Stormwater Management by 1D and 2D Hydraulic Simulation in the Main Surface Water Collection Canals (Case Study: Mianrud Canal – Tehran)

Abbassi P*, Aminnejad B and Ahmadi H

Civil Engineering, Islamic Azad University, Iran

*Corresponding author: Peyman Abbassi, Civil Engineering, Islamic Azad University, Roodehen Branch, Iran, Email: peyman756@yahoo.com

Abstract

The importance of urban floods can be considered because of the harmful effects they can have on urban structure, human health and the environment. Therefore, familiarity with stormwater management and how to assess damage and deal with it to minimize and control it is very important in urban management systems. There are several methods for flood control that are considered depending on the hydraulic conditions. The use of main canals for surface water collection, flow diversion, catchment management, etc. are among the methods considered by urban designers. Meanwhile, the use of various software such as SSA, HEC-RAS and the use of engineering tools such as GIS in its environment has attracted the attention of many researchers. In this paper, the hydraulic studies of Mianrud canal in the area of District 5 of Tehran Municipality, which is one of the important surface drainage arteries of Tehran, have been considered with the help of mathematical model for flood risk zoning. Vulnerable areas have been identified and finally management strategies to control and reduce flood risks have been discussed according to the river regime and the conditions of the region.

Keywords: Critical points; District 5 of Tehran; Mianrud Canal; HEC-RAS

Introduction

Background

Statistics show that flood damage in the last five decades has accounted for more than half of all-natural disasters in the world. Iran's climatic and geographical conditions are such that every year we see the occurrence of floods along with its many damages. The escalation of the flood damage in the last two decades has led to an understanding of the fact that efforts must be made to reduce its harmful and destructive consequences. Meanwhile, we are witnessing a decrease in water infiltration in urban areas mainly due to the destruction of upstream watersheds (such as destruction of vegetation and road construction, as well as the uncontrolled expansion of urban and industrial lands). Urban runways and residential areas adjacent to rivers have the greatest potential for flood risk. Therefore, the implementation of new policies regarding land use management, rational urban development in order to reduce the effects of its destruction is essential.

Importance of Storm Water Management in Tehran

The city of Tehran is located in the southern foothills of the Central Alborz Mountains and downstream of several

catchment areas. The area of Tehran up to an altitude of 1133 meters has caused a structural difference in the physical texture of this city and as a result, it has become prone to natural hazards such as floods. On the other hand, the predominant precipitation regime in Tehran is in the form of thunderstorms, which reduce the chance of rain penetrating into the soil, and as a result, a significant part of the precipitation becomes surface runoff. Therefore, rivers and lakes of urban watersheds have a high degree of risk for flooding and damages. Achieving sustainable urban development requires the design of appropriate models for the management and protection of rivers and lakes in urban watersheds.

Flood Zoning Maps

Therefore, in these areas, determining the level of flood progression and its height relative to the land surface figure and also determining the characteristics of flood in different return periods (flood zoning) is important and is a prerequisite for designing structures in canals. One of the most common methods is to use the geographic information system and combine it with hydrological and hydraulic models. After determining the flood zoning maps, it is necessary to prepare flood risk maps in which the safe areas are identified. Proper flood estimation and the resulting risk, in addition to determining the points with the highest risk, make it possible to identify the organizing points and reduce the growth rate of flood damage. Experts believe that if structural methods are combined with non-structural methods, they will be the optimal solution to minimize flood damage. This case highlights the need for a comprehensive study of floods in the upper basins of Tehran.

Research Purposes

Flooding of the floodplain and its use in spatial planning is one of the non-structural measures to reduce flood damage. This study tries to investigate the risk of flooding in the area of Mianrud canal in Tehran using the hydrodynamic model of Hydrologic Engineering Center - River Analysis System (HEC-RAS) and Geographic Information Systems (GIS).

Literature Review

Today, flood zoning maps are prepared by developing many techniques and methods, including GIS, Digital Elevation Model (DEM). Some of these methods are based on hydrological data and information layers such as land use, soil type, basin slope, rainfall, and so on. The success of these methods depends on the accuracy of the information layers and their assumptions. But there are other methods based on the use of hydraulic models (such as Autodesk® Storm and Sanitary Analysis (ASSA), HEC-RAS, and MIKE Flood) and combining their results with geographic information

systems. In these methods, with the help of numerical models, the flood flow is simulated and after calculating the flow profile by the model, the flood zone is transferred to the study area with different return periods.

In order to widen the floodplain, one-dimensional models have been used repeatedly due to low data requirements, ease of execution, and fast computations. The HEC-RAS one-dimensional model has been used for this purpose for many years. This model includes river hydraulic calculations in the steady-state and non-steady state for water surface profile calculations and sediment transfer calculations at the moving boundary. These three components use a common geometric data display and the same process of geometric and hydraulic calculations. Due to the nature of the flow in the channels, one-dimensional models such as the ASSA model are still good results for modeling in such cases.

However, in flood risk analysis, especially in urban areas, the depth of flooding attracts attention, however, the potential role of flow rate is undeniable. This is felt by considering factors such as multiple uses along canals and main tunnels for collecting and transporting surface water, especially in sudden floods. Research on flood-prone areas shows that, regardless of the management operations applied in those areas, flood risk-based zoning is largely based on the depth or return period of the flood.

