PFHA of NPP site considering extreme precipitation in Korea

2020. 2. 19.

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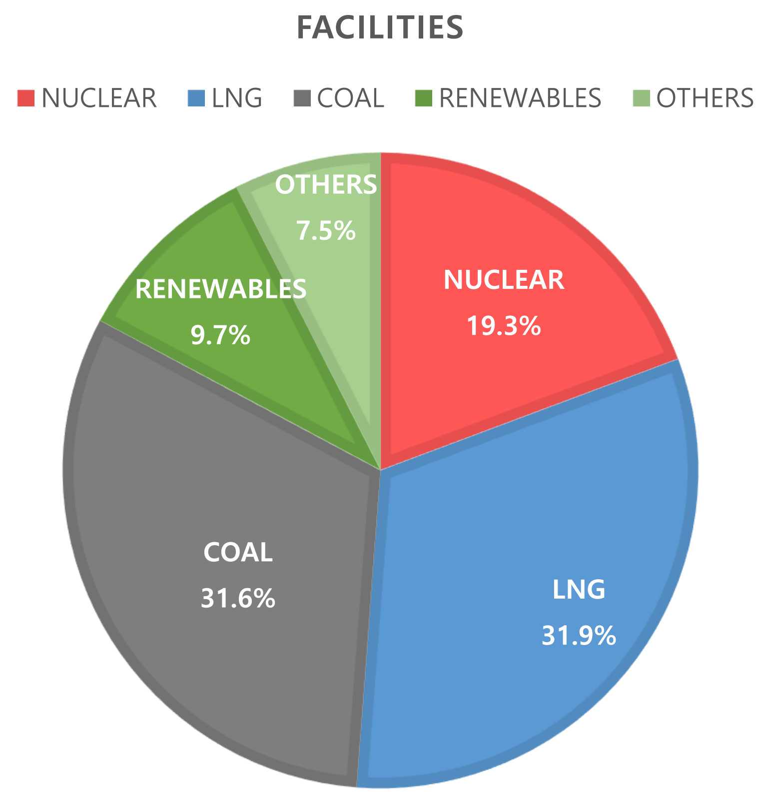
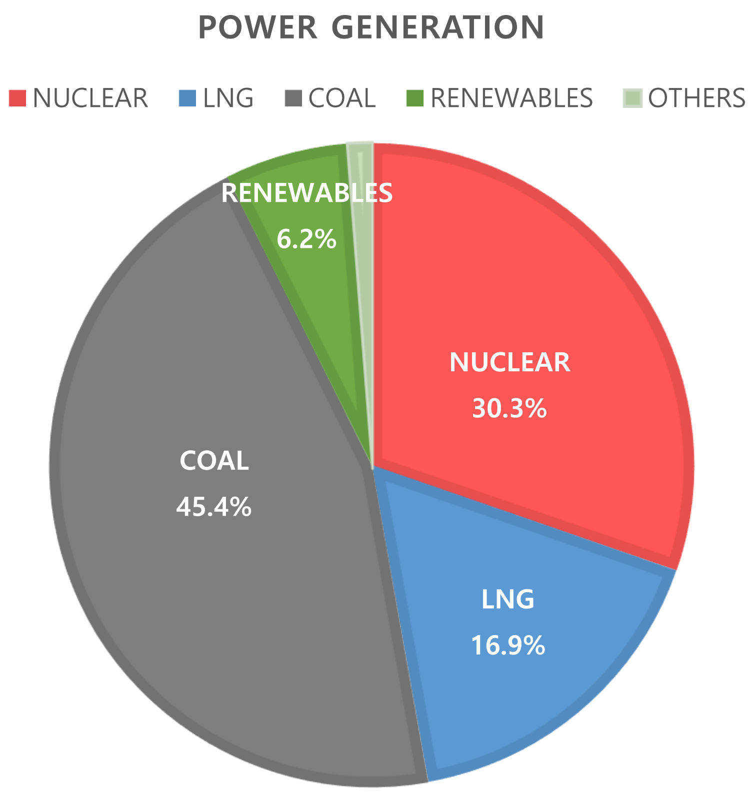
Contents

Power Generation Capacities in Korea(2017)

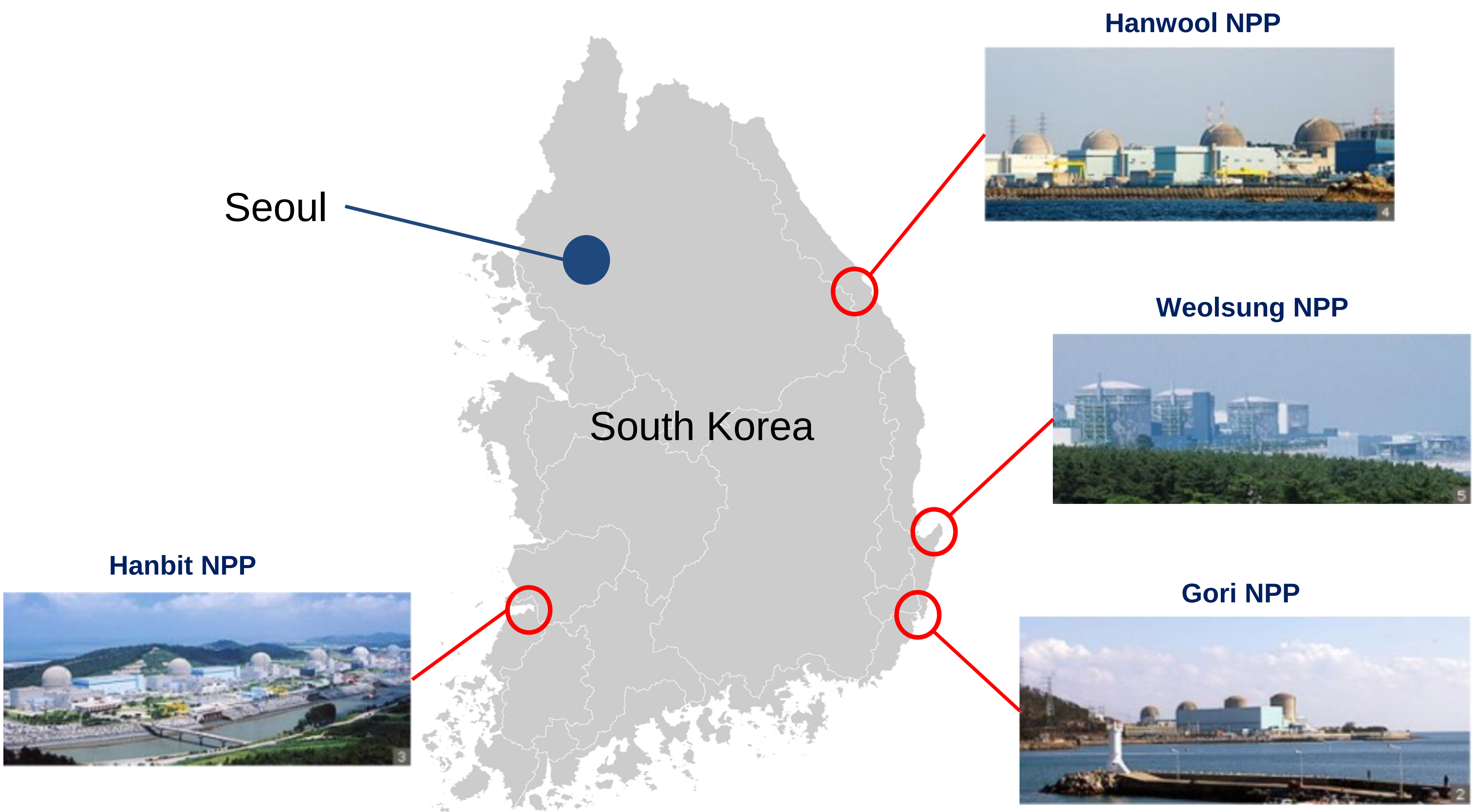




(Total Power Generation Capacities : 117GW)

(https://www.motie.go.kr)

Nuclear Power Plants in Korea(2017)



(https://terms.naver.com/entry.nhn?docId=3571558&cid=58941&categoryId=58960)

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Research Objectives

Research Objectives

- In recent years, the risk of external/internal flooding of major national facilities such as NPP has increased significantly due to the local intensive precipitation under climate change.
- Refined walkdowns have been carried out at the site to investigate specifications for flood protection facilities, location, critical height and conditions of seals.
- Flood hazard curve by frequency has been developed through a quantitative analysis of extreme rainfall, inundation depth and inundation intensity by occurrence frequency.
- Fragility assessment has also been carried out for major structures, systems and components(SSC) by identifying flow paths through the results of walkdowns.

