standard GSM station - the mobile phone). By means of this device, the signal is transmitted through the public mobile network to the user (desktop application, web application or GSM station). Owing to the universal registration and control unit M 4016-G3 it is possible to set up required alarm values whose evaluation serves for reporting alarms or process information.

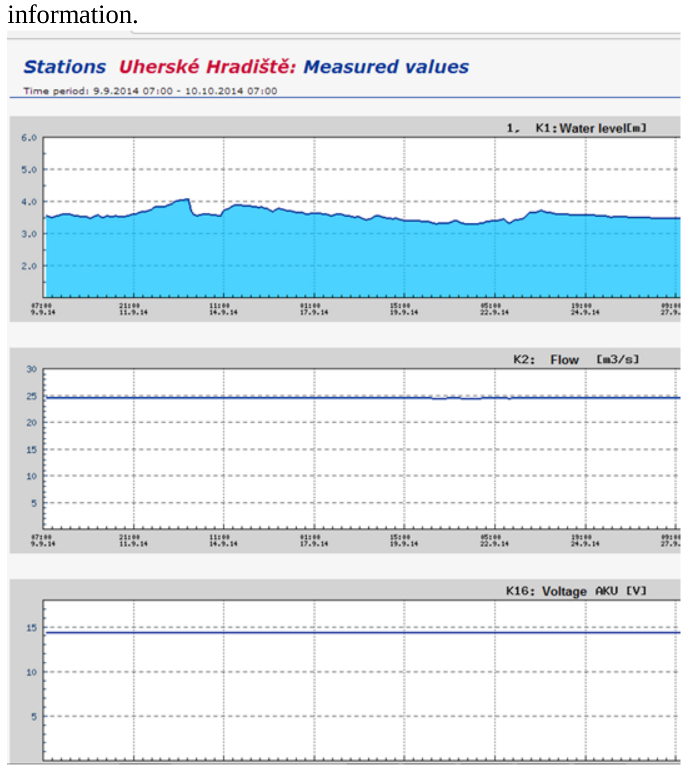

Fig. 5. Web application for station output monitoring [4]

