Flood hazard map of Korea

Joo-Heon Lee[1], Yongwon Seo[2], Sung-Sik Park[3], and Hyo-Seob Cho[3]

1) Joongbu University, Republic of Korea
2) Yeungnam University, Republic of Korea
3) Water Resources Information Center, Han River Flood Control Office, Republic of Korea

Tables of Contents

1. Introduction

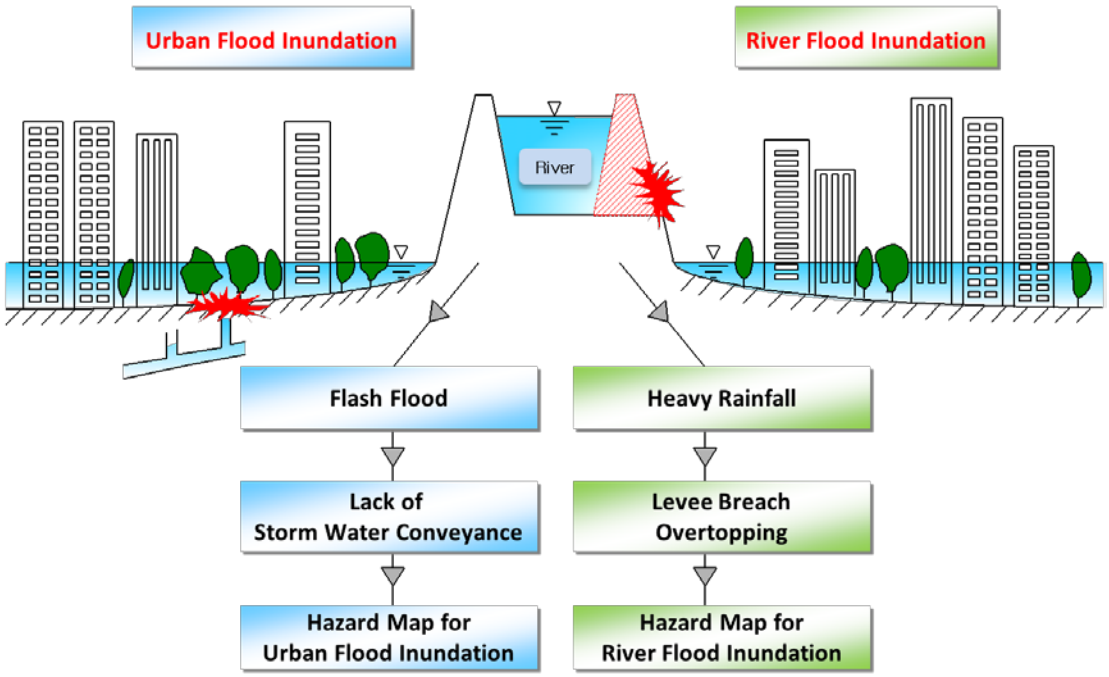
1.1 Flood disasters of Korea

South Korea have been suffered from flood year by year despite all the investment and efforts for flood prevention or mitigation. The total flood damage during the last hundred years from 1916 to 2015 is up to 43 billion USD and the annual average flood damage is up to 498.9 million USD in Korea. During the new millennium, the flood damages are even unprecedented and summed up to 24 billion USD from 2000 to 2015 primarily due to unexpected and extreme severe heavy rainstorms and typhoons. Accumulated flood damage for last 10 years are most severe in Han River Watershed followed by Nakdong River, Geum River, Seomjin River, and Yeongsan River. The flood damage of Han River Watershed was greatest for six years during last 10 years among other watersheds. The flood damage of Nakdong River Wastershed was greatest for four years during last 10 years compared to other watershed. For last 10 years, flood damages were 93.5% of total damages (65.3% from heavy rainstorms and 28.1% from typhoons) and 99.5% of total casualties from natural disasters.

In addition, a recent analysis for flood-prone areas showed that 26.6% of total damages was due to river overflows, whereas 73.4% was due to other causes such as low elevation (22.01%), insufficient drainage capacity (14.23%), insufficient pumping capacity (14.11%), overflows from manhole (13.48%), and insufficient conduit capacity (11.22%).

1.2 Concept of flood hazard map

Flood hazard map provides fundamental information of expected flood depths and extents in case of river flood and urban flood inundation in forms of paper or electrical maps. The production of flood hazard maps includes flood hazard maps for each river due to river flooding (or overflowing) and flood inundation hazard maps for important urban areas due to rainfall events that exceed the design criteria and drainage capacity. The spatial range of river flood hazard map includes all river intervals, connected tributaries and expected flooding areas depending on flood scenarios. In contrast, the spatial range of flood inundation hazard map includes total drainage zones and flooding areas due to exceeding rainfall events, water level rise in river, and pump failures and so forth depending on scenarios.



[Figure 1] Conceptualization of river flood and urban flood inundation

1.3 Practical use of flood hazard map

As mentioned earlier, flood damages are constantly increasing due to changing environments. Flood prevention measures can be divided into structural measures such as levee, dam and detention/ retention reservoirs and nonstructural measures such as flood forecasting, floodplain management, flood insurance, and flood hazard map. Structural measures are important but uncertainties of their effect keep increasing due to increasing flood risks and changing environment such as rapid urbanization and climate change and so on.