Research Method

LIP Analysis

Consideration for Climate Change and RCP Scenarios (4.5 & 8.5)

Point and Regional Frequency Analysis

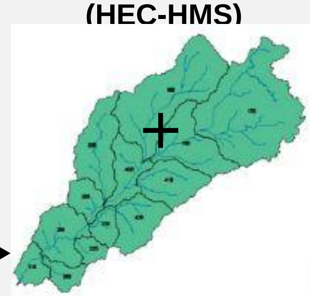
GEV/Gumbel/GLO/GNO Distribution (100-10^7year)

PMP Analysis Considering Climate Change

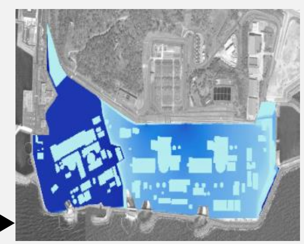
Hydrologic/Hydrodynamic Analysis

Initial and Boundary Conditions (Ex. Digital Map, Landuse Map, Flow Condition, Baseflow Rate, Soil Moisture Condition, Downstream Boundary Conditon…)

Hydrology (HEC-HMS)

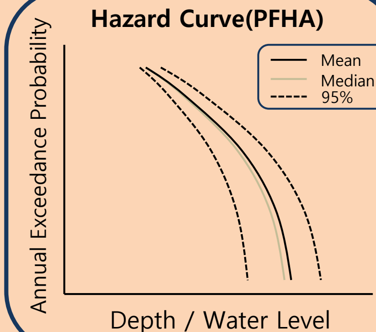


Hydrodynamics (FLO-2D)

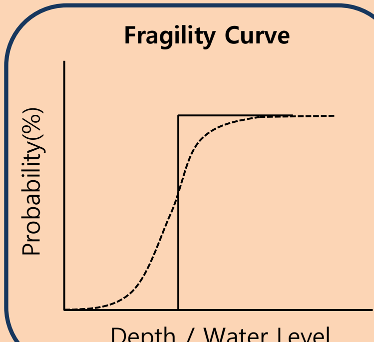


Parameter Analysis (Distribution of Rainfall, Roughness Coefficient, Channel and Sewer Pipe Data)

