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SIMULATING FLOOD URBAN DRAINAGE NETWORKS THORUGH 1D/2D MODEL ANALYSIS

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الملخص

الهدف من تصميم أنظمة تصريف مياه الأمطار، هو توفير الحركة الآمنة للمركبات والمشاة وكذلك حماية الممتلكات من التلف أثناء حدوث العاصفة. ينبغي تنسيق نظم تصريف مياه الأمطار في المراحل المبكرة من التخطيط الحضري، للوصول إلى نظام تصريف مياه أمطار فعال وإقتصادي.

المشكلة الرئيسية هي أن خلال العواصف الثقيلة (١٠٠ سنة كفترة تصميمية) يحدث مبدأ التصرف الكلي. حيث يتجمع التصرف المغطى مع التصرف السطحي في الخارج بسبب حدوث طفح في النظام المغطى. وذلك بسبب أن تصريف مياه الأمطار في المناطق الحضرية يصمم لإستيعاب عواصف كثيرة التردد (٢ - ١٠ سنين) بخلاف نظم صرف المجمعات الرئيسية التي يتم تصميمها العواصف الثقيلة.

تهدف إلى دراسة إستخدام نموذج أحادي و ثنائي الأبعاد (1D/2D) للوصول إلى ناتج أدق للتدفق المشترك (المغطى/سطحي) الذي يصب في المجمع الرئيسي. استخدمت منطقة الدراسة لتطبيق تقنيات تحليل لسريان مستقر، غير مستقر وأحادي ثنائي الأبعاد (1D/2D) على نظام صرف الأمطار السطحي و المغطى خلال العواصف المختلفة. تم فحص و مقارنة النتائج، مما يسمح بتوجيه مهندسي التصميم لإختيار التصميم الأمثل لتصريف الأمطار. وعلاوة على ذلك، تقديم طرق مختلفة لإستخدام نموذج (1D/2D) لمحاكاة حلول متعددة للفيضانات في المناطق الحضرية.

ABSTRACT

Storm drainage design aims to provide a safe travel of vehicles and pedestrians, as well as protect properties from damage during storms. The design process must begin in the early phases of urban planning in order to achieve an effective, efficient and economical system.

The main problem is that during 100-year rainfall events, urban drainage systems can become flooded. This is due to the fact that unlike main collector systems, which are designed to accommodate such a flow, urban drainage systems are designed to convey runoff from storms of less frequencies, around 2 to 10 years.

This paper adopts a 1D/2D PCSWMM model to illustrate the dual drainage concept and investigate how to achieve a more realistic estimation of the coupled flow discharging into a main collector. As well as simulating different scenarios to reduce the damage that could result from extreme events

The results were examined and compared, providing guidance for engineers to reach an optimal storm drainage design. Furthermore, presenting different ways to utilize 1D/2D models in simulating multiple solutions for urban flooding.

Keywords: 1D/2D flood Models, PCSWMM, Storm Drainage, Urban Flooding, Coupled flow.

INTRODUCTION

Storm drainage design aims to provide a safe travel of vehicles and pedestrians, as well as protect properties from damage during storms. The design process must begin in the early phases of urban planning in order to achieve an effective, efficient and economical system. (FederalHighwayAdministration, 2001)

The main problem is that during 100-year rainfall events, urban drainage systems can become flooded. This is due to that fact that unlike main collector systems, which are designed to accommodate such a flow, urban drainage systems are designed to convey runoff from storms of less frequencies, around 2 to 10 years. (FederalHighwayAdministration, 2001)

Conventional one-dimensional (1D) models (either steady or unsteady analysis) are usually used to simulate flow in flood channels and gravity collection networks but will be inadequate to simulate phenomenon such as street flooding and overbank flow in floodplains that occur during extreme events. 1D/2D and 2D models have begun to be used but their complexity, cost and significant data requirements have limited their application (Leondro, 2009).

It is currently easier to adopt 2D models in order to estimate and analyze a more realistic simulation of the coupled flow draining into a main collector as well as illustrating the overland surface and floodplain that occurs during extreme events due the availability of high quality Digital Elevation Model (DEMs), the increased power of desktop computers as well as the need for more realistic simulation of flooding have all contributed to the adoption of 2D models for floodplain mapping and the analysis of overland flows (Leandro, 2011).

ALALA'ALYAH DEVELOPMENT

AlAla'alyah is a new development in Saudi Arabia, the project area is approximately one million km^2. Data collected from previous hydrology studies show the stream path affecting the study area as exhibited in **Error! Reference source not found.**.

Since a main stream is passing through the project area, a channel was proposed to allow flood flow, as shown in Figure , the channel is designed to hold the peak flow resulting from100-year return period rainfall event.