Given the importance of the issue of urban runoff, especially with the emphasis on climate change and rapid urban floods, a variety of approaches at different scales have addressed how to deal with this issue on a practical level. The following are some of these studies in Iran and the world:

	Sources
Flood plain zoning by HEC RAS model	**[23-1]**
Flood plain zoning by SWMM model	**[43-24]**
Flood plain zoning by other models	**[52-44,40,1]**
Investigation of risk, vulnerability, flood damage	**[59-53,16,6,1]**
New, qualitative, environmental approaches	**[65-60,34]**

Research Methodology

As expected, due to the increase in impenetrable levels in the cities, the volume of runoff will increase significantly and will cause overflow of runoff transmission channels and many problems in the city. To simulate the hydraulic behavior of the urban runoff transmission system and flood zoning, first the information needed to implement the model such as the geometric characteristics of the canal, the flow rate of the

discharge channel, the roughness coefficients of the main waterway and the floodplain of the study area are prepared, then the flood zoning using Hydraulic models such as HEC RAS are performed in ArcGIS environment for 10, 25, 50 and 100 year scenarios.

Problem Theories

Two-dimensional HEC-RAS Model

The HEC-RAS model is used to display the water surface profile, simulate the flow of steady and unsteady state, calculate the sediments transferred to the shores and qualitative analysis of water. In flow analysis, this model has the ability to provide water surface profile in supper-critical and sub-critical conditions, and through it, hydraulic structures such as bridges and ports can be modeled. Due to the high capabilities of this model, it has been widely used to manage rivers and floodplains. To define the topography of the region in the two-dimensional HEC-RAS model, we can directly use the Digital Elevation Model (DEM), and unlike the other one-dimensional model, there is no need for HEC-GeoRAS and cross-sectional definition. All steps in the software itself are done with the help of RAS-Mapper module. In many two-dimensional models such as CCHE2D, FLOW2D, IRIC and etc. a computational cell can be either dry or wet, but in the new HEC-RAS model, a computational cell can be both dry and wet. This model uses the concept of sub grid variability to calculate the flow parameters within each cell, while most two-dimensional models do not have such a valuable capability. The model can be run in two modes: Diffusion Wave and Full Momentum. Momentum equation is assumed to be an incompressible flow according to the following equation:

$$\frac{\partial \upsilon}{\partial t} + u\frac{\partial \upsilon}{\partial x} + \upsilon\frac{\partial \upsilon}{\partial y} = -g\frac{\partial H}{\partial y} + \upsilon_t\left(\frac{\partial^2 \upsilon}{\partial x^2} + \frac{\partial^2 \upsilon}{\partial y^2}\right) - C_f\upsilon + fu \quad \text{(Eqn 1)}$$

In this regard, u and v are the velocity components in the Cartesian coordinates, H is the height of the water surface from the base level, g is the gravitational acceleration, v_t is the eddy viscosity coefficient, C_f is the bed friction coefficient and f is the Coriolis parameter.

Validation of the Model

To be sure, the manning coefficients obtained in the measurement model were added to the obtained coefficients by 15 to 30% and then deducted, and then the model was re-executed for the new values obtained and the difference in level, depth and speed. It was measured that in all the results obtained, the difference was small.

Study Area

The metropolis of Tehran, with an area of about 700 square kilometers, is one of the largest cities in the world with special features and specifications. Tehran's drainage system has many complexities that are mostly due to the heterogeneous development of the city, regardless of the comprehensive criteria of urban planning and urban planning in recent decades. Due to the fact that the whole metropolitan area of Tehran is surrounded by high mountains, in addition to surface water in the urban area, rainwater runoff in the northern and eastern mountains of Tehran enters the urban area of Tehran by rivers and some problems. The Mianrud Canal route in Tehran, which was designed in the 1960s, is one of the most important water collection routes in western Tehran, directing the floodplains of the Darkeh, Farahzad, Nizar and Hesarak rivers and flowing into the Kan River. As one of the main surface water management facilities in the west catchment area of Tehran, this canal is located in the vicinity of important infrastructures such as Tehran-Karaj freeway and lines 4 and 5 of Tehran metro. Therefore, its critical points are among the floodplains of priority for a city in Tehran.
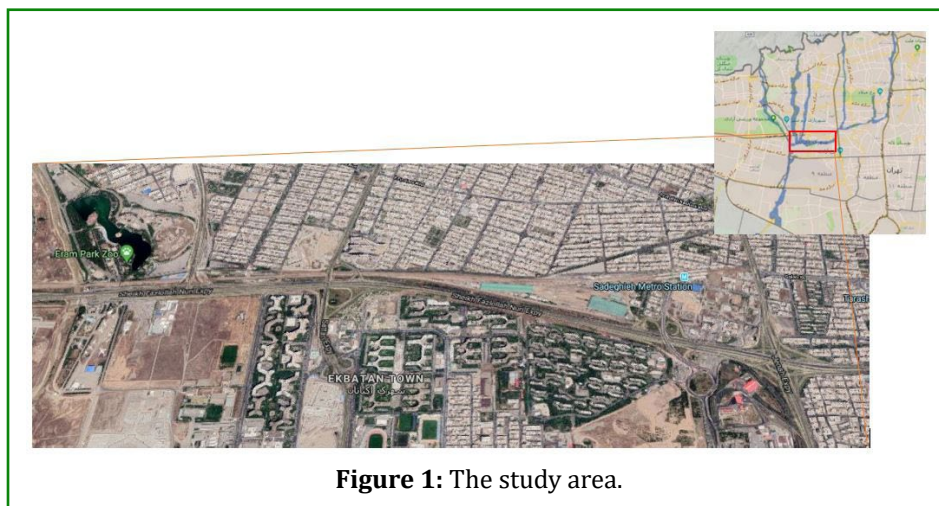

Figure 1: The study area.