Hazard Curve



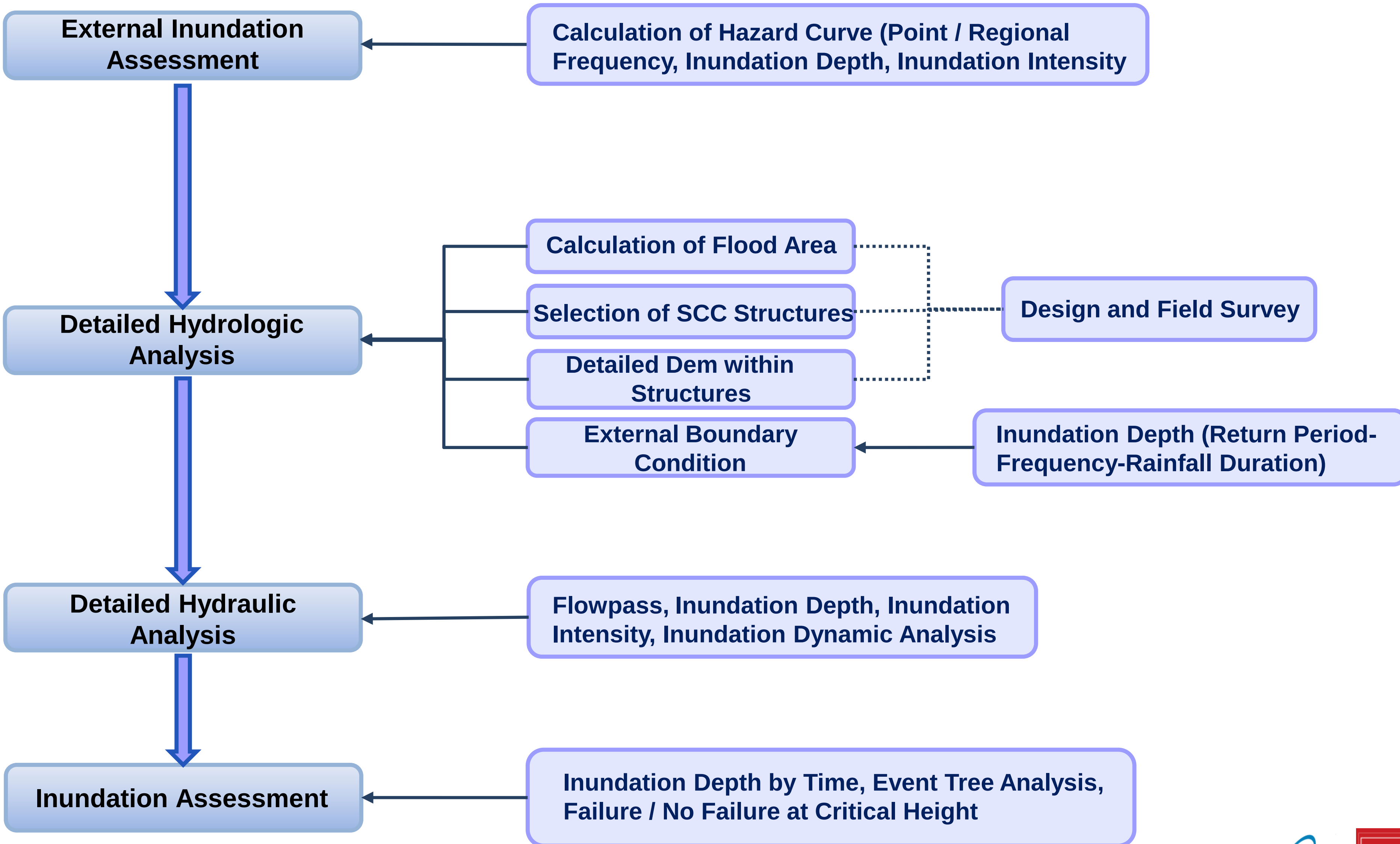
Probabilistic Flood Risk Assessment



Research Method

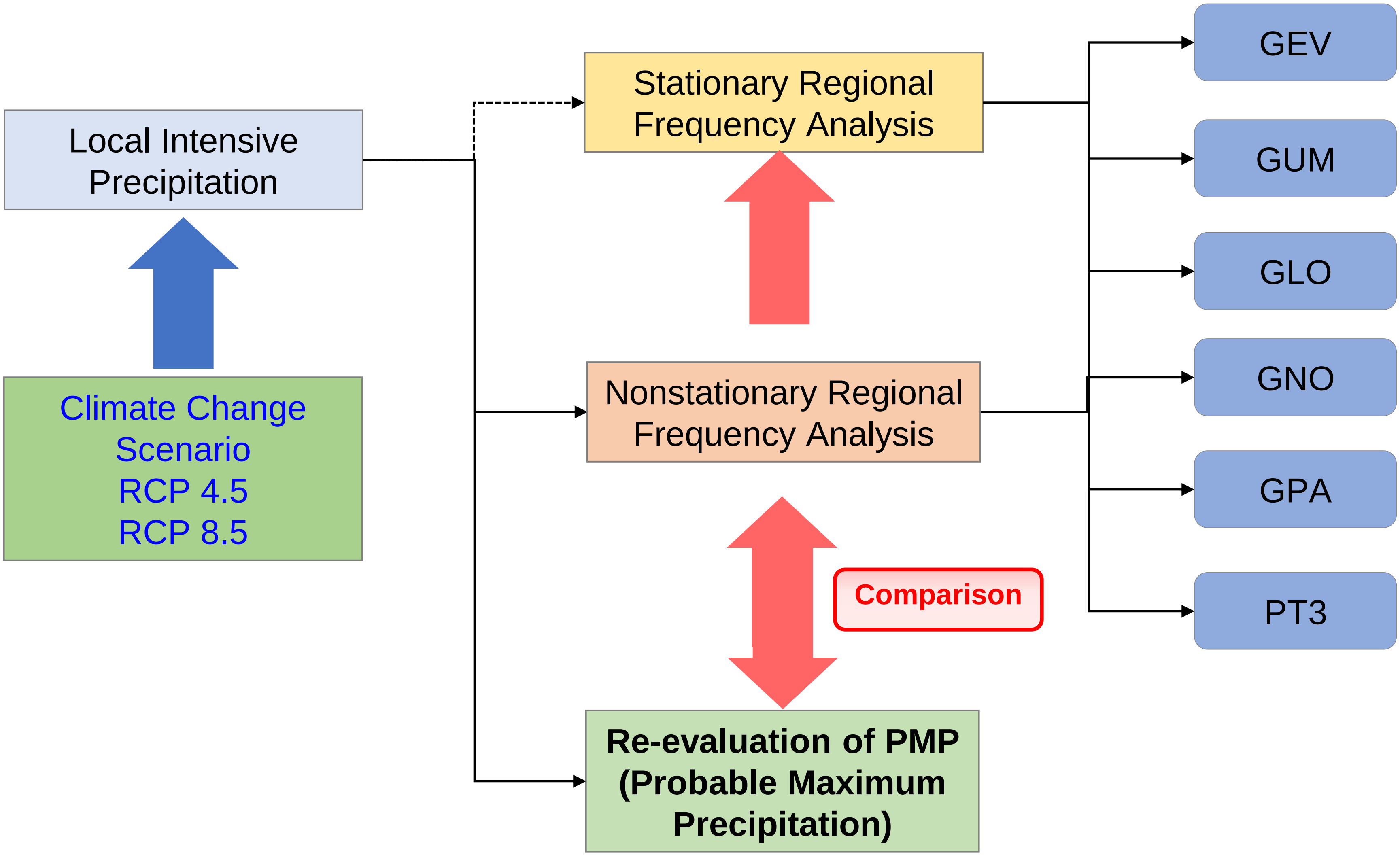
- Probable Maximum Precipitation(PMP) considering the climate change scenarios of RCP4.5 and RCP8.5 are computed and compared with the probability flood by frequency analysis to estimate the LIP.
- In order to evaluate the external flooding risk on these structures, 2D hydraulic analysis is performed and the frequency hazard curve is developed using the results of flood depth and velocity.
- To evaluate the flood risk, the safety factor of the performance function was calculated, then safety probability assessment was suggested under various risk conditions including the failure probability of system response, occurrence probability, exposure investigation and expected loss.

Research Method



Local Intensive Precipitation Analysis

Local Intensive Precipitation



Local Intensive Precipitation

Type		Probability Density Function and Cumulative Distribution Function
Gumbel	PDF	$f(x)=\frac{1}{\alpha}\,exp\left[-\frac{x-\epsilon}{\alpha}-exp\{-\frac{x-\epsilon}{\alpha}\}\right]\ (-\infty<x<\ \infty)$
	CDF	$F(x)=exp\left[-exp\left[-\frac{(x-\epsilon)}{\alpha}\right]\right](-\infty<x<\ \infty)$
GEV	PDF	$f(x)=\frac{1}{\alpha}\left\{1-k(\frac{x-\epsilon}{\alpha})\right\}^{\left(\frac{1}{k}-1\right)}exp\left[-\left\{1-k(\frac{x-\epsilon}{\alpha})\right\}^{\frac{1}{k}}\right]$
	CDF	$F(x)=exp\left\{-\left\{1-k(\frac{x-\epsilon}{\alpha})\right\}^{\frac{1}{k}}\right\}$

(Source : Heo, J.H, Statistical Hydrology, 2016)

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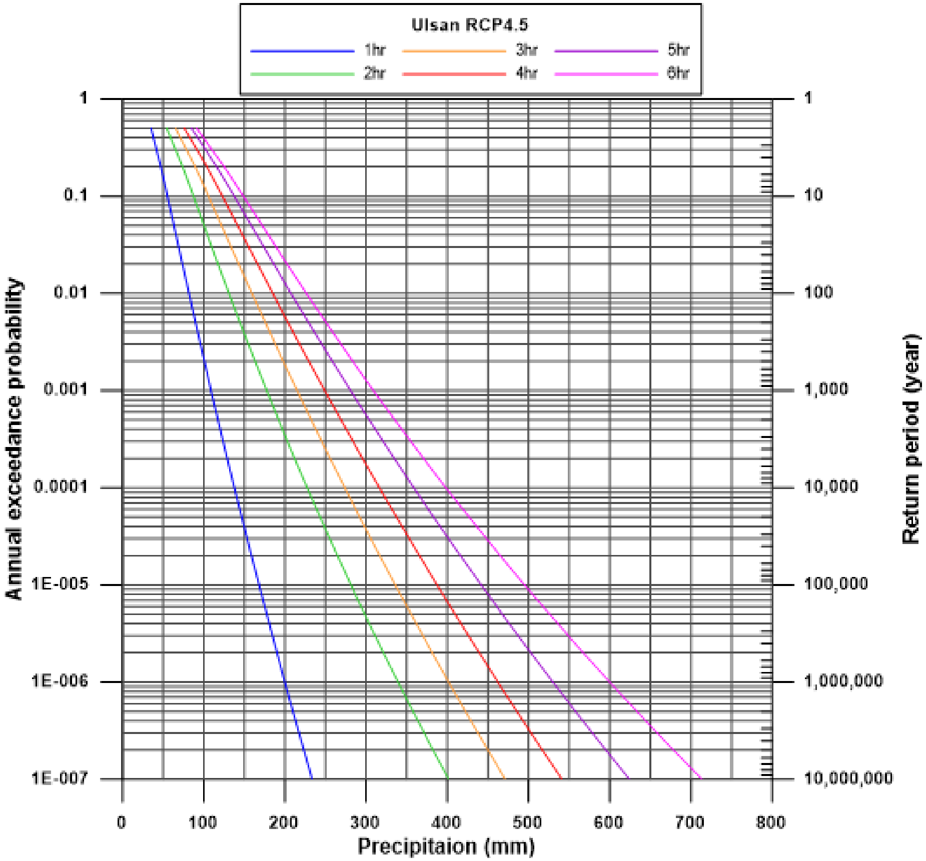
Local Intensive Precipitation

