



Arid Lands Flood Evaluation and Mitigation Measures Using HEC-HMS Model and Best Management Practices (BMPs)

Ahmed N. Bdour

Civil Engineering Department, Faculty of Engineering, the Hashemite University, P.O. Box 330127, Zarqa 13133, Jordan.
Email: bdour@hu.edu.jo

Received: 23 Dec 2021; Received in revised form: 20 Feb 2022; Accepted: 03 Mar 2022; Available online: 11 Mar 2022
©2022 The Author(s). Published by Infogain Publication. This is an open access article under the CC BY license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract— This study emphasis on draining and slowing runoff volumes in arid and semi-arid lands regions using HEC-HMS model linked with various Best Management Practices (BMPs) alternatives. The proposed methods may help significantly in reducing flash flood precipitation and improving instream water quality. It provides facilities to increase flood retention times and infiltration rates. This study proposed a modern and progressive flash flood management scheme that would emphasize on enhancing soil infiltration and runoff attenuation by construction facilities that would absorb runoff water. We formulated five proposals for flood mitigation derived from BMP techniques for the purposes of stormwater management. Results for investigating the construction of dry dams' option showed a significant reduction in both peak volumes and time to peak and consequently, the mitigated flood spreads longer. Furthermore, downstream calculations prove the contributions of other events on increasing flood hazards downstream. Outlet bottom size and storage capacity are the major parameters that control flood hazards. Outcomes of this study would help water resources managers and decision-makers who need immediate action plans and operational responses when floods occur. Discharge outflow rates were assessed using HEC-HMS and CN methods, and modeling the studied area using Geographic Information Systems (GIS). This study reveals runoff volumes ranges of 0.04 to 0.77 cm/hr.

Keywords— Flash Flood, Arid Land, HEC-HMS model, Best Management Practices, CN method.

I. INTRODUCTION

Water-powered engineers' endeavors have been embraced for quite a long time to lessen flood harm. More often, the point was to forestall floods and guarantee a fast outpouring of runoff volumes. Streams were channelized, redirected, fixed, and corseted in levees, with next to zero ideas for waterway elements and biodiversity protection. This methodology is presently generally reprimanded (Loucks, 2006). Initially, speeding up the stream regularly brings about exasperating floods downstream. Besides, the interruption of the regular examples can upset the residue balance, thus causing disintegration or stores. Lastly, the results on biological systems are regularly terrible (Lowe et al., 2020). The most effective method to both shield

residents from floods and biodiversity from flood-the executives' plans is a hot issue (Jenkins et al., 2017). We promote that ecologist and hydraulic practitioners should work intently together to supplement applicable flood mitigation solutions with eased effects on the environment.

In arid environments like the east region in Jordan, precipitation storms display solid spatial fluctuation, particularly during thunderstorms and localized torrential rainstorms (Almazroui, 2010). All through the most recent couple of years, flooding has been one of the most exorbitant calamities as far as both property harm and human setbacks in the Kingdom. In 2018 almost all of the kingdom witnessed heavy rain and flash floods. The hot springs the surroundings Dead Sea flood was the most

influenced. Approximately 21 individuals are accounted for to have been killed and the number of missing people remains unknown. Many other cities in the country have witnessed streets were under a meter (two feet) of water on 26 October, and a large number of the casualties were accepted to have suffocated in their vehicles. No less than 1200 vehicles were cleared away or harmed.

The climatological dispersion of yearly precipitation saw by downpour measures across Saudi Arabia is displayed in Fig. 1 and the 10-year climatological satellite image is displayed in Fig. 2 (Habib and Nasrollahi, 2009). Dryness is the predominant climatic attribute of Saudi Arabia besides in the Asir district (shown in Abha in Fig. 1), which gets yearly precipitation > 300 mm because of its special geological setup and the nearby mountains, and an optional pinnacle situated in the upper east, which is related with winter precipitation. Precipitation in the majority of Saudi Arabia is < 200 mm.

In arid environment like Saudi Arabia and Jordan, rainfall patterns exhibit strong temporal and spatial variability, particularly during heavy rainfall storm event and localized flash floods (Almazroui, 2010). Throughout the last few

decades, the kingdom has witnessed several flood events and it has been cost a lots of damages to public and private properties and deaths and human casualties. For example, the most intense flood was the 2009 event in Jeddah and other areas of Makkah Province (western coast of the kingdom) (Huffman, Bolvin, 2009). Civil defence officials described the flood as the worst in the 30 years.

Rainfall gauge stations are distributed across the kingdom as shown in Fig. 1. Fig. 2 shows 10-year climatology observed by satellite (Habib and Nasrollahi, 2009). Most areas of the kingdom have dry climate characteristics except Asir region in the southern part of the kingdom, where it has special topography and local mountains, which usually receives annual rainfall greater than 300 mm. On the contrary, most areas in Saudi Arabia receive annual rainfall less than 200 mm.

Meteorological parameters are critical for any hydrological studies. Rainfall intensities and distribution should be measured accurately for any application studies of rainfall data. Additionally, assessing runoff volumes and surface storage are important to supply domestic, agricultural, and industrial demands (Goodrich et al., 2004).

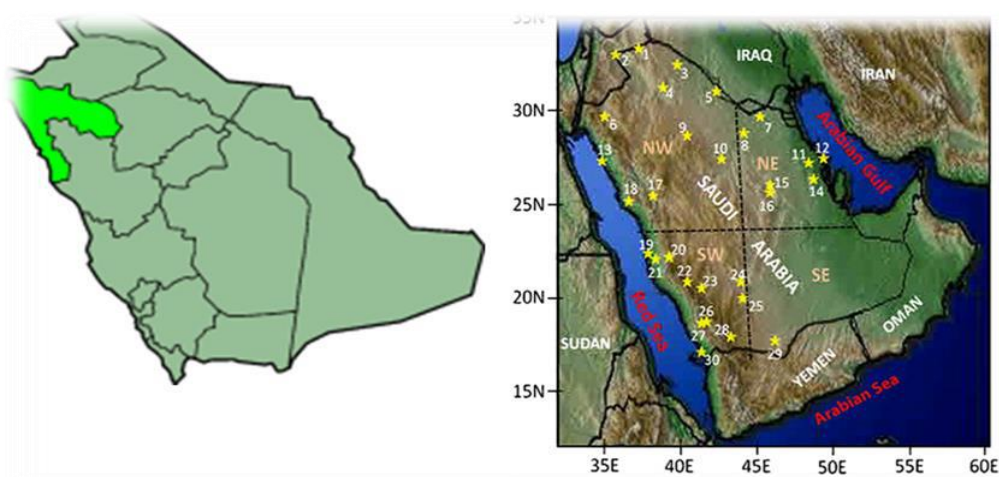


Fig1. (a) Vicinity of Tabuk Region. (b) Rainfall gauge stations cover entire Saudi Arabia (after Almazroui, 2010).