Results and Discussion

Hydrological Results of Critical and Dangerous Points

One of the most important bottlenecks in the floodplain canal is the bridges and culverts built on it. Bridges and Culverts are structures for the passage of cars and citizens, and while they are part of the network of streets and inner-city roads, they are also part of Tehran's main surface water network. Proper design and implementation of bridge and caliber structures will minimize the flow of energy at the intersection with these structures. Improper implementation of them not only increases the rate of energy loss, but also causes problems such as water receding or turning the structure into floodplains. The impact of these facilities, especially in times of flooding, cannot be ignored, so a closer look at the impact of these structures on the hydraulics of the canal flow has been considered.

Analysis of the allocated capacity in relation to the critical points located in the network includes reviewing the flow capacity of discharge through sensitive sections on the network channels as well as the amount of their capacity shortage and the percentage of filling of the upstream channel for discharge flood with return periods of 10, 25, 50 and 100 years. The following are the results of hydraulic modeling of flood points and modeled bridges, separated by the intervals in the channel.

Findings

The First Bridge
The improper deck of the bridge has blocked most of the canal by 40.47 %. The following figure shows a view of the bridge and its hydraulic modeling specifications.
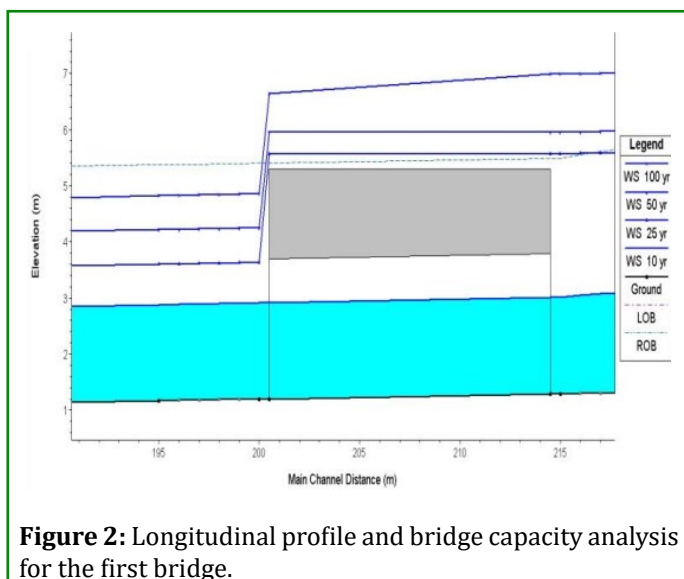

Figure 2: Longitudinal profile and bridge capacity analysis for the first bridge.

The capacity of this bridge is sufficient for floods with a 10-year return period, and the flow passes through the bridge in a free surface, observing the free height. For floods with a return period of 25, 50 and 100 years, the type of flow in crossing the bridge is under pressure and overflows the canal and the deck of the bridge (Figures 4 & 5).

The Second Bridge
The deck of the bridge has reduced the cross-sectional area of the canal by 27%. Figure 3 shows the results of the hydraulic modeling of the bridge. The capacity of this bridge is sufficient for floods with a return period of 10 years, and the flow passes through the bridge in a free surface, observing the free height. For floods with a 25-year return period, the flow is converted under pressure by observing the free height, and in 50-year floods, the flow overflows from the upstream canal, and in 100-year floods, in addition to the upstream canal, it overflows (Figures 4 & 5).

The Third Bridge
The deck with a height of 1.8 meters has reduced 47.37% of the canal cross section (Figure 3). The flow at the crossing of this bridge is free for flooding with a 10-year return period under pressure with respect to free board. For floods with a return period of 25, 50 and 100 years, the stream overflows the deck and upstream canal (Figures 4 & 5).

The Fourth Bridge
The deck of this bridge is part of the ramp of Sattari Street, which has been built on the Mianrud canal. The width of the upstream canal, 25 meters from the bridge, is gradually reduced from 9 meters and reaches 6.2 meters at the entrance of the bridge. Also, the reduction of the cross-sectional area of the canal due to the bridge deck is 28.95% (Figure 3). For floods with a return period of 10 years, the flow passes through the bridge under pressure by observing the free height. For floods with a 25-year return period, the flow will be under pressure. In this case, although the flow does not overflow from the bridge deck, it exits through the upper channel and the left wall; And it enters the Tehran-Karaj metro area and the center's catchment area. For floods with a return period of 50 and 100 years, the flow overflows the canal and the deck of the bridge, and as a result, the capacity of the flow passage through the channel under the bridge is not sufficient (Figures 4 & 5).

