"Flood Warning-Decision Support System Design for Urban Flash Flood Mitigation-Case study: Northern Tehran Basin"

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Urban flash floods happen rapidly and cause severe damages to facilities and social structures in a very short time. The main reason is considered as climate change together with increased human-nature interference. On July 1987 the 26th a devastating flood happened to north of Tehran. The number of death people registered as 300 and a large amount of losses was happened to different stakeholders.

There have been hired a variety of structural(S) and non-structural(N.S) approaches to flood loss mitigation upon the time. The application of flood warning system as one of the non structural flood management approaches has appeared successfully in flood loss reduction especially in urban areas worldwide.

Decision support system (DSS) is one of the kinds of knowledge-base systems that aids decision makers in adopting efficient decisions when facing with disastrous situations which in turn leads to make better decisions and to find better solutions in the mean time. The combined set-up of FWS and DSS consists of several elements and layers containing some hydrological(rainfall-runoff), hydraulic and meteorological models that convert the related data of prediction including meteorological data(precipitation, snow, cloud) into flood related information(the depth, encroachment area and magnitude of flood) in real time. Then the degree of the foresight flood can be estimated as low, medium or high based on the flood parameters itself and also the side effects. Having in mind that the flood degree is an efficient parameter of decision making in emergency situations and is considered as a basis for doing any action by local authorities in preparation phase and also in response to the flashflood.

This paper focuses on designing the architecture of a practical DSS-FW system for northern Tehran basin which is part of an ongoing project. The outcomes of the study show that meteorological prediction together with organizational set-up plays a vital role in emergency management of the study region.

Key word: *Urban Flash Floods, Flood Management Criteria, Flood Warning System, Information Management System, Decision Support System*

1-introduction

Many regions experience severe flooding from natural causes. The problem is particularly pronounced in areas of steep, complex topography where there can be a rapid buildup of storm conditions. In past decades the severity and rapidity of flooding has increased due to urbanization, causing higher runoff rates and more rapid catchment responses [1]. On July, 1987, a devastating flash flood occurred on northern Tehran the capital of Iran. The addressed basin catchment (named Golabdareh & Darband) discharged about 250 m3/s runoff (excluded mud flow) in 30Km2 watershed area that caused some 300 human losses and a large amount of losses to public and individual properties. A huge amount of mud, boulders and stones were deposited on the streets in an urban area. Many houses and other proprieties were also buried under loads of sediment. [2].

The recent flood in Golabdareh was an example of urbanization impact that heightens the degree of severity and rapidity of flooding in mountainous basins adjacent to large cities. After happening this event, the ministry of interior announced for leading serious study focused on flood cause and flood mitigation measures in the region. It should be noted that despite there have been developed some structural measures in the basin, it still lacks acceptable safety level against flash flood. In the recent years, it has been concluded to hire an appropriate nonstructural measure in the basin. After evaluating practical alternatives it was found of benefit to study about Flood Warning criteria. The objective of the project was the development of a comprehensive operational system for handling urban flood emergencies that combines traditional technology of data gathering system with more advanced forecasting of meteorology and hydrology using data acquisition sensor network system together with emergency operation cell encapsulated in a DSS.

Flood forecasting and real time monitoring have been found necessary to help taking reactive measures such as issuing flood warnings and planning emergency activities in the basins with rapid response to flood and also with the short lead time.

The purpose of the DSS is to manage the dynamic information acquired by data acquisition sensor network system, feed these data along with relevant static data to an array of modeling tools, forecast flooding conditions and assist public authorities in decisions regarding emergency measures.