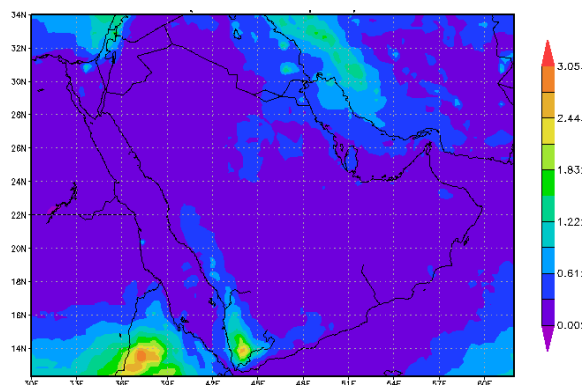


Fig. 2. 10-year climatology observed by satellite for Saudi Arabia.



This study proposed a modern and progressive flash flood management scheme that would emphasize on enhancing soil infiltration and runoff attenuation by construction facilities that would absorb water such as rain gardens and bio swales, rainwater collection systems, and water reuse systems. We formulated five proposals for flood mitigation derived from BMP techniques for the purposes of storm water management. Various flood mitigation structural measures proposed by hydraulic engineers and biologists will be checked for the purpose of proposing operational plans responses to be implemented once flash flood occur. The implementations of these proposal required a coordinated effort between all parties involved and to be conducted on a long-term policy.

II. RESEARCH METHODOLOGY

2.1 Data Collection

Runoff Volume Calculations

Commonly, the Rational Method used for hydrological analysis of runoff. It uses the general form of the equation $Q=CiA$, in which Q is the runoff volume in acre-in/hr or cubic feet per second (cfs), C is the runoff coefficient for a given surface material and condition, i is the rainfall intensity in in/hr, and A is the catchment area in acres (Gupta, 2001). The runoff coefficient C is requiring accurate evaluation, hence, it depends on soil type, land use, surface cover and slop of drainage basin. Agricultural and forest land usually have low runoff coefficients in the range of 0.05-0.4 (Alsharhan et al., 2001). On the contrary, paved and concrete surfaces have much higher runoff coefficients of about 0.9 (Alsharhan et al., 2001).

NRCS TR-55 is another common method for estimating surface runoff, more complicated than Rational Method since it employs several equations to calculate runoff peak volumes (Gupta, 2001). CN is the most critical parameter that affect the runoff calculations, it is a function of land use and soil group. Similar to runoff coefficient, a higher CN value associated with high runoff volumes, and lower CN value indicates low runoff. Typical CN value for arid lands is 91, while for agricultural land CN ranges of 30 to 84, depending on soil surface conditions (Mays, 2001).

In this study, city area will be subdivided to assess runoff volumes and contributions in the overall flood. Also, soil infiltration capacity and infiltration rates will be evaluated. This analysis is necessary to identify areas where mitigation action plans should be focused.

2.2 Mapping and Modeling

In this study, Geographic Information System (GIS) was employed to calculate the area of each surface group type. We coupled GIS with Hydrological Modeling System (HEC-GeoHMS) (Mays, 2001). HEC-HMS model was developed by US Army Corps of Engineers, Hydrological Engineering Center. The coupled version of these models contains Arc Hydro tool, which has been used to delineate two sub watersheds for Tabouk watershed. Inputs for GIS modeling are surface topography, land cover, land use, soil type, stream flows data, and physical characteristics of the watershed. Various HEC-HMS input models were created for Tabouk Sub watersheds. These models will be used later on to simulate rainfall and runoff volumes produced from storm water event.

2.3 Soil Properties Investigation

Soil infiltration rates in the study area are evaluated using Darcy's law. This law contains parameters of hydraulic conductivity, soil porosity, and hydraulic gradient. Such parameters are best describe soil nature, land cover, porosity, and hydraulic conductivity of the soil column.

$$Q_z = \frac{ka\Delta H}{nL}$$

In which Q_z is the volumetric seepage rate, k is the hydraulic conductivity, A is the area of watershed of interest perpendicular to the direction of flow, $\Delta H / L$ is the change in hydraulic head divided by the seepage depth, and n is the soil porosity.

III. STUDY AREA

3.1 Topography of the Tabuk Area; Tabouk city has a desert climate surrounded by low relief of local mountains from east, west, and south, while the city is open to the north. The city has an elevation of 700-800 m above main sea level. Mountains in the west of study area has an average elevation of 1200 m above main sea level. Most of the catchment drainage area is located in the north side of the city. Basically, the Tabouk basin is flat, drainage network extends southwards to Harrah, three main wadis are located in the basin, namely Wadi Al-Khader (east) and Wadi Abu Nishaiah (east), and Wadi Al-Baggar (west) (Al-Baradi, 2000). Tabouk city is underlain by a shale formation where silt and sandy soils are prevailed in

several parts of the province. Fig. 3 shows geological map of the study area (Masoud, 2009).

3.2 Climate of Tabuk; the climate of Tabouk city is dry most of the year, it has occasionally influenced by Mediterranean Sea climate. Mean annual temperature in summer is about 28 C° and 12 C° in winter. Average

annual rainfall is about 20 mm as shown in Fig. 5 and Fig. 6. Evaporation rates are high and is almost about 40 mm. In winter season, sometimes the penetration of cool Mediterranean air mass brings frontal rainfall events with high intensities (Alsharan and others, 2001).