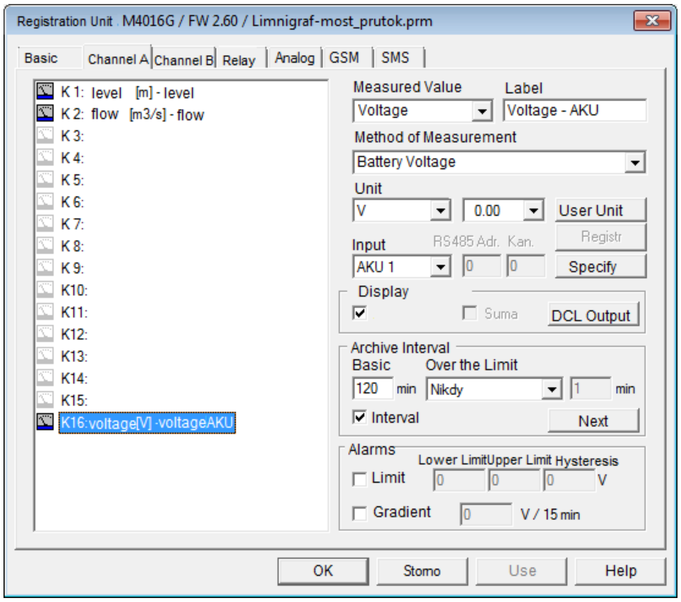

Fig. 6. Configuration of the basic parameters of the station

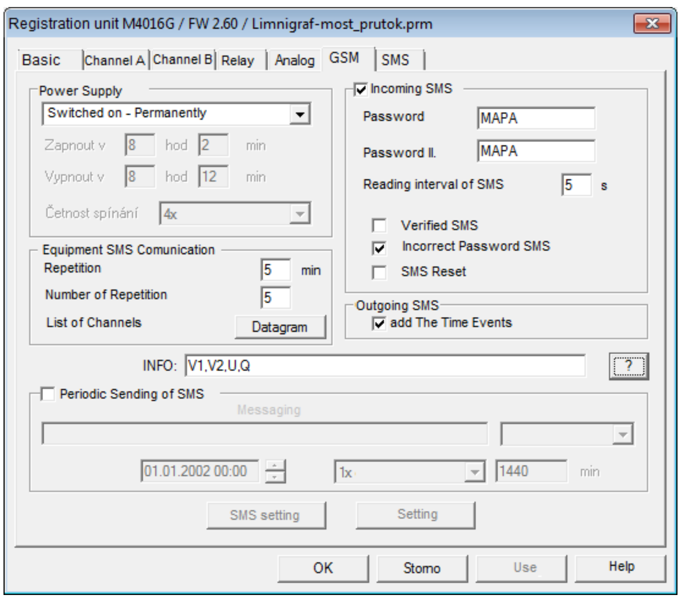

Fig. 7. Configuration of the basic parameters of the station

Once the limit values are reached and evaluated by the gauging station, the alarm signal (SMS) is transmitted to the server and individual mobile stations.

The universal registration and control unit M 4016-G3 has 20 relays that allow the connection of up to 20 input devices. Apart from the sensors for water surface (e.g. PTX 7500), it is possible to connect rain gauges and other technological equipment. Owing to this fact, the station can be used as a comprehensive weather unit. Warnings and informational SMS can then be sent from each input separately.

C. Workstation for monitoring the outputs of the local system for early warning (LSEW) and other data sources

The centralized workstation for data collection and processing for the purpose of flood forecasting and detection is an efficient tool for protection against floods [13]. The main objective of the research was to design, create and test possibilities of the workstation for monitoring of the LSEW outputs and other data sources. The workstation operates on the basis of the interconnection of technical equipment and data. It is intended for monitoring and forecasting most types of floods. The main aim is the centralization of all data flows allowing the possibility of unified management of prevention, rescue operations and clearance. Such a workstation represents a unique system suitable for training of prospective personnel in the field of protection against floods. Centralization of data significantly increases the efficiency of decision making and thus it reduces damage to property and the environment as well as the loss of human lives resulting from flooding.

The workstation is modular, which means that a module can easily be added or removed. Modularity enables the workstation to be fairly flexible and appropriate for use under various conditions. It allows the workstation to be connected to other information systems designed for emergency management. The basic version of the workstation includes a total of 8 modules:

- Web viewer of outputs from the gauging station: provides processing of data from one particular workstation and its presentation. It also serves for the configuration and control of the station;
- Gauging station: its task is to obtain input data on the current state of water flow and transfer this data to other modules for further processing. For its configuration the SW "MOST" is used which is included in the workstation's SW;
- SW tool "Posim": provides monitoring of the data output from several gauging stations and its projection onto the base map. It also enables simulations of the flood origin, which serves for the purposes of training and preparation of the personnel operating the given workstation;
- Web application of the meteorological forecasting service: is used for monitoring of meteorological conditions and notifying operators of the workstation of meteorological warnings. Also, the application has the access to "Meteoalarm"–the Europe-wide warning system against the negative meteorological phenomena (including floods). Data found in this application is guaranteed by the Czech Hydrometeorological Institute;
- Central workstation: allows centralization of data so that it can be processed and evaluated. The workstation also provides a high level of data visualization. Besides other things, this workstation is the main module intended for management of all other modules and monitoring of their outputs;
- Camera system: serves for optical monitoring the level of the river, or obtaining a real overview of the situation. Primarily, it is used for simple verification of conditions reported by other modules;
- Unmanned aerial devices (vehicle – UAV): contain a camera with HD resolution and serve as a supplement to the camera system, in particular for optical monitoring of the

overall situation in the given area;

• System of notification and warning of the population: serves for notification and warning of the population against an impending flood. Warnings are done by means of the alarm sirens located within the town with the possibility of providing voice information. In order to notify the population, the direct output from a microphone can be used.

