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EFFECTIVENESS OF FLOOD RESILIENCE MEASURES FOR INCHEON GYO WATERSHED IN KOREA

Lian Guey Ler[1,*], Gyewoon Choi[1], SeongJoon Byeon[2]

[1] Incheon National University, Korea; [2] International Center for Urban Water Hydroinformatics Research & innovation (ICUH), Korea;
[*] *Building 8A, 12-1 Songdo-dong, Yeonsu-gu, Incheon, Korea <406-840>, E-mail: lianguey@gmail.com*

ABSTRACT

With the rapid acceleration of urban development, cities have been threatened by flood disasters more severely. The design and implementation of resilience floods countermeasure was presented by the modelling simulation for Incheon Gyo watershed of Korea Peninsula. It is an old developed flat region that is heavily urbanized and is connected to the Yellow Sea downstream. Because of this, it experiences flood especially during heavy rainfall occurs concurrently with high tides in the Yellow Sea. In this paper, a review of the climate change projections on rainfall is conducted and used in the modelling of Incheon Gyo watershed. It is found that there will be an increase of up to 1m flood level in the manholes between now and 2100. This shows that there is a need to have flood measures that are resilience and flexible to cope with the future. Also, the effectiveness of measures like green roofs, permeable pavements and underground storage tanks are investigated and it has shown that a combination of the above-mentioned measures is able to cope with the floods.

KEYWORDS
Climate change; flood resilience; green roof; MOUSE modelling; urban flooding.

1. INTRODUCTION

Over the years, urban flooding has become a frequent occurrence during flood seasons in the Korean Peninsula. The problem is expected to be exacerbated as Korea becomes more and more developed, and the development of the urban flood infrastructure is not able to keep up with the speed of the urbanization. Coupled with the fact that the climate has been becoming more erratic and uncertain, with rainfall intensity becoming more and more difficult to predict, there is an increased flood risk and corresponding challenges to urban flood risk management (Ashley et al., 2007; Nie et al., 2009). Thus, it is of great interest to investigate alternative solutions that are effective and promote resilience to the current and future conditions.

In Korea, rainfall events have been getting more serious for the past decades. Analyses of the last 100 years (1911-2010) of climatic data show that extreme rainfall events associated with urban flooding have statistically significantly increased in Seoul in the Republic of Korea. In September 2010 and July 2011, the Gwanghwamun area in Seoul was inundated for more than two hours due to the insufficient capacity of the drainage system to cope with the torrential rain. The occurrence of these floods has been deemed man-made due to the inadequate drainage systems, and was worsened by the low elevations of the city. Thus there is a need to take effective anti-flood measures to protect the citizens' lives and property.

In this paper, a review on the historical climate trend and future climate change trends will be conducted, in order to have an overview of how the climate trends will be changing, especially the rainfall. Also to investigate the effectiveness of using flood resilience measures, a hydrologic-hydraulic sewer model (in this case DHI MOUSE is used) will be set up for a flood-prone region where various flood resilience measures are implemented to reduce the flooding.

2. CLIMATE CHANGE

The global mean temperature has increased by 0.6±0.2C° in the 20th century, and it has been forecast that is will increase by a further 1.4C° to 5.8C° before the end of 2100 depending on the emission scenarios. This paper summarized the estimates obtained for the SRES A1B scenario selection comes from the IPCC 4th Assessment Report. Here is the forecast rainfall from Korea Meteorological Administration (KMA) for Incheon city until 2100.

The SRES A1B scenario is used for this research were results of rainfall intensity increase rate analyzed by Kim, H.S (2011), which was used to compute the rainfall input data for the MOUSE modelling. For the rainfall input of the MOUSE modelling, the rainfall intensity of 50min critical time is used as it gives the largest peak discharge.