2-A brief description of Flash floods in urban areas

Urban storm water runoff can cause the flooding of local rivers as well as of the urban area itself. Urbanization drastically alters the drainage characteristics of natural catchments, or drainage areas, by increasing the volume and rate of surface runoff. While the impact on major river systems may be minimal, the carrying capacity of small streams may be quickly exceeded, causing flooding and erosion problems. Often, the runoff from intense rainfall exceeds the carrying capacity of the sewer system, creating a backup in the system and hence the flooding of basements.[3] Moreover, storm water runoff generally increases most significantly due to extension of paved areas and surfaces.[4] One of the greatest difficulties in addressing flash flood problems is defining them. It is generally agreed that flash floods have the following characteristics:

1. they occur suddenly, with little lead time for warning;
2. they are fast-moving and generally violent, resulting in a high threat to life and severe damage to property and infrastructure;
3. they are generally small in scale with regard to area of impact;
4. they are frequently associated with other events, such as riverine floods on larger streams and mudslides; and
5. they are rare[5].

Having in mind the above characteristics, a very short time of the lead time limits the scope of any reaction to the flood by local people and authorities. So it is of significance to make use of real time meteorological data beside data input from data acquisition sensor network system.

3-Review of flood management criteria

The commonly used approaches of flood management can be outlined as: (a) reduction of peak flow by reservoirs, (b) restrict the flow within a predetermined channel by levees, flood walls or a closed conduit, (c) reduction of the peak stage by increasing velocities with river training works (d) diversion of the flood waters through bypasses or floodways, (e) [6] temporary evacuation of the floodplain, (f) flood proofing of specific properties, (g) reduction of flood runoff by land use management , (h)flood action plan, and (I) flood insurance[4].

From the above measures, the first 4 are considered as structural approaches yet the remaining categorized as non-structural ones. Structural intervention alone cannot provide a complete protection against floods since, among other reasons; the design capacity of structures is limited, operational defects are possible and structures could fail. Some reports indicate that reliance on protection by structural measures may actually increase the risk associated with flooding [7].

In addition, there are usually some limitations in implementing structural measures in urban areas and non-structural ones are more respectful to the environment.

On top of the above, implementing structural approaches is more justifiable economically and also requires less time in implementation phase comparing with structural measure. However it has proven the advantages related to installing non-structural approaches in combination with structural ones in the view that this togetherness would lead to synergy.

3-1-Flood Warning System

Flood warning is the advanced notice that a flood may occur in the near future at a certain geographic point. Actions that are intended by warnings are warnings about potential dangers and warnings about imminent dangers that require emergency action. A warning of a flood event implies an existing threat of danger to life and property and it invites responsive action to reduce threat.

The purpose of warning about impending floods is to enable and persuade people and organizations to take action to increase safety and reduce the costs of flooding. Generating appropriate responses, from the people and organizations at risk and from the agencies with responsibilities during flood times, is the goal of any flood warning system. In addition, effective warnings maximize the opportunities of agencies to fulfill their roles during periods of flooding. Agencies have many tasks to carry out, and most of them can only be carried out properly if adequate warning time is given.[8]

3-2-The outline of the flood warning system

A forecasting and warning system needs to be established, composed of a number of six components as follows:

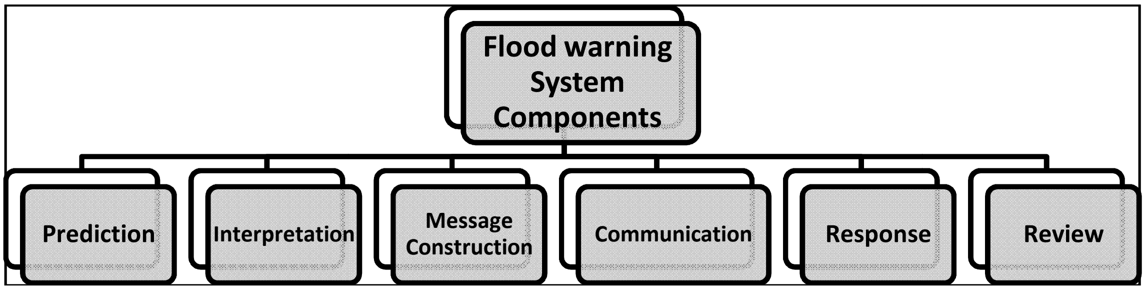


Figure1: Flood warning System's Components[8]

