Flood Protection for a City in the Desert

Project Hafar Al-Batin in Saudi Arabia

"Flood protection for a City in the Desert" is not a joke! In November 2014 for example strong rainfall led to floods in the Ouarzazate area in Morocco. Several people died and severe damages occurred in an area with a mean annual rainfall of less than 100 mm. Another example is Jeddah in Saudi Arabia, where some 122 people are reported to have been killed in a flash flood in 2009.

If strong rainfall occurs in arid regions, consequences can be even more dramatic as they are in regions with a humid climate like for instance in Central Europe. One reason it the low retention capacity in the catchment, due to missing vegetation and soil characteristics. High rainfall intensities lead to fast runoff with relatively high runoff coefficients. Very often flood events in arid areas come along with heavy erosion, as shown in **figure 1**.

Another reason is the lack of awareness among people and in the administration. Because floods are such a rare event, the risks are often not considered in building design and city planning. Many cities do not have any stormwater drainage system and floodplain or flood risk maps are usually not available. After a flood event the awareness decreases even faster than in Europe.

The City of Hafr al Batin in Saudi Arabia also experienced several floods in recent years (see **figure 2**), although the damages were not as severe as in Jeddah. However, alarmed by other dramatic flood events in the country – e.g. in Riyadh in 2013 – the government asked for a flood modelling and mitigation study as a base for the construction of flood protection measures.

Figure 1: Example for a flood event in arid areas (Ouarzazate, Morocco, 2014)

Figure 2: Flood events in Hafar Al Batin, Saudi Arabia

The Project

Hafar Al-Batin is a Saudi Arabian city located in the northeastern Ash Sharqiyah province (**Figure 3**). With a population of approx. 390,000 it is known as an important highway junction linking Saudi Arabia with Kuwait, Jordan and Iraq. The city is situated in the valley of the Wadi Al-Batin, a dry riverbed with water flow only after heavy rainfalls during winter months.

Although a stormwater drainage system within the city area as well as several dams and embankments around the city exist, Hafar al Batin suffers frequently from flooding. The floods are causing heavy damages in and around the city.

After studying the local conditions and historic events it becomes obvious that there are different reasons for the flooding problems in Hafar Al-Batin. Beside of the discharge from of the Wadi Al Batin itself, runoff from the subcatchments of the secondary streams (called fleej), direct rainfall within the city boundary and also backflow from the existing reservoir north of the city may cause flooding. In addition the ineffectiveness of current protective measures (embankments, channels, culverts) can create problems in the city. Scope of the study is to address all the

Figure 3: Location of Hafar Al-Batin in Saudi Arabia

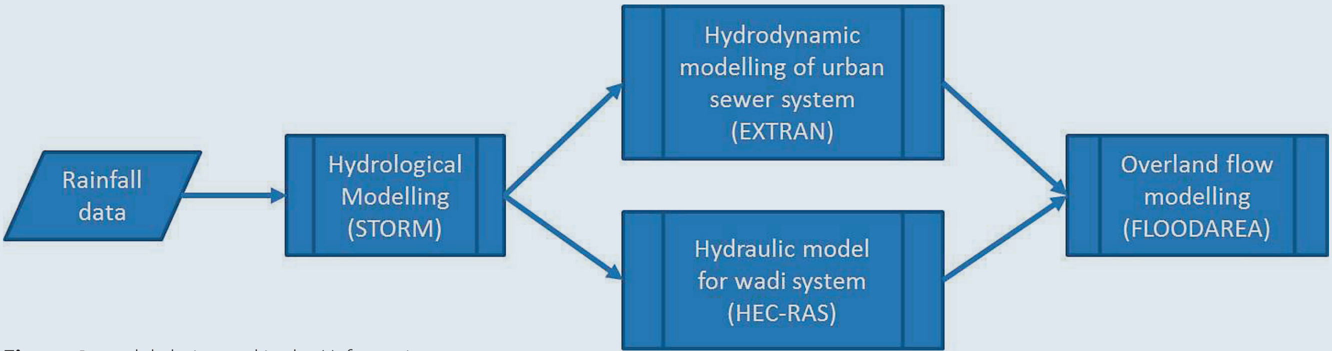

Figure 4: model chain used in the Hafar project

flood causes mentioned above and to develop an integrated flood mitigation concept.