Table 1. Forecast Incheon rainfall from the IPCC 4th Assessment Report

Classify	Present	Rainfall Considering Climate Change		
		2011-2040	2041-2070	2071-2100
Increase Rate (%)	-	1.4	12	12
Rainfall Intensity of 1hour critical time (mm/hr)	75.23	76.28	84.26	84.26
Rainfall Intensity of 50min critical time (mm/hr)	68.01	68.96	76.17	76.17

3. SOFTWARE

DHI MOUSE software is used for the modelling of the pipe system of Incheon Gyo watershed. In this program, there are 2 components: mainly the rainfall-runoff model and the pipe-flow model. In the rainfall-runoff model, a Time/Area method is used. In this model, the runoff amount is controlled by the initial loss, size of the contributing area and by a continuous hydrological loss. The shape of the runoff hydrograph is controlled by the concentration time and by the time-area (T-A) curve. As for the pipe flow model, the computation is based on an implicit, finite difference numerical solution of basic 1-D, free surface flow equations (Saint Venant).

4. CASE STUDY AREA

The case study area for the hydrologic-hydraulic sewer model is Incheon Gyo watershed which is an urbanized area located in Incheon city, near the Incheon Port. This area has been developed very early in the 1980s, with low and flat terrain that are almost completely covered with factories and buildings, making this area having high imperious ratio number. This makes it more vulnerable to torrential rains where the overland flow is slow due to the gentle terrain. In order to cope with the increasing flood situation, the government has made large investments in traditional flood measures in the form of pipe extension works. However, with the increasing rainfall intensity, the extended pipes are no longer able to cope with the runoff during the rainy months, especially in July. This causes localised flash floods which results in inconvenience and property damages to the region and its citizens.

The Incheon Gyo watershed has an area of 34km² and length of 8 km. The elevation of the Incheon Gyo watershed which is linked with Yellow Sea through two retention pond is within 5.4m to 6m. As mentioned above, the slope of Incheon Gyo watershed is very mild (S=0.01%) and has an 81.4% of impermeability layer with a complicated drainage network system. It should be noted that the large tidal range of Yellow sea (9m) which is linked with Incheon Gyo watershed has a additional impact on the drainage of the Incheon Gyo watershed as the rainfall runoff are not able to be release downstream when the tides in the Yellow Sea is high.

Located in the northwest part of Incheon, Korea, it is divided into seven sub-catchments: the Songhyun, Seknam, Gajwa, Dohwa, Juan, Ganseok1 and Ganseok2 sub-catchment areas as shown in Figure1.

