



Flash Flood Early Warning System

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Abstract:

Global forecasts, from various sources, indicate that the Kingdom will be exposed in the coming years to a heavy rain seasons, as a result of the drastic climate changes.

Knowing that most of kingdom cities and their villages are not ready to deal with such risk, in addition to the lack of infrastructure for disaster management and forecasting, means that there is a potential exposure of cities to serious environmental disasters, Flash flood disasters.

"Flash floods can be described as dangerously fast moving floods caused by a large amount of heavy rain in a localized area, this torrential downpour may transform a normally calm area into a powerful river of death in only a few short minutes. Many people are caught unprepared for the power and speed of a flash flood, which results in dangerous situations". World Meteorological Organization (WMO),1999

For this reason it's required to implement a flash flood early warning systems within the framework of Multi-Hazard Early Warning Systems which aim to realize the following objectives;

1. To provide a real time weather and flash flood updates.
2. To provide a flash flood early warning in the event a flash flood will occur.
3. To assist and improve the capabilities of Civil Defense, and other governmental and non-governmental agencies, in term of preparedness to deal with the flooding disaster and other emergency situations, and to build a historical records and statistics.

This paper presents the concept of flash flood early warning system with all related component.

The paper includes examples that demonstrate the power of such system in solving environmental problems.

Key words: Flash flood, risk assessment, Heavy Rain, Land use, Spatial data, Early Warning Systems (EWS).

Most of this paper was extracted from Flash Flood Early Warning System Reference Guide2010 produced by NOAA in 2010 National Oceanic and Atmospheric Administration.

1. Introduction

Flash flood is the most lethal form of natural hazard (based upon the ratio of fatalities to people affected), and cause millions of dollars in property damage every year. This is because flash floods, which are flood events of short duration with a relatively high peak discharge, tend to occur frequently but at a very small scale. Flash floods are typically caused by

Definitions of "Flash Flood"

1. World Meteorological Organization: a flood of short duration with a relatively high peak discharge.

2. American Meteorological Society: a "...flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area."

3. U.S. National Weather Service: a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of the country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.



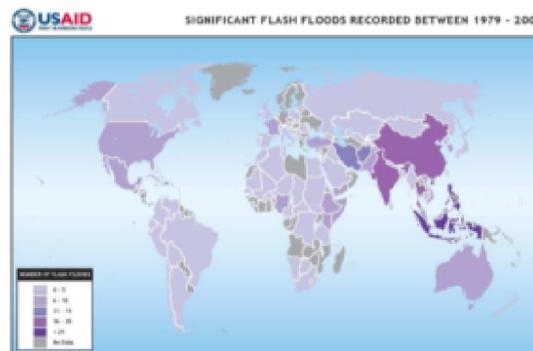
torrential rainfall, but can also occur from a dam break, a levee break, or even ice jams in rivers during the winter and spring months. Urban flash flooding is a serious and increasingly common problem as cities grow and spread out. Impervious surfaces like concrete or compacted bare soils, along with alterations to the natural drainages, create instant high energy runoff from heavy rainfall that can inundate roads and buildings very quickly.

"World Meteorological Organization, *Global approach to address flash floods*, in MeteoWorld (June 2007)"

www.hrc-lab.org/publicbenefit/downloads/wmo-flashflood.pdf

"Recent findings of the WMO country-level survey where of the 139 countries, 105 indicated that flash floods were among the top two most important hazards around the world and require special attention"

"On the average, these events kill more people worldwide than any other natural disaster – in an average year, flash floods kill over 5,000 unsuspecting people and cause millions of dollars of property damage" (WMO 2008).



WMO Climate and Water Department "Regional Flash Flood Guidance and Early Warning System WMO"

Few countries have implemented flash flood warning systems. Some countries have established Flash Flood Early Warning Systems (EWS) and have not sustained them. Recent computer modeling, precipitation sensing, and communications technology advancements are making flash flood EWS increasingly affordable, effective, and sustainable. Flash-flood have a range of options for creating local or regional early warning systems or even participating in global early warning systems capable of providing some protection from flash floods. These options include:

- 1) Heavy rain event detection via rainfall/stream flow gauge networks, radar networks, satellite sensors, or some combination of the three.
- 2) Manual or computerized short-fused now casts of imminent flash floods from diagnosed heavy rain events.
- 3) Atmospheric fine-scale models, possibly coupled with distributed hydrology models, to forecast the risk of flash flooding in a basin or basins a short time in the future.