- **Detecting**: changes in the environment that leads to flooding, and predicting river levels during the flood.
- **Interpretation**: identifying in advance the impacts of the predicted flood levels on communities at risk.
- **Message Construction**: devising the content of the message which will warn people of impending flooding.
- **Communication**: disseminating warning information in a timely fashion to people and organizations likely to be affected by the flood.
- **Response**: generating appropriate and timely actions from the threatened community and from the agencies involved.
- **Review**: examining the various aspects of the system with a view to improving its performance.[8]

In order to have an effective flood warning system, all of the above mentioned components should work in an appropriate way in coordination with each other. Therefore, while designing the system, the essential working of the all components alone and in cooperation with other components should be taken into consideration. The status operation of sub-systems must be reviewed on a regular basis and, if necessary, constantly updated. In the following figure (F.2), there have been drawn a schematic relationship between different activities that performed by the outlined components of the system.

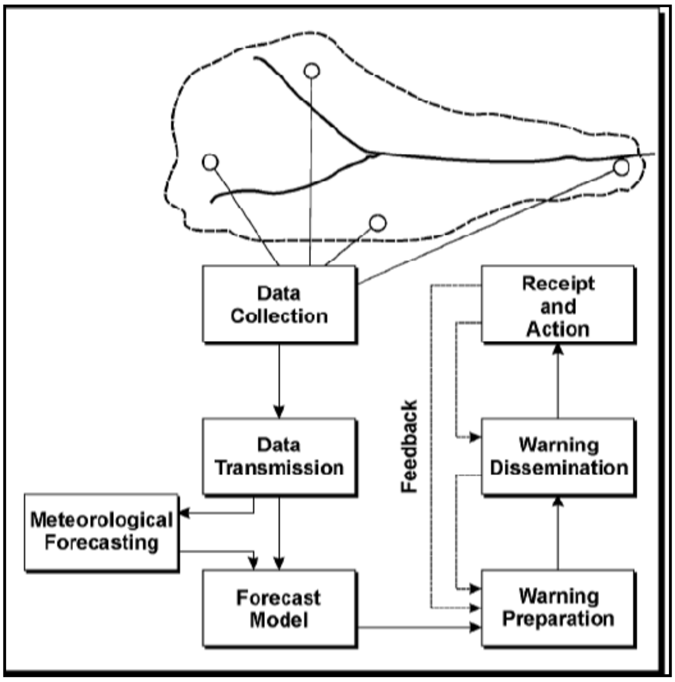


Figure 2: Typical forecasting and warning activities[4]

3-3-Considerations in designing a flashflood warning system for urban areas

As it was noticed earlier about the features of flash flood events; they occur within a few or less hours of the occurrence of heavy precipitation, which is often too short a time to take preparatory measures by local authorities and the public. Thus, providing an adequate warning lead-time would be of great essential to handle the flood response activities such as flood fighting and evacuation. In urban basins with the immediate basin response to flood, this situation will happen. In these areas, the use of observed precipitation does not allow sufficient lead-time and to issue warnings. Thus, besides hydrological weather forecast, incorporation of the meteorological forecast to predict precipitation would play an essential role in awareness of local authorities in the early stages of the imminent flood formation (e.g 72 hours before flood formation). This early warning helps them to arrange for any reaction at the time of flood occurrence.

Therefore the meteorological weather forecast would be considered as the triggering phase in flood warning system. Besides forecasting, appropriate interpretation of the weather forecast, strengthens the nexus between weather forecast and issuing warning. On the other hand, the results from the prediction models cannot be used directly because they still have to be interpreted by a meteorologist, since there is a high level of uncertainty in the results from the models due to the complexity of weather phenomena.

After interpreting the data gained from weather prediction, and recognizing how sever the promising flood would be, then it is the time for deciding to who announce the alarm and by which degree of certainty.

The other area of concern is the poor condition of decision making in the situations facing with urban flash floods. Facing with these conditions, the authorities are highly under pressure and cannot recognize which alternative would be the best one.