The Fifth Bridge
The reduction of the cross section of the canal at the entrance of the bridge compared to the upper canal is 22.86% (Figure 3). For floods with a return period of 10 years, the flow passes under the bridge under pressure without observing the free height. For flooding with a 25-year return period, the flow has been under pressure, although the bridge deck is not submerged, the flow overflows from the upper channel. For

floods with a return period of 50 and 100 years, the stream overflows the canal and the bridge deck. (Figures 4 & 5)

The Sixth Bridge
At a distance of 27 meters from the entrance of the bridge, a ramp with a length of 15 meters has reduced the width of the canal cross section from 14.8 meters to 7.8 meters. The cross-sectional area of the canal covered by the bridge has been reduced by 57.18% compared to the upstream canal with a width of 14.8 meters (Figure 3). The narrowing of the cross-section of the existing ramp, the arrival of discharge from the evacuation of the Vesk canal, and the reduction of the cross-sectional area of the canal at the bridge site have led to a leak from the canal for flooding with 10, 25, 50, 50 and 100 year; In 25, 50 and 100 years discharge, in addition to the flow out of the upstream canal, it will also cross the

bridge deck and flood the access route to Eram Park (Figures 4 & 5).

The Seventh Bridge
The bridge was built at the end of the Flood Diversion Channel of West Tehran and 27.28% of the cross section of the canal at the bridge site has been reduced by its deck (Figure 3). For floods with a return period of 10 and 25 years, the flow passes through the bridge as a free surface with respect to free height, and for floods with a return period of 50 years, the flow passes through the bridge under pressure without observing free height. In this case, the current is placed on the border of the overflow from the bridge deck. To flood with a 100-year return period, the stream overflows the bridge deck and its upper canal (Figures 4 & 5).
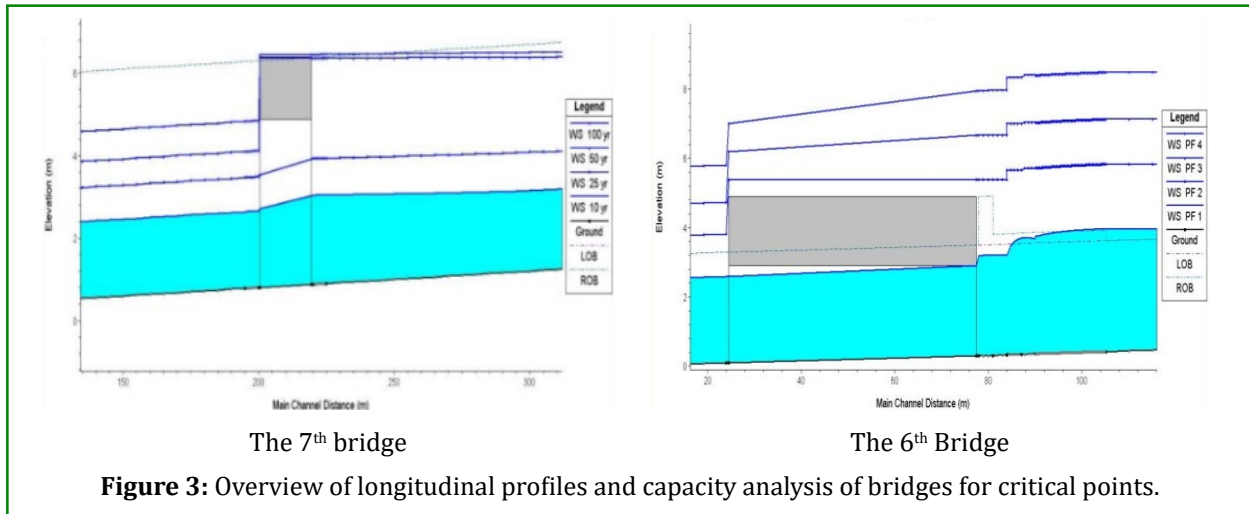