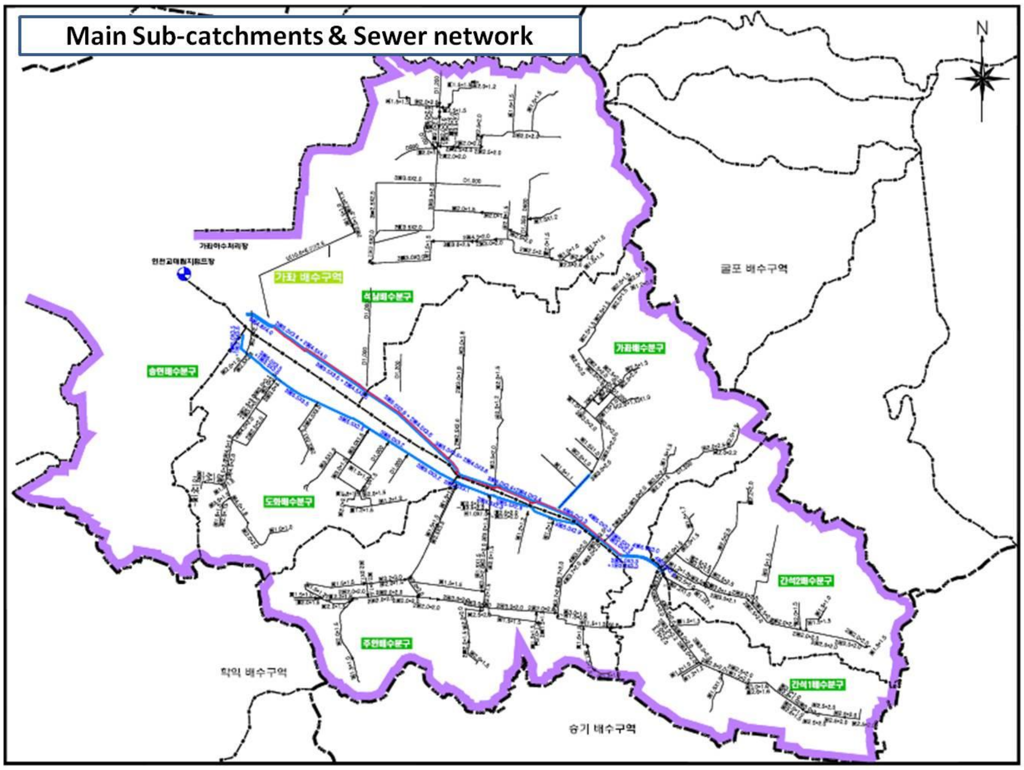

Figure 1. Sub-catchments of Incheon Gyo watershed

The landuse allocation of the Incheon Gyo Watershed is shown in Table 2.

Table 2. Outline of the Incheon Gyo Watershed (Unit: ha)

Characteristics of Basin		Drainage Zones	Total	Dwelling	Business	Industry	Farmland
Incheon Gyo	Left side Bank	Ganseong 1	312.1	255.7	33.2	-	23.2
		Juan	533.7	333.5	75.3	71.0	53.9
		Dohwa	337.8	145.1	37.4	155.3	-
		Subtotal	1,183.6	734.3	145.9	226.3	77.1
	Right side Bank	Ganseong 2	346.4	249.5	47.8	-	49.1
		Gajwa	650.8	115.3	-	353.3	182.2
		Subtotal	997.2	364.8	47.8	353.3	231.3
	Subtotal		2,180.8	1,099.1	193.7	579.6	308.4
Seognam waterway		Seongnam	910.9	204.4	38.4	357.9	310.2
Drainage		Songhyeon	302.8	161.6	67.4	61.7	12.1
Total			3,394.5 (100%)	1,465.1 (43.2%)	299.5 (8.8%)	999.2 (29.4%)	630.7 (18.6%)

5. EVALUATION OF PROPOSED FLOOD PROTECTION MEASURES

In the Incheon Gyo watershed, the implemented measures included non-structural measure: Green Roof; and structural measures: storage tank under the playground of school, pond storage in the park and infiltrated packaging of the road measures.

IMPLEMENTATION OF GREEN ROOF

Green roof technology has been used in many urban settings to improve storm water management by reducing total quantities of rooftop runoff and peak flow rates during high-intensity rains. The water quantity retention performance of green roofs has been measured and documented for a range of conditions and design parameters. Green roofs will absorb significant amount of stormwater during low to moderate rainfall and during extreme events, will delay and reduce peak flows. Research has shown that green roofs with 3" to 4" of growing medium vegetated with a mixture of sedum plants plus a commercial drainage mat, a root barrier and standard waterproofing generally retain stormwater runoff by 50-100% during most rains resulting in an average of about 50% - 75% total water retention from rainfall over a typical year (Johnson 2008).

In Korea however, there is no such research for the effectiveness of green roof on retaining the rainwater. Thus we used the findings from a case study in USA where it determines that a green roof measure can reduce 20% rainfall (IPSWICH) as shown in Figure.3 below. The findings are based on 70 storms from the two roofs which were monitored for 18 months over 2007 and 2008, conducted by the U.S. Geological Survey (USGS) in Ipswich. As there is no formal research done in the context of the Korean case study area, an assumption is made that the above findings will be directly applicable to the Korean case.

To implement the effect of the green roof on rainfall retention, the rainfall intensity input is reduced accordingly with the amount of buildings coverage in the watershed. The buildings (both industrial and residential) cover about 30% of the watershed, and an assumption that 2/3 of the buildings are retrofitted with green roofs. This resulted in a 4% reduction of probability rainfall (critical time at 50th minute) from 68.01mm to 65.09mm.