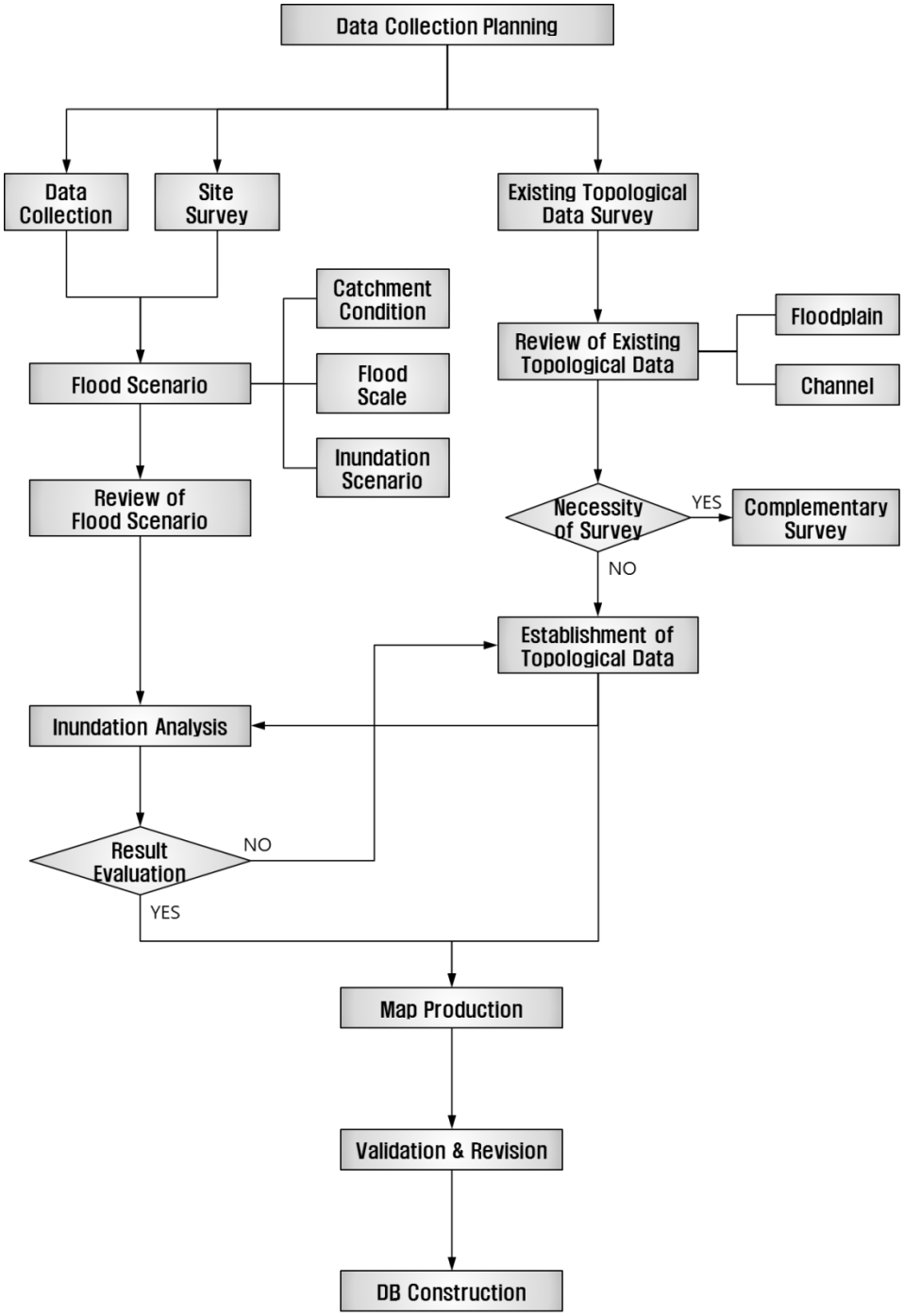
Flood hazard map as one of nonstructural flood mitigation measures is to overcome the limitation of structural measures. The purpose of flood hazard map provides some of the basic information of potential flooding areas as a form of maps to regional governments and relevant authorities for effective disaster prevention such as evacuation, flood insurance, land use regulation and so forth.