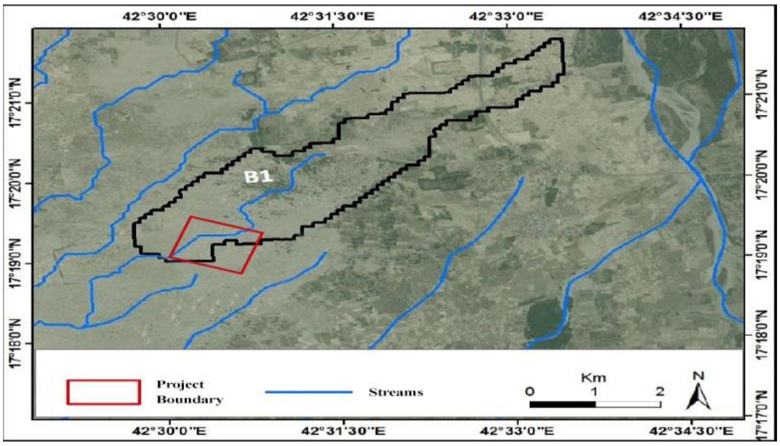

Figure 1layout of the AlAla'alyah new development area

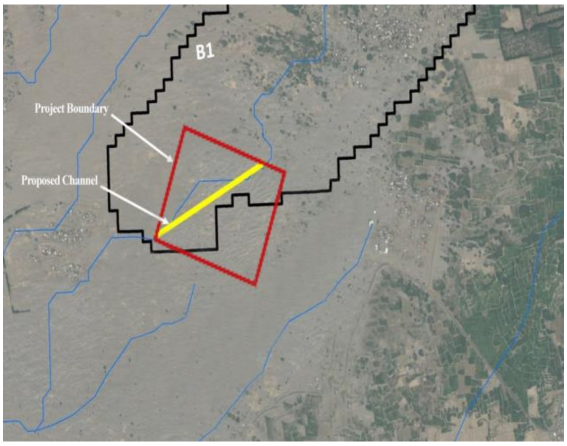

Figure 2 Stream Paths and Basins affecting the case Study

The maximum rainfall depth was obtained at frequencies 5, 10, 25, 50 and 100 years, the depth values are shown in Table 1.

Table 1: Maximum rainfall depth at different frequencies

Return period(year)	5		10	25	50	100
Rainfall depth (mm)	51.5		62.3	75.9	86	96

Figure 1, shows hydrograph of the channel crossing the project area which is caused by the watershed due to a storm of 100-year return period. The peak flow of 7.1 m^3/s.

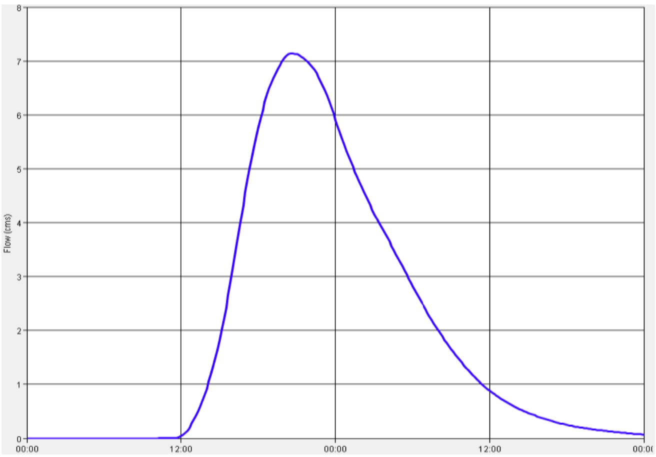

Figure 1: Hydrograph resulting from 100-year return period of the stream crossing the project area

Figure 2, represents the pipe network diameters distribution on the masterplan and illustrates how the subsurface network is integrated with the channel crossing the study area.

