Dynamic Simulation of Storm Surge and Storm Water-Combined Inundation on the Jeju Coastal Area
폭풍 해일 및 폭풍우로 인한 제주 해안역에서의 동역학적 범람 모의

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Abstract

A storm-induced coastal inundation model (SICIM) is presented to simulate the flood event during typhoon passage that often results in significant rise in sea-level heights especially in the upstream region of the basin. The SICIM is a GIS-based distributed hydrodynamic model, both storm surge and storm water inundations are taken into account. The spatial and temporal distribution of the storm water level and flux are calculated.

The model was applied to Jeju Island since it has an isolated watershed that is easy to handle as a first step of model application. Another reason is that it is surrounded by coastal area exposed to storm surge inundation. The model is still advancing and will be the framework of a predictive early inundation warning system.

Keyword : Storm Surge, Storm Water, Inundation, Hydrodynamic Runoff Model, Jeju Island

1. Introduction

Korea has suffered from serious floods and storm surges associated with heavy rainfall accompanied by typhoons. Recently, Korea has also received 70 to 80 percent of their annual average rainfall in the 10 days of August. Such "guerrilla rains" causing flash flood have left many people homeless, damaged or destroyed many homes and roads and bridges, and washed away even graves. Thus, trends in annual rainfall indicate that it has increased at all stations as well as Jeju stations (see Figure 1).

In addition, there is a steady process of urbanization, especially along the coast line. As a result, more and more people and properties have been concentrated in coastal cities. Urbanization resulting in the increase of the impervious area significantly reduce infiltration and increase surface runoff, which has changed evidently: (1) flood water quantity increasing,

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(2) runoff coefficient becoming bigger, (3) the value of flood crest becoming bigger, (4) flood crest occurring quicker. Meanwhile, the flood water flow has become complex because the structures and the distributions of the buildings of cities are so complicated. Therefore, we face a challenge to calculate and forecast the urban flood specially combined with storm surge accurately and timely.

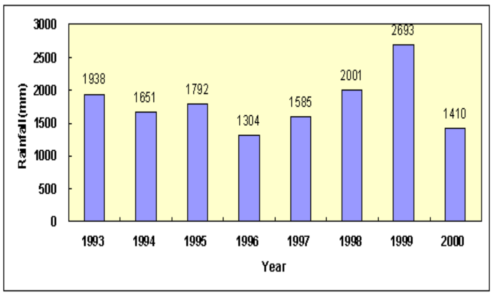

Figure 1. Annual trend in rainfall in Jeju

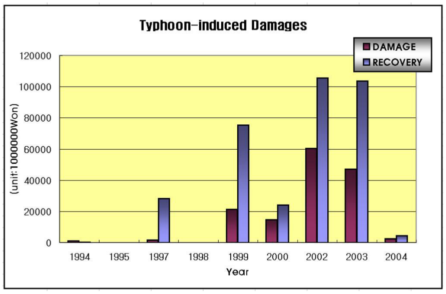

Figure 2. Variation of typhoon-induced damage amount in Jeju

The SICIM is presented to simulate the flood event during typhoon passage that often results in significant rise in sea-level heights especially in the upstream region of the basin. The model is a GIS-based distributed hydrodynamic model, both storm surge and storm water inundations are taken into account. The spatial and temporal distribution of the storm water level and flux are calculated.

The model was applied to Jeju Island since it has an isolated watershed that is easy to handle as a first step of model application. Another reason is that it is surrounded by coastal area exposed to storm surge inundation.

2. Jeju Island

The Jeju island, the largest island in Korea, is 73km wide and 41km long with a total area of 1,848㎢. At the center, it possesses one towering Mt. Halla which rises 1950 m above sea level as shown in Figure 3. The island came into existence 700 to 1,200 thousand years ago when lava spewed from a sub-sea volcano and surfaced above the waters. Then 100 to 300 thousand years ago, another volcanic eruption formed the base of the current Mt. Halla. At the summit of the mountain, there is a crater lake, Baekrok-dam formed during the final volcanic eruption approximately 25 thousand years ago.

The Jeju coast presents many other scenic and interesting features such as black sand beaches, lava seacliffs, and volcanic islands, that make it an especially interesting destination. Although no perennial streams exist due to the high permeability of the underlying lava rock, totally 73 streams are observed in Jeju. In the watersheds of Jeju-si, Seogwipo-si, Namwon-myun, and Pyosun-eup in particular, relatively long valley streams are developed as shown in Figure 4.