2. Flood Hazard Mapping

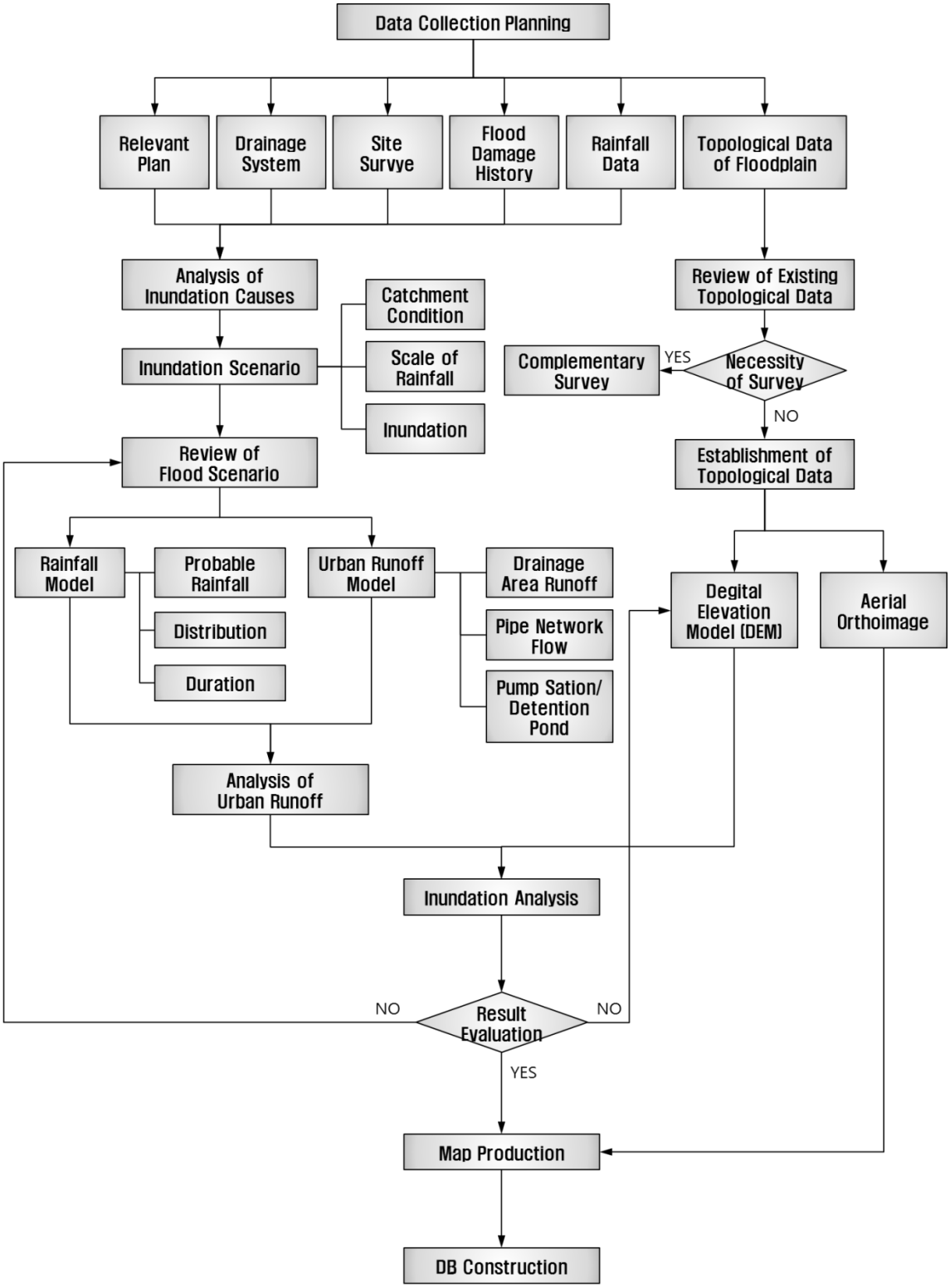
2.1 Flood hazard mapping methodology

The process of flood hazard map includes site survey, topological data construction, flood scenario, inundation analysis, and map production and DB construction. The site survey includes collecting basic hydraulic and hydrologic information, relevant plans, flood damage history and existing survey data for the target river or drainage areas. The topological data construction is a process to obtain topological information such as ground elevation for inundation analysis and, hence, it should

guarantee the required accuracy and precision for inundation analysis. A flood scenario consists of catchment condition, flood scale, and inundation scenarios. Flood and inundation analysis is performed based on flood scenarios with a methodology determined by land use and land cover. Flood inundation results are obtained by validation and revision process comparing historical flood records such as depth and water elevations. These results are mapped as a flood hazard map or flood inundation hazard map and kept in a DB system.



[Figure 2] Mapping process for river flood inundation



[Figure 3] Mapping process for urban flood inundation

2.2 Geometry for mapping

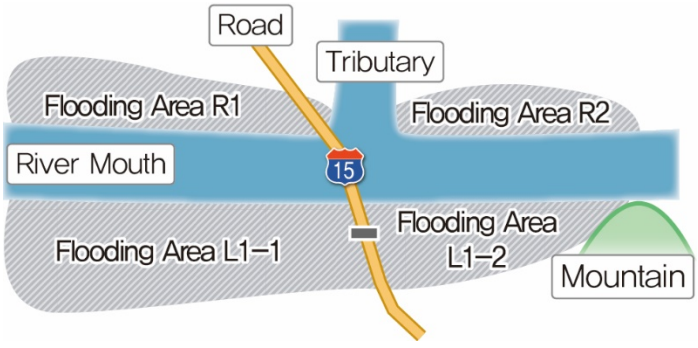
Topological data collection is a most important procedure for the inundation analysis. It can be collected from previous data and additional survey. The collection procedure can be different depending on which areas are targeted. Topological information for river flood mapping is divided into channel and floodplain. The topological data for channel is obtained from bathymetry survey and the data for floodplain is obtained from high-resolution and high-accuracy digital elevation model (DEM). The accuracy tolerance for the DEM is ±0.5 m in Korea. For the areas outside the primary urban areas, DEM (5 m×5 m) from National Geographic Information Institute (NGII) can be used. For the purpose of urban flood inundation, additional information is required for the analysis such as drainage network, pumping stations and storages.

2.3 Scenarios for flood hazard mapping

Flood scenarios determine the proper conditions of maximum inundation or flooding based on objective reasoning for the target areas. The scenarios can be divided into three types depending on the procedures as follows:

(1) Watershed scenario

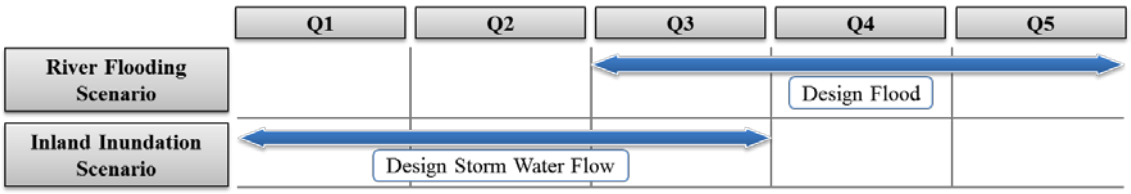
- Overall conditions that affect flooding such as land cover, land user plans, flood mitigation measures
- Separate a target area as a zone considering land use and geography such as tributaries for river flooding analysis
- Separate target areas as a drainage zone considering drainage systems and characteristics



[Figure 4] Zoning flooding area effected by given flood event

(2) Flood magnitude scenario

In case of river flood inundation analysis, it is required to calculate flows for each return period, which is the same for urban flood inundation analysis considering river flows.



[Figure 5] Scenario of flood magnitude

(3) Flood inundation scenario

Flood inundation scenarios consist of river flood inundation (external causes) and urban flood inundation (internal causes). Design of scenario does not just mimic the previous flooding but comprises all possible conditions that result in potential flooding depending on the purpose of flood hazard map. Moreover, the scenario aims to delineate the flood-prone low land areas considering various conditions of flooding.

- River flood inundation assumes,
  - Overflows
  - Levee breach
  - Categorizing inundation types depending on analysis tools

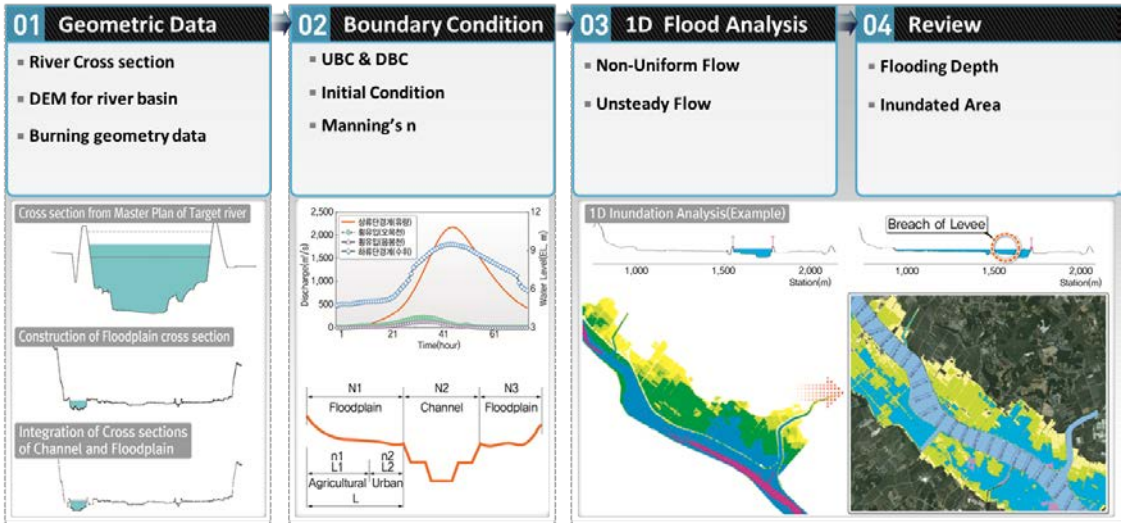
- Urban flood Inundation assumes,
  - Exceeding pipe (conduit) capacity
  - Confluence of low lands
  - Drainage failure due to higher river water level
  - Pumping station failure