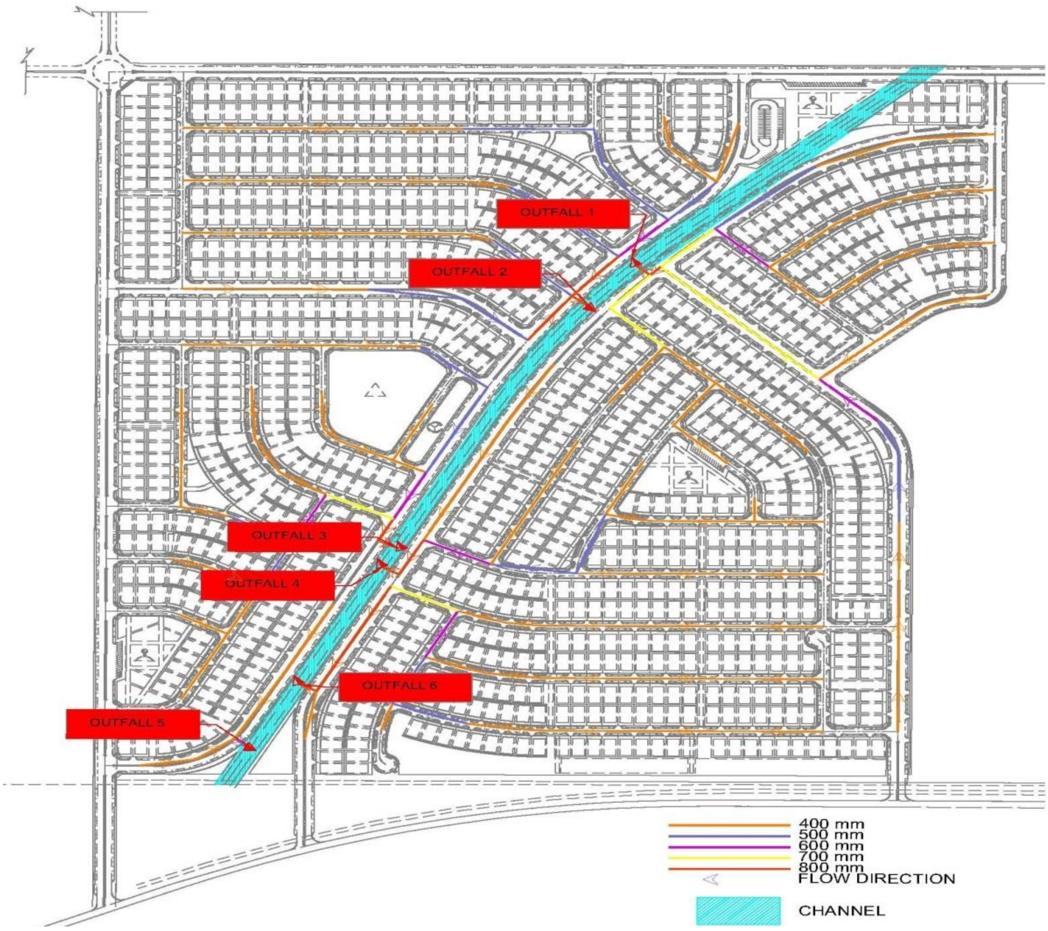

Figure 2: Proposed Masterplan of AlAla'alyah showing the proposed diameter distribution and the channel crossing the case study

METHODOLOGY

In this case study, the urban drainage system will be designed to hold the run off a 10-year rainfall event at most. While, the size of channel crossing the project area shall be designed to accommodate the run off a 100-year rainfall. During 100-year rainfall events, the drainage system is not capable to divert the incoming hydrograph to the channel crossing the study area, the sewer system can become surcharged and flooding will occur. An illustration is needed for how the system performs during extreme events through a 1D/2D model as well as simulating further alternatives to assist in the decision-making process of either accepting the flood or reducing its effect.

UNSTEADY STATE ANALYSIS USING 1D/2D APPROACH:

One Dimension/Two-dimension (1D/2D) models link 1D unsteady flow calculations which simulate flow in in the subsurface network with 2D calculations where the flow is actually two dimensional. The 1D model uses a link-node system, while the 2D domain is defined by a grid of cells that carry attributes of slope and roughness. During extreme storms, water flows out of the subsurface system and may either may gravitate towards a neighboring inlet, or pond in the lack of an adjacent inlet. In the drainage networks obstructions or inadequate capacity may cause flow to backup or reverse direction. (W.J. Syme, 2009). The program used to simulate (1D/2D) is PCSWMM (by CHI). PCSWMM uses EPASWMM for numerical solving in case of 1D simulations (Shrestha, 2014)

PCSWMM 2D extends the fully dynamic 1D approach in PCSWMM/EPA SWMM5 to 2D free surface flow (James, 2012). It uses (St-Venant equations) for solving each component ..of a computational cell, along a network of junctions and open conduits that represent the problem.

ANALYSIS & RESULTS

A 2D mesh was generated from the Digital Elevation Model within the study area. The 2D mesh link with the 1D model is illustrated in Figure 3 as well as the final setup of the model prior to starting the analysis.