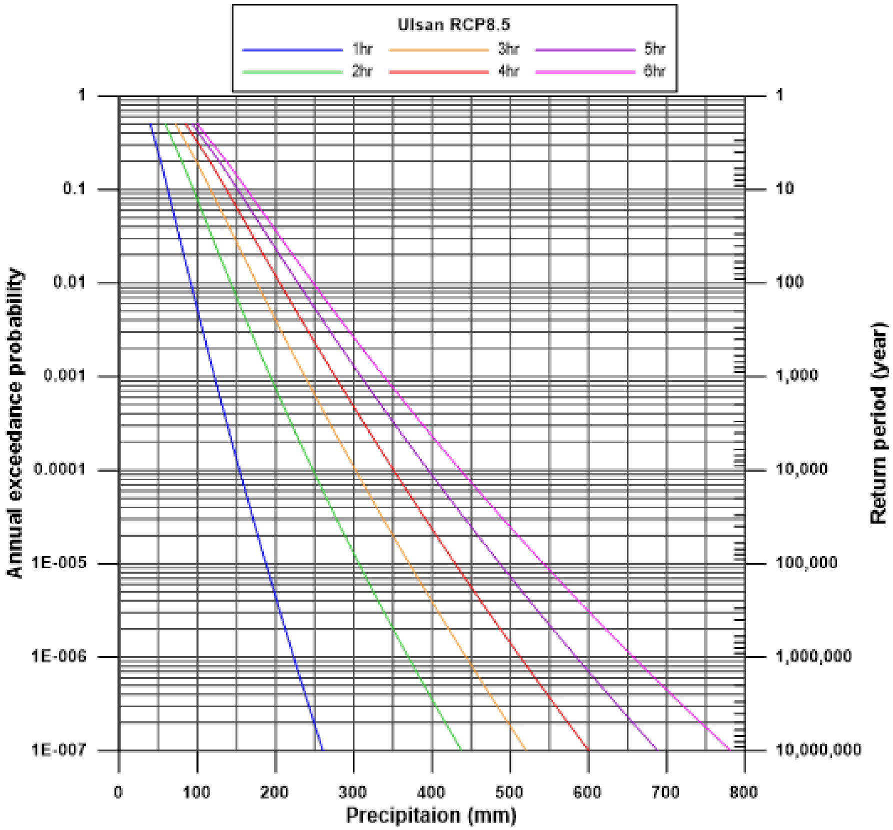
Type		Probability Density Function and Cumulative Distribution Function
GLO	PDF	$$f(x) = \frac{1}{\alpha}\left\{1 - k(\frac{x-\epsilon}{\alpha})\right\}^{\left(\frac{1}{k}-1\right)}\left[1 + \left\{1 - k(\frac{x-\epsilon}{\alpha})\right\}^{\frac{1}{k}}\right]^{-2}$$
	CDF	$$F(x) = \frac{1}{\alpha}\left\{1 - k(\frac{x-\epsilon}{\alpha})\right\}^{\left(\frac{1}{k}-1\right)}\left[1 + \left\{1 - k(\frac{x-\epsilon}{\alpha})\right\}^{\frac{1}{k}}\right]^{-1}$$
GNO	PDF	$$f(x) = \frac{k}{2\alpha\Gamma(\frac{1}{k})} exp\{-\left\lvert\frac{x-\epsilon}{\alpha}\right\rvert^{k}\}$$
	CDF	$$F(x) = 1 - \frac{\Gamma(\frac{1}{\beta}, (\frac{x-\epsilon}{\alpha})^{\beta}}{2\Gamma(\frac{1}{\beta})}$$

Local Intensive Precipitation

	Regional Frequency Analysis (Nonstationary-Climate change-R2 Region)						Regional Frequency Analysis (Nonstationary-Climate change-R2 Region)						PMP		
Scenario	RCP4.5			RCP8.5			RCP4.5			RCP8.5			Existing	RCP4.5	RCP8.5
Duration	GLO	GEV	GUM	GLO	GEV	GUM	GLO	GEV	GUM	GLO	GEV	GUM	-	-	-
10min	-	-	-	-	-	-	-	-	-	-	-	-	62.8	-	-
1hr	501.1	209.2	193.1	499.8	208.7	192.6	535.6	199.4	198.2	534.2	222.1	197.7	175.8	211.3	280.4
2hr	928.6	386.6	304.0	915.8	381.3	299.9	904.7	338.3	315.8	892.2	369.3	311.4	261.8	300.5	341.6
3hr	1363.8	571.6	374.8	1374.8	576.2	377.8	1066.4	402.1	387.7	1075.0	444.2	390.9	330.4	377.9	413.6
4hr	1776.1	751.0	433.7	1796.8	759.6	439.6	1222.0	461.8	447.1	1239.2	511.7	453.3	389.8	450.6	498.6
5hr	2144.6	913.8	485.9	2161.1	920.7	490.4	1401.3	529.5	499.8	1414.2	583.9	504.5	443.1	513.6	560.5
6hr	2450.9	1049.7	530.4	2463.9	1055.3	533.2	1585.0	600.1	543.9	1593.4	657.7	546.8	492.0	568.8	604.7
7hr	2683.4	1152.1	566.5	2704.6	1161.3	570.7	1760.5	669.9	578.4	1773.6	732.2	582.6	537.5	620.7	653.3
8hr	2858.4	1228.2	596.3	2895.5	1244.2	603.8	1942.3	741.1	606.2	1967.1	813.1	613.7	580.4	670.9	711.0
9hr	2999.1	1288.9	622.1	3052.3	1311.7	633.2	2151.7	817.2	630.9	2189.8	908.2	642.1	621.0	719.2	774.7
10hr	3124.5	1343.0	646.2	3188.4	1370.4	659.5	2399.5	901.5	655.5	2448.6	1020.7	669.0	659.8	765.3	840.0
11hr	3238.0	1391.9	668.8	3308.6	1422.3	683.5	2654.9	996.0	679.8	2712.9	1136.7	694.7	696.9	808.1	900.1
12hr	3338.8	1435.1	689.8	3415.7	1468.1	705.7	2876.7	1102.6	702.7	2942.9	1237.7	718.9	732.6	846.9	947.3

Hazard Curve with LIP(RCP 4.5 & 8.5)





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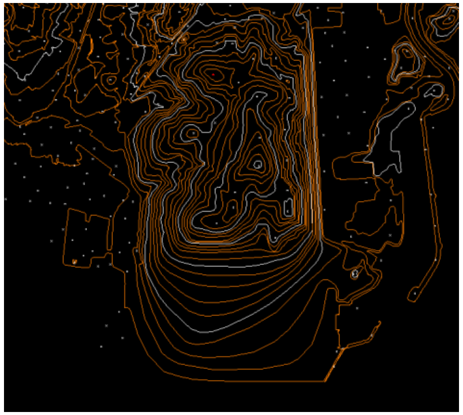
Detailed Hydrologic/Hydrodynamic Analysis

Topographic Analysis

Gori NPP site

- Study Area : Nuclear Power Plant site, Korea
- Area : 0.38km^2
- Precipitation : Probability Precipitation considering Climate Change



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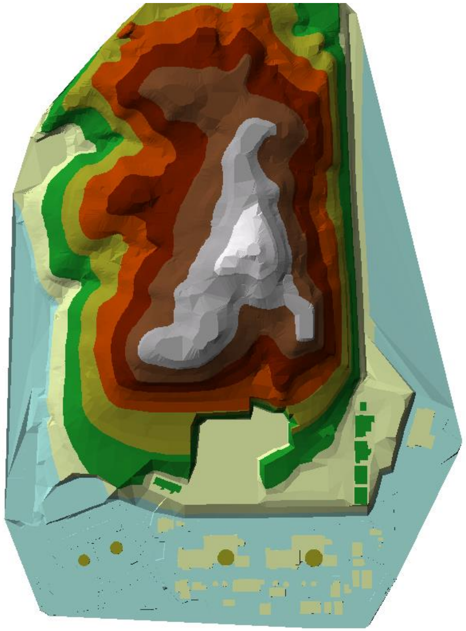