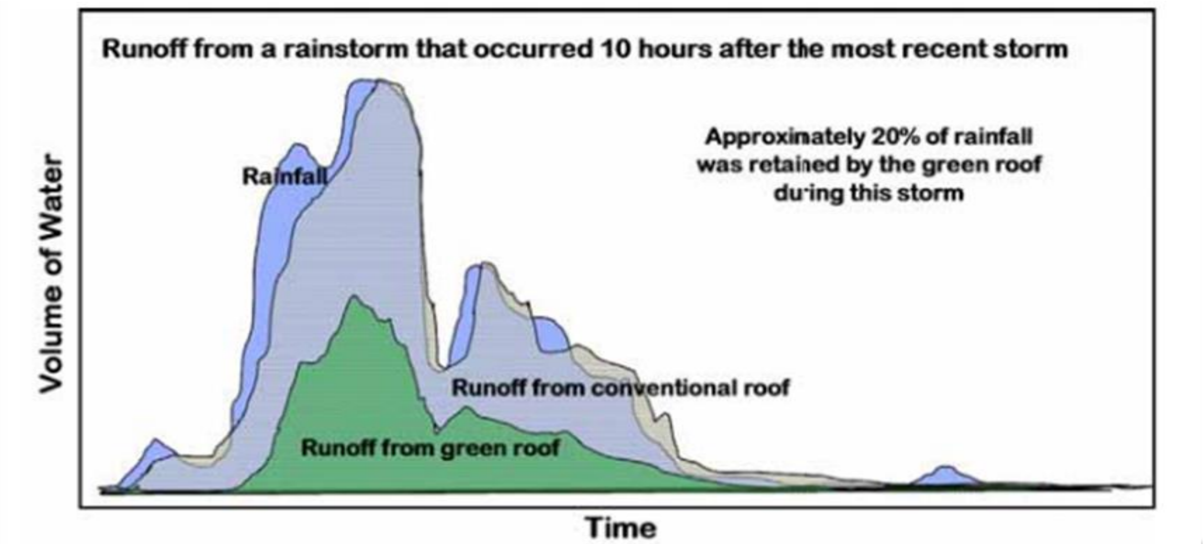

Figure 2. Effect of Green Roof Measure

IMPLEMENTATION OF UNDERGROUND STORAGE TANK IN SCHOOL PLAYGROUNDS

Additional storage tanks are implemented in 3 selected schools with large fields present. They are Sinseok primary school, Seoknam middle school and Seoknamseo primary school. Figure 3 shows their locations, and Table 4 gives the dimension sizes of three storage tanks.

One should note that there are more possible schools available for the implementation of the underground storage tanks. The reason the above mentioned sites are chosen is because of the more severe floods occurring near these 3 locations.

IMPLEMENTATION OF UNDERGROUND STORAGE TANK IN PARK

Figure 4 shows the location of the of underground storage tank in the selected park - Seknam Park. The dimension size of storage tank is about 1,170m long, 88m wide and 2m deep.

Table 1. Dimension Size of Storage Tanks

Location of storage tank	Size of storage tank (m)
Sinseok primary school	80×80×2.0
Seoknam middle school	54×54×1.5
Seoknamseo primary school	90×90×1.5