The 3rd Bridge

The 2nd Bridge

The 5th Bridge

The 4th Bridge

The 7th bridge   The 6th Bridge
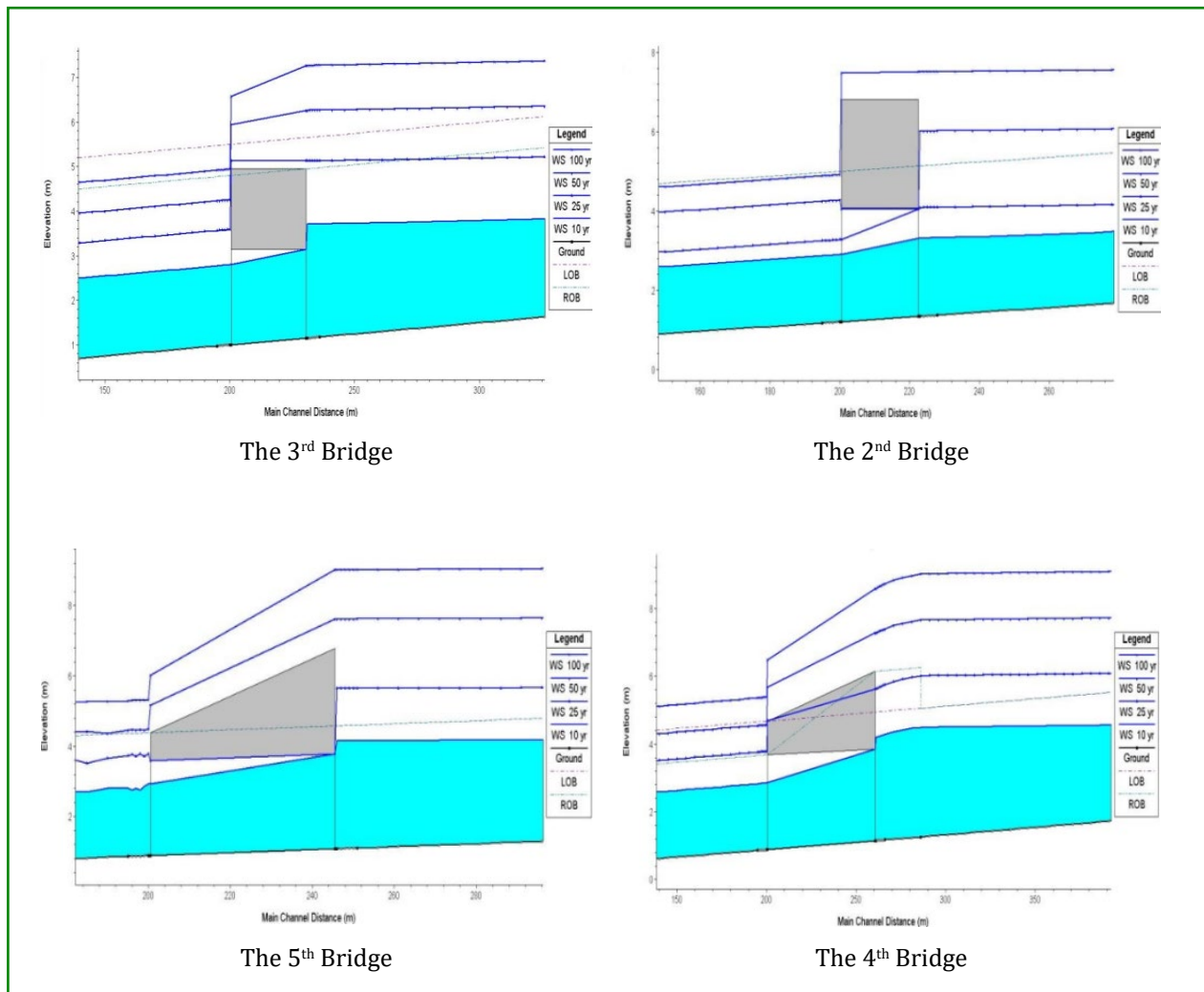
Figure 3: Overview of longitudinal profiles and capacity analysis of bridges for critical points.
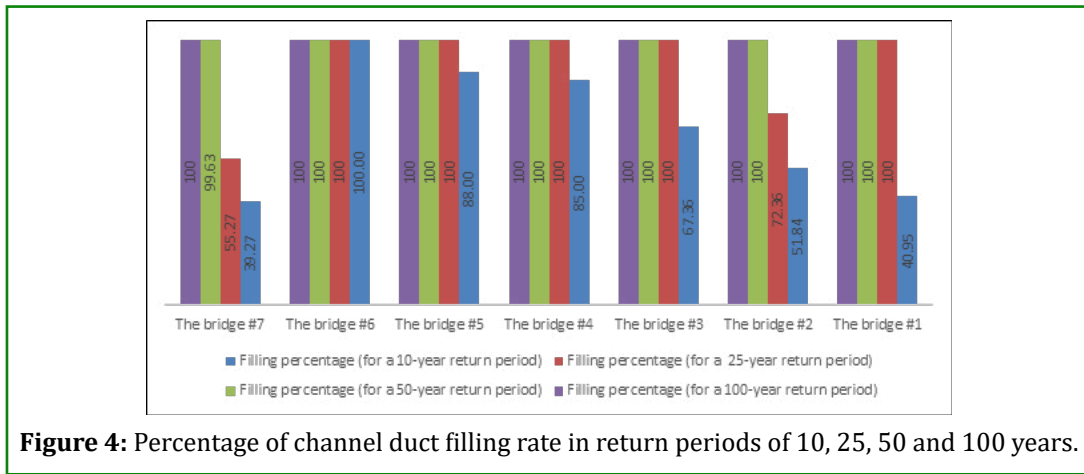

