# Inundation analysis of urban areas by using GIS – Application to the Tokai Heavy Rain Flood

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ABSTRACT: A numerical method to construct automatically the mesh cohered with road networks has been developed, which enables the chase of inundation caused by levee breach as well as local rainwater through taking into account of sewage systems. This method was applied to 2000 Tokai Heavy Rain Flood and validated through the comparison with the data obtained by the questionnaire survey. The pumping effect of the sewage system in this inundation is also discussed.

## 1 INTRODUCTION

Continuous concentration of population and property in urban areas ever increases disaster vulnerability. The 2000 Tokai Heavy Rain Flood caused damage to property estimated at about 850 billion Yen at Nagoya City with two million population and the surrounding communities in Aich Prefecture. About the half of the damage was due to automobile wreck. The water spilled from levee failure as well as local rainwater expanded the inundation, and sank cars and lower floors of houses in the area.

To get good understanding on complex mechanisms of urban inundation disasters we have developed a numerical model that takes account of levee failure and drainage by sewage systems. The mesh cohered with road networks, MCRN is our important inclusion, because the subsurface sewage networks are mainly constructed under the surface road networks. Different behavior between roads and resident areas in rainfall infiltration and water spread also requires this mesh.

## 2 MESH COHERED WITH ROAD NETWORKS

Although there are many advantages in MCRN, the construction of the mesh mainly done by handwork was exhausting and time consuming work especially if we consider wide area. Many countries are recently developing Geographical Information System, GIS that contains the database on the positions of roads and resident areas, and on the information connecting these. This has the potential to develop MCRN through a computer program.

The Geographical Survey Institute in Japan has developed Digital Map 2500 which has the same spatial resolution as the topographic map of a scale 1:2500 and contains vector data on the centerlines of roads and rivers, and on the polygons enclosing resident areas for all cities and towns. The MCRN used in our inundation analysis is composed by a set of polygons of residential areas, roads and crossings. By using the map, we have developed a method to construct automatically MCRN in the following steps;

(1) Input arcs indicating residential area boundaries and connect them to form closed polygons. Then simplify each of the polygons by reducing nodes of the sides into such a quadrilateral, pentagon, hexagon, etc. This procedure eases the correlating process between roads and sides of residential areas because the map expresses curved sides by a number of short straight lines.
(2) Input centerlines of road segments. Then find the adjacent residential areas and the corresponding sides for each segment. This is realized by comparing the distances between the middle points of the road centerline and the sides, and by selecting the minimum distance. Through this correspondence, all the connectivity among the adjacent roads and residential areas is completed.
(3) Compute the polygons of crossings from the sides of residential areas and complete the connectivity among the joining roads.

Thus the objective area is covered by polygons of residential areas, roads, and crossings the connectivity of which is known. This method is applied to the 2000 Tokai Heavy Rain flood.

## 3 APPLICATION FOR THE OF THE TOKAI HEAVY RAIN FLOOD

### 3.1 Flood outline

The stationary front stimulated by the typhoon 14 brought heavy rainfall reaching 567mm in total at Nagoya City on September 11 to 12, 2000. Figure 1 shows the hourly rainfall and cumulative rainfall observed at Nagoya. The rain caused record-breaking floods in the Shonai river passing through the city and breached or spilled over a dozen of levees of the major and minor rivers. Tsujimoto (2001) reports the damage of more than 63,000 houses inundated and ten people killed in Aich Prefecture.

The discharge split from the Shonai river through the spill-weir exceeded the flow capacity of the branch of the Shin River. Spilled water breached the left levee of the Shin river over 100 meter length and inundated the adjacent urban area where low land stretches along the river. Although there exists a drain system for rainfall in this area, the operation was stopped because of high stage of the river. Thus the inundation was grown by the river water inflow at the breaching as well as the rainfall collection in the area.

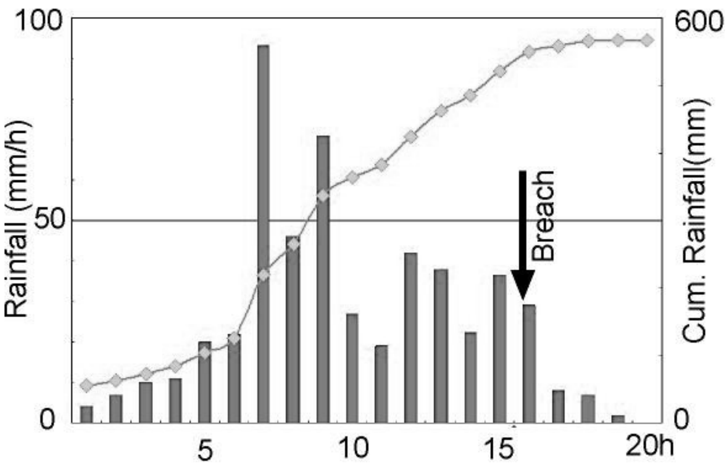


Figure 1. Hourly rainfall intensity and cumulative rainfall at West Public Work Office of Nagoya City. The elapsed time in the abscissa originates at 12:00, September 11.