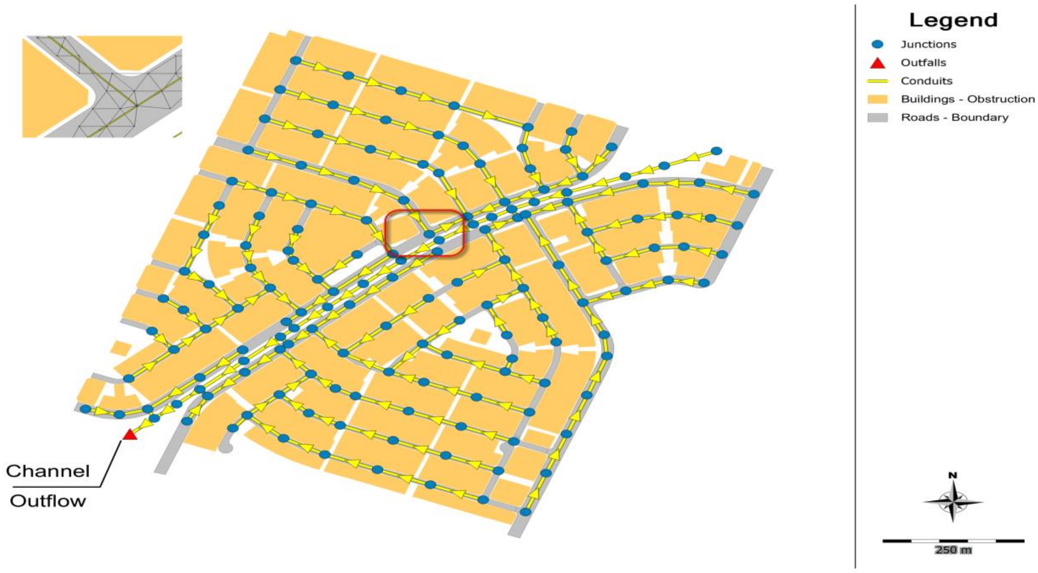

Figure 3: Final Setup of the Model, and the 2D Mesh connected to the 1D Network

Results of the analysis show a flood plain that will be generated in the study area. Figure 4 Represents the flood plain analysis where the blue areas reflect the maximum water depth locations. The maximum depth occurring during flooding is 0.14 m, and the duration of flooding is approximately 1 hour and 12 minutes.

Figure 4: Flood Plain Analysis

Figure 5 Shows the flow at the outfall of the channel, there are two peaks in the hydrograph one is caused by watershed Basin 1 and the other is caused by the study area which is 9.10 m3/sec, both peak flows do not occur at the same time. This allows us to have a realistic and accurate estimation of the flow discharging into the channel instead of adding the peak flows of both areas (the study area and the Basin) linearly. The peak flow computed by the study area takes into consideration the flooding, ponding and rerouting of the flow through the pipes and roads which provides a more rational estimation of the peak flow from the study area.

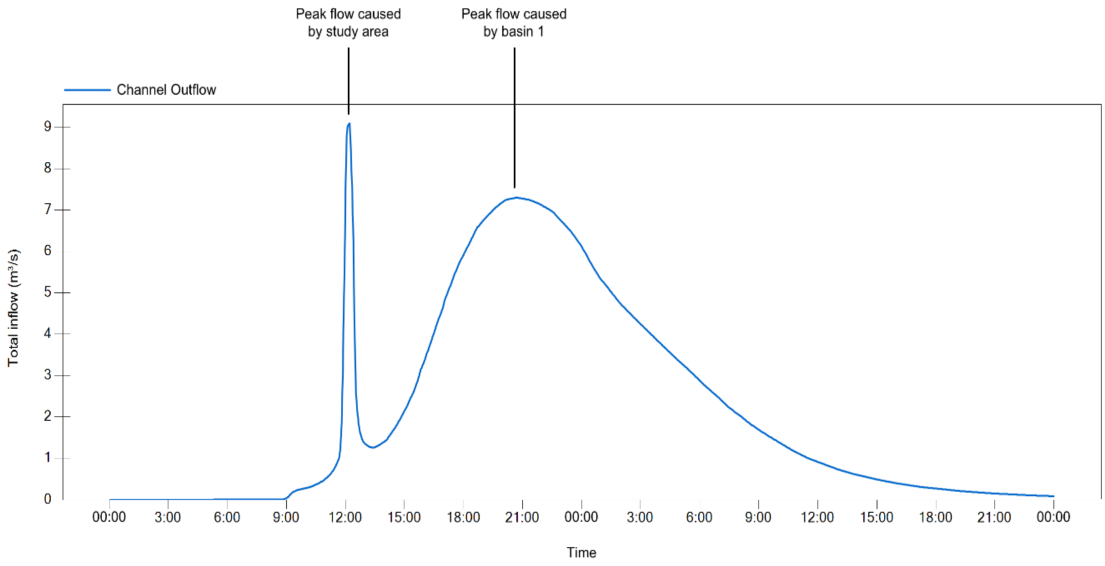

Figure 5: Hydrograph at Outfall of the Channel

NETWORK ALTERNATIVES

Flooding is allowed when analyzing a 100-year return rainfall event, however the ability to view the routing of the flow that is flooding from the manholes allows us to assess the destructiveness of the flood as well as, the acceptability of its duration and depth consequently planning for cost effective solutions that do not involve increasing the pipe diameters.