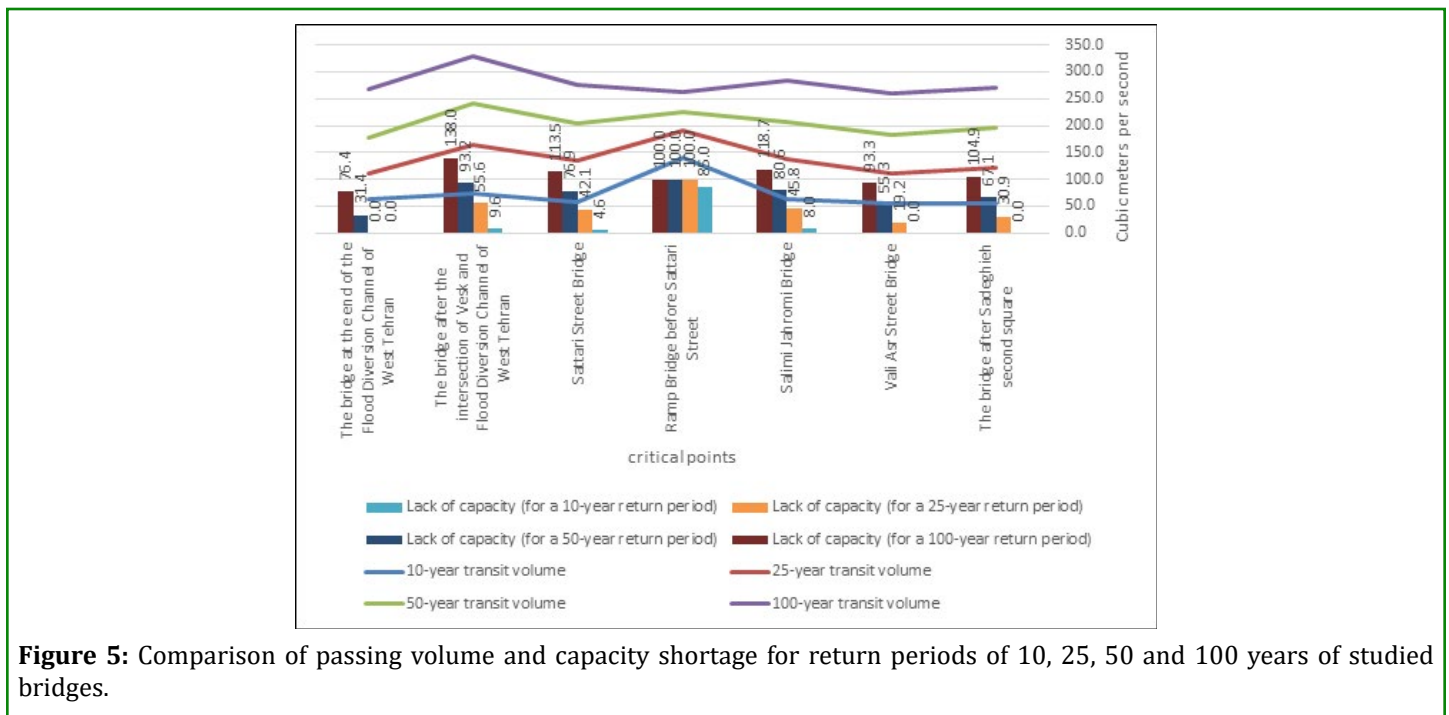**Figure 4:** Percentage of channel duct filling rate in return periods of 10, 25, 50 and 100 years.

Figure 5: Comparison of passing volume and capacity shortage for return periods of 10, 25, 50 and 100 years of studied bridges.

Conclusion

- The results of vulnerability studies in these areas show that a combination of upstream and urban factors exacerbates the vulnerability of these areas. Factors such as providing bridge deck space in the canal and ignoring the volume of water collection and transfer canals, vertical slope levels and curvature coefficients are involved in determining the vulnerability of urban areas.

- The results indicate that not paying attention to the stream area and rivers has caused a rapid growth in the frequency of floods and the amount of damage.

Suggestions

- The flood phenomenon, despite all its complexities, can be studied, and appropriate methods can be introduced to control and reduce its damage. Accordingly, emergency management (in the form of flood guidelines and action plans) is very important to prevent and reduce flood damage.

- Managing and accessing the vulnerability of urban areas to surface water in metropolitan areas is of particular importance, because planning upstream of these areas will lead to better management in downstream human centers.

- Correction and reorganization of the route of the canals can reduce flood damage and help the proper use of its water resources. Therefore, it is suggested to consider the climatic, biological, topographic and hydrological conditions of a basin and its waterways, and to construct the required structure in it.

References

1. Alaghmand S, Abdullah RB, Abustan I, Eslamian S (2012) Comparison between capabilities of HEC-RAS and MIKE11 hydraulic models in river flood risk modelling (a case study of Sungai Kayu Ara River basin, Malaysia). International Journal of Hydrology Science and Technology 2(3): 270-291.

2. Butt MJ, Umar M, Qamar R (2012) Landslide dam and subsequent dam-break flood estimation using HEC-RAS model in Northern Pakistan. Natural hazards 65(1): 241-254.

3. Cook AC (2008) Comparison of one-dimensional HEC-RAS with two-dimensional FESWMS model in flood inundation mapping. Graduate School, Purdue University, West Lafayette,

4. Heydari M, Sadeghian MS, Moharrampour M, Shahiriparsa A (2013) Flood Zoning Simulation byHEC-RAS Model (Case Study: Johor River-Kota Tinggi Region). in International Postgraduate Seminar, Organized by Faculty of Civil Engineering 1(1).

5. Hicks F, Peacock T (2005) Suitability of HEC-RAS for flood forecasting. Canadian Water Resources Journal 30(2): 159-174.

6. Iosub M, Chelariu OE (2015) The use of HEC-RAS modelling in flood risk analysis. Aerul si Apa. Componente ale Mediului, pp: 315-322.

7. Klimeš J, Benesova M, Vilímek V, Bouška P, Rapre AC (2014) The reconstruction of a glacial lake outburst flood using HEC-RAS and its significance for future hazard assessments: an example from Lake 513 in the Cordillera Blanca, Peru. Natural hazards 71(3): 1617-1638.

8. Knebl MR, Yang ZL, Hutchison K, Maidment DR (2005) Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event. Journal of Environmental Management 75(4): 325-336.

9. Mehta D, Ramani M, Joshi M (2013) Application of 1-D HEC-RAS model in design of channels. Methodology 1(7): 4-62.

10. Mohammadi SA, Nazariha M, Mehrdadi N (2014) Flood damage estimate (quantity), using HEC-FDA model. Case study: the Neka river. Procedia Engineering 70: 1173-1182.