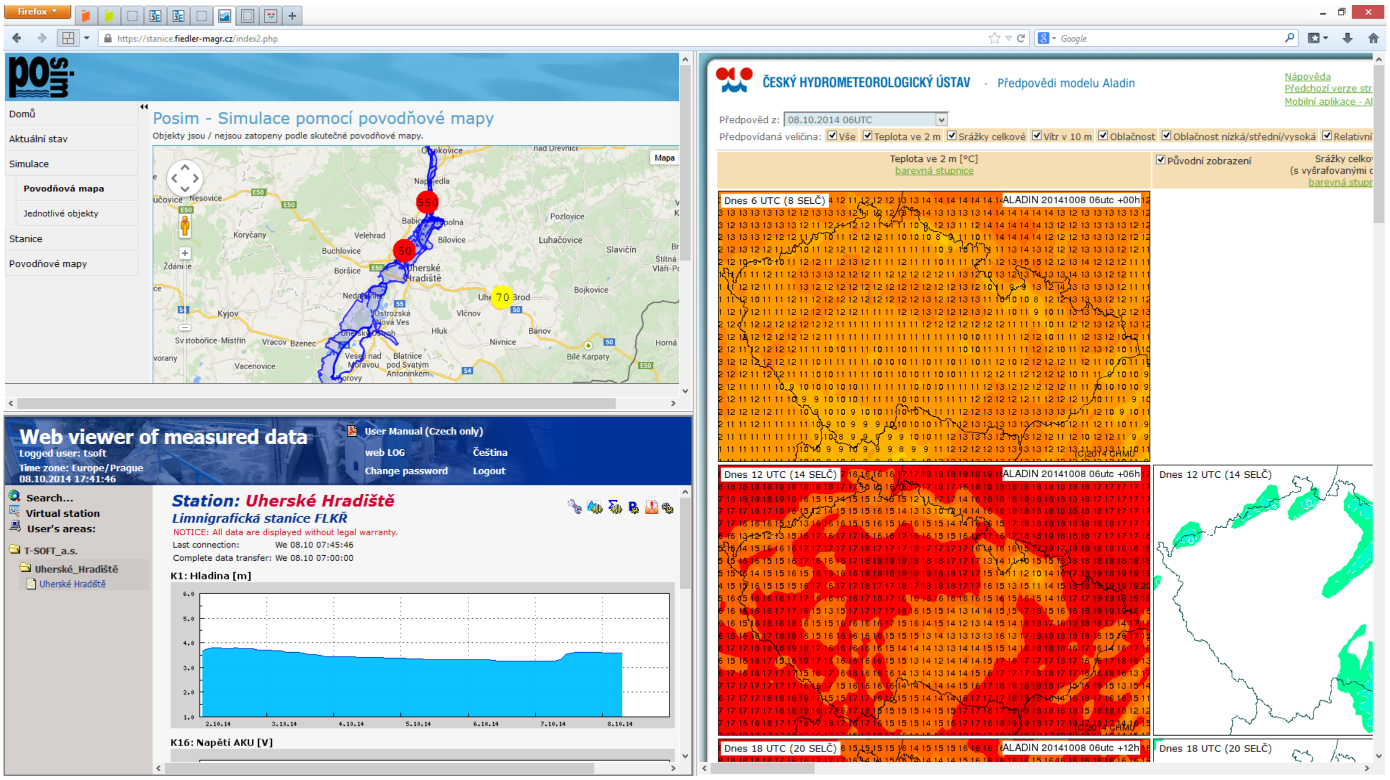

Fig. 8. The basic window of the Workstation for monitoring the outputs of the local system for early warning and other data sources. [4]

If needed, the system can be supplemented by other modules. For instance, this can be a module called "public media" which allows watching the current situation from the perspective available to the public by means of public broadcasting. Emergency management module enables communication of the services dealing with planning and realization of protection against floods and protection of population in general. This is done by means of the specialized SW "Emoff". Furthermore, simulation of leakage of harmful substances from objects affected by floods is processed by SW "Terex", which also has additional functions required for the actual management of extraordinary events and states of crisis. A detailed scheme of the workstation is depicted in Fig. 8.