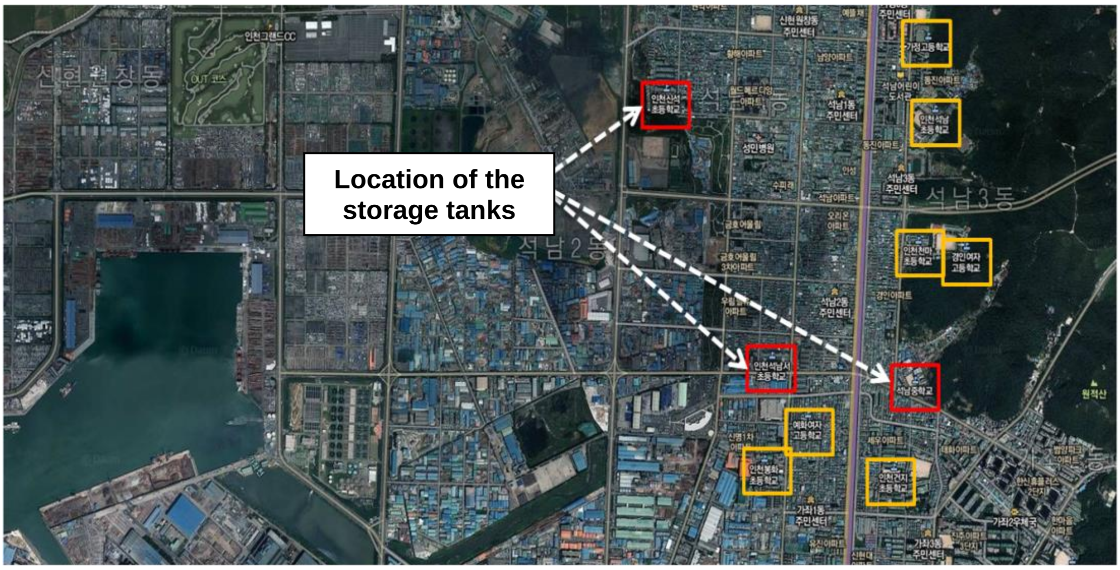

Figure 3 Location of the underground storage tanks under the three schools' playgrounds

Figure 4. Location of underground storage tank under the park

IMPLEMENTATION OF PERMEABLE PAVEMENT

To implement the effect of the permeable pavement on runoff infiltration, the runoff coefficient of the watershed catchments are reduced accordingly. A research conducted in Korea (Beum et al. 2007) shows that a permeable pavement can reduce about 30% of the rainfall runoff when compared to a normal asphalt road. This result in the reduction of the runoff coefficient of 3.3% when one consider retrofit all the roads (about 11% coverage of the watershed).

EFFECTIVENESS OF THE FLOOD MEASURES

In the existing conditions, flood is observed at many locations with flood level of up to 5.5m occurring at some manholes shown in Figure 5. With the implementation of the above mentioned measures, there is no more flood occurrences observed. This shows that a combination of resilience measures like green roof, permeable pavements and underground storage tanks are able to curb flooding without the need to enlarge or extend the existing pipe networks.