11. Ostad-Ali-Askari K, Shayannejad M (2015) Usage of rockfill dams in the HEC-RAS software for the purpose of controlling floods. American Journal of Fluid Dynamics 5(1): 23-29.

12. Pappenberger F, Beven K, Horritt M, Blazkova S (2005) Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations. Journal of Hydrology 302(1-4): 46-69.

13. Parhi PK (2013) HEC-RAS Model for Mannnig's Roughness: A Case Study. Open Journal of Modern Hydrology 3(03): 97-101.

14. Parhi PK, Sankhua RN, Roy GP (2012) Calibration of channel roughness for Mahanadi River,(India) using HEC-RAS model. Journal of Water Resource and Protection 4(10): 847-850.

15. Patel DP, Ramirez J, Srivastava PK, Bray M, Han D (2017) Assessment of flood inundation mapping of Surat city by coupled 1D/2D hydrodynamic modeling: a case application of the new HEC-RAS 5. Natural Hazards

89(1): 93-130.

16. Pistocchi A, Mazzoli P (2002) Use of HEC-RAS and HEC-HMS models with ArcView for hydrologic risk management, pp: 305-310.

17. Quiroga VM, Kure S, Udo K, Mano A (2016) Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5. Ribagua 3(1): 25-33.

18. Selvanathan S (2009) An algorithmic approach to iterative floodway modeling using HEC-RAS and GIS. Journal of Flood Engineering 1: 77-88.

19. Thakur B, Parajuli R, Kalra A, Ahmad S, Gupta R (2017) Coupling HEC-RAS and HEC-HMS in Precipitation Runoff Modelling and Evaluating Flood Plain Inundation Map. in World Environmental and Water Resources Congress.

20. Timbadiya PV, Patel PL, Porey PD (2011) Calibration of HEC-RAS model on prediction of flood for lower Tapi River, India. Journal of Water Resource and Protection 3(11): 805-811.

21. Wiles JJ, Levine NS (2002) A combined GIS and HEC model for the analysis of the effect of urbanization on flooding: the Swan Creek watershed, Ohio. Environmental & Engineering Geoscience 8(1): 47-61.

22. Xiong Y (2011) A dam break analysis using HEC-RAS. Journal of Water Resource and Protection 3(6): 370-379.

23. Yang J, Townsend RD, Daneshfar B (2006) Applying the HEC-RAS model and GIS techniques in river network floodplain delineation. Canadian Journal of Civil Engineering 33(1): 19-28.

24. Babaei S, Ghazavi R, Erfanian M (2018) Urban flood simulation and prioritization of critical urban sub-catchments using SWMM model and PROMETHEE II approach. Physics and Chemistry of the Earth, Parts A/B/C 105: 3-11.

25. Barco J, Wong KM, Stenstrom MK (2008) Automatic calibration of the US EPA SWMM model for a large urban catchment. Journal of Hydraulic Engineering 134(4): 466-474.

26. Burger G, Sitzenfrei R, Kleidorfer M, Rauch W (2014) Parallel flow routing in SWMM 5. Environmental Modelling & Software 53: 27-34.

27. Burszta-Adamiak E, Mrowiec M (2013) Modelling of green roofs' hydrologic performance using EPA's SWMM. Water Science and Technology 68(1): 36-42.

28. Chen W, Huang G, Zhang H (2017) Urban stormwater inundation simulation based on SWMM and diffusive overland-flow model. Water Science and Technology 76(12): 3392-3403.

29. Gironás J, Roesner LA, Rossman LA, Davis J (2010) A new applications manual for the Storm Water Management Model (SWMM). Environmental Modelling & Software 25(6): 813-814.

30. Gülbaz S, Kazezyılmaz-Alhan CM (2017) An evaluation of hydrologic modeling performance of EPA SWMM for bioretention. Water Science and Technology 76(11-12): 3035-3043.

31. Huber WC, Rossman LA, Dickinson RE (2005) EPA storm water management model, SWMM5. Watershed Modeling; CRC Press: Boca Raton, FL, USA, pp: 339-361.

32. Jain GV, Agrawal R, Bhanderi RJ, Jayaprasad P, Patel JN, et al. (2016) Estimation of sub-catchment area parameters for Storm Water Management Model (SWMM) using geo-informatics. Geocarto International 31(4): 462-476.

33. Jiang L, Chen Y, Wang H (2015) Urban flood simulation based on the SWMM model. Proceedings of the International Association of Hydrological Sciences 368: 186-191.

34. Juan A, Fang N, Bedient P (2013) Flood Improvement and LID Modeling Using XP-SWMM. Houston, Rice University, pp: 01-11.

35. Kim S, Kim D, Song CG, Lee S (2018) Stormwater Inundation Analysis in Small and Medium Cities for the Climate Change Using EPA-SWMM and HDM-2D. Journal of Coastal Research 85(1): 991-995.

36. Kourtis IM, Kopsiaftis G, Bellos V, Tsihrintzis VA (2017) Calibration and validation of SWMM model in two urban catchments in Athens, Greece. in International Conference on Environmental Science and Technology (CEST).

37. Leandro J, Martins R (2016) A methodology for linking 2D overland flow models with the sewer network model SWMM 5.1 based on dynamic link libraries. Water Science and Technology 73(12): 3017-3026.

38. Lee JH, Yeon KS (2008) Flood inundation analysis using XP-SWMM model in urban area. Journal of Korean Society of Hazard Mitigation 8(5): 155-161.