The project is financed by the municipality, which in Saudi Arabia is a department of the provincial government. The local administration (called Baladiya) is of course involved in the project but not the official client. The German team was contracted by Saudi Geophysical, a local consultant based in Al Khobar which got the contract from the municipality.

Methodology

Different tools are required to develop a detailed model of the present drainage situation and to understand the performance of potential flood protection measures. **Figure 4** shows the main components of the model chain used in the Hafar project.

Data Acquisition

For a flood modelling and mitigation study extensive data has to be acquired.

- Survey: All existing channels including sections such as road culverts have been examined by a terrestrial survey to obtain the precise capacity, relative elevations and slopes across the entire channel system.
- Soil: geological data has been gathered by means of a number of boreholes throughout the city and infiltration tests were done all over the catchment of the Wadi Al-Batin to determine infiltration rates.
- Digital Elevation Model (DEM): a nationwide 10 m DEM is available in Saudi-Arabia, which has been used for the hydrological modelling of the natural catchment. For the city area (approx. 600 km^2) a high-resolution DEM (four points per m^2) have been created by LIDAR technique especially for this project.
- Rainfall and other climate data: Daily values are available from the weather station at the nearby airport in Qaisumah. Rainfall with a higher resolution could be gathered from special satellite data. Design storm intensities (Intensity-Duration-Frequency-Curves) are available for major cities in Saudi-Arabia. They are surprisingly high even for shorter return period (approx. 80 % of the intensity in Berlin for a design storm with return period of 1 year).

Overall, the data base can be assessed as good and sufficient for the modelling and design tasks. The surface data (survey/DEM) is excellent. However, there are no measurements available to calibrate the hydrological and hydraulic model. For verification photos of recent flood events and information from local people have been used.

GIS Model

For the Wadi Al-Batin valley as well as the catchment of the tributaries a GIS model including DEM, land use map, soil map, etc. has been created. The GIS database is used for:

- delineation of (sub-)catchments,
- determination of the flow path network,

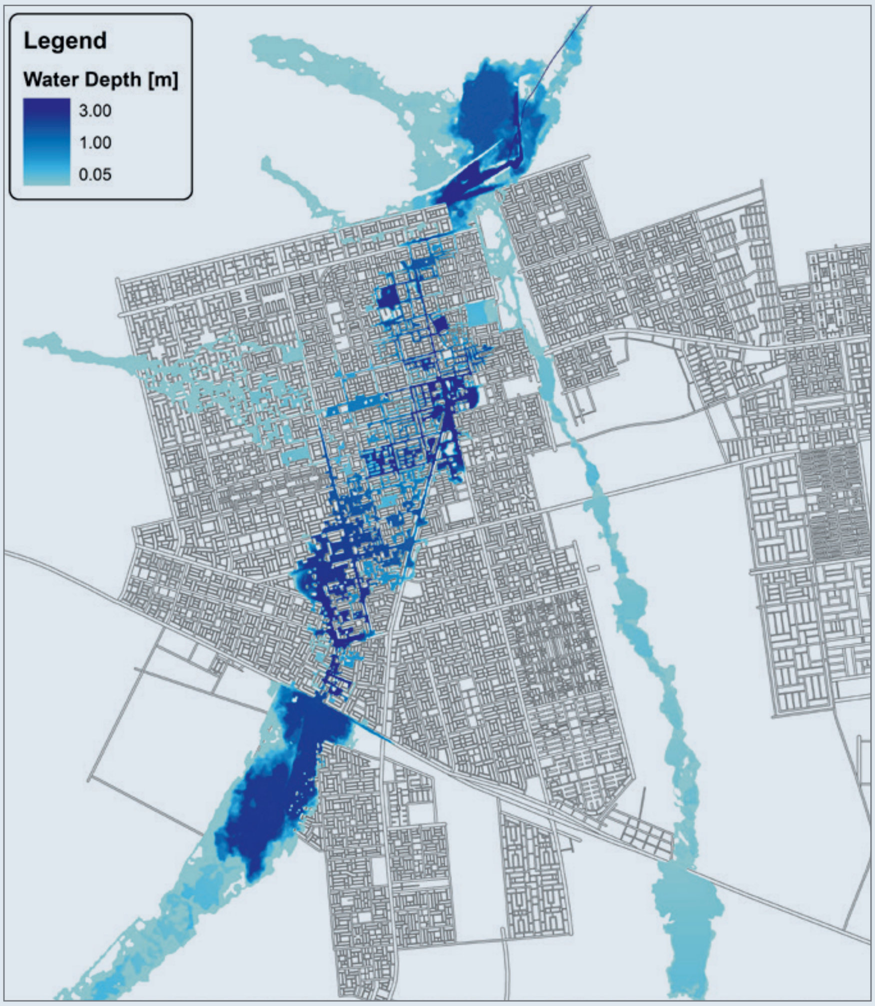

Figure 5: Flood modelling results: water depth for a storm event with a return period of 100 years

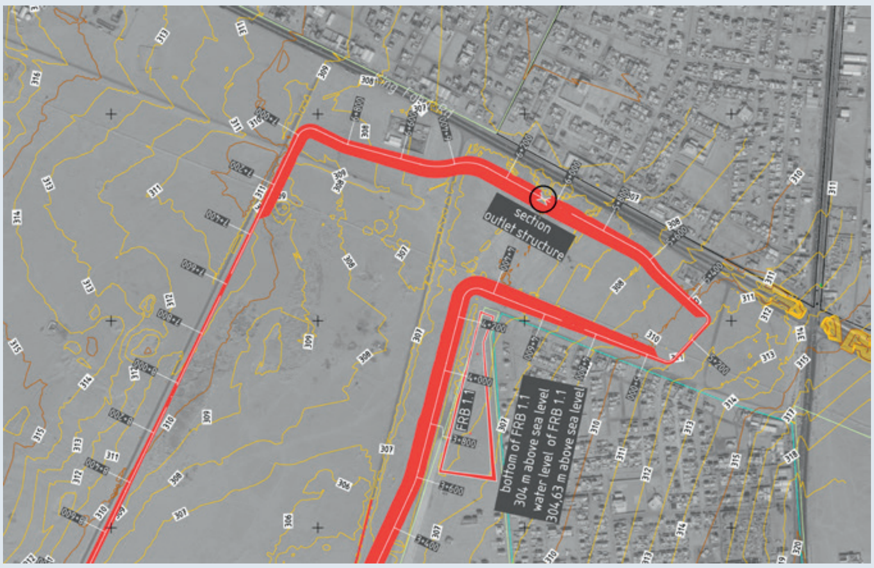

Figure 6: Proposed flood mitigation measures

- calculation nof infiltration and runoff parameters,
- development of TAF curves (Time Area Function).

Hydrological simulation model

To calculate the runoff from the various catchments (Wadi Al-Batin, tributaries, city area) a detailed hydrological model has been setup with the software STORM (IPS). STORM is a hydrological water cycle model with various modules. With this tool flood peak flows can be calculated for small urban catchments as well as for larger river basins.

Hydraulic Model for the drainage system and the fleej (1D)

The existing drainage system as well as proposed extensions and improvements are modeled with the 1-D hydrodynamic models EXTRAN (inner-city artificial channels) and HEC-RAS (natural fleej). As input (inflow to the drainage system) the output of the hydrological simulations with STORM has been used.

Hydraulic Model for the surface runoff (2-D)

Finally a 2-D hydraulic model for the surface runoff has been setup with the software FloodArea (geomer). FloodArea is an ArcGIS extension for the calculation of flood areas (flow path, inundation depth). Again the inflow for the surface runoff simulation comes from the hydrological model.