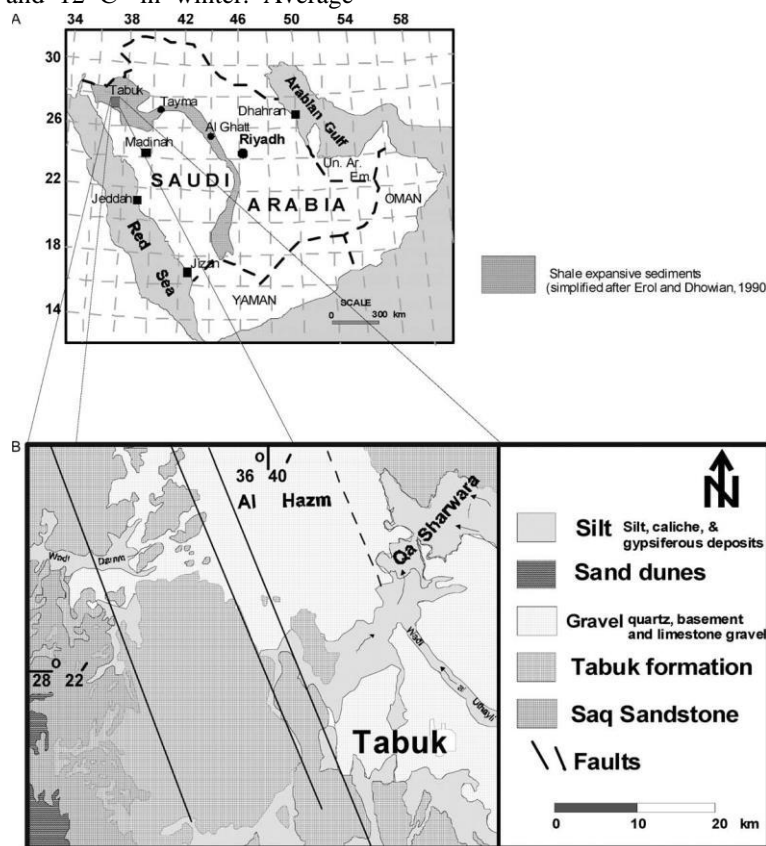


Fig. 3. Geological map for the Tabouk area.

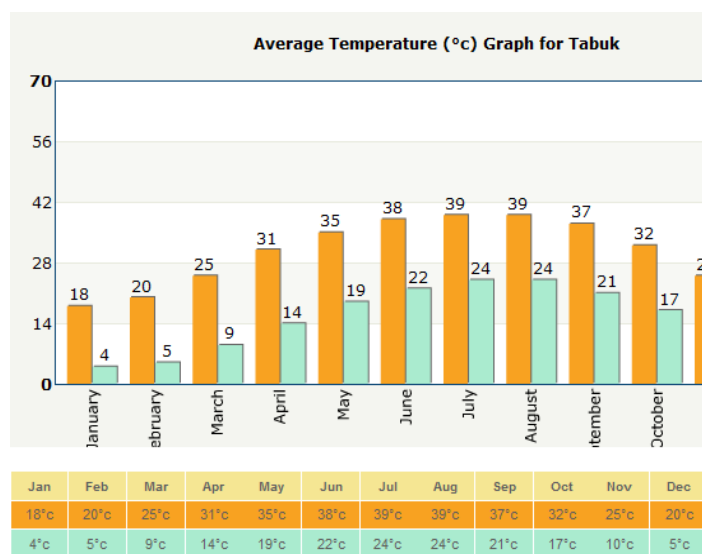


Fig. 4. Average Temperatures for Tabouk city

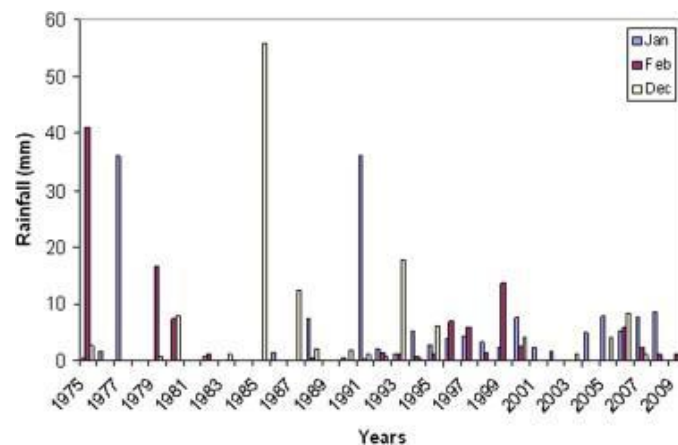


Fig. 5. Annual rainfall values for Tabouk City in mm (1975-2019)

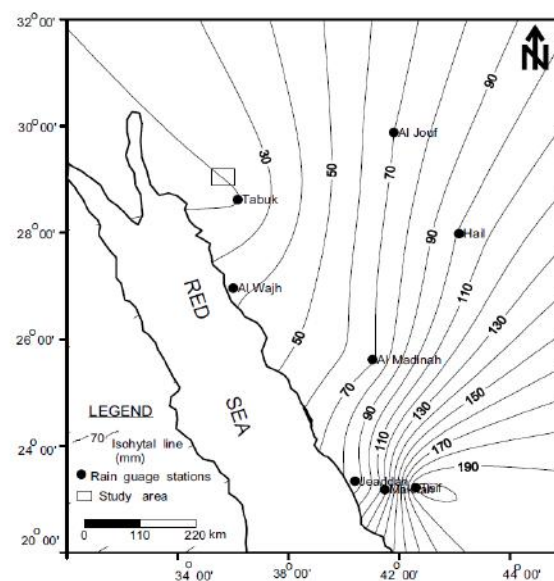


Fig. 6. Isohyetal map shows average annual rainfall for Tabouk city

IV. RESULTS AND DISCUSSION

Low cost and nonstructural structures used in mitigation floods in urban settings are commonly known as Best Management Practice (BMP). Non-structural measures are used in rural areas. These structural measures are used to reverse the disturbances caused by urbanization, many of these structures proven promising efficiency for controlling and lessen damages caused by flash flooding and combined sewer systems (Glas et al., 2020). Selection of these mitigation structures are usually consider entire watershed characteristics, technical feasibility, economical aspect, sustainability,

environmental integrity, and public acceptance. Determination of the BMPs to propose will be based on past and practical experience gained upon the implementation and monitoring of these mitigation measures. In addition, theoretical and common engineering sense will be used for the purpose of the assessment. It is a learning by doing process based as shown in Fig. 7. Two main principles are embedded in this practice, namely promoting natural drainage systems and urbanized surfaces. It combines both storm water components and flood control components (Bathrellos et al., 2016).