2. Problem History and Description:

The risk of flood in the KSA and what happened in Jeddah , Jazan, Hael, and Tabouk is not far and could gets repeated in any place or in any city of the Kingdom and at any time. It is sure that what happened in Jeddah is a result of accumulated errors from different faults stretched and accumulated in nearly four decades, Therefore studying the problem, analyzing, and proposing solution at the level of the whole Kingdom before repeating the season must be given top priority.



The basis of the right decision is the information. Therefore, the absence of the accurate information and non-availability to the decision maker in the right time is one of the biggest factors leading to the wrong decision and the result is a tragedy similar to the one took place in Jeddah. Following are brief analysis points to the history and origin of the problems of flooding in the kingdom :

1. Rain and hydrological cycle in Saudi Arabia, according to the climatic conditions and records, is around, and the revisit cycle brings heavier rain and floods.
2. Cities and hamlets and rural areas and villages in the Kingdom developed during the last thirty years past in exponential way, not linear, the evidenced is the rise of the census in the Kingdom of about seven million from three decades ago to about 28 million today ;
3. Most of the valleys that enter the cities comes from long distances and beyond the domain of urban cities which can't be controlled by one authority.

Because of the high expectations that the Kingdom will be exposed in the coming years to big rain seasons, Saudi cities will be exposed to large environmental disasters, particularly to a flash floods. It is a must to take the necessary measures and precautions and to identify the disaster prone areas and the magnitude of the risk in advance.

3. The Objectives:

The objective of this paper is to present and explain the concept of a model for building a complete flash flood early warning system as per **Flash Flood Early Warning System Reference Guide 2010 produced by NOAA in 2010** National Oceanic and Atmospheric Administration.

and to put the outlines of the local Flash Flood Warning system in Tabouk which will be as a supplementary research for our current paper



Flood in Jazan



Flood in Jeddah



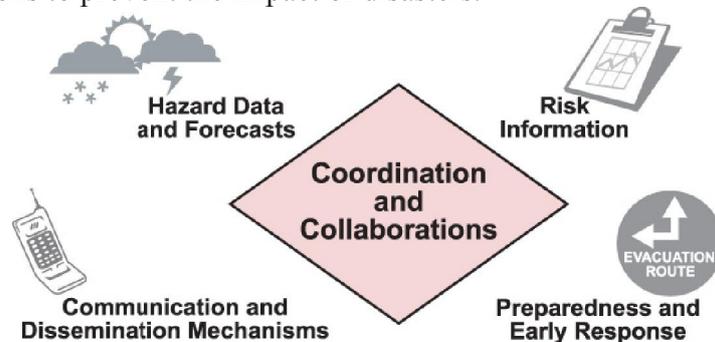
Flood In Tabouk

4. System concepts-Requirements and outputs.

The main stages of the work summarized as follows:



Rainfall forecasting, early warning of the flood and building central database of basic information to represent the topographical data using geographic information systems and the establishment of operating accurate information to produce it in its final cartographic and tabular form in daily or hourly reports, all of these are the basics info essential in finding indicators precautions to prevent the impact of disasters.



Simplified version of an original figure produced by WMO on components of an effective Early Warning System
Flash Flood Early Warning System Reference Guide

What Is an Early Warning System (EWS)?

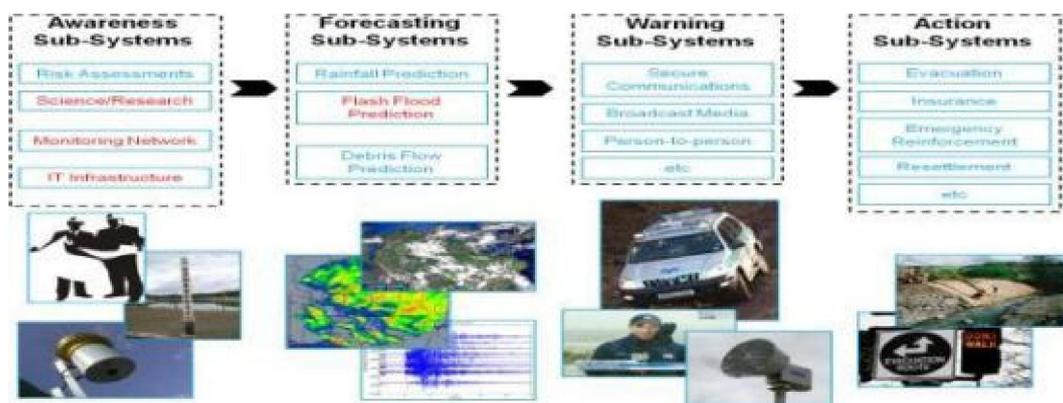
"EWS are increasingly recognized at the highest political level as a critical tool for the saving of lives and livelihoods, and there are increasingly more investments by national and local governments, international development agencies, and bilateral donors to support such systems. EWS". launched at the Third International Early Warning Conference (EWC – III), in Bonn, Germany (March 2006),