Modelling results

The modelling results are showing clearly the deficits of the actual situation. **Figure 5** for example shows the water depth resulting from a storm event with a return period of 100 years, considering only the runoff from the surrounding catchment without taking the inner-city runoff into account. Major parts of the city would be flooded with water depth up to 3 m. Just from the Wadi-Al-Batin catchment a peak flow of 150 m^3 per second is generated and a runoff volume of 15 million m^3 flows towards the city.

On the other hand the actual capacity of the drainage channel system in the city centre is less than 1 m^3 per second. This capacity is much too low to handle the runoff from city area (approx. 3,000 hectares impervious area), not to mention the runoff from the surrounding catchment areas. Therefor extensive flood mitigation measures are necessary to protect the city.

Flood Mitigation Measures

The general strategy for flood mitigation in Hafar Al Batin is to keep as much water out of the city as possible. As a consequence the flood mitigation measures shown in **figure 6** are proposed:

1. South of the city two new reservoirs will be created. The total storage volume will be 15 million m^3 which is enough to store a 100 year flood event. The downstream storage will drained with max. discharge of 10 m^3/s. To recharge the aquifer infiltration pits will be constructed within the reservoirs.
2. To avoid runoff from the area north-west, a dam will be constructed which directs the flow to the reservoir located downstream of the city
3. The reservoir located north (downstream) of the city will be extended to enhance the storage volume and to avoid backwater effects. From this reservoir the water will finally flow to the downstream wadi, where it infiltrates into the aquifer or evaporates.
4. A new open channel will guide the flow from the South fleej (tributary of Wadi Al Batin) also directly into the reservoir. In conjunction with an existing dam flooding of the city centre will be avoided.
5. Finally the capacity of the existing channel system in the city has to be enlarged, so that a) the runoff from the urban areas can be handled and b) the southern reservoirs can be emptied within an acceptable time.

After discussing the overall concept with the municipality, an engineering design for each of the individual measures is prepared. **Figure 7** shows a detail of the design for the new reservoir south of Hafar Al-Batin.

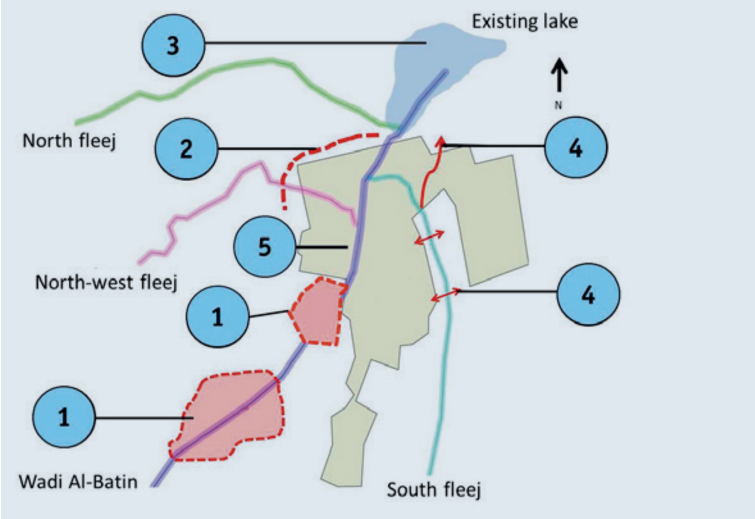

Figure 7: Detail of the design for a new reservoir south of Hafar Al-Batin

Conclusion and Outlook

The proposed measures are designed to prevent the city area from floods up to a return period of 100 years which complies with international standards. However, like in every flood risk management concept a 100 % protection is not possible. Therefore an emergency response plan should be developed to be prepared for flood events. It should contain clear structures of responsibility. In the case of heavy floods the system of retention reservoirs must be supervised to take action in case of leakages resp. to remove blockages in channels and culverts.

In addition, a flood warning system could enhance the security, as the large areas for the reservoirs will be furthermore used, e. g. as grazing land. Flood waves can arise very quickly. A warning system could give more time to evacuate these areas, to verify the full functionality of all constructions and to prepare measures like information of the population.

Finally it is important to maintain the flood protection measures. Especially the open channels and culverts must be kept clean of waste and sediments to maintain their full capacity. Also embankments must be checked regularly to ensure the required stability and leak tightness.

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