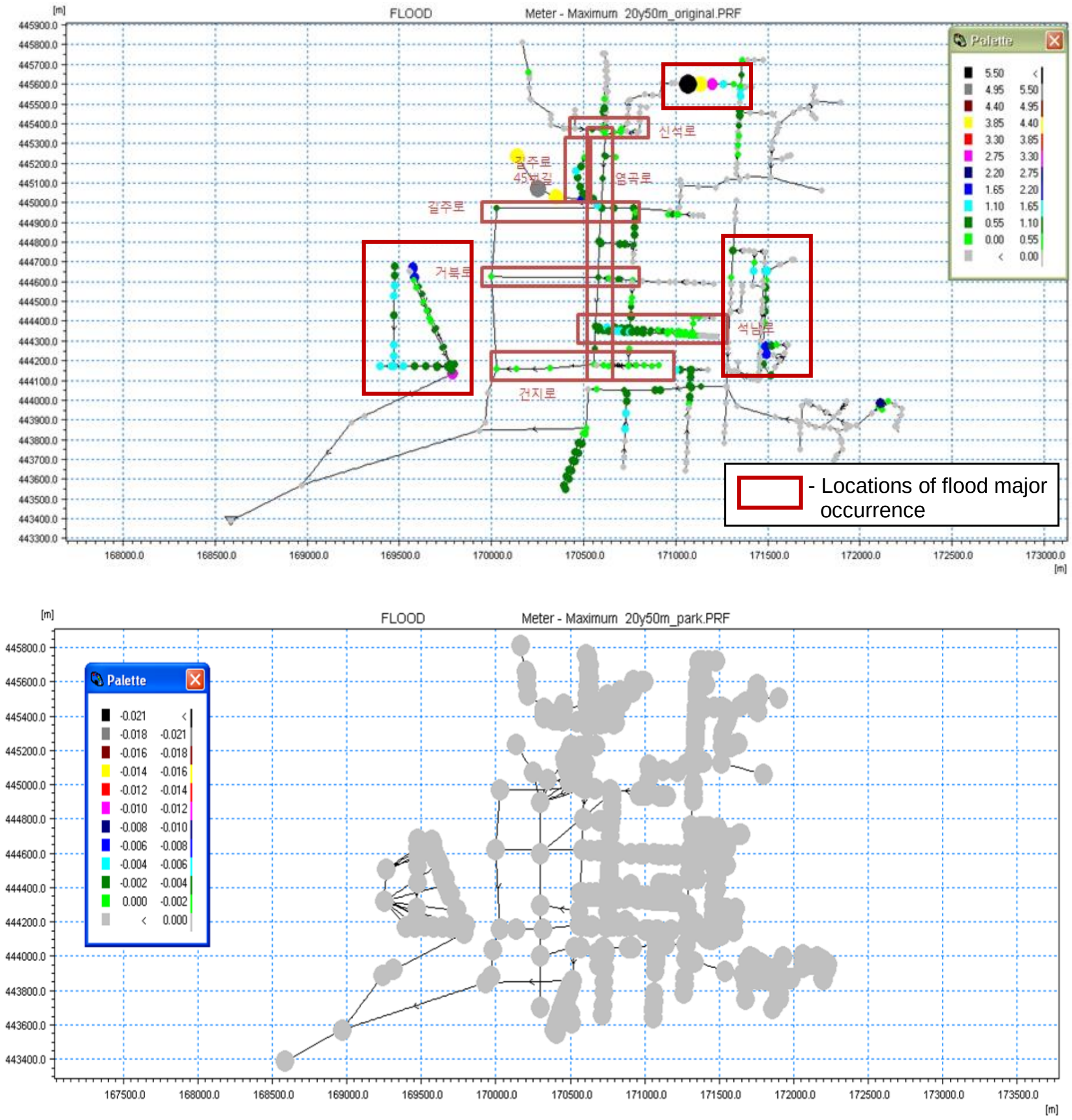

Figure 5. MOUSE results before (top) and after (after) implementation of flood measures

IMPACT OF CLIMATE CHANGE

Also, simulations of the Incheon Gyo watershed are run with the climate change scenario of A1B for 3 different time slices: present, 2011-2040 and 2040-2100. The results are shown in Figure 6 below where one can see that there is an increase of about 1 m of flood level from between present time and 2100. This shows that the flood situation in Incheon Gyo watershed will get worse in the future, and that the current measures taken should be resilience and flexible enough to respond to the increase flood level.