The four elements in natural hazard early warning systems:

1. Risk Knowledge – systematic assessment of hazards and vulnerabilities, and mapping of their patterns and trends.
2. Monitoring & Warning Service – accurate and timely forecasting of hazards using reliable, scientific methods and technologies.
3. Dissemination & Communication – clear and timely distribution of warnings to all those at risk.
4. Response Capability – national and local capacities and knowledge to act correctly when warnings are communicated

"Early Warning Systems – A Public Entity Risk Institute Symposium"

A System of Systems





Components of a flash flood EWS.

Flash Flood Early Warning System Reference Guide 2010

Flash Flood Science:

A *flash flood* is generally defined as a rapid onset flood of short duration with a relatively high peak discharge (World Meteorological Organization). The American Meteorological Society defines it as a "...flood that rises and falls quite rapidly with little or no advance warning, usually as the result of intense rainfall over a relatively small area."

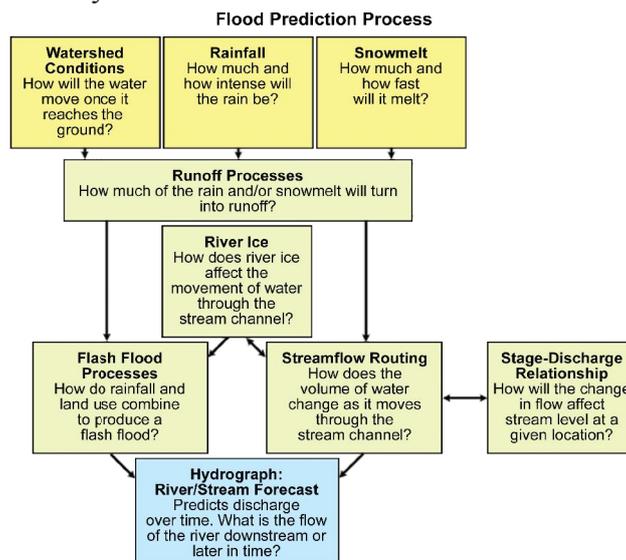
A. Flash Flood Processes:

Flash Flood happened when we have a combination of a high rainfall rate with rapid and often efficient runoff production processes. Therefore, the nature of the rainfall and the anticipated runoff processes are key elements in the forecast process.

"In general, the greater the precipitation intensity, the more likely it is that significant surface runoff will be generated. Higher precipitation intensity can result in more runoff because the ground cannot absorb the water quickly enough. Although prior ground saturation increases the flash flood risk, many flash floods occur when the ground is not saturated. Flash floods can and do occur with dry soils and drought conditions". *Flash Flood Early Warning System Reference Guide*.

Hydrologic influences of the ground surface can have a major impact on the timing, location, and severity of flash flooding. Although rainfall is often considered the most important factor for forecasting floods, what happens to the rain once it is on the ground can sometimes be of greater importance. In some cases, runoff production processes may be more important than rainfall characteristics.

- Hydrologic Influences :
 - Soil Moisture: most important
 - Soil Texture: also affects rate of infiltration
 - Soil Profile: e.g. soil over bedrock
- Basin Influences
 - Shape and Size
 - Slope
 - Roughness
 - Stream Density



Flood prediction process

Flash Flood Early Warning System Reference Guide

The above figure describes the overall flood forecast process and how flash floods relate to that larger process and showing that :



- A combination of high rainfall rate and very efficient runoff production is common to most flash flood events.
- In some situations the runoff characteristics can be as or more important than the rain rate.
- Soil moisture, soil permeability, soil surface alterations, and vertical soil profile are important soil characteristics that affect runoff production and hence help define flash flood prone areas.
- Basin characteristics, (e.g., size, shape, slope, land cover) influence runoff and hence flash flood occurrence potential.
- Urbanization and fire can greatly increase flash flood potential by increasing both the potential volume of runoff as well as the speed with which the runoff occurs.