2.4 Hydraulic modeling for estimation of expected inundation area

In general, flood inundation caused by river flooding (external flooding) and urban flooding due to drainage issues (internal flooding). In case of external causes, the flooding is divided into three types: advection type, storage type from one-dimensional (1-D) analysis, and diffusion type from two-dimensional (2-D) analysis, which are caused by overflows or breaches. In case of internal causes, the flooding depends on its causes such as drainage issue, pumping station failure,

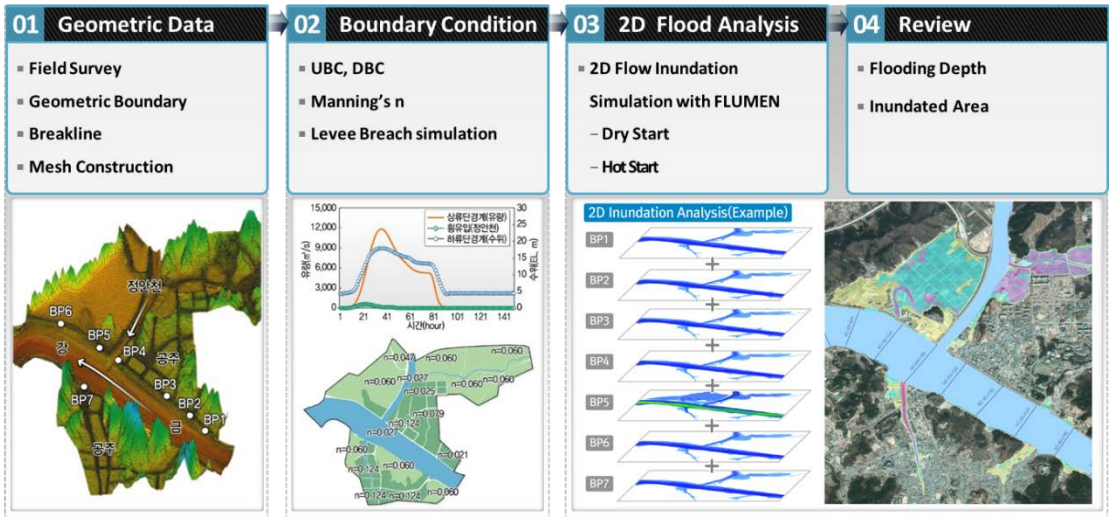
insufficient conduit capacity, and so forth.

For one-dimensional analysis, HEC-RAS is utilized in Korea and the application procedures are depicted in Figure 6.



[Figure 6] 1-D hydraulic modeling for estimation of expected river flood inundation area

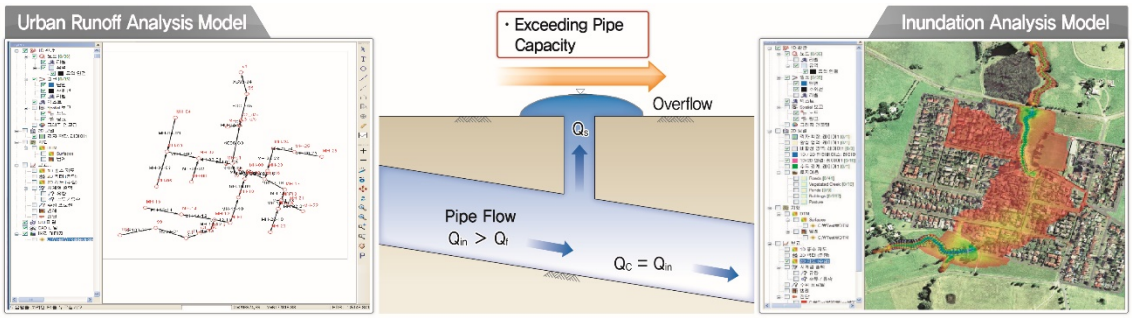
External flooding requires two-dimensional unsteady simulations considering channels and floodplains simultaneously. However, channels and floodplains can be separately modeled with appropriate modeling techniques for the purpose of modeling efficiency. In Korea, FLUMEN is utilized for two-dimensional unsteady flooding simulation and the procedures are described in Figure 7.



[Figure 7] 2-D hydraulic modeling for estimation of expected river flood inundation area

In case of internal flooding analysis, two-dimensional unsteady analysis can be adopted to simulate

tributary flooding and inundation. Typically, flooding volume is calculated considering drainage networks and pumps capacities, which leads to flooding depth analysis with urban flooding modeling schemes.



[Figure 8] Urban drainage modeling for estimation of expected urban flood inundation

3. Dissemination of Flood Hazard Map Information

Flood hazard maps are distributed to central and regional governments for the purpose of flood prevention/mitigation policies and activities. Ministry of the Interior and Safety (MOIS) utilizes flood hazard map as a basis for hazard map, flood insurance map, life safety map, and so forth. Regional governments utilizes flood hazard map as a basis for flood insurance map, flood-prone area management “Countermeasures against Natural Disasters Act” and “Storm and Flood Insurance Act. Flood hazard map can provide basic information for natural disaster management policies and reduce the budget and effort at the same time.