Annual average precipitation for 8 years between 1993~2000 was 1,797mm in Jeju. Average annual precipitation is higher than the mainland by about 600mm. In that period the greatest rainfall of 2693mm was in 1999 and the smallest was 1,304mm in 1996. Precipitation analysis on elevation exhibits a distinct increase as shown in Figure 5. Annual average precipitation is 1482mm under 100m elevation, 1,751mm between 100~200m, 2,081mm between 200~400m, 2,393mm between 400~600 and 2,621mm at elevations over 600m. The precipitation increases from coast region to the top of Mt. Halla by the orographic effect. The leeward side receives less rainfall.

There are 4 meteorological observatories (Jeju, Seogwipo, Seongsan, and Gosan) under jurisdiction of Jeju meteorological office, 13 AWS systems run by Jeju meteorological office, 30 observatories under control of Jeju fire and Disaster management department (Figure 6), an observatory of Jeju Airport and a few others.

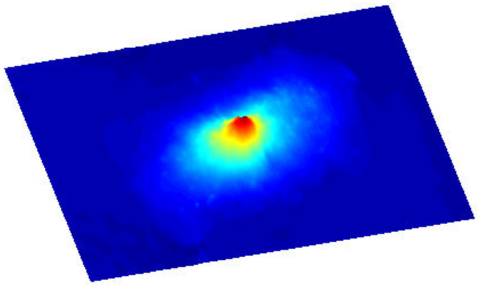

Figure 3. 3D view of Jeju inland and bathymetry

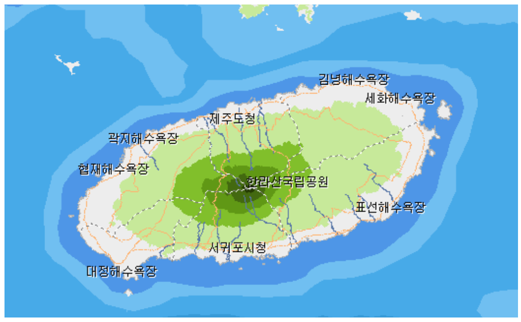

Figure 4. Jeju major streams

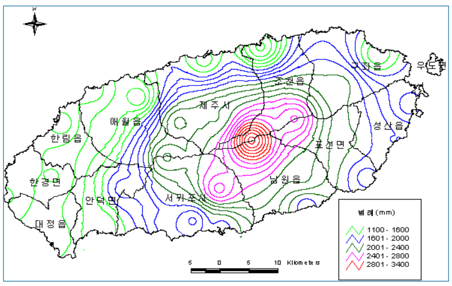

Figure 5. Rainfall distribution

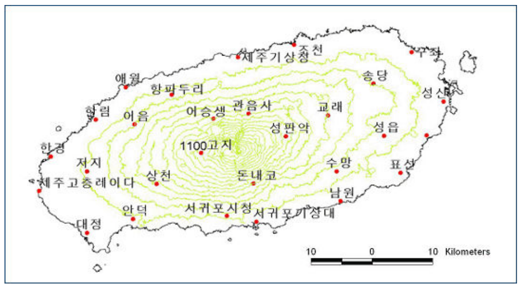

Figure 6. Meteorological observatories

The underlying rock significantly affects the hydrology of watersheds in various and complex ways. The basalt lava flows that host the aquifer are very porous and permeable due to emplacement processes and fracturing during cooling. On the most part of Jeju where the underlying substrate is the basalt lava, rubble zones between lava flows and cooling fractures allow very rapid flow of water in the saturated zone, and rapid infiltration of water and contaminants. Consequently, there is little sustained stream flow on the island despite the heavy rainfall in summer, and torrential runoffs occurring during and right after large rain events immediately infiltrate the ground, due to the high permeability of the volcanic rocks

(Hahn et al., 1997).

Besides the soil physical properties, surface management practices (forest, tillage, and cropping patterns) influence the runoff very significantly and thereby infiltration. Jeju lacks of studies on such runoff-related data. Runoff in Jeju was reported to be from 19 to 21% of total precipitation although it receives total annual precipitation between 3.385 billion to 3.516 billion cubic meters. The Jeju Provincial Office now operates 17 stream gauging stations, 67 ground water level stations, and 24 rain gauges in its data network.