B. Hydrometeorological Sensors

- Radar Networks
- Rain Gauges
- Streamflow Gauges
- Satellite Imagery

Portable Weather Radar:

A primary function of a weather radar network is to provide high-resolution, real-time gridded rainfall estimation over a region of interest. Weather radars are powerful tools for hydro meteorological monitoring and forecasting because of their ability to characterize precipitating clouds over a large area as opposed to the point measurement of an in situ gauge. Radar should detect the formation of clouds, track their movement and evolution, probe their internal structure, and make quantitative estimates of the amount of precipitation they produce at the surface.

The radars are providing :

- ✚ Real time information about thunderstorms up to specific required range, including ca-ppi, max, RHI, VIL, echo tops, rainfall measurements, storm tracking and wind velocity.
- ✚ Scan of backscatter from the radar horizon volume.
- ✚ Transformation of data into spatial matrix and input data processing.
- ✚ Display images and data on site and at risk center
- ✚ Able to cover all of requested region including the mountains .
- ✚ Able to support warning of local regions for storm rainfall.
- ✚ Warning for floods.
- ✚ Warning for storm rainfalls, thunderstorms, hails.
- ✚ Forecast for thunderstorm evolution and movement.

Rainfall Gauges:

For flash flood applications, rainfall gauges will consist of a precipitation measurement device, data collection platform (DCP), power supply and management unit, and communication device. These can be coupled with a range of common weather sensors that measure temperature, humidity, barometric pressure, and other standard weather parameters like wind speed and direction.

Stream flow gauges

to estimate discharge by measuring the water surface elevation in the channel.

- ✚ The sensors installed at the above locations, and their RTUs shall be networked back to the Management Risk center site by mobile cellular services.
- ✚ The contractor shall procure the necessary equipment, and procure and pay for the necessary connectivity services until handover to the Operations and Maintenance provider.
- ✚ Sensors and RTUs shall be solar-powered.



✚ A lightning detection network shall also be installed by the contractor, sufficient to cover the Studyarea and all surrounding valleys.

The Gauge Networks should be accurate, reliable, and timely gauge data which essential to the success of a flash flood early warning system

• **Satellite Networks**

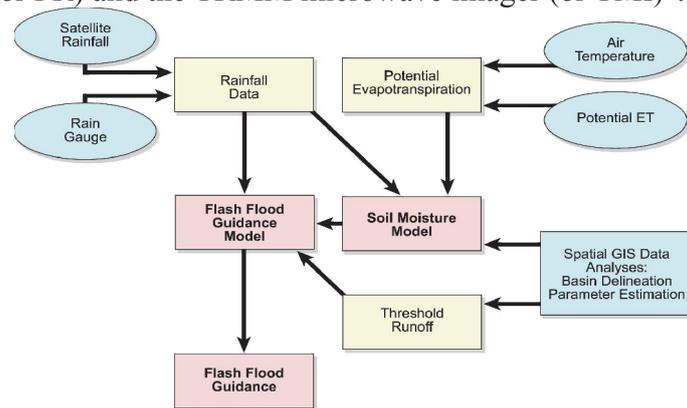
The mission of meteorological satellites is generally twofold: collection of observational data such as infrared and visible imagery, and dissemination of this data and other products that are uplinked from the meteorological service that controls the satellite. Additionally, these satellites perform a communications role in relaying data from various Data Collection Platforms (DCP) such as stream flow and rain gauges.

○ Satellite estimates of precipitation can be partially corrected by coincident rain gauge “ground truth” data.