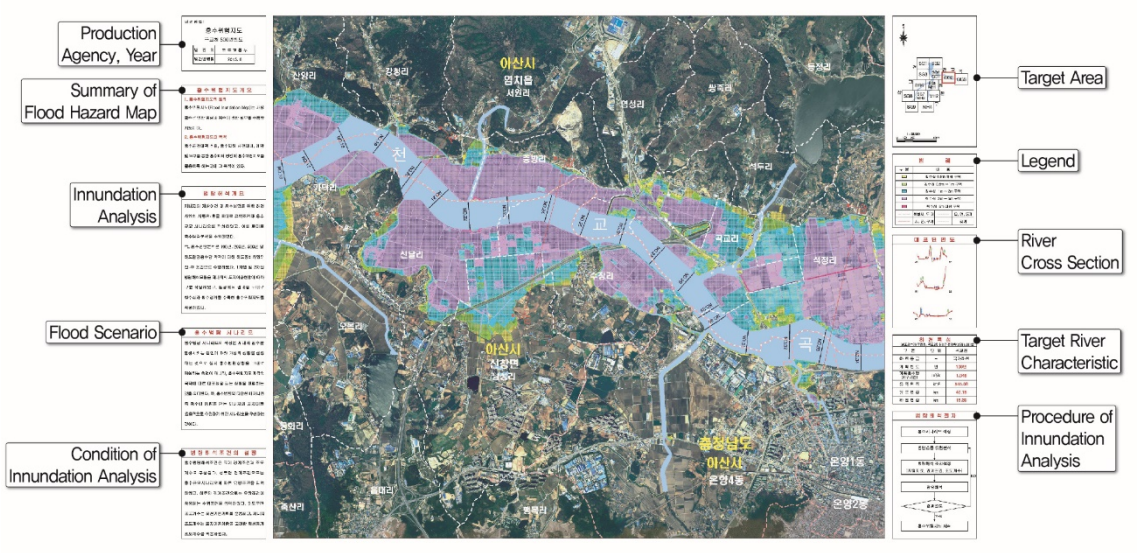
Moreover, relevant authorities such as research institutes can utilize flood hazard map for research purposes and even people can identify flood risk areas based on flood hazard maps. Currently, announcement to public is quite limited due to secondary causes such as complaints. However, more notification is expected in the future through the form of life safety guidance. Basin information of flood hazard map is distributed as a form of paper map or electronic map with all the results from the production processes.

[Table 1] Sharing and dissemination of flood hazard map information

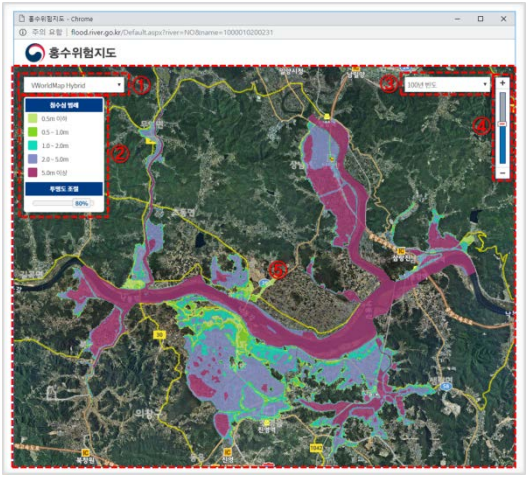
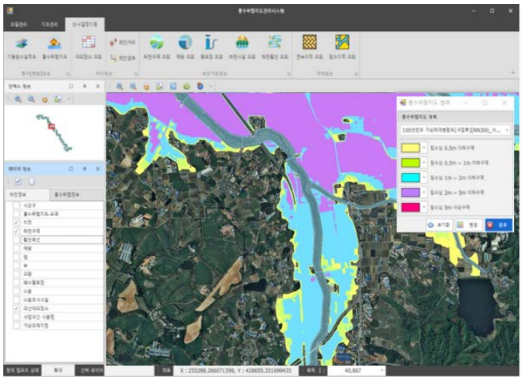
Index		Relevant task	Resource
Government	Central (MOIS) and regional	• Disaster map • Storm and Flood insurance map • Regional risk assessment • Insurance rates • Natural disaster mitigation plan • Preliminary natural disaster assessment • Flood risk areas and management • Flood forecasting • Structure management	• Flood hazard map • Analysis results • Electronical DB for target areas

Research institutes	• Flood risk map • Natural disaster research
Public	• Identification of flood prone areas

Flood hazard map has a form of paper map and system (electronical) map. The map overlays flood risk areas over existing maps, which provides integrated information to readers. Paper maps follows a standardized form including map structure, revision frequency and other information. Electronical maps provides two ways: one from a web-based and the other from standalone systems.

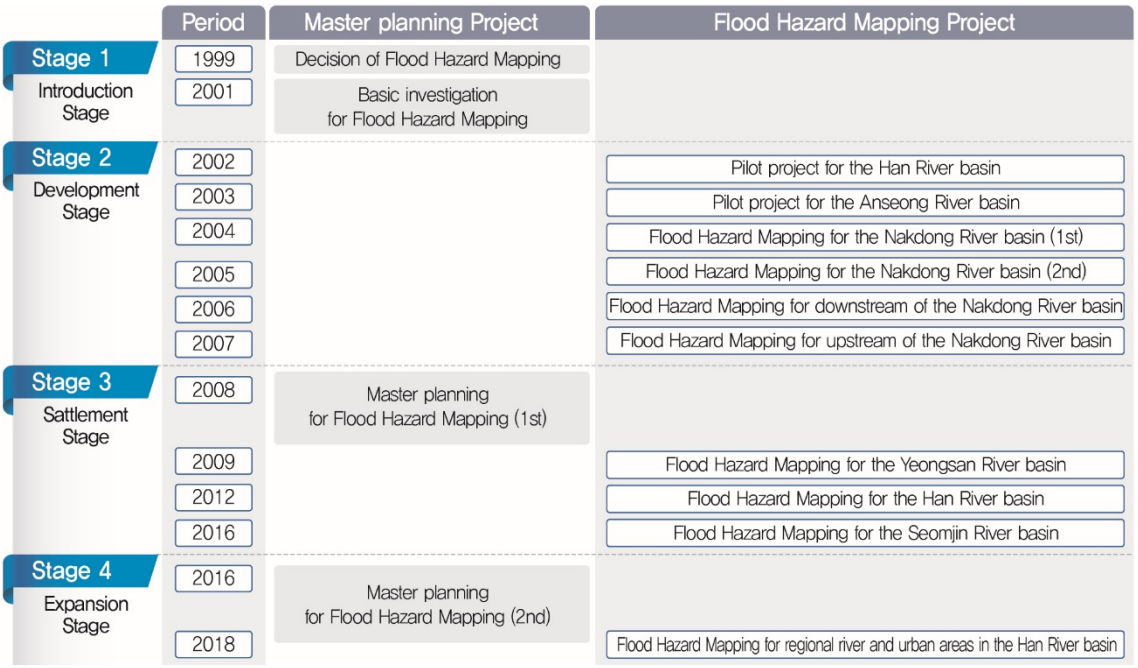


[Figure 9] Flood hazard map (sample)