All in all, the decision making process is a very important feature which can support outcomes of different components of the system in several phases. This feature will be repeated in any other executive phases of the system such as during flood response activities and also in recovery stage. As discussed earlier, the workability of the system highly depends on the correct decision making on any phase. Hence, there is of significance to combine the system with advanced technology of decision support system.

4-incorporating decision support system in flood warning system architecture

Decision support systems (DSS) are the area of information systems (IS) devoted to supporting and improving human decision-making. The DSS field began in the early 1970s as a radical alternative to large-scale management IS (MIS). Over time, major changes in information technology (IT) have enabled new decision support movements.[9]

On the other hand, a decision support system allows decision-makers to combine personal judgment with computer output, in a user-machine interface, to produce meaningful information for support in a decision-making process. Such systems are capable of assisting in solution of all problems (structured, semi-structured, and unstructured) using all information available on request. They use quantitative models and database elements for problem solving. They are an integral part of the decision-makers approach to problem identification and solution. The purpose of DSS is not to replace humans but to support decision makers in making informed choices. In the end, the time and the steps necessary to find a satisfactory solution to a problem are essentially shortened.[10]

A DSS for flood management essentially makes use of one or more models to make forecasts and a data acquisition sensor network system for data gathering. The choice of models depends on factors such as the hydro-meteorological characteristics of the area, the desired level of accuracy, the intended forecast time and the cause of flooding.

For floods mainly due to excess flow in rivers, a routing model using upstream data may be used, or even more accurate forecasts can be made by tracing the depth contours using a series of stage gauges. When the travel time of the flood peak gets shorter and the main cause of flooding is local precipitation, the latest observed precipitation could be used along with a runoff model. However, the use of observed precipitation data might not ensure adequate forecast time. In that case precipitation forecasting may be required.

Generally, forecast accuracy decreases as the forecast horizon increases. Even in using forecasted precipitation, different forecasting methods trade-off forecast accuracy with lead time.[1]

5-Case study

Golabdare & Darband catchment located on the mountainous northern part of Tehran. This region is considered as one of tourist attract points with the total area of 30 km^2 is exposed to heavy rainfalls especially during spring and summer. The mentioned basin lacks enough vegetation cover due to change in land use pattern thus, cannot detain the run-off flow. One of the other results of the land use change in the basin over years is the harsh modifications of hydrological characteristics such as concentration time which has been decreased to almost 1 hour. (kuritkara Co, 2006)

Having in mind the above features, the basin is faced with high rate of discharge flow plus a very short time for flood response by individuals and local organizations. Despite there have been developed some structural measures in this area, still it lacks adequate safety level against flood event. The severity of the flood incidents and the need for issuing immediate response provokes the necessity for incorporating meteorological predictions in the promising flood warning system.

6-Design considerations for the Fw-DSS in the study area

As it was noticed earlier, there are some considerations in the design of a flood warning system for the study area such as: a short time of concentration and the existing traditional system of data acquisition. In order to provide enough time of response to flood, the meteorological prediction of precipitation could be carry on by Meteorological Organization of Iran/Tehran. These predictions would be issued 72 hours before the event but the degree of certainty is a parameter to be taken into consideration for any decision making.

In order to upgrade the data acquisition sensor network system, it is being upgraded with the modern equipments of data sensor network system. A number of sensors with different parameter set such as precipitation (P), temperature and humidity (T&H), wind speed(W.S), water level(W.L), water weight of equal snow(W.W.E.S) have been installed at different locations of the basin. The total number of each type of the sensors are sum up in the following table.

Table1:number of data sensors installed in the study area[2]

sensor type	P	T&H	W.S	W.L	W.W.E.S	data logger
no	3	3	3	2	1	5

With the significance of any measured parameter for rainfall-runoff models, different types of data should be measured at different periods. Hence, it has been considered to set the sensor observation distance by its users. In table bellow, it has been outlined the sensor observation distance in different conditions.