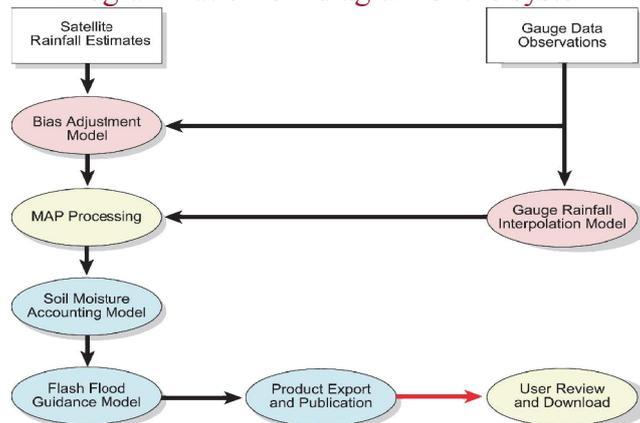
○ Gridded rainfall estimates are the primary source of precipitation information for areas that lack radar networks and networks of rain gauges.

○ Rainfall estimates can be computed for the entire planet by making use of both Polar Orbiting and Geostationary satellites.

"The Tropical Rainfall Measuring Mission (TRMM), launched in 1997, was conceived as a satellite mission to study tropical rainfall for climate studies and is the precursor to the Global Precipitation Measurement (GPM) mission. The two most important missions are an onboard precipitation radar (or PR) and the TRMM microwave imager (or TMI)".



Programmatic flow diagram of the system



Processing of real-time rainfall in the system

C. Communications Requirements, Technology Infrastructure:

Flash flood forecast support application functions can be divided into several categories:

- **Collecting** earth observation data in real time, especially rainfall and stream flow data.
- **Processing** and storing data in real time.



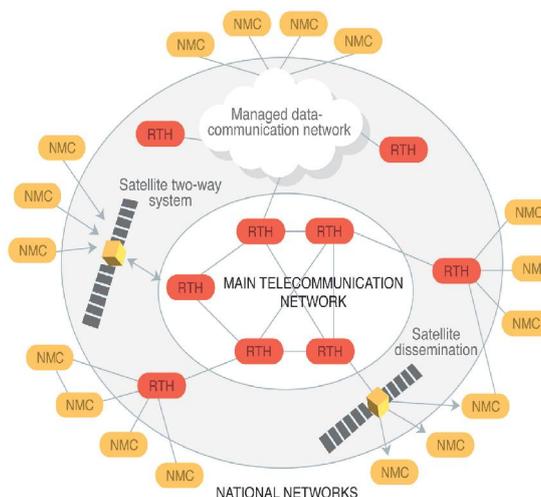
- **Monitoring** data for exceedance of threshold criteria.
- **Computing** parameters that must be derived from observed data.
- **Displaying** data and derived information for the forecaster to maintain situational awareness.
- **Creating and Disseminating** text and graphic products to customers and other forecast centers.

The main tasks required from this technology are to:

- + Collecting, decoding, and digitally storing earth data observations
- + Managing relational database of observations and metadata
- + Checking incoming observational data for quality and flagging or rejecting suspect readings
- + Displaying data
 - Numerical tabulations of gauge reports
 - Graphical displays of gauge reports
 - Mapped displays of gauge reports
- + Comparing precipitation estimates to Flash Flood Guidance (FFG) and alerting forecaster when guidance is exceeded as illustrated in the example in Figure 4.1
- + Comparing precipitation estimates to Flash Flood Potential Index (FFPI) or other programs that modify FFG (see Chapter 5) and alerting forecaster
- + Computing rate of change at gauges, extrapolating future values, and alerting the forecaster when FFG levels are exceeded
- + Routing rainfall downstream and comparing to flood stage, etc.
- + Mapping and displaying radar reflectivity data in real time and alerting the forecaster when reflectivity thresholds are exceeded
- + Displaying radar-observed incremental storm total precipitation data and alerting the forecaster to potential problem areas
- + Comparing radar reflectivity data through ZR relationships, for instance, the relationship between radar reflectivity and rain rate in a power law form, and relating to FFG and/or FFPI
- + Generating text and graphical summaries of observed data, routine forecasts, and warning products
- + Disseminating products to appropriate communications channels.

D. International Observation Data and Information Collection - GTS

The Global Telecommunication System (GTS) is defined as: “The coordinated global system of telecommunication facilities and arrangements for the rapid collection, exchange and distribution of observations and processed information within the framework of the World Weather Watch.” – WMO No 49 Technical Regulations.