In this section several alternatives (solutions) will be discussed to find an economic solution to reduce the flooding effect, taking into consideration that flooding is acceptable during extreme events as long as it’s not damaging.
The proposed solutions will be as follow:

1- Implementing Curb openings at the ponding locations adjacent to the channel to allow the flow to reach the channel faster.
2- Implementing a flushed curb at the roads adjacent to the channel, which allows the flooding to flow to the channel by surface drainage.
3- Reducing the pipe diameters, and check if the duration of flooding and ponding depth is acceptable.

Implementing Curb Openings

Implementing curb openings at the ponding areas on the roads adjacent to the channel is a cost-effective solution, and it won’t impact the urban planning negatively.

In-order to simulate the curb openings, orifices where added to the hydraulic model to connect the mesh with the channel, Figure 6.

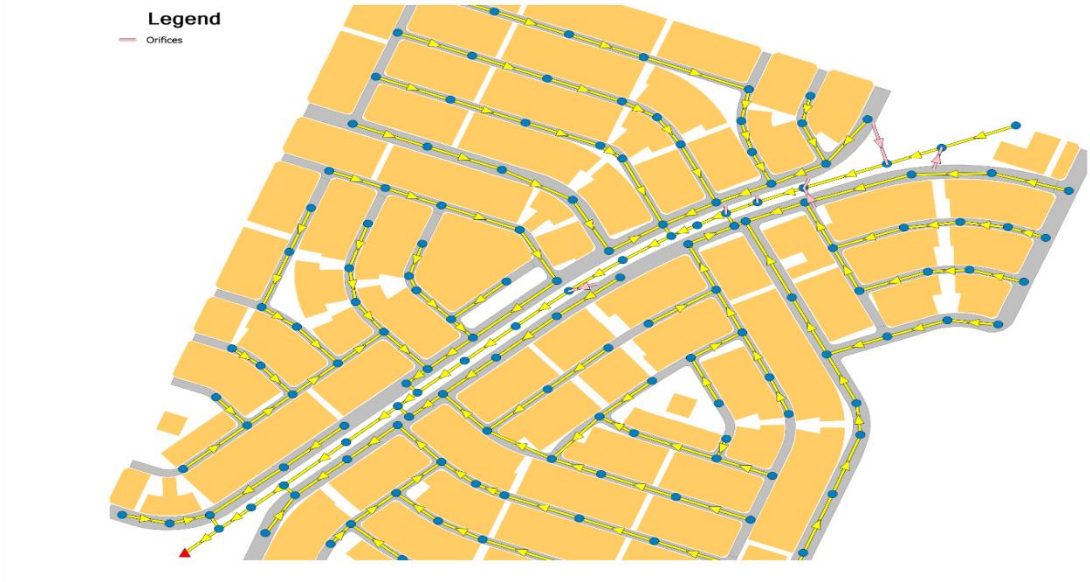

Figure 6: Orifices Connecting 2D Mesh with Channel to Simulate Curb Openings

Figure 7 Shows the ponding area of the case study, after applying the curb openings. The maximum depth reached during flooding is 0.14 m as well, while the duration of flooding is approximately 50 minutes.

Figure 7: Ponding Area after Simulating Curb Openings

Figure 8, Shows the flow of the channel, the peak flow caused by the study area is 9.42 m3/sec. The flow is significantly higher than and the flood duration is remarkably lower than before implementing the curb openings as the flow was rerouted to the channel faster by the curb openings.