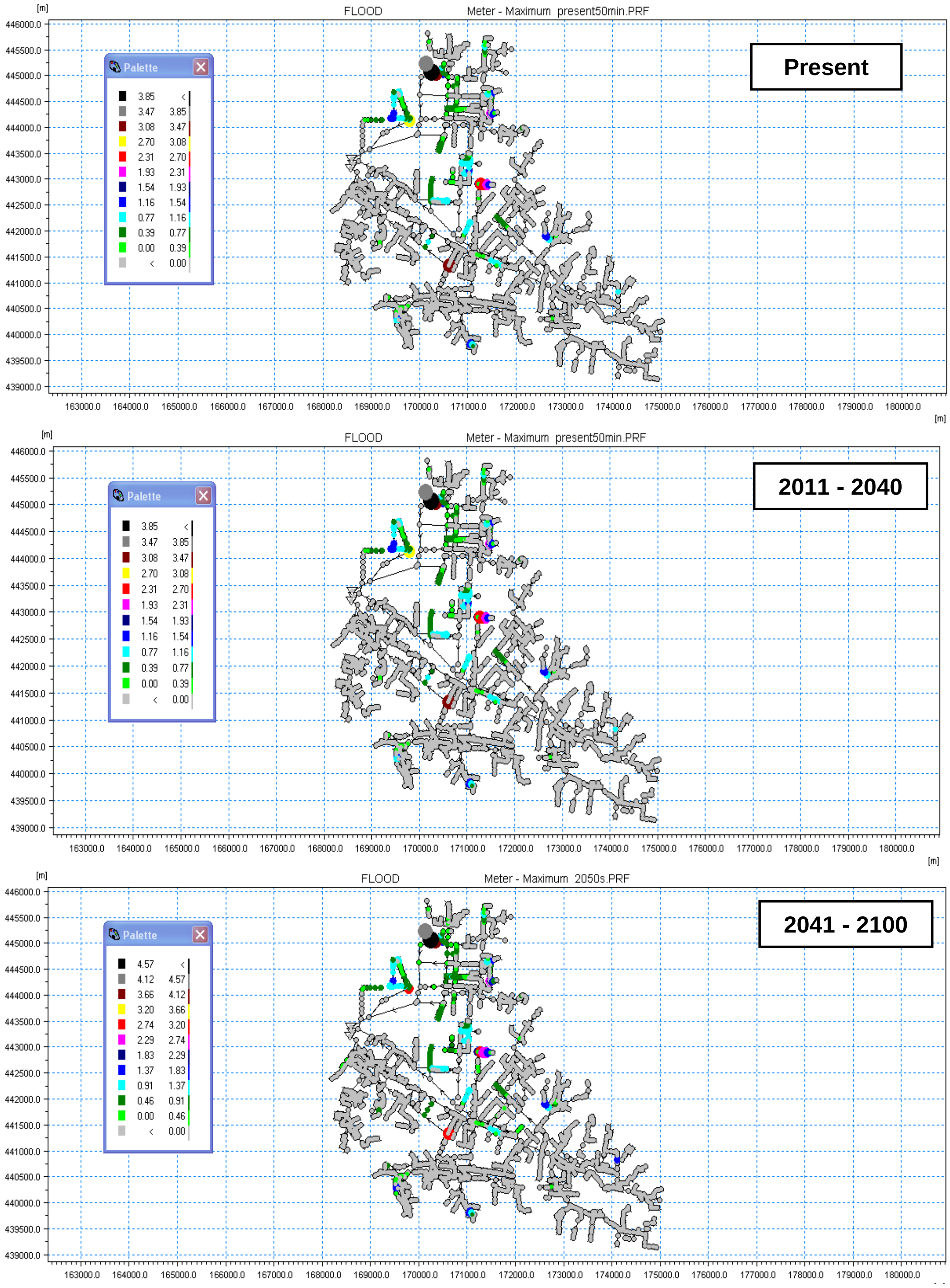

Figure 6. MOUSE results due to climate change for present (top), 2010-2040 (middle), and 2041-2100 (bottom)

6. CONCLUSIONS

In this paper, a hydrologic-hydraulic model is setup for Incheon Gyo watershed located in Incheon city to investigate the effectiveness of resilience flood measures. The results obtained show that a combination of resilience measures like green roof, permeable pavements and underground storage tanks are able to curb flooding without the need to enlarge or extend the existing pipe networks.

In addition, simulations of the hydrologic-hydraulic model for Incheon Gyo watershed is conducted for future climate scenarios and the results show that the there will be an increase of up to 1m flood level for the manholes in Incheon Gyo watershed. This shows that there is a need to have flood measures that are resilience and flexible to cope with the future.

It should be noted that the proposed implemented measures in the MOUSE model are flexible and can be further extended or add-on to cope with the additional flood in the future.

In the model, only 2/3 of the buildings are fitted with green roof with a 20% rainfall removal rate. It is strongly believed that in the future, the rainfall removal rate will be improved and coupled with an additional 1/3 of the buildings coverage, green roof as a solution is definitely one of the flexible flood alternative measures for the future. Also, only 3 out of 10 schools are fitted with underground storage tanks. This too shows that more underground storage tanks can be added to the existing pipe network to cater for future requirements.

In summary, this research has shown that green roofs, permeable pavements and green spaces coupled with underground storage tanks can provide flexible flood measures to cope with the increased rainfall in the future.

7. ACKNOWLEDGEMENTS

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