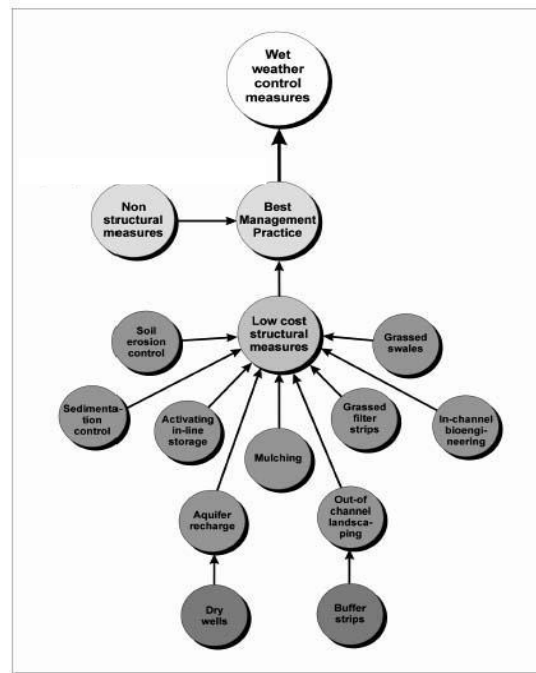


Fig. 7. BMP low cost structural measures

Herein, we formulated five proposals for flood mitigation techniques for the purposes of storm water management;

4.1 Construction of dray dams

This study investigated the constructing a dray dam across floodplain, the dam has a bottom outlet for the purpose of discharging main channel flow. All hydraulic, hydrological, and civil engineering characteristics were described accordingly with typology thus minimize impacts of river biodiversity. Outflows that exceed conduit capacity have been modified.

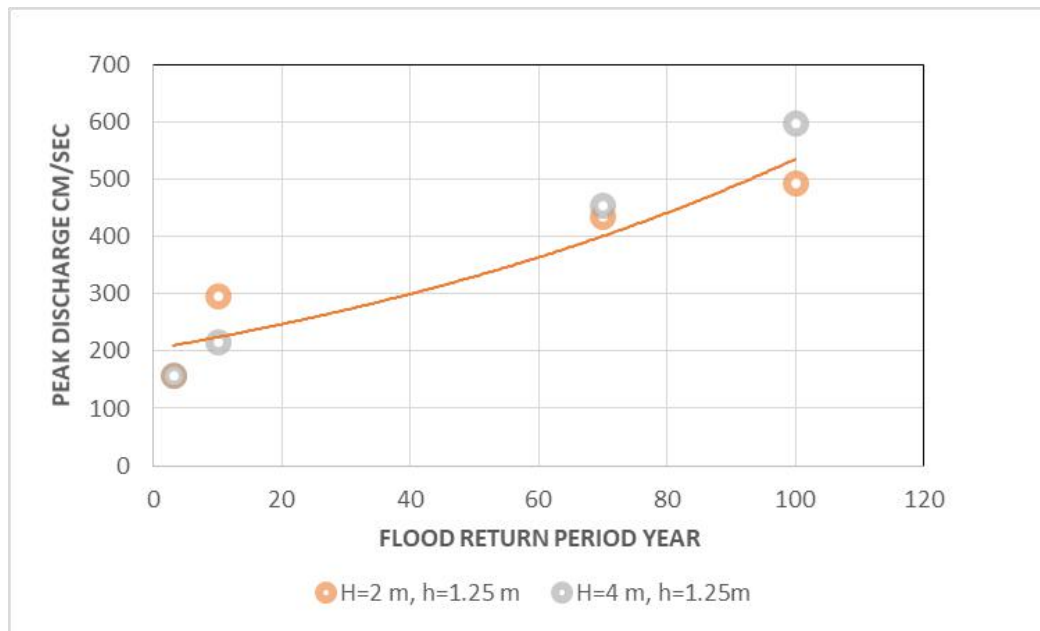
Fig. 8a shows the dry dams' responses to various flood magnitudes differently. Two types of dry dams are proposed, dam#1 with $H=2$ m, $h=1.25$ m, and dam32; $H=4$ m, $h=1.25$ m. All calculations were taken at 1000 m downstream of the dry dams. Outflow discharges are shown in Fig. 8b. Primarily, the existence dry dams affect the hydraulics of flash flood by delaying peak flows while it's obvious that flood waves last longer. The adverse impact of this response that in some cases of delayed peak may become associated with other runoff minor events which ultimately will increase flood hazards downstream. Commonly, two significant parameters in flood mitigation; size of bottom outlet and its storage capacity. Large runoff volumes can fill up storage capacity quickly and thus there is a great need for flow control structures (flow weirs and over spillway devices) to be provided to drain excess flows (Liu et al., 2021). Usually, flood risks drop consequently after overflows happen (Lai et al., 2020).

On the other hand, small flow outlet reaches faster the maximum storage capacity which permit earlier mitigation actions.

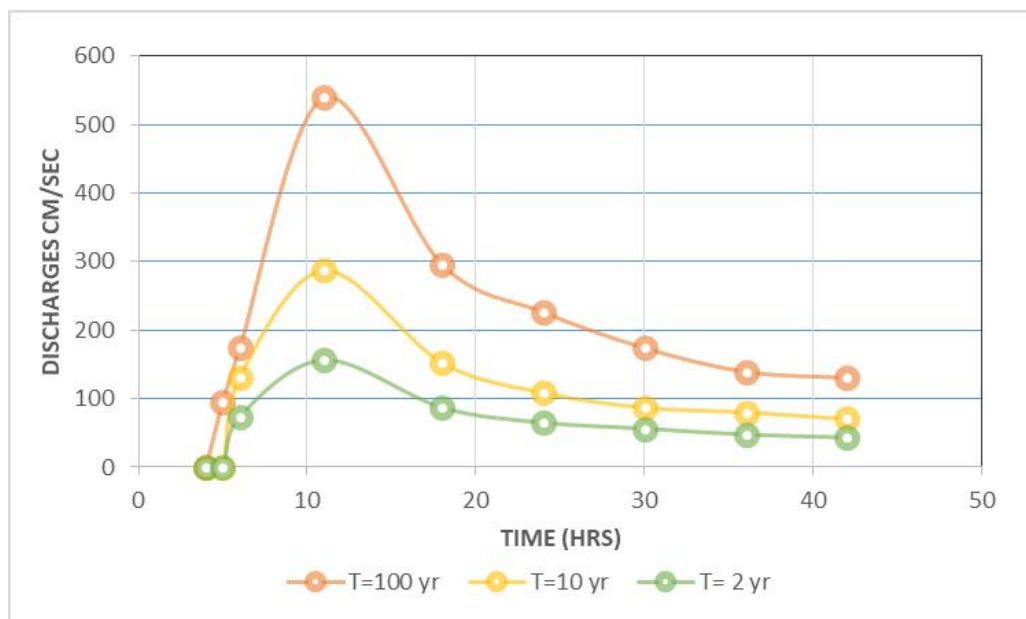
4.2 An Extended Detention Basins (EDB) Design Criteria

An extended detention basin is a structure that permit a temporal storage for runoff. The design of such structure with outlet device detains and attenuated the outflow runoff and allow settling of sediments. Usually, EDB has multi stage facility for storage and attenuation. EDB provides a better management tool for storm water quantitatively and qualitatively. Expected removal of suspended solids varies from 40-70 percent, mainly depending on the designed settling time of the basin.