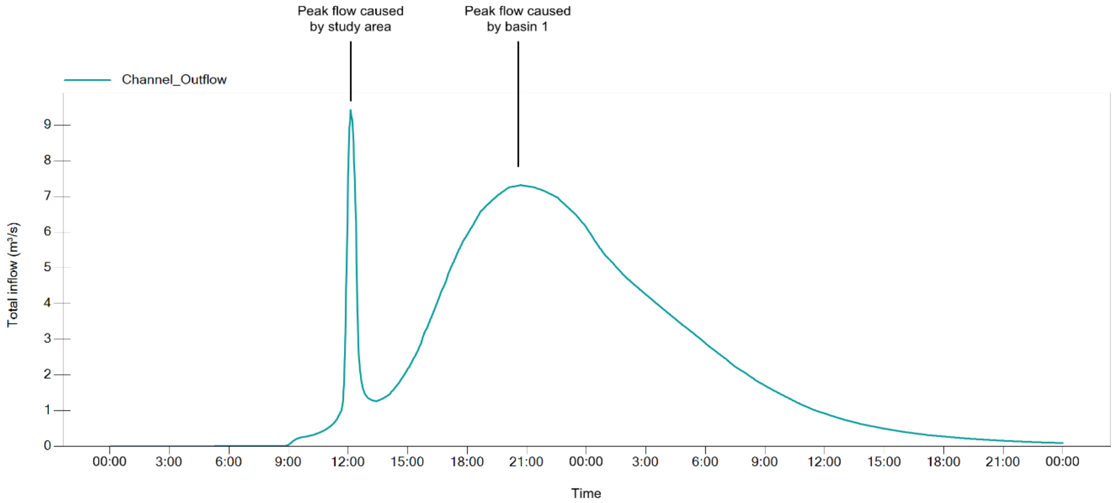

Figure 8:Hydrograph at Outfall of the Channel After Implementing Curb Openings

Implementing Flushed Curb

Implementing a flushed curb on the roads adjacent to the channel is a cost-effective solution as well, that assists in discharging the ponding areas on the roads adjacent to the channel in an economical manner.

To be able to simulate that, the boundary layer was modified to include the channel, accordingly a new mesh was created that contains the channel as shown in Figure 9.

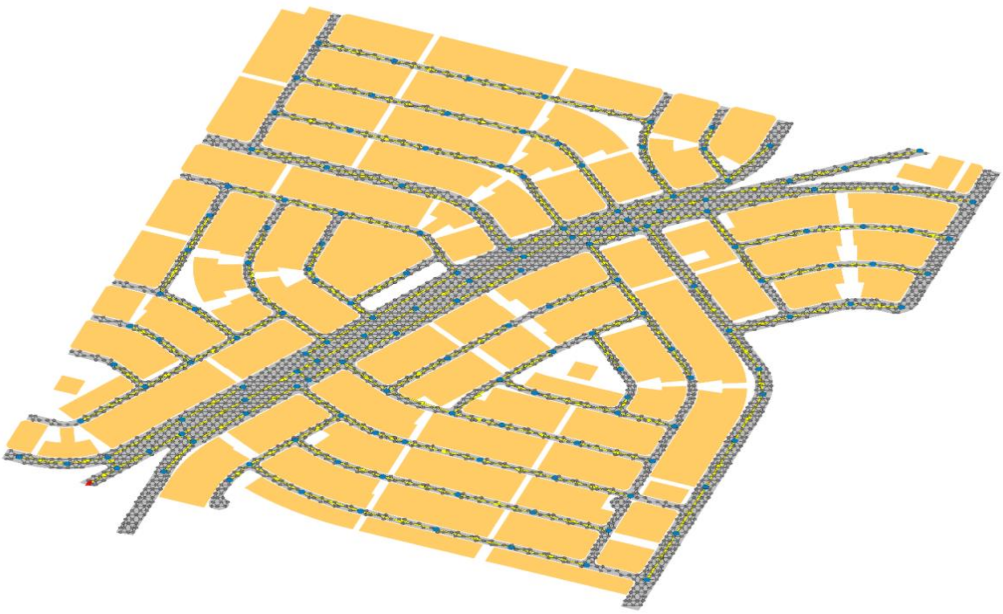

Figure 9:2D Mesh to Simulate Flushed Curb

Figure 10 Shows the ponding area of the case study, after applying the flushed curb solution. The largest depth reached during flooding is 0.12 m, and the duration of flooding is approximately 1 hour.

Figure 10:Ponding Area after Simulating Flushed Curb

Figure 11, Shows the flow at the outfall of the channel, the peak flow caused by the study area is 9.20 m3/sec. The flow is also higher due to the flow being rerouted to the channel faster.