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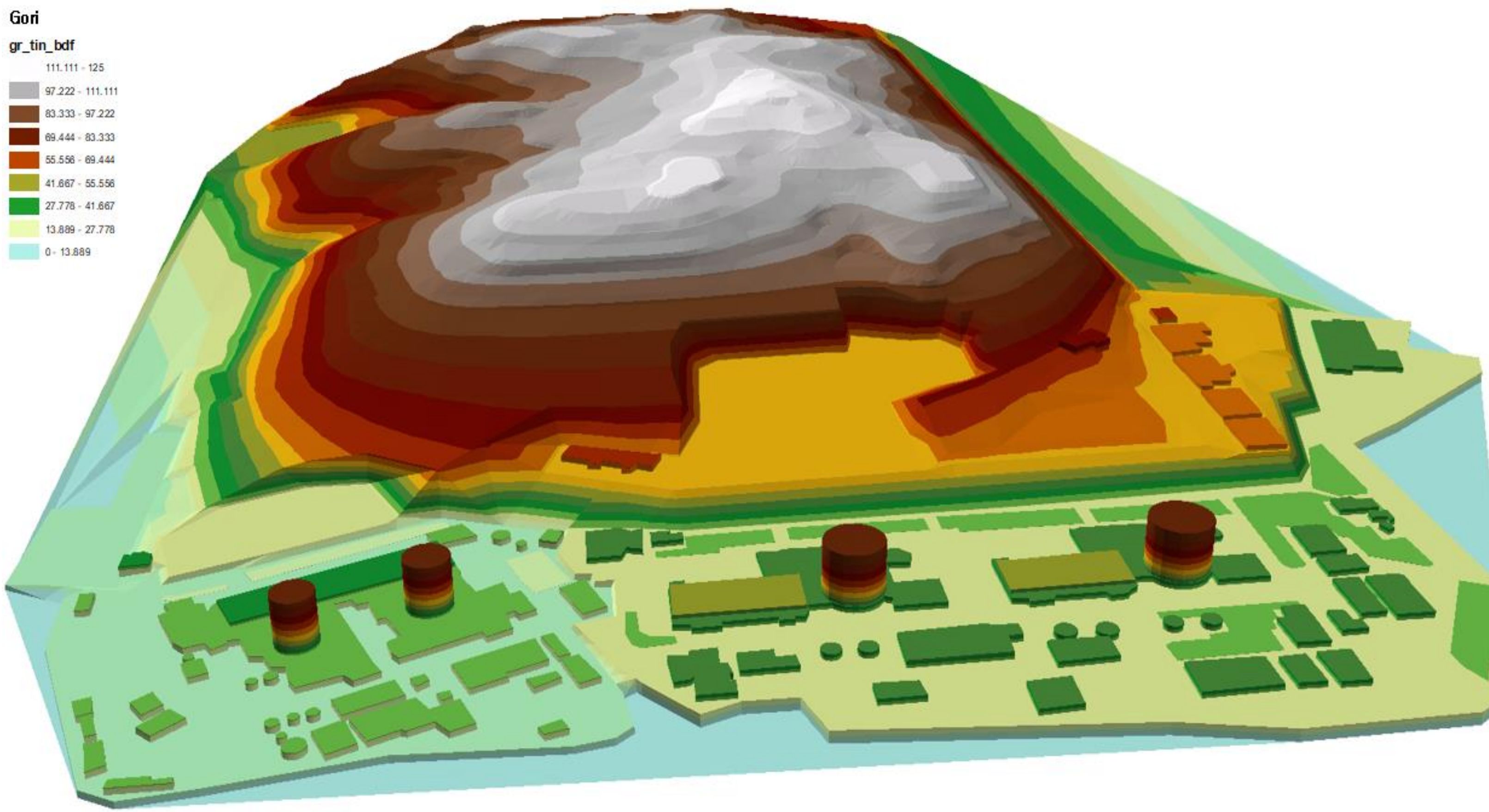
Hydrologic Analysis

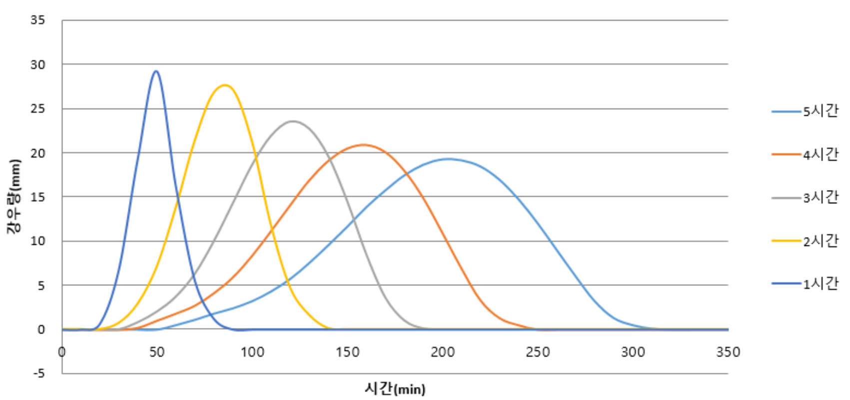
Topographic Map

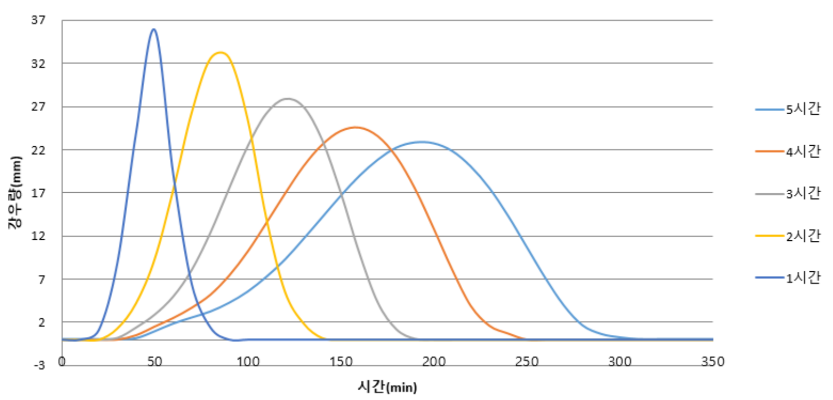


Hydrologic Analysis

▶ Based on the topographic data generated, 45 scenarios were constructed combining nine return periods from 100 year to 1x10^7 year and rainfall duration conditions from 1 hour to 3 hours.