Typical components of EDB are shown in Fig. 9. Storage volume and detention time parameters must be designed carefully for an extended detention basin. Detention time usually defined as the time from maximum storage is reached in the basin till 10 percent of that storage remains in the basin. The combination of the two parameters would control the outflow runoffs velocities and travel times. Eventually, the construction of such structure must slowly drain outflows and consequently increase detention time. Furthermore, design should provide enough detention time to ensure the treatment of runoff volumes generated by storm event. Better efficiency can be achieved for orifice diameter greater than 9 cm.



(a)



(b)

Fig. 8. (a) Dry dams construction effects; (b) Computed hydrographs delay and attenuation.

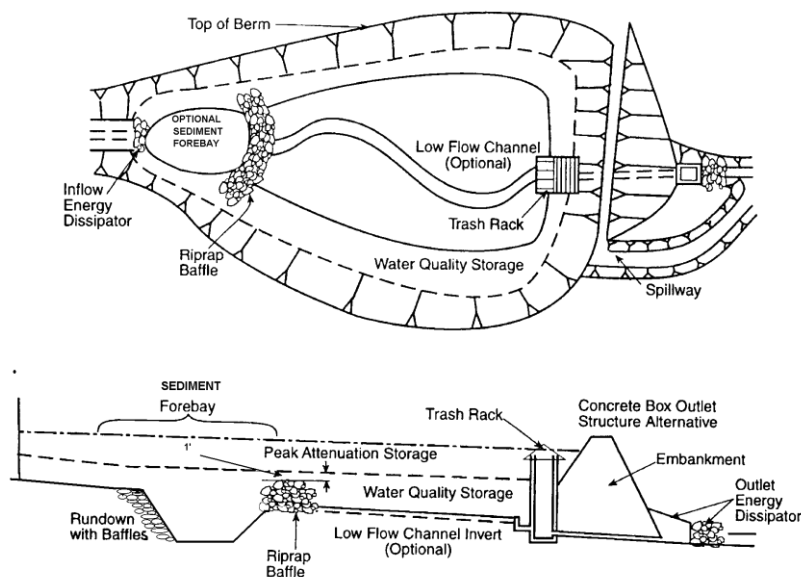


Fig. 9. An extended detention basin basic Components

4.1 Land Erosion Control

Sedimentation and soil erosion control measures should be coordinated with any construction of land undergoing development. Control measures like berms, mulching, silt traps and others are recommended to put into service in conjunction with infrastructure grading operations and before the construction of any increment of urbanization or land development. These measures are crucial for the removal of suspended sediments from runoff storm waters draining from urban areas. Furthermore, stream banks should be maintained and stabilized, removal of vegetation covers and cut of trees should be prohibited. Construction of roads, drainage improvements works, and utility rights of way may consider as exceptional case. Pavement with concrete or asphalt within trees zones should not be allowed. Installation of permanent vegetation cover should be installed immediately as soon as all utilities are in place and final grading phase is achieved.

Runoff attenuation and retention structures should preserve natural topography and vegetation, where possible. All constructed mitigation measure (on-site) should be properly monitored and maintained by the owner of this site. This practice is important to operate these facilities appropriately and not become a source of nuisance to public. For example static water and improper storage may

result excessive algae growth and uncontrolled runoff volumes, respectively. Outlets conduits should be designed to prevent or to minimize stream bed erosion.

4.2 Source control measures

In rural areas, where a natural and undeveloped watershed exists, the spatial distribution of runoff are in the form of mobilized small volumes which result in slowing down the runoff flow volumes. Usually, wetlands, flood plains, previous soils, and natural depressions are good storages for such small waters. Urbanization and development may cause serious damage to these natural ways of attenuation and cleaning storm runoff though decreasing permeability of soil, removing vegetation cover, altering these natural way and transforming into culverts and channels, and finally by leveling off the irregular natural ground surface (Poulard et al., 2010).

Source control measure are considered as an extra effort to improve methods of maintaining natural drainage system behavior. It's a supplementary tool and does not cancel the role of other conventional structural practices. Figs. 10-12 represent number of urban low-cost effective structural measures that proved to be very efficient as flood mitigation measures.

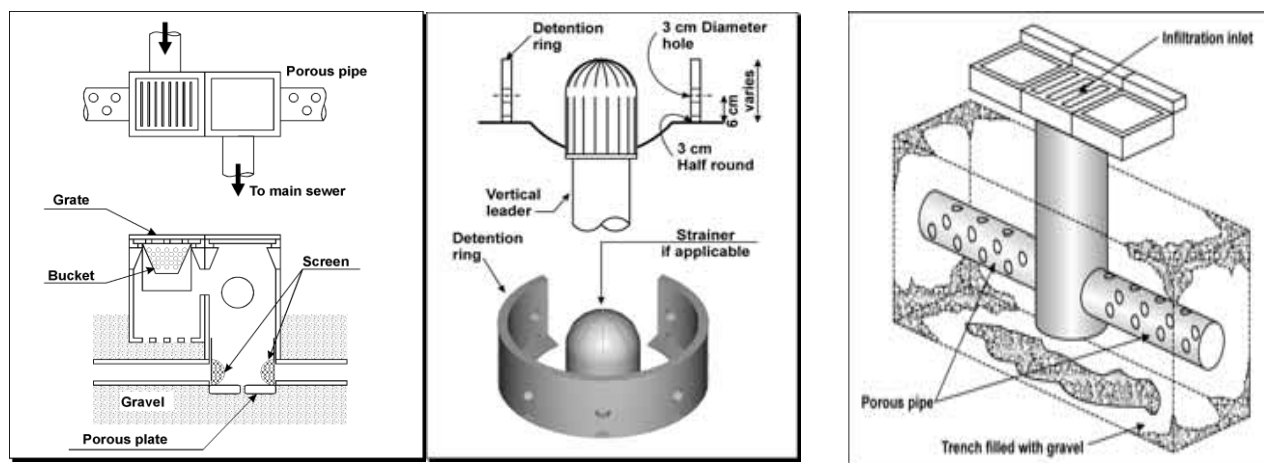


Fig. 10. Examples on source control measures (Rooftop, infiltration inlet and trench)