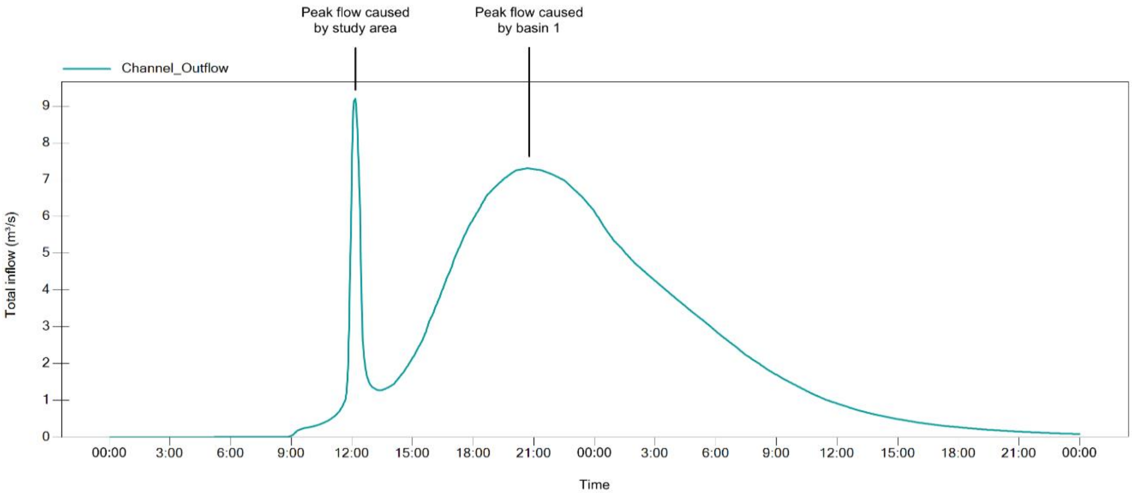

Figure 11: Hydrograph at Outfall of the Channel After Implementing Flushed Curb

Reducing Pipe Diameters

Pipe diameters are reduced to 600mm maximum, in order to assess whether the flooding duration is acceptable leading to a more economical solution. Figure 12 shows the reduced pipe network diameter distribution.

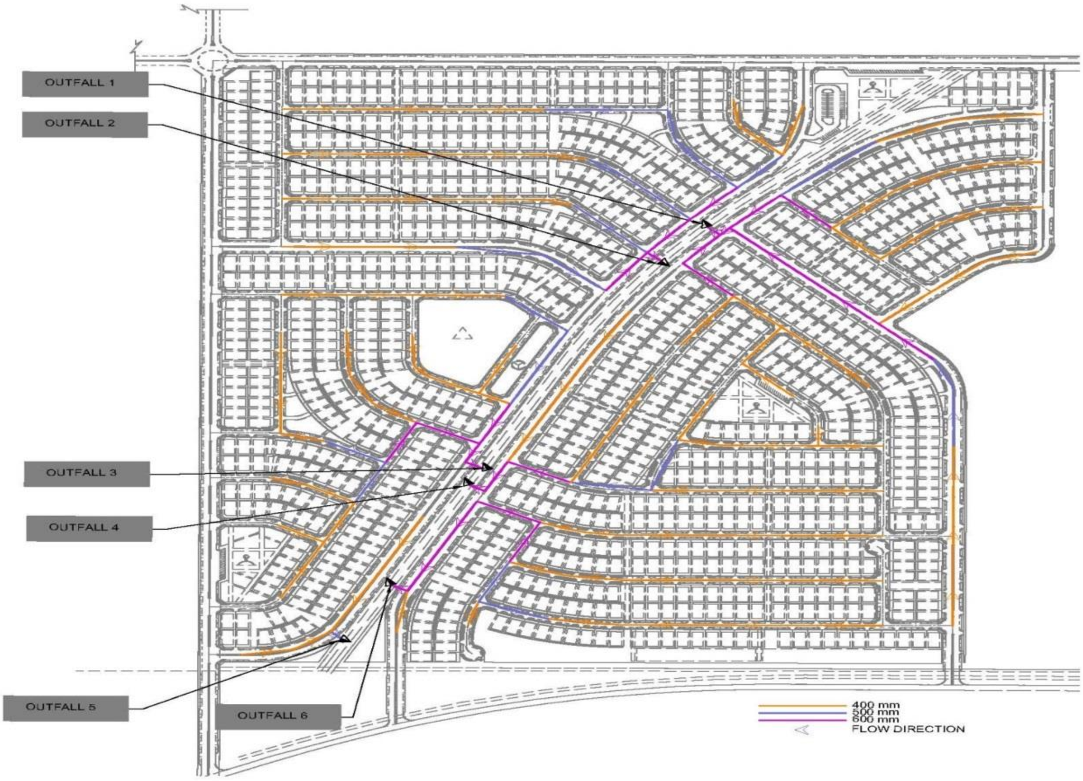

Figure 12: Reduced Diameter Distribution

The floodplain increased as a result of the reduction as illustrated in Figure 13 due to the incapability of the reduced drainage network to store the excess flow. The biggest water depth reached during flooding is 0.36 m which is remarkably higher than the previous alternatives, while the duration of flooding is almost 3 hours and 16 minutes.