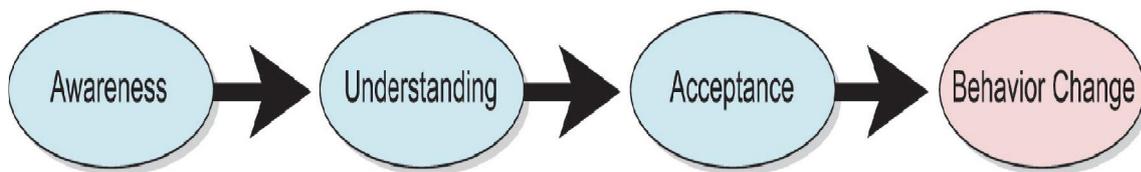


Basic structure of the WMO Global Telecommunications System

Warnings Dissemination & Notification and Other Flash Flood Products

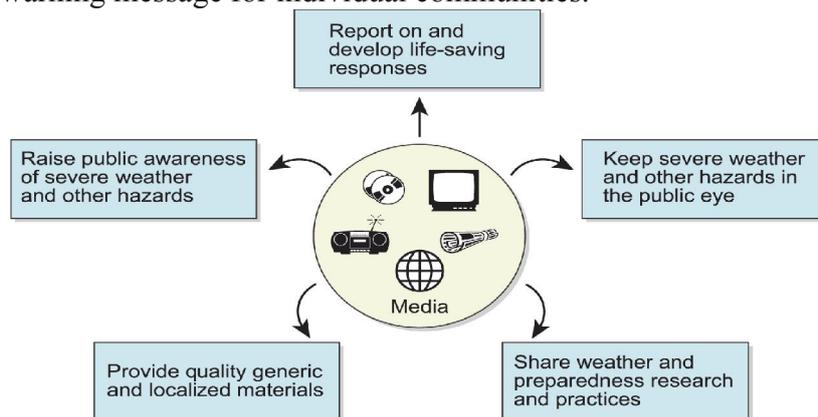
- ✚ Warnings and other flash flood products – the Ready, Set, Go concept
- ✚ Dissemination – physically delivering a warning message to constituents
- ✚ Notification – the understanding of the received message by the target audience and the initiation of appropriate actions by those at risk.

Communications Continuum



Stages of persuasive communication

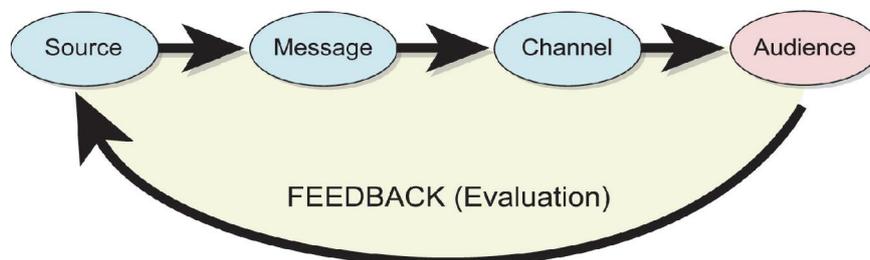
link between scientific experts and the community. Without the media, rapid dissemination of warnings cannot occur. This community partner can also relay, interpret, and supplement warning information from the warning center. Media also have the ability to localize the preparedness and warning message for individual communities.



Print and broadcast media roles

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Communication Process



Communication model

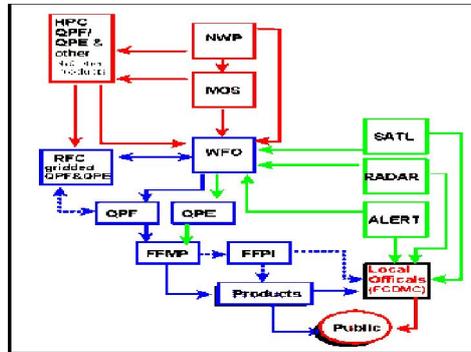
Flash Flood Early Warning System Reference Guide

5. Examples of End-to-End FFEWS

- ✚ USA
 - national hydro-meteorological guidance, local hydro-meteorological expertise and constituent-operated gauge networks
- ✚ Central American Flash Flood Guidance System (CAFFG)