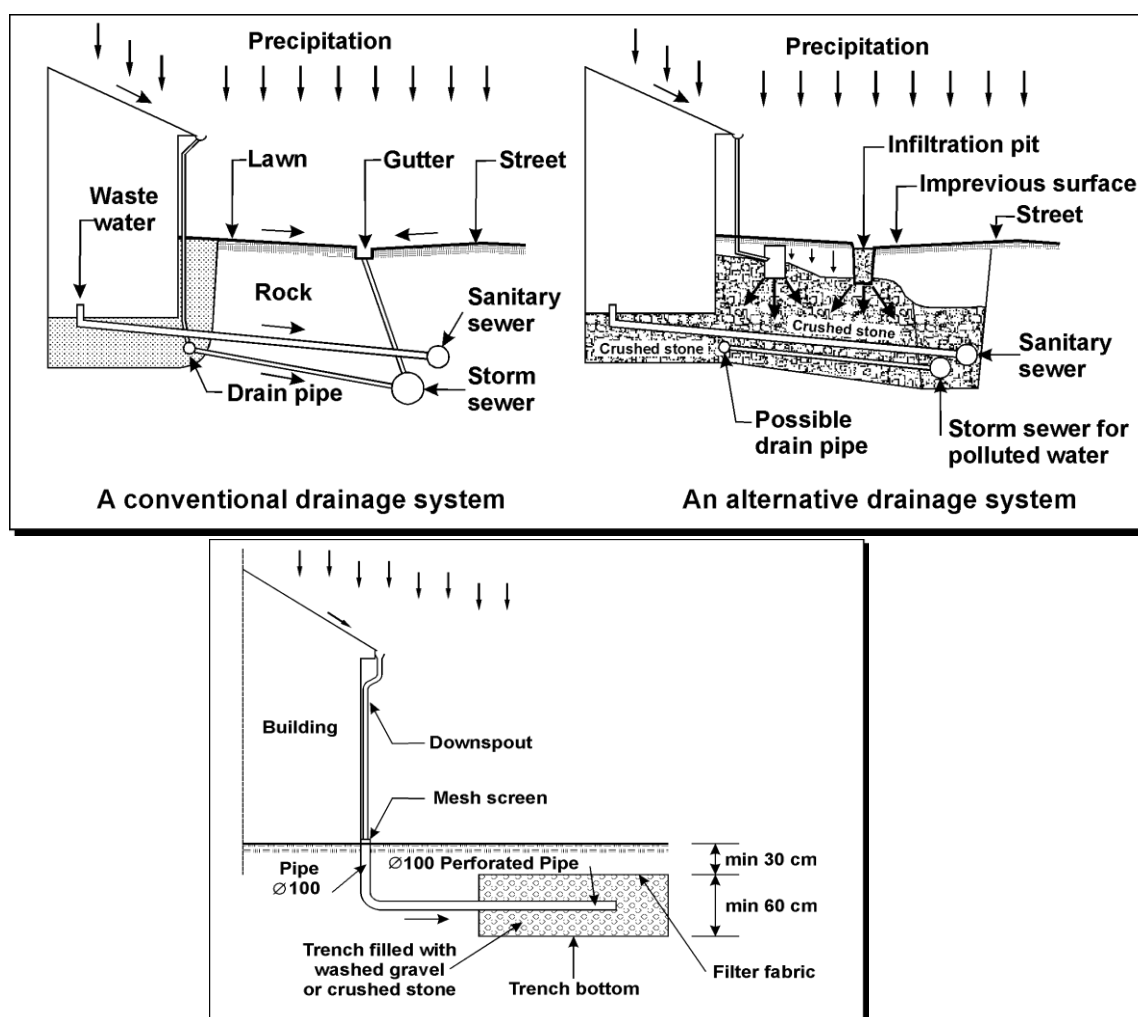


Fig. 11. Infiltration trenches as an example on source control measures

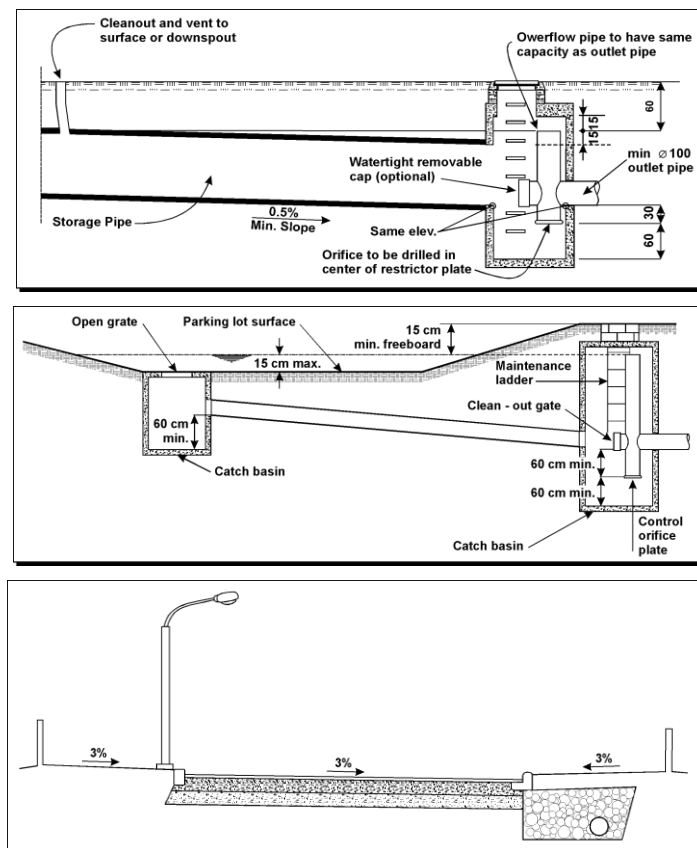


Fig. 12. Source control measures examples (pipe storage, parking lot, porous pavement)

4.5 HEC-HMS Modeling

Nowadays engineers are capable to study and analyze impacts of various floods with various intensities on a hydraulic structure. The analysis involved calculations for all hydrological parameters like peak flows and flood hazards maps. In addition, modelers are able to do economical assessment by comparing several technical solution, estimating the costs of avoided damages. Various flood scenarios with different return period (different probabilities) can be tested. Such analysis is invaluable to predict flood occurrence and to protect human lives and their properties. Also, it helps in protecting flood mitigation structures by considering the safety check floods (i.e., maximum peak flow which the dam can withstand without risk of failure and low-probability but devastating dam-breaks).