The design and installation of HW and SW of this workstation were followed by testing of its operation with particular attention to the reliability and performance of data flows of individual connected modules. For the purpose of the test the flood was simulated. In order to simulate the flood the SW "Posim" was employed. By means of this tool the states of the LSEW output corresponding to individual stages of flood (1, 2 and 3) were simulated. Together with information about the simulated level of water surface and simulated discharge flow corresponding with individual flood stages, the area affected by the simulated flood was displayed. In order to determine the affected areas the flood maps included in the SW "Posim" were used. The data required was obtained from the Morava river basin authority.

The performed test verified the operation of the workstation and its suitability for training and preparing personnel involved in protection against floods. The graphical output of the course of the test is depicted in Fig. 9.

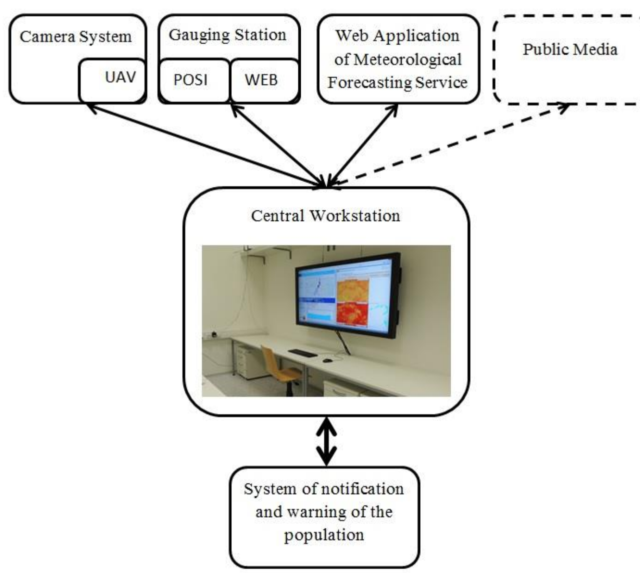

Fig. 9. The scheme of the scheme workstation.