3. Brief Description of Model and Its Results

The SICIM is combined with several models such as infiltration model, overland flow model, channel flow model, sewer flow model, etc. The model uses GIS as its primary method of data management, manipulation and presentation. The use of GIS allows easy inclusion of model topography changes to assess floodplain impacts. The rate of water entering and leaving ground surface per unit area is determined by rainfall excessive intensity, land infiltration properties, etc.

The depth-integrated shallow water equations on the overland surface are solved by using an implicit and Lagrangian finite-difference method. Unlike many depth-integrated 2-D flow models, it handles flow regime changes with rapid wetting and drying. The model is more stable than traditional finite-element and many finite difference models and is capable of routing flows on steep river systems. The model is being imbedded with several features such as land infiltration data and drainage system-related coefficients.

The model is applied to an imaginary typhoon event, which may cause the devastating damages, due to the fearful floods and storm surges. The rainfall and surge height were assumed uniformly 100mm/hr in all domain (the orographic effect will be included in the following study) and 3.7meter (approximately corresponds to LMSL+100yr extreme sea level; Choi, 2004) all over the coast. The computational domain for the present simulation is composed of a grid system of 780×340. In estimating runoff rates, all areas are classified into five categories; forest, channel, clear, high-density urban and low-density urban. Figure 7 shows the computed water levels after 1 hour. Inundation depths combined with surge impacts were computed deeper along the coasts of Jeju-si and Seogwipo-si since the detention time is relatively short. The results seem to be reasonable but it is necessary to improve the model performance through the verification by observed data.

4. Conclusions

The model was applied to Jeju Island since it has an isolated watershed that is easy to handle as a first step of model application. For the performance test for a extreme case, it was examined for an imaginary typhoon event, which may cause the devastating damages, due to the fearful floods and storm surges.

The model is being imbedded with several features such as land infiltration data and drainage system-related coefficients for the use as a more efficient warning system.

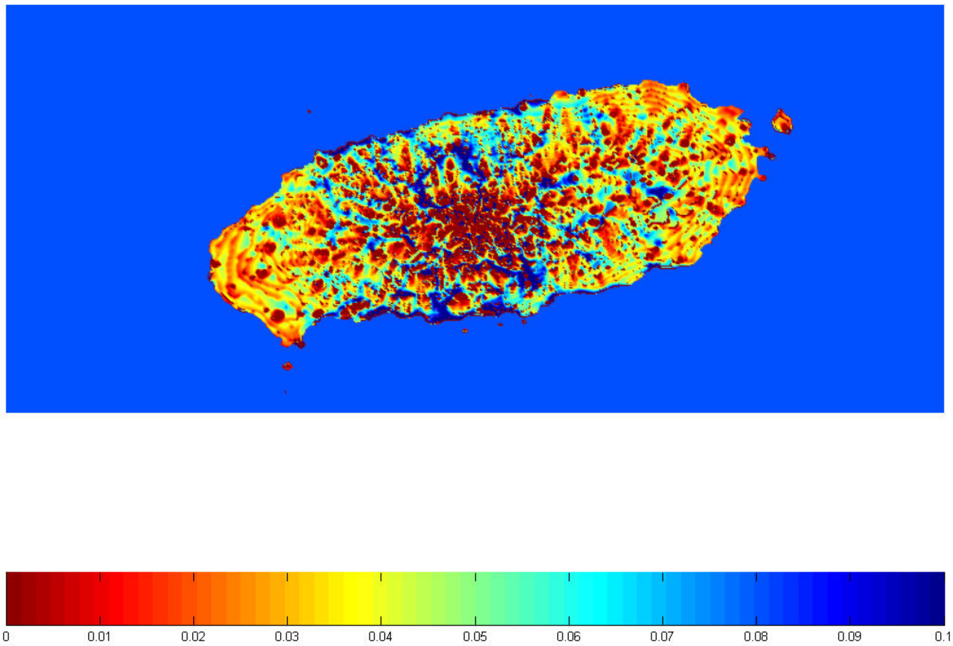

Figure 7. Computed water levels (unit:meter)

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