Table2: sensor observation distance in different conditions[2]

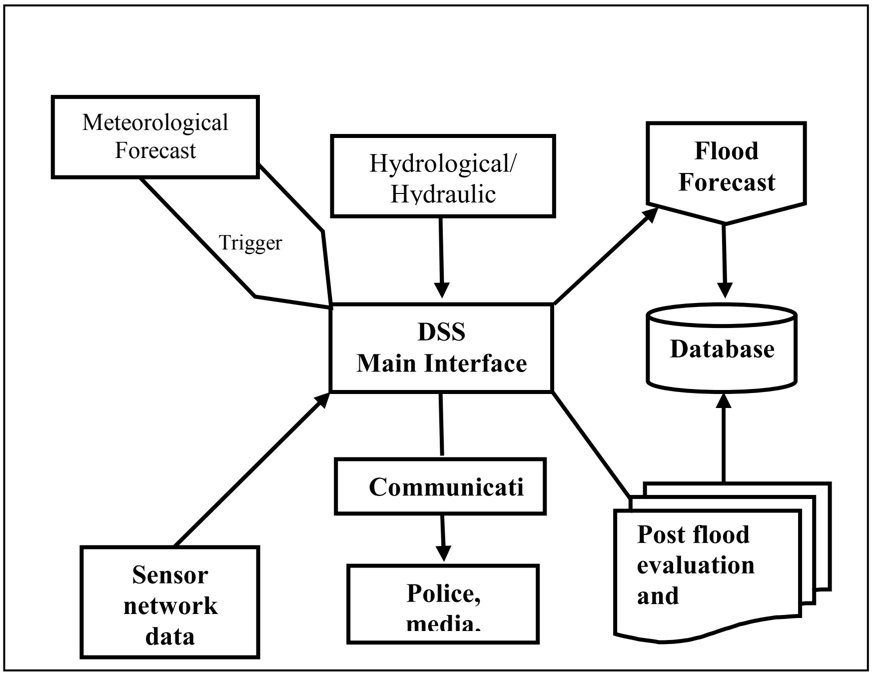
Seasion	P	T	H	W.S	W.L	W.W.E.S
flood	1min	10min	30min	30 min	1min	1 hr
cold	15min	1 hr	1 hr	1 hr	15 min	12 hr
warm	12 hr	12 hr	12 hr	12 hr	12 hr	12 hr

6-1-Outline of FW-DSS designed for the study area

The DSS is designed to work at the centre of other essential components such as the hydro meteorological forecast models, the data acquisition sensor network and related databases. Figure 3 shows the operational link between the DSS and these components.

The main role of DSS is to help decision makers define the situation of flood, to help them decide whether or not on issuing the warning at which level and by which degree of certainty, to decide on the quality of responsive activities and also on recovery works. In the outlined FW-DSS there have been hired a number of hydrological, hydraulic, damage assessment and models that have been calibrated in accordance with basin parameters which have been listed in table 3. The criteria for choosing them are the basin area, their publicity among Iranian engineers and ease of use.

At this initiating phase, there is not any intention to hire the most update software models yet their arrangement should be in a way to lead to the best operational result. For meteorological predictions, this responsibility is undertaken by the Meteorological Organization of Iran. This organization is capable of issuing the alarms to DSS center from 168 hr before the event. The sound engineering judgment says that 72 hr prediction time would be adequate to start alarming the DSS center meanwhile the data received from data acquisition sensor network would be processed by the related models and the outputs will be compared with meteorological forecasts. In addition, a range of predefined scenarios have been produced in DSS center to be operated in correspondence to any of the scenarios in any time section.



Figur3: The outline of FW-DSS[2]

Table 3:software models used in DSS center[2]

meteorological models	**MM5**
hydrological models	**HEC-1, HEC-HMS, WMS, HEC-GeoHMS**
hydraulic models	**Hec-Ras, Hec-GeoRas**
damage assessment	**Hec- FDA**

6-2-Operational method

An important criteria used for decision making is the water level threshold which represents the degree of flood in any point of the basin. Based on past experiences and also running the model using hypothetical precipitation and watermark data, 3 thresholds produced. Each of the describes the quality of flooding in relation to water level and also flooded area of the basin and the downstream of the basin. The mentioned degrees are entitled as low, medium and high. These thresholds relatively elaborate the severity of the flooding hence the corresponding actions would be arranged. Table 4, presents the definition and impacts related to each threshold. For each threshold, a number of water ways, culverts and bridges are affected by the flood water.