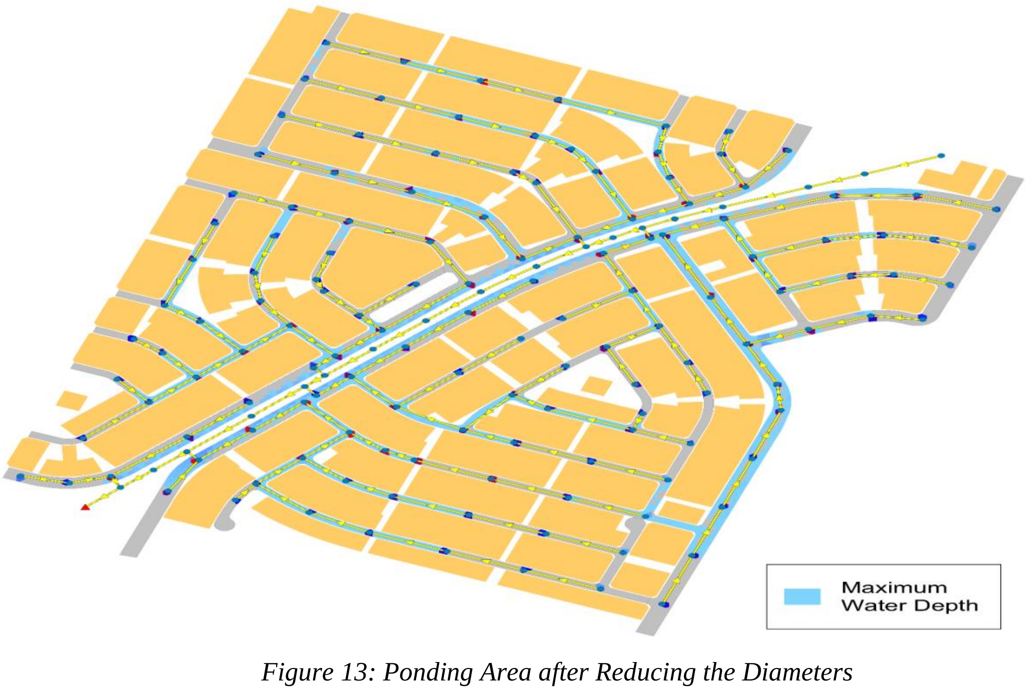

Figure 13: Ponding Area after Reducing the Diameters

Figure 14, Shows the flow at the outfall of the channel, the peak flow generated by the study area is 7.41 m3/sec. This is due to dual drainage caused by the flooding of manholes. The flow is notably lower than any of the above analysis as flooding in manholes occurred, and the streets are undaunted by the flood, up until the manholes and pipes where empty enough for the flow to get back in the manholes and pipes.

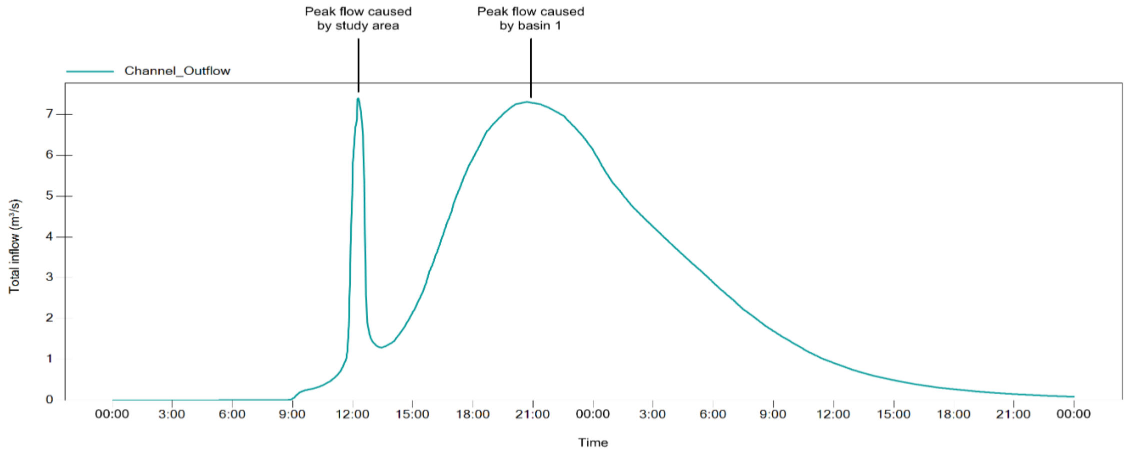

Figure 14: Hydrograph at Outfall of the Channel After Reducing the Diameters

CONCLUSION

Storm network inundation leads to two cases:

- The flooded storm water eventually returns to the storm network.
- The flooded storm water ponds in certain areas and doesn't return to the system.

This can be easily represented by the (1D/2D) storm model which is one of its main advantages.

(1D/2D) models are effective in better understanding the storm network performance, especially during extreme events and providing a realization of the pathway of the storm water flooding and the ponding location, allowing the designer to find solutions that reduce their effect such as placing catch basin, or in the case of the study area, implementing curb openings or applying a flushed curb system.

In some cases, the optimum solution is to reduce the pipe size diameters, if the flood duration is acceptable and there is no risk of damaging properties or danger to the lives of people in-order to design a more economical storm network, in addition to the fact that this leads to reducing the flow entering the channel due to flow attenuation caused by the flood, hence decreasing the size of the channel leading to an overall thriftier solution.

In a nutshell, a solution should be provided after viewing the flooding location simulated by (1D/2D), for a better decision-making process.

Further work could be carried out to examine the effectiveness of additional simulations such as study another scenario which combines reducing the diameters and implementing curb openings., with a more detailed DEM, and analyze the cost of each proposal.

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