39. Liao W, Wang C, Zhou X, Wang Z (2014) Simulation and application on storm flood in Dongguan city based on SWMM. in 2014 International Conference on Mechatronics, Electronic, Industrial and Control

Engineering (MEIC-14). Atlantis Press.

40. Parsa V (2013) Runoff Coefficient of the Watershed Basins Using Simulation Models STORM-CAD and EPA-SWMM in GIS, MSc. Thesis, University of Shahid Beheshti, Tehran.

41. Rai PK, Chahar BR, Dhanya CT (2016) GIS-based SWMM model for simulating the catchment response to flood events. Hydrology Research 48(2): 384-394.

42. Sharifan RA, Roshan A, Aflatoni M, Jahedi A, Zolghadr M (2010) Uncertainty and sensitivity analysis of SWMM model in computation of manhole water depth and subcatchment peak flood. Procedia-social and behavioral sciences 2(6): 7739-7740.

43. Wanniarachchi S, Wijesekera SNT (2012) Using SWMM as a Tool for Floodplain Management in Ungauged Urban Watershed. Engineer: Journal of the Institution of Engineers, Sri Lanka 45(1): 01-08.

44. Parsa V, Motiei H (2013) Modelling urban flooding using StormCad (Case study: West flood-Diversion and Kan watersheds in Tehran). in The 5th conference on Iranian water resource management, Tehran, Iran (In Persian).

45. Arman AK, Hasan MRA, Arman MS (2014) Design of Wastewater and Stormwater Collection Network for AL-YAMOUN Using Sewer CAD and Storm CAD.

46. Jaradat FA, Jalboush IA, Marie N (2014) Design of Wastewater and Stormwater Collection Network for Ya'bad Town Using Sewer CAD and Storm CAD.

47. Nile BK (2018) Effectiveness of hydraulic and hydrologic parameters in assessing storm system flooding. Advances in Civil Engineering.

48. Ock J, Issa RRA, Flood I (2016) Development of Stormwater Controls on Construction Sites Using Computer Analysis Tools, pp: 403-409.

49. Olson T, Linton L, Maeder C (2010) Automation Innovations in Stormwater Modeling Case Study: City of Ramsey, Minnesota, Surface Water Management Plan, in Watershed Management 2010: Innovations in Watershed Management under Land Use and Climate Change, pp: 552-562.

50. Goanta AM (2011) Aspects on the use of version autodesk inventor 2012 within autodesk inventor suite. Annals of the University Dunarea de Jos of Galati: Fascicle XIV, Mechanical Engineering, pp:05-11.

51. Ock J, Issa RRA, Flood I (2016) Analysis tools for stormwater controls on construction sites. in Proceedings

of the 2016 Winter Simulation Conference. IEEE Press.

52. Goanță AM (2011) Aspects on the Use of Version Autodesk Inventator 2012 Within Autodesk Inventator Suite.

53. Dunaieva I, Popovych V, Traverso E (2010) Overview of GIS applications, risk assessment and risk management of climate change hazards. Newsletter, pp: 01-57.

54. Masood M, Takeuchi K (2012) Assessment of flood hazard, vulnerability and risk of mid-eastern Dhaka using DEM and 1D hydrodynamic model. Natural hazards 61(2): 757-770.

55. Masseroni D, Cislaghi A (2016) Green roof benefits for reducing flood risk at the catchment scale. Environmental Earth Sciences 75(7): 579.

56. Popescu I, Jonoski A, Andel SJV, Onyari E, Quiroga VGM (2010) Integrated modelling for flood risk mitigation in Romania: case study of the Timis–Bega river basin. International Journal of River Basin Management 8(3-4): 269-280.

57. Schanze J, Zeman E, Marsalek J (2006) Flood risk management: hazards, vulnerability and mitigation measures.

58. Shariat R, Roozbahani A, Ebrahimian A (2019) Risk analysis of urban stormwater infrastructure systems using fuzzy spatial multi-criteria decision making. Science of the Total Environment 647: 1468-1477.

59. Shariat R, Roozbahani A, Ebrahimian A (2019) Risk Assessment of the Urban Runoff Collection Networks Using Spatial Multi Criteria Decision-Making (Case Study: District 11 of Tehran). Journal of Water and Wastewater 30(1): 01-17.

60. Gülbaz S, Cevza M (2014) Investigating effects of low impact development on surface runoff and TSS with a calibrated hydrodynamic model. La Houille Blanche 3(3): 77-84.

61. Kaykhosravi S, Khan UT, Jadidi A (2018) A comprehensive review of low impact development models for research, conceptual, preliminary and detailed design applications. Water 10(11): 1541.

62. Palla A, Gnecco I (2015) Hydrologic modeling of Low Impact Development systems at the urban catchment scale. Journal of hydrology 528: 361-368.

63. Zhu Z, Chen X (2017) Evaluating the effects of low impact development practices on urban flooding under different rainfall intensities. Water 9(7): 548.

64. Chen JC, Chang NB, Chang YC, Lee MT (2003) Mitigating the environmental impacts of combined sewer overflow by web-based share-vision modelling. Civil Engineering and Environmental Systems 20(4): 213-230.

65. Salunkhe S, Wagh M, Sawant S, Rathod S, Salunke PJ (2018) Applications of software's in environmental engineering. International Journal for Advance Research and Development 3(1): 187-191.