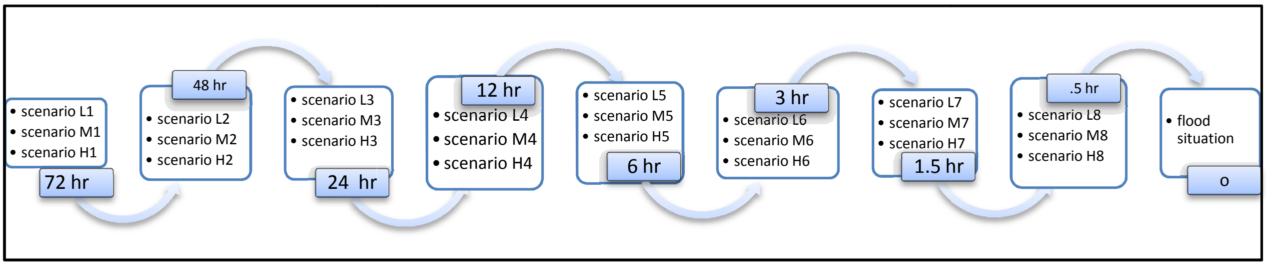
These flooded points have been marked on the basin map. The method used by FW-DSS for alarming local authorities and to the public is a scenario based method. There have been designed some scenarios from 72 hr beforehand for each predicted precipitation rate. There would be assigned 3 scenarios for each time section according to each threshold. So the number of scenarios will sum up to 24. It should be mentioned that each threshold in different time sections is associated with different operational activities. The level of operational activities would develop while approaching to the real situation of the flood of any threshold. Since, by decreasing the interval from the flood situation, the level of prediction certainty will increase.

Figure 4 presents the time arrangement for alarms and associated operational scenarios. In every scenario there have been assigned a range of activities such as channel cleaning, deploying cleansing machinery to the bridges and culverts by municipality, rescue & relief activities by mountain guard, fire fighting and public communities and many other related organizations. So there have been designed a range of responsibility matrixes for each scenario and a list of contacts to key persons.

Table 4: definition of flood degree thresholds in and downstream the basin area[2]

Degree	Definition	impacts
low	decrease in discharge of main channel and due to precipitation upstream of the basin and surface water in water ways.	interrupting people doing entertaining activities in floodways
medium	high discharge of flow in river and main channel, sediment transport, decrease in surface water in pedestrian ways and streets before the main square located downstream of the basin	interrupting human activities, mountain climbing and any traffic, mudflow to houses and shops
high	overspill from the river, washing out basin and large size sediment flow, flood water and sediment transport from flood ways to the downstream streets and houses, high surface runoff in pedestrian and motorways.	high interruption in urban activities both in basin and downstream (north of Tehran)

Figure 5: the sequence of time scenarios for flood emergency operation based on flood prediction



7-conclusion

Based on the above description of the designed system of FW-DSS in the study area, decision making in a very short time of flood formation is out of imagination. In order to help handle the flash flood event, it has been found of value to incorporate meteorological weather forecasting in the configuration of the designed flood warning system. Furthermore, in order to have a real time hydrological prediction system, there have been concluded to install a data acquisition sensor network system to sense a cluster of data in definable time intervals. Then these predictions can be compared together to provide a rather safe forecast. Warning messages would be discussed over in order to decide on when sending the messages and to which authority.

The efficient way of planning for the imminent flooding emergency situation is to synthesis a spectrum of scenarios in correspondence to time and the severity of the foreseen event. It would help local authorities to arrange for preparation activities and deployment of equipment and emergency work force.

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