Subbasin-2	10^{-6} probability		10^{-7} probability	
	Rainfall(mm)	Peak Discharge(m^3/sec)	Rainfall(mm)	Peak Discharge(m^3/sec)
1hr	254.1	29.51	300.4	35.91
2hr	369.3	27.11	437.4	32.61
3hr	444.2	23.51	521.1	27.91
4hr	511.7	20.81	599.3	24.61
5hr	583.9	19.21	688.0	22.81

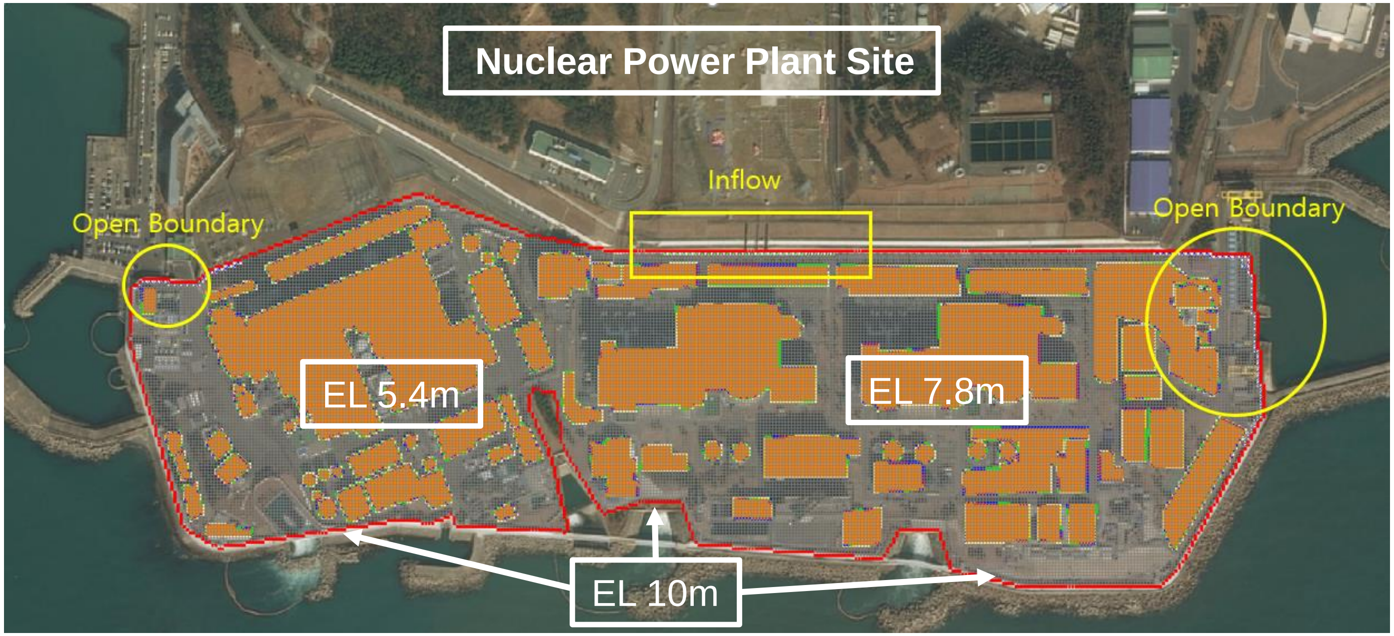




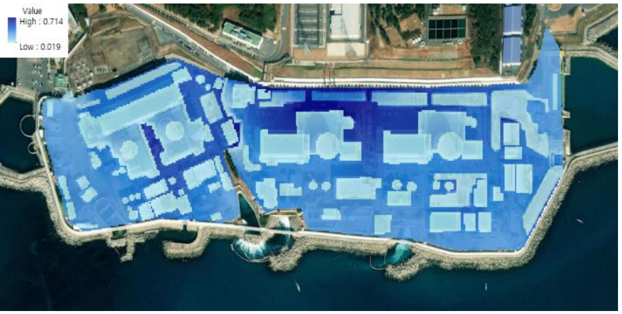
2D Hydrodynamic Analysis

External 2D Simulation and Hazard Analysis

- The grid size was 3m x 3m for two-dimensional analysis, and total simulation time was 12 hr.
- FLO-2D model was applied to external/internal flood inundation for the simulation of flood depth and velocity.



2D Hydrodynamic Analysis



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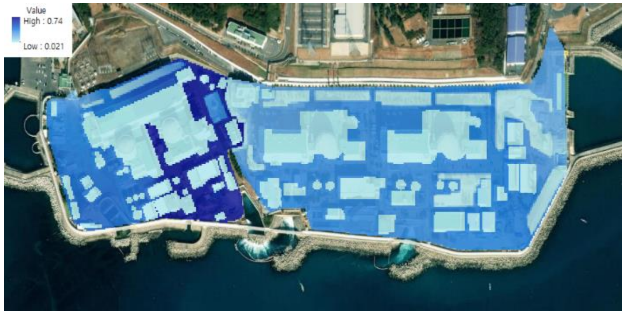

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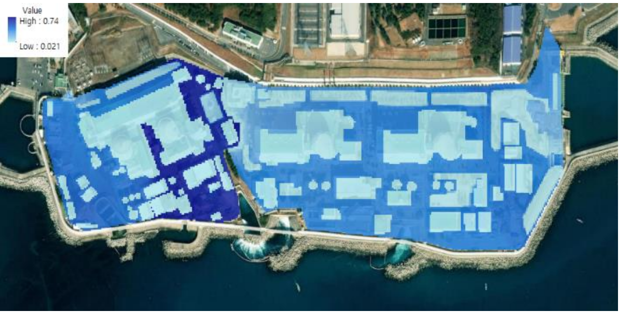

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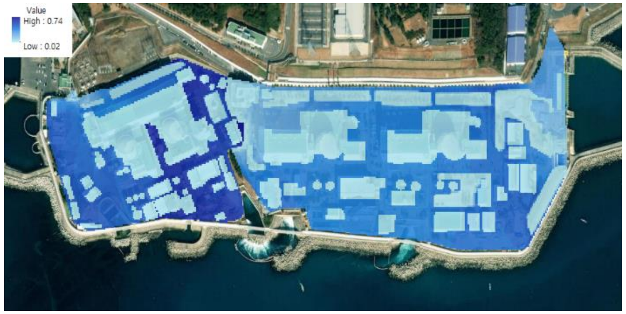

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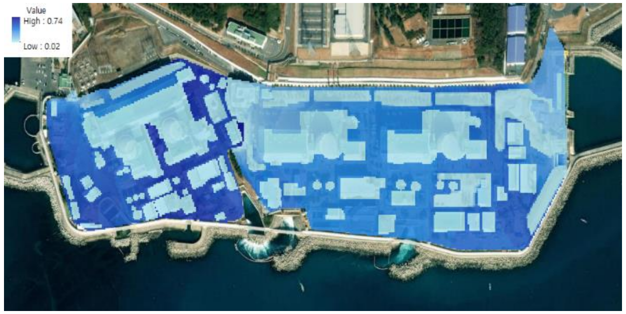

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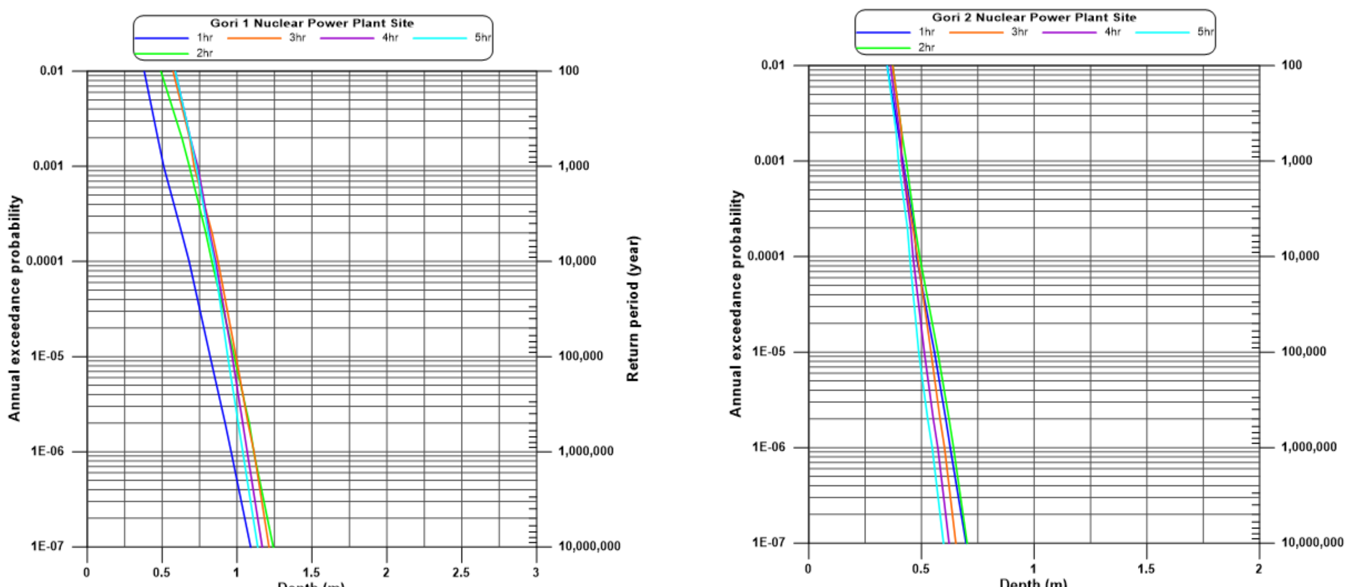
<Time variation of external flood inundation depth(10^7 year)>