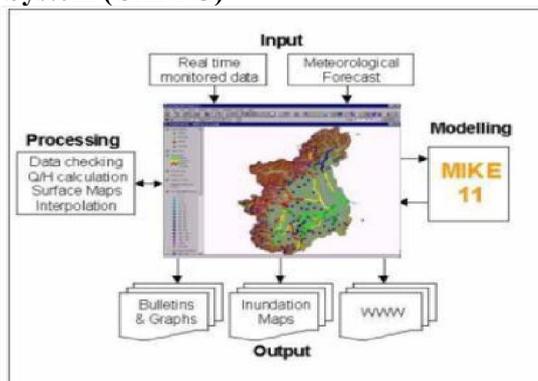
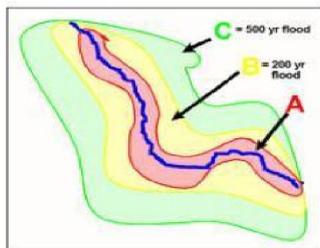
- based primarily on satellite data
- Italian Piedmont Region Multi-disciplinary System
ALERT and Real-time Flood Forecasting System
- Columbia: Aburrá Valley Natural Hazard Early Warning System
currently in the planning stages.



USA Flash Flood EWS



Central America Flash Flood Guidance System (CAFFG)



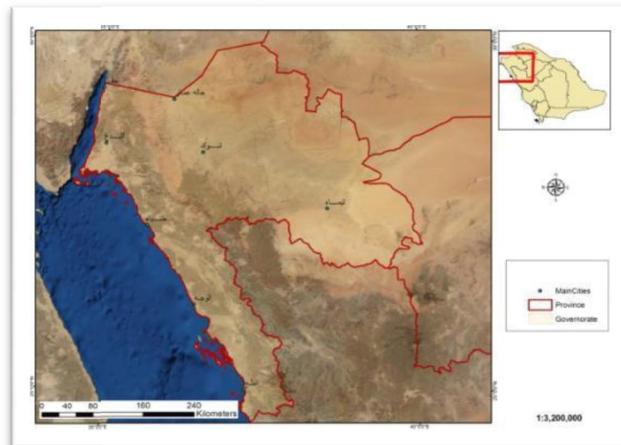
Italy: Piedmont region hydro-meteorological ALERT and Real-time Flood Forecasting System
6. Tabouk as Case study need urgent Local flood monitoring System:



Local Flood Warning Subsystems (LFWS) In Tabouk:

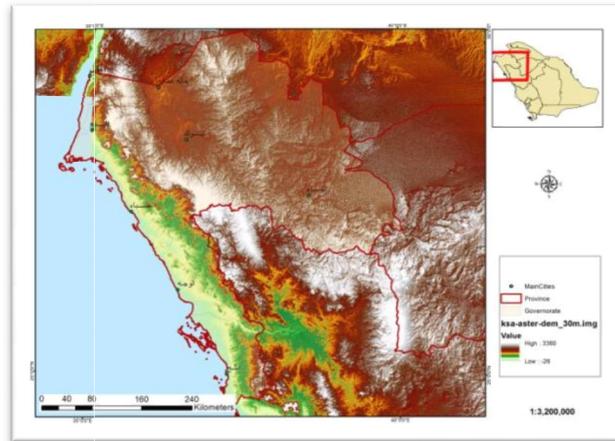
Tabouk region Located in the northwestern part of the kingdom between mountain Hasmy in the West and Chroy in the East and the Algosaúmin the north and Mountains Rice and Alhiabh in the south, it's also located in the low plain at the sea level between 600-800 meters , The geographical location of Tabouk make it surrounded by very big valleys, Dr. Massad bin Eid Al-Atwi head literary Club said that the valleys of Tabouk extends from the Alrh and Ayred and Hasmy which flowing into the plains of Tabouk , including green Valley , which extends from south of Shibana mountain and weter and many valleys are discharging into it to flow then into east Tabouk, also many vallyes are flowing into valley Otana like « Alkrac and bite and Alramadh and Rashdan Sudair and Najia to connect then Valley Aldiqih who flow into the valley Alhathel where Ghada and lanugo Valleys ostrich also flowed, Alhathel Valley flowing in the Ibonchevh valley east of Tabouk, it separates between Tabouk and green Valley. from the western side of tabouk Aynd , Qena and haddrah valleys are flowing in the Bakar valley to discharge into the agriculture bottom west of Tabouk then flows in Mahttab at the famous gate of Tabouk ..

Attaa Allah Al Omrani , Al Riyad newspaper 9-12-2009.