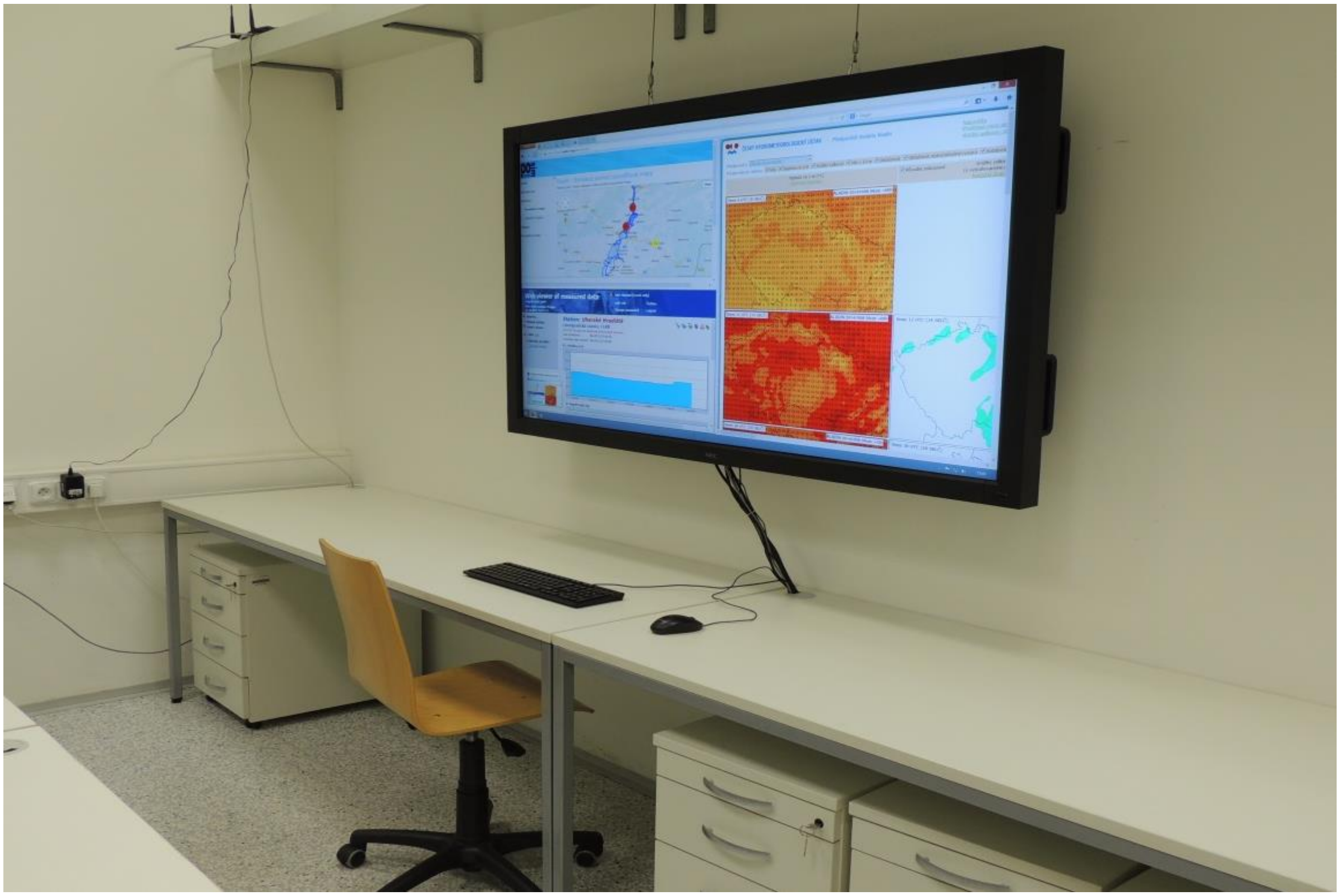

Fig. 10. Workstation for monitoring the outputs of the local system for early warning and other data sources

IV. Conclusion

Local systems for early warnings enable a significant increase in the quality of protection against floods. They are important for the protection against the so-called “flash floods” as well as common types of flooding. The manner of their use is fully dependent on the location of their installation and nature of the watercourse. The actual installation is constrained by several conditions that allow obtaining accurate and useful data. Ideally, it should be possible to acquire information on the high probability of flooding several hours in advance. In real-life situations, however, it is possible to obtain warnings in advance of dozens of minutes up to an hour.

Nevertheless, the local systems for early warnings using the gauging station and GSM information transmission have one major disadvantage. This disadvantage is the dependence on the functionality of the GSM networks. At present however, the risk of failure of GSM networks is acceptable because of two reasons. The first reason is a high reliability of GSM networks only with occasional failures due to network overload. The second reason is vital for public administration, whose staff, in the Czech Republic, is responsible for dealing with the flood situation. There are the so-called “emergency SIM cards” that operate within GSM networks even when the service is blocked for ordinary users. The probability of malfunction of GSM networks is thus minimal.

Another advantage of employing local systems for early warning is their relatively low price and the possibility of obtaining real-time data.

Another great advantage of the workstation’s outputs is that it can be supplemented by other information related to the overall meteorological situation and visual information in the given area. Besides, its projection on the base map contributes significantly to it being relevant in real-world conditions in the field of protection against floods. The final workstation with the possibility of controlling the system of notifications and warnings, together with other tools of information support for emergency management, forms a unique approach to the prevention and protection against floods. The merit of the given system is, in particular, its modularity which allows easy connection of new modules, which contributes to the versatility of the workstation.

The previously described characteristics were verified during a test installation and operation of the gauging station in Uherské Hradiště. Results obtained from the installation, and the operation of it proved it to be a highly reliable system. However, they also revealed a possible large deviation when determining discharge flows. A possible approach for improving accuracy in discharge flow measurements is a topic for further research. An area worth further research appears to be the interconnection of outputs of the gauging station with other SW applications, technological equipment or the creation and addition of more modules into the system of the workstation for the monitoring of outputs from the local system of early warning and other data sources.

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