In this project, HEC-HMS has been employed to estimate various runoff volumes resulted for the several scenarios we proposed. HEC-HMS is a commercial model developed by US Army Corps of Engineers, several sub-models are embedded inside the model to compute hydrological parameters such as channel routing values, rainfall losses, runoff generations, and base flows. HEC-

HMS package comprises of three main model, namely basin model, precipitation model, and control; model (Romali et al., 2018). Basin model calculates watershed and routing variables, and basin connectivity data as well. All rainfall data and computations are embedded in the precipitation model. Timing information are included in control model. Uses has the option to assign the proper data sets for each model, then the whole run is executed using all data sets from the basin model, precipitation model, and control model. Model structures and processes are given in the technical manual (USACE-HEC, 2000, 2008, and 2018). Follow to this section a brief description of the model employed in this project is provided.

The HEC-HMS model contains three main sub-models. The basin model provides watershed physical elements (i.e., subwatershed areas, reaches, junctions, diversions, reservoir, sources and sinks, and hydrologic model for each element as shown in Fig. 12. Terrain processing module (ArcHydro) was used to delineate basin and sub-basin boundaries as networks as needed for the basin model. DEMs data was obtained using an existing contour map 1:100,000 scale. HEC-HMS model was employed to calculate initial model variables using model default

values. HEC-GeoHMS then was used to develop soil maps and land use maps, CN for each grid was assigned (10 m x 10 m resolution). Averaging method linked within spatial analyst module of ArcGIS was used to evaluate the weighted CN values for each sub watershed. CN values were approximately in the range of 83-95 for studied sub watersheds.

This study shows that basin-hydraulic responses are in the form of runoff hydrographs and tables for hydrologic characteristics (such as, peak discharges, time to peak and lag time). Runoff, infiltration rates and interception are presented in the form of a numeric form. Table 2 display the main hydrological values used in this modeling. Repeated revisions for storms of return periods 2, 10, and 100 years at different durations of 0.75, 1.25 and 1.75 hours were employed and analyzed. Analysis proved that least frequent storms (large return period) bring rain more

than the most frequent ones (small return period). HEC-HMS model calculate runoff volume rates in the range from 0.04 to 0.77 cm/hr. Fig. 13 show the runoff distribution for two sub-basins within the study area.

Table 2. Primary values used in the HEC-HMS model runoff calculations

Variable	Value
Rain fall duration (hr)	2.20
Rainfall intensity (cm/hr)	0.87
Area ratio (R_A)	0.25
Length ratio (R_L)	2.00
Bifurcation ratio (R_B)	2.00

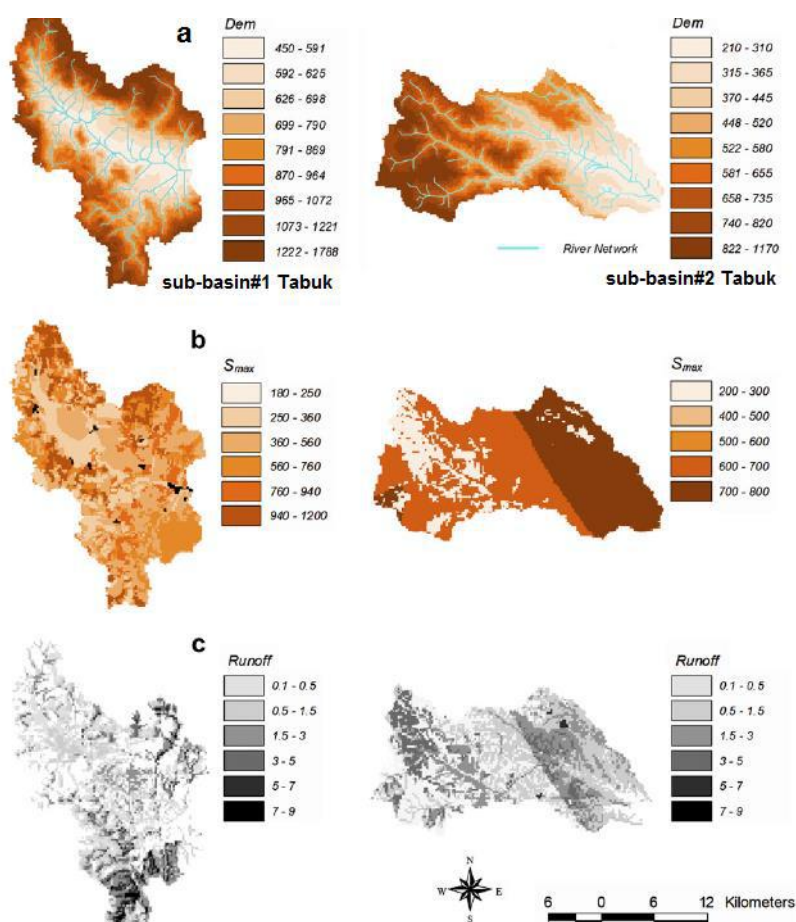


Fig. 13: Physical characteristics for selected sub-basins considered in the HEC-HEM modeling. (a) Stream network, (b) Soil type and (c) Runoff values

V. CONCLUSIONS

Nonstructural flood control and mitigation measures provided useful tools for prevent or avoid serious damage

consequences of flash floods in arid lands. Traditional plans treat the results of flood rather than focus on operational or action plans to avoid floods. Five proposals of BMPs were described in this study and general concepts

were introduced, as follows:

- Optimal technical engineering solutions may not be the best due to social and political constraints
- Urbanization should consider hydrological principles for planning in addition to the administrative instructions
- To prevent flood consequences in arid lands, the management plans should be comprehensive in terms of storm water drainage, pollution control, and flood mitigation as well.
- Public participation and data accessibility are key practices to build the trust between officials and the public to reach a successful management tool.