	
Web system	Stand alone

[Figure 10] Management system of flood hazard map

4. History of Flood Hazard Map Project of Korea



[Figure 11] History of flood hazard mapping of Korea

In 1999, the Flood Disaster Prevention Planning Board decided to produce flood hazard map as one of nonstructural measures for flood mitigation. Basic investigation started in 2001 and the completion of the flood hazard map for national rivers was 2016 for 62 sites and 2,332 km lengths nationwide. Han River Flood Control Office (HRFCO) continues to produce flood hazard maps for regional river and urban areas and expects to complete the map production for entire rivers in Korea by 2021. Rivers in Korea are divided into “national” and “regional” rivers depending on management authority. The total lengths of 3,776 regional rivers nationwide are up to 26,872 km. Moreover, HRFCO established a guideline for flood hazard map production to ensure the map quality and regularly revise considering the most up-to-date technologies and methodologies.

[Table 2] Contents of Guideline for flood hazard mapping of Korea

Chapters	Contents
Chapter 1. Overall rules	• Purpose • Application scope • Relevant regulations • General Terms
Chapter 2. General guidelines	• Institute • Project Scope • Project Duration • Expert council and advices

Chapters	Contents
	• Consultation with relevant authorities
Chapter 3. Data investigation	• Hydrologic data collection • Relevant planning • Flooding history • Site survey • Other investigation
Chapter 4. Survey and topologic data collection	• Accuracy tolerance • Existing data collection and applicability • Survey scope • Methodology • Topologic data collection
Chapter 5. Flood scenario	• Catchment condition scenarios • Flood scenarios • Inundation scenarios
Chapter 6. Flood and inundation analysis	• 1D modeling for river flood inundation • 2D modeling for river flood inundation • Urban flood inundation
Chapter 7. Map production and quality control	• Terms on reports • Terms on map production • Quality control
Chapter 8. Database and system	• DB • Flood Mapping Web System
Chapter 9. Utilization	• Emergency action plan • Disaster map • Natural insurance management map • Integrated planning of natural disaster mitigation and management • Other applications

5. Administrative, Legal and Institutional framework

Flood hazard map in Korea is produced following Article 7 “Act on the Investigation, Planning and Management of Water Resources” to promote management before and after a flood event for the mitigation of casualties and property losses as much as possible. Flood hazard map can be utilized to produce hazard maps specified by “Countermeasures against Natural Disasters Act”, of which purpose is to support evacuation primarily. The authority in charge of production of flood hazard map is the minister of Ministry of Environment and, if necessary, a head of a regional government can produce flood hazard maps for the extents of jurisdiction and notify the results to the minister and relevant authorities’ heads.

[Table 3] Administrative, legal and institutional framework for flood hazard mapping of Korea

Index	Act on the Investigation, Planning and Management of Water Resources	Countermeasures against Natural Disasters Act
Act and	• Act: Article 7 (Investigation of	• Act: Article 21(Various types of maps

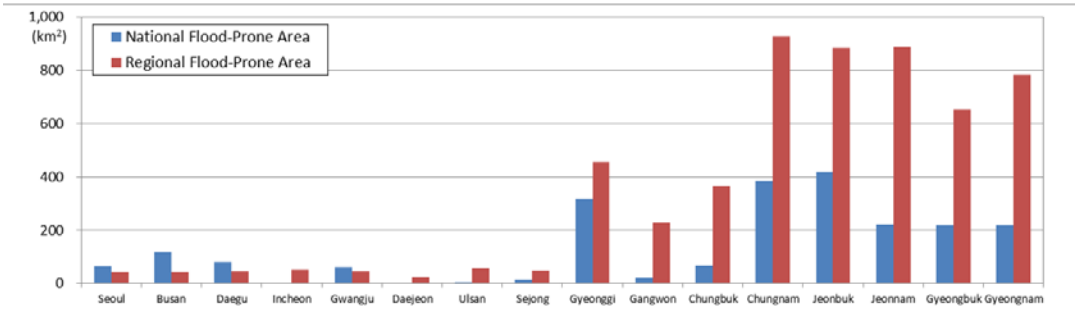
ordinances		flood/drought damage) • Ordinance: Article 5 (Production of flood risk map/ drought vulnerability map)	production and utilization) • Ordinance: Article 18(Types of disaster maps)
Authority		• Ministry of Environment	Ministry of Interior and Safety
Flood	Before	• Production of flood hazard map • Distribution and utilization of flood hazard map	• Production and utilizationof disaster information map • Evacuation/disaster informative/education • Flood forecast map • Flood risk map/coastal flood map
	After	• Investigation and analysis of flooding • Flood depth, duration, area	• Flood marks investigation/map production and reservation • Site flood marks management map (electronic form)

6. Good Practices, Lessons Learned and Gaps

6.1 Utilization of flood hazard map in regional areas

HRFCO investigates utilization rate of flood hazard maps every year targeting regional governments. The results showed that the utilization rate is 69.8% in 2018. The results shows more than half of the regional government utilized flood hazard maps and the rate keeps increasing yearly. Recently, MOIS started to utilize the maps for the production of natural disaster insurance management map and life safety guidance map services. The investigation showed that 25.52% of the regional governments utilized the maps to establish integrated natural disaster mitigation plans. 17.24% of the governments answered that they utilize the flood hazard map for preliminary natural disaster assessment, 14.48 % for designation of flood-prone areas, and 13.10% for production of disaster information maps.

The reasons for not utilizing the flood hazard maps include insufficient notification for the map production (37.27%), insufficient notification for relevant acts and regulations (24.55%) and emotional complaints from residents (15.45%). Mostly, regional government required the production expand to regional rivers and urban flood inundation or flood maps. After the completion of flood hazard maps in 2021, the utilization rate is expected to keep increasing.