Flood Hazard Analysis

Hazard Curve with 2D External Flood Analysis

▶ Based on the results of the 2D analysis, flood hazard curves for the inundation depth with the various frequency and duration conditions was developed at specific area of major facilities. The internal flooding within structure, system and components caused by external flood inundation in the major facilities was also evaluated.

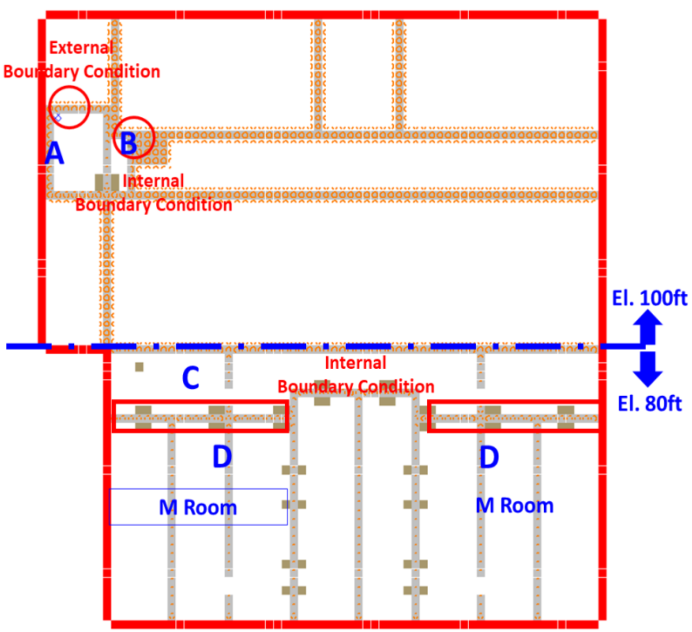


<Hazard curve of external flood event >

Flood Hazard Analysis

Internal Inundation and Hazard Analysis

- The grid size was 1m x 1m for 2D analysis, and total simulation time was 12 hr.
- A total of 4 areas form A to D in small flood areas.

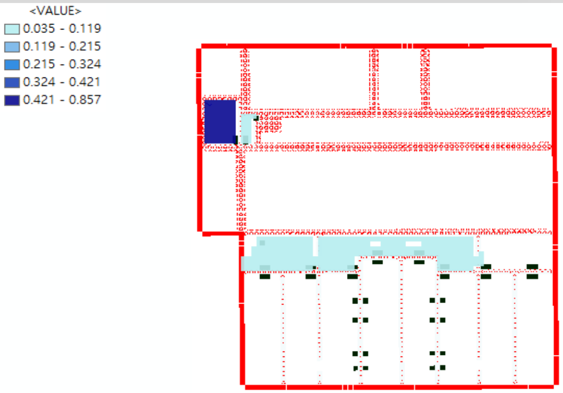


<Internal flood inundation analysis area>

Name of Building	100ft CB Door	100ft CB Stair Area	80ft M Facility Area	80ft M Facility Room
Area Mark	A	B	C	D

Flood Hazard Analysis

Result of Internal Flood Analysis(2D)



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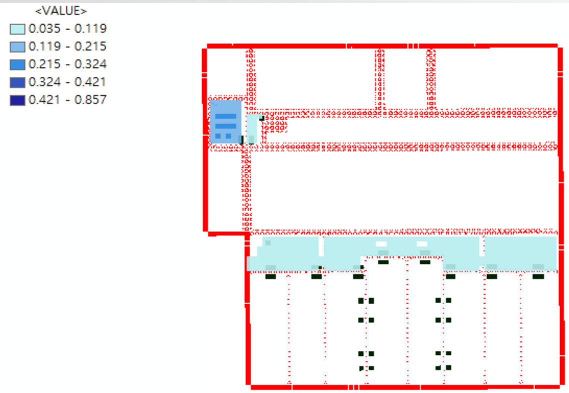

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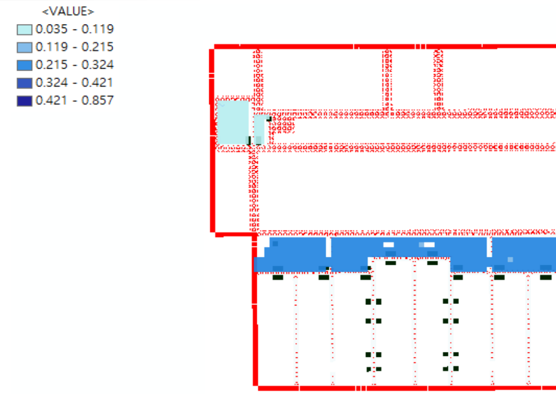

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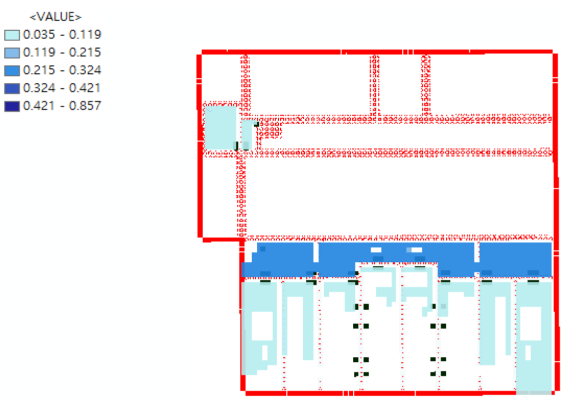

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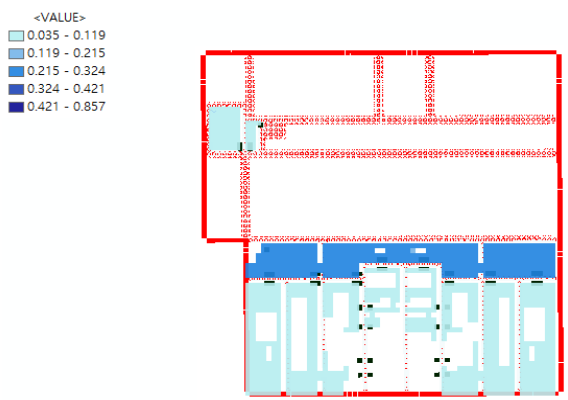