The closest most important five valleys:

- Wadi Green : a valley of the largest valleys of Tabouk.
- Wadi Bakar : located west of Tabouk and very dangerous for the buildings in west tabouk.
- Wadi Dom:
- Wadi Ghwell:
- Wadi Abu Nchevh : one of the important and dangerous valleys to the city of Tabouk in case of flood since it's composed of 2 main Shoaibs which flow to the lowest area of Tabouk and discharging there causing flood.



Proposed System Engineering Concept :

Build Early Warning Systems:

- Develop maps of flood risk showing flood heights, safe havens, and routes to safety.
- Undertake surveys from the people living in Tabouk.
- Develop, Install , and test the model and Gauges with many scenarios
- Undertake studies of how people access and interpret early warnings and then apply the lessons to dissemination processes.
- Develop performance standards and guidelines for different types of early warning systems.

The system will :

- provide and install a state-of-art Flash Flood model,
The Flash flood model shall be integrated with all data systems which feed the model (including sensor data on rainfall in the catchments and water levels, satellite data, and GIS data for basins). The product should be displayed on a GIS map.
- provide a state-of-art display system (including GIS map of Tabouk that shows the areas of flash flood prediction.

❖ **First: The first stage:** the study of the current situation and the availability of data and systems

❖ **Design Phase :** Database Design, System Design, Application Development & Choose best location for the sensors. (Rain Gauge & Stream Gauge).

❖ **Implementation & Operation :** Implementation, Integration and Testing, System Verification, Operations & Maintenance, Assessment.

❖ **Start Production :** System Proposed Products:

- Publishing - Transmitting warning messages to The Authorities.
- Tabouk Prediction flood risk map.

System Requirements:

Once the data are available from observing subsystems and Tools are available to analyze to tables, graphs and charts which derived from average rainfall and flood indices. Computer systems can include sophisticated data management, modeling, forecasting, and automated warning dissemination. Individual components from the basic to the complex may be combined to satisfy the needs and constraints of a particular flood warning system, and many components may be modified to improve the efficiency, reliability, and lead time provided by the system.

System Components:

- Flash flood modeling.



- Ground truth data gathering - including a sensor network, and data loggers.

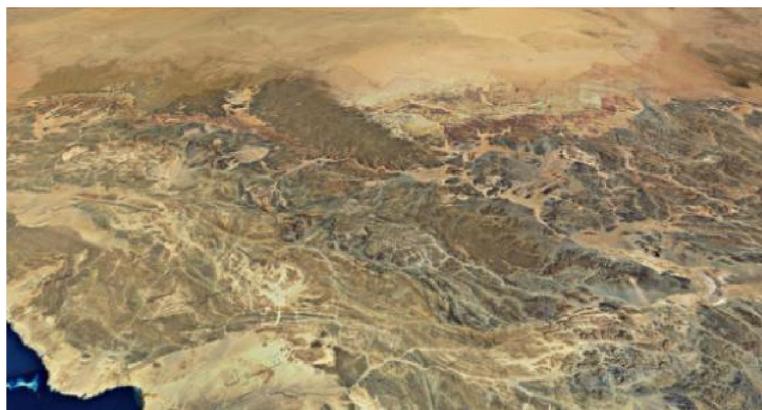
Methodology:

Heavy rainfall is usually the main factor of flash flood, but a given amount and duration of rainfall may or may not result in a flash flood, depending on the hydrologic characteristics of the watershed where the rain is occurring, which include:

- Magnitude, efficiency, and direction of runoff
- Size of the drainage basin
- Precipitation intensity & duration
- Storm location, movement, and evolution with respect to the basin
- Soil type, soil depth, and antecedent soil moisture conditions
- Amount and type of vegetation covering the soil
- Land use characteristics including urbanization and deforestation
- General topography and slope of the land
- Time of year (season)

In the development of Local Flash Flood Risk, an extensive historical research will be conducted along with continuous successive field visits with the development and analysis of the following maps:

- Slope Morphometry Map
- Geological/Lithological Map
- Soil Type Map
- Hydrological Map
- Soil Thickness Map
- Relative Relief Map
- Land Use / Land Cover Map
- Rainfall Map
- Drainage Density
- Drainage Map
- Base Map
- Slope Analysis Map
- Catchment area map.
- Average Annual Rainfall.



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