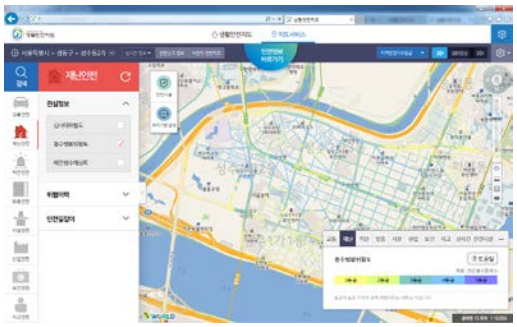
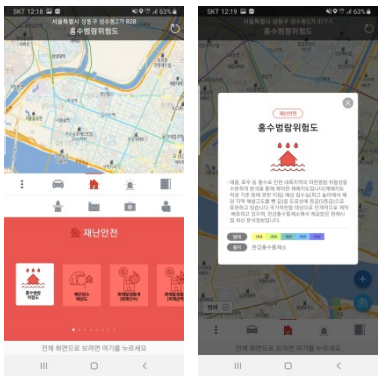
[Figure 12] Regional flood-prone areas of Korea

6.2 Public disclosure of flood hazard map information

Institutionally, the utilization of flood hazard map is limited by worries about public complaints about disclosure of flooding information. The flooding information of flood hazard maps has been provided to regional government but limited to public. However, the request for disclosure of information keeps increasing due to highly developed information society, public right to know, and ensuring safety. Moreover, extreme hydrologic events potentially by climate change start to threaten the safety standard of existing structural measures such as levees and dams, which require all the citizen to identify flood risks nearby exactly.

However, the disclosure of flood information should be done gradually based on agreement and understanding of the public. It is necessary to make citizens understood that the flood information is useful and beneficial to them. Therefore, the flood information provided by flood hazard maps can be categorized by characteristics and delivered to the citizens when they actually need it. This would help to change the public understanding of flood slowly but steadily. For example, practical maps such as life safety maps or life sympathy maps provided by various authorities and governments can be an excellent platform to present the flood information more friendlily. Especially, more practical purposes such as traffic information considering flooding areas can be a good example to provide flood information.

Recently, MOIS started to provide hazard information as a form of life safety maps to promote citizens to identify and prepare themselves more actively. The safety information provided by life safety maps includes traffic, disaster, public order, facilities, industry, hygiene, accident information. The safety maps also provide disaster information such as flooding, coastal flooding, landslide, earthquake information. Currently, flood hazard maps provide flood risk information as one of disaster information to the public in forms of web services and mobile application services.

	
Safety map web service for Living	Safety map mobile application service for

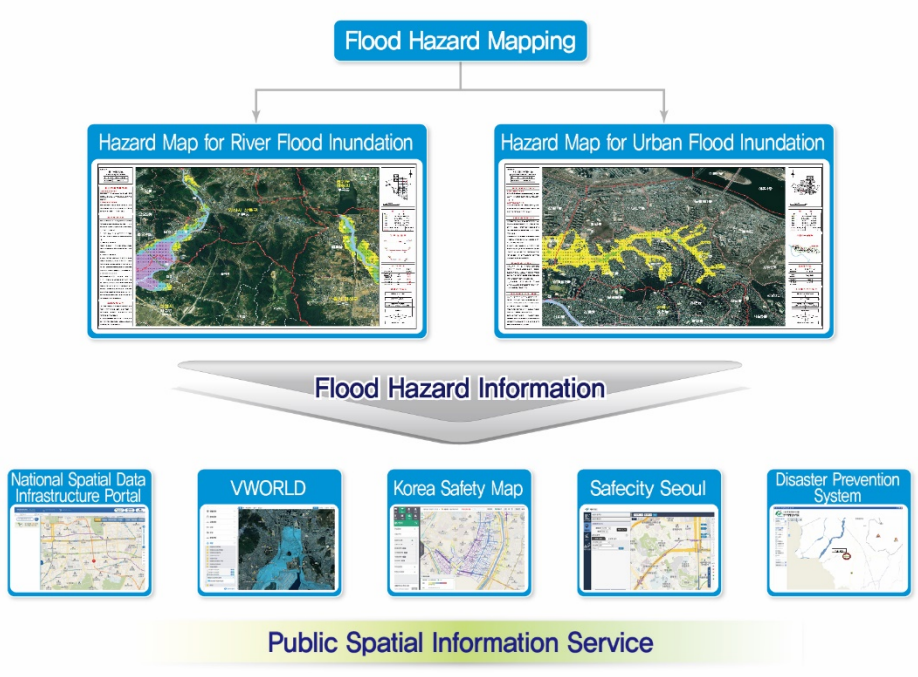
Environment	Living Environment

[Figure 13] Information system of flood hazard map

7. Future Plans for Flood Hazard Map Usage

7.1 VWORLD service and flood hazard map

Currently, the Ministry of Land, Infrastructure and Transport (MOLIT) provides the VWORLD map service where geographic information is categorized into land, life/safety, culture/tour, transportation/aviation, industry, environment, agriculture/forestry, and marine. Especially, life/safety category map service provides safety map, protection facility map, pedestrian priority, and landslide risk information. The information from flood hazard map can be integrated into a VWORLD category to support policy makers and decision makers in terms of national water resources management and planning.



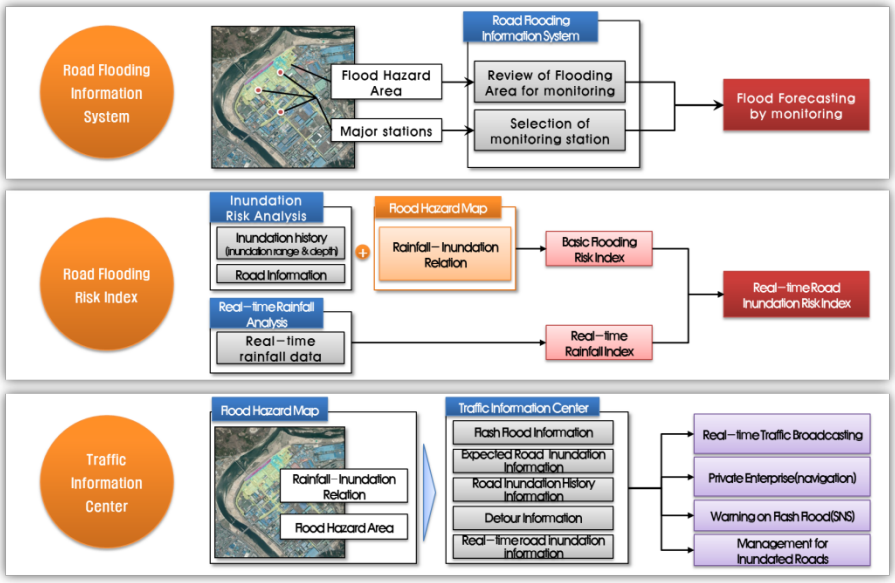
[Figure 14] Incorporating public geographic information service with flood hazard maps