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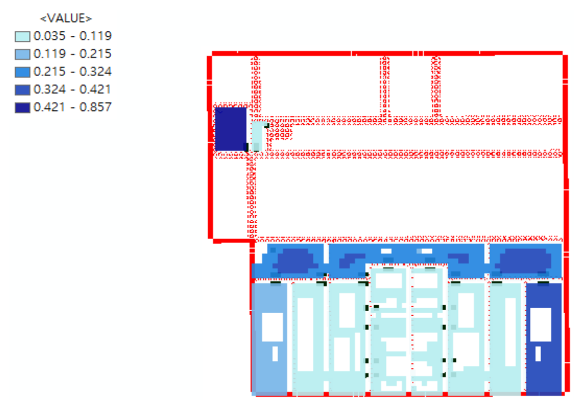
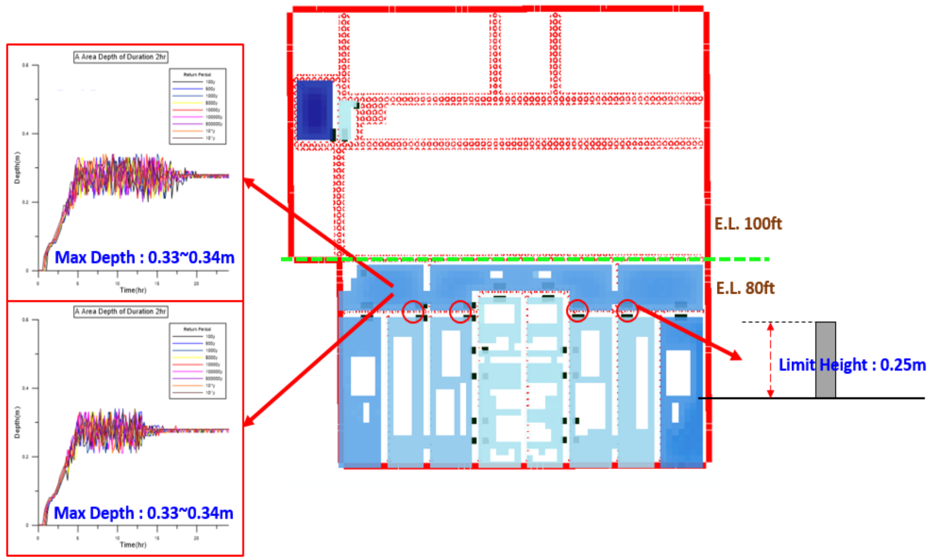


<Max Depth>

<Time variation of Internal inundation depth (10^7yr)>

Flood Hazard Analysis

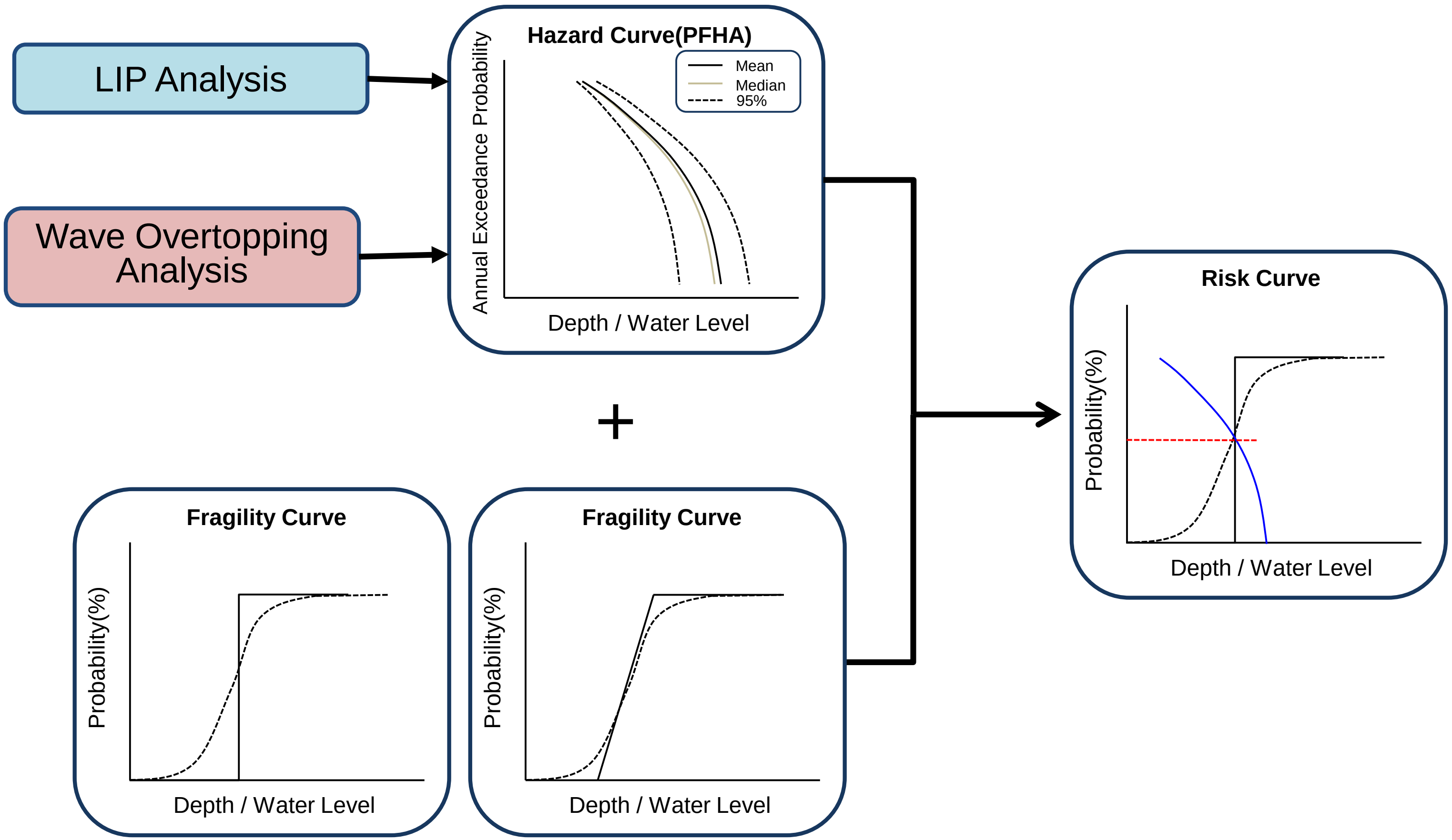
Result of Internal Flood Analysis(2D)



<Internal flood inundation depth (A to D area) >

- ▶ The maximum depth of NPP no. 3/4 of C area was 0.33 ~ 0.34m.
- ▶ In the design of nuclear structures, the average critical height of major equipment is 0.25m.
- ▶ Therefore, flooding in Zone C is likely to cause flooding into Zone D and Units 3 and 4 were considered vulnerable to internal flooding.

Future Study Plan



Conclusions

Conclusions

- In order to estimate the probability rainfall of 1 million years and 10 million years at target NPP, it was judged that the Gumbel distribution of regional frequency analysis was most appropriate.
- In order to estimate the extreme flowrate through the topographic analysis and hydrologic analysis, each of the nine frequencies (100 years, 500 years, 1000 years, 5000 years, 10,000 years, 100,000 years, 500,000 years, 1 million years, 10 million years) were considered to calculate the runoff hydrograph for 1 to 5 hours durations.
- As a result of the calculations, the critical duration was found at 1 hour at all frequencies, and 29.5 m^3/s for 1 million years and 35.9 m^3/s for 10 million years were calculated respectively.

Conclusions

- As the results of this study, the basic data for the probabilistic risk assessment of external floods that could occur at the site of the NPP from the extreme flood conditions due to river and watershed flood were established.
- The probabilistic flood risk assessment method will be able to assess the risk associated with vulnerability at the site of the major NPP site, and it can be used as a technical basis for comprehensive and detailed quantitative risk assessment, as well as for establishing structural/non-structural measures and for various regulation tools against severe flooding at major NPP site.

Thanks for your attention.

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