Repeated revisions for storms of return periods 2, 10, and 100 years at different durations of 0.75, 1.25 and 1.75 hours indicate that least frequent storms bring rain more than the most frequent ones.

Eventually, dry dams' construction may create unexpected new flooding zone in area where floods were not witnessed before. This anthropogenic disturbance to ecosystem may have serious consequences and possible damages on the ecosystem and river basin dynamic system. Also, a significant change in the river water table may occur. Remediation measures for river repair is substantial, an interdisciplinary collaboration with specialists from various fields such as ecology, sociology, restoration and river engineers, and environmentalists are involved.

This study assessed multi-alternative tools which may help in applying flood mitigation measures using well-defined structures/methods. Certainly, managers need immediate responses and operational plans – when a flood occurs, the demand for such action is robust. Managers and decision-makers need quick and efficient plans to respond to flood prior to their occurrence. More researches are needed on a case-by-case basis to find the most appropriate and efficient management scheme. The linkage between the conceptual approach and the operational plans is necessary to facilitate the transfer of knowledge, the exchange of technicalities, and promote sharing progress developed by all involved parties.

VI. ACKNOWLEDGEMENT

Author of this work would like to thank the Centre of Environmental Education, Ministry of Environment, Saudi Arabia for their support and assistance during the course of this study.

REFERENCES

- [1] Al-Baradi, W. A. (2000). Using Time Series for Prediction Groundwater Level in Saq Aquifer in Part of Tabuk Area, B. Sc. Project (Arabic), Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Saudi Arabia.
- [2] Almazroui, M., (2010). Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009, Atmos. Res. (2010), doi:10.1016/j.atmosres.2010.11.006
- [3] Alsharhan, A. S., Rizk, Z. A., Nairn, A. E. M., Bakhit, D. W. and Alhajari, S. A. (2001) Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas, Elsevier, Amsterdam.
- [4] Bathrellos, G.D.; Karymbalis, E.; Skilodimou, H.D.; Gaki-Papanastassiou, K.; Baltas, E.A. (2016). Urban flood hazard assessment in the basin of Athens Metropolitan city, Greece. Environ. Earth Sci. 2016, 75, 319
- [5] Climate, 2020. Weather and Climate in Saudi Arabia Available at: <http://www.southtravels.com/middleeast/saudi-arabia/weather.html2020>.
- [6] Jenkins, K.; Surminski, S.; Hall, J.; Crick, F. (2017). Assessing surface water flood risk and management strategies under future climate change. Sci. Total Environ. 2017, 595, 159–168
- [7] Habib, E.H., Nasrollahi, N., 2009. Evaluation of TRMM-TMPA satellite rainfall estimates over arid regions. American Geophysical Union. Fall Meeting 2009, 2009AGUFM.H2012A.2002H.
- [8] Huffman, G.J., Bolvin, D.T., 2009. TRMM and Other Data Precipitation Data Set Documentation. Laboratory for Atmospheres, NASA Goddard Space Flight Center and Science Systems and Applications, Inc.. Available at: http://precip.gsfc.nasa.gov/pub/trmmdocs/3B42_43B43_doc.pdf.
- [9] Glas, H.; De Maeyer, P.; Merisier, S.; Deruyter, G. (2020). Development of a low-cost methodology for data acquisition and flood risk assessment in the floodplain of the river Moustiques in Haiti. J. Flood Risk Manag. 2020, 13, e12608.
- [10] Goodrich, D.C., Williams, D.G., Unkrich, C.L., Hogan, J.F., Scott, R.L., Hultine, K.R., Pool, D., Coes, A.L. and Miller, S. (2004). Comparison of methods to Estimate Ephemeral Channel Recharge, Walnut Gulch, San Pedro River Basin, Arizona. In: Groundwater Recharge in a Desert Environment. The Southwestern United States, Eds. Hogan, J.F., Phillips, F.M. and Scanlon, B.R. Water Science and Application 9, American Geophysical Union, pp 77-99
- [11] Gupta, R. (2001) Hydrology and Hydraulic Systems. Waveland press, USA
- [12] Lai, C.; Chen, X.; Wang, Z.; Yu, H.; Bai, X. (2020). Flood risk assessment and regionalization from past and future perspectives at basin scale. Risk Anal, 40, 1399–1417
- [13] Lowe, R.; Arnbjerg-Nielsen, K. (2020). Urban pluvial flood risk assessment-data resolution and spatial scale when developing screening approaches on the microscale. Nat. Hazards Earth Syst. Sci., 20, 981–997

- [14] Liu, W.-C., Hsieh, T.-H., & Liu, H.-M. (2021). Flood Risk Assessment in Urban Areas of Southern Taiwan. *Sustainability*, 13(6), 3180. doi:10.3390/su13063180
- [15] Loucks, and D.P. Loucks (2006). Modeling and managing the interactions between hydrology, ecology and economics, *J. Hydrol.*, 328 (2006), pp. 408–416
- [16] Masoud Eid Al-Ahmadi (2009). Hydrogeology of the Saq Aquifer Northwest of Tabuk, Northern Saudi Arabia. *JKAU: Earth Sci.*, Vol. 20 No. 1, pp: 51-66
- [17] Mays, L. (2001). Storm water collection systems design handbook. McGraw-Hill. USA
- [18] Poulard, C., Lafont, M., Lenar-Matyas, A., & Łapuszek, M. (2010). Flood mitigation designs with respect to river ecosystem functions—A problem oriented conceptual approach. *Ecological Engineering*, 36(1), 69–77. doi:10.1016/j.ecoleng.2009.09.013
- [19] Romali, N. S., Yusop, Z., & Ismail, A. Z. (2018). Hydrological Modelling using HEC-HMS for Flood Risk Assessment of Segamat Town, Malaysia. *IOP Conference Series: Materials Science and Engineering*, 318, 012029. doi:10.1088/1757-899x/318/1/012029
- [20] US Army Corps Engineers. Hydrologic Modeling System (HEC-HMS) Application Guide: Version 4.3; Institute for Water Resources— Hydrologic Engineering Center: Davis, CA, USA, 2018.
- [21] USACE-HEC, 2000. Hydrologic Modeling System HEC-HMS Technical Reference Manual. US Army Corps of Engineers, Hydrologic Engineering Centre (HEC), Davis, USA.
- [22] USACE-HEC, 2008. Hydrologic Modeling System HEC-HMS v3.2 User's Manual. US