7.2 Road inundation information

Number of flooding roads keeps increasing due to convectional summer storms potentially due to climate change. It is important to identify and distribute information about flooding roads beforehand and flood hazard map can be utilized in this. In Korea, insurance companies built road information systems by themselves that provide flooding information especially for flood-prone areas. Central and regional traffic information centers provides traffic safety information about

changing road conditions to relevant authorities and organizations through a traffic information management system. Flooding information, such as flood-prone areas and real-time weather information, belong to the traffic safety information that the system provides. However, the information from flood hazard maps is not currently utilized and not even recognized by the system builders and managers. Therefore, the information provided by flood hazard maps can be combined into road information system of the insurance companies to improve the system performance by feedback from both sides such as real time flood depth forecast based on expected amount of potential rainfall.

The traffic safety information provided by the central and regional traffic information centers can be improved by the results of expected flooding areas based on flood hazard maps. The flood forecasting system can be combined with the traffic information system to support real time flooding forecasts that can be delivered to the public, organizations and relating authorities. Moreover, flood hazard map can contribute to improve accuracy of real time road flooding information or risk index based on real time rainfall amounts. Integrating spatial geographic information and flooding depth also can contribute to the flood hazard monitoring system.



[Figure 15] Road inundation information based on flood hazard maps

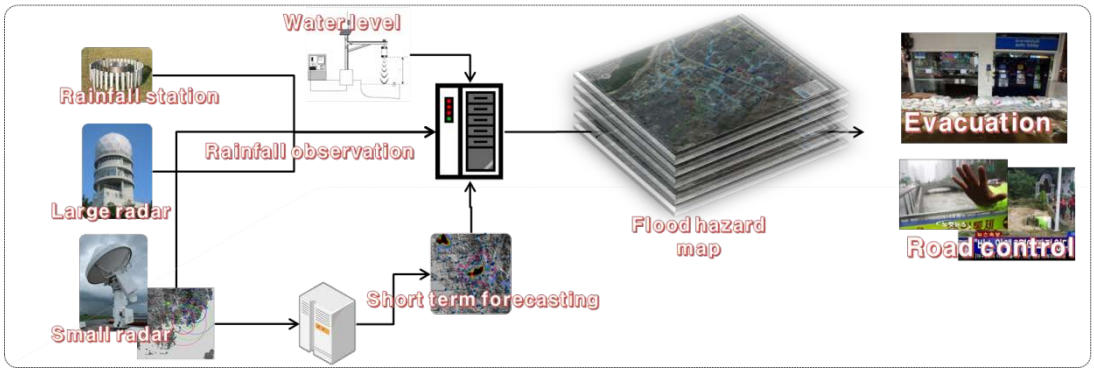
7.3 Improvement of flood forecasting system

Flood hazard map can contribute to improve the flood forecasting system by spatial presenting real time flood area forecast by spatial flood forecasting system. Spatial flood forecast can be divided into spatial flood forecast based on scenarios and dynamic spatial flood forecasting based on real time flooding analysis. Flood hazard map can contribute to improve the scenario-based spatial flood

forecast because the production of flood hazard map is based on a scenario-based procedure. The database built for flood hazard map can be directly used to improve the spatial flood forecasting based on scenarios shortly.

In addition, real time spatial flood forecasting can be obtained by real time flood simulation and analysis in a long term. However, current computing power limits the application of real time flood simulation due to long simulation time, which deteriorates three factors of flood forecasting including accuracy, proper timing and reliability. It is expected that substantial amount of technical advances and infra are necessary to accomplish this.

Currently, the scenario-based spatial forecasting system, combined with river flood hazard maps and urban flood risk maps, is regarded as the best alternative for improving flood forecasting system. It is expected that real time dynamic spatial flood forecasting system would be possible in near future with technical advances.



[Figure 16] Improvement of flood forecasting system

[Table 4] Comparison of spatial flood forecasting methodology

Flood forecast	Scenario-based spatial flood forecast	Real time simulation-based spatial flood forecast	Remarks
Summary	· Utilizing existing information from flood hazard maps	· Dynamic spatial flood forecasting based on real time simulation	
Buildup	· Integrating existing flood hazard map information - River flooding: WSE-flood extent -Urban flooding: Rainfall-flood extent	· Combined modeling of rainfall runoff modeling and flood inundation modeling · Improved technical background	
Pros and Cons	· Quick evaluation of flood extent utilizing existing information · Limitation of scenario-based modeling	· Computing power limitation · Uncertainties for forecast	

Flood forecast	Scenario-based spatial flood forecast	Real time simulation-based spatial flood forecast	Remarks
Evaluation	Short term improvement of spatial flood casting based on flood hazard map information	Long term improvement of spatial flood forecasting based on real time simulation	

7.4 Integrated toolkit for river management

Flood hazard map is a special form of a map that provides flood inundation information, such as flood depth and extents, combined with catchment's geographical information. Flooding is divided into external and internal flooding depending on its causes. Flood hazard map for each river illustrates flooding area extents by levee overtopping or breaches. In contrast, urban flood inundation map illustrates flooding areas extents by insufficient drainage system capacities. The management of a river system has been focused on river structures such as levees so far but not much focused on urban areas that can be potentially affected by river flows.

Levee is a structure along river protecting urban areas. Understanding the characteristics of each urban area protected by levees is essential for effective flood mitigation and river management. These areas have their original conditions and characteristics affecting flood. In this regard, river flood hazard maps and urban flood inundation maps is considered as a flood map in a narrow sense or a basic system to expand river management from rivers (lines) to protecting areas (areas) in a broad sense at the same time, which enables us to combine all the information provided by flood hazard maps, such as structures, assets under flood risks, flood vulnerability, casualties and so forth, in order to provide integrated river flood management. In addition, the information provided by flood hazard map can be utilized as a basis for the assessment of flood mitigation measures and alternatives.

[Figure 17] Integrated river flood management

8. References

MOLIT (2008) Basic planning for flood hazard maps, revised (2nd)

MOLIT (2008) Guidelines for flood hazard map production

MOLIT (2016) Basic planning for flood hazard maps, revised (3rd)

MOE (2018) Flood hazard map for regional urban rivers in Han River Watershed