### 3.2 Computational method

The object of the analysis is the inundated area along the Shin river. The residential area polygons in Figure 2(a) and the road network in Figure 2(b) are used to produce the

MCRN. Superimposition of 10-meter mesh Digital Elevation Map gives the polygons elevation attribute. The register chart and book on the sewage system relates the road and sewage networks major channels of which was taken into account as shown in Figure 3. The two networks are connected by manholes mainly installed at crossings.
The water surface elevation on the ground is computed at the center of polygons by using the continuity equation and discharges at the sides. The discharge on the ground is computed at the midpoints of the polygon sides by the Manning formula. The Manning roughness factor $n$ employed is 0.043 for roads and 0.067 for residential areas. The discharge between the residential area and road is modified by the reduction coefficient $\beta = \sqrt{1-\lambda}$ with the occupation ratio of houses $\lambda$ after Inoue (1999).
The discharge at the breach point is computed by using the Honma spilling formula(1940) and the observed data on water stage at the Shin River.

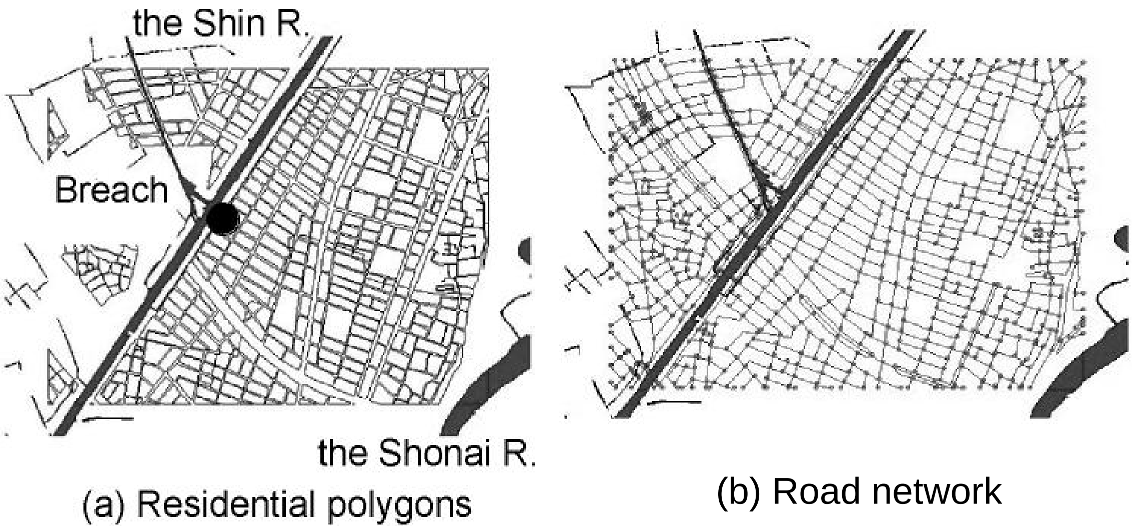


Figure 2. The residential area polygons along the Shin river and road network

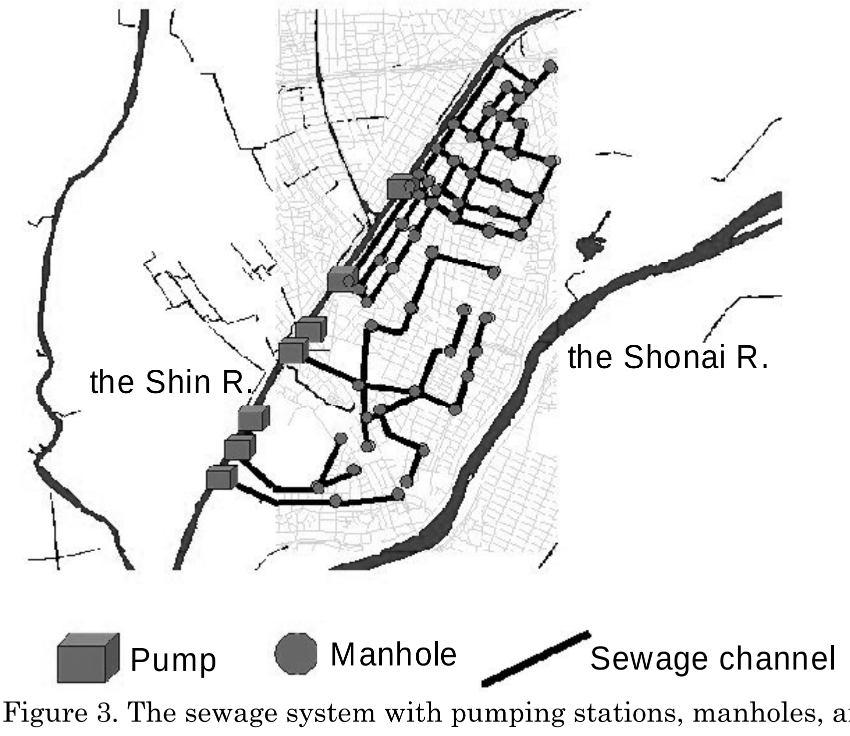


Figure 3. The sewage system with pumping stations, manholes, and sewage channels.

The water surface elevation in the manholes is computed by using the continuity equation and the discharges from / to the ground surface and sewage channels. The discharge from / to the ground surface is evaluated by the Homma formula. It contains flowing out from the manholes to the ground surface. The discharge in the sewage channel is computed by using the Manning formula. If the depth is less than the diameter of the channel, then the hydraulic characteristic relationship between the dimensionless depth and discharge is used. The roughness coefficient was 0.012.

### 3.3 Data collection

Questionnaire survey in this area were conducted in October, 2000 by Katada etal.(2001). 9743 questionnaires were distributed and the 32% collected. The question articles are on the times when the inundation started under the floor, spilled over the floor, reached the highest, and disappeared. The answer shows more than 59 % of the households in this area suffered inundation over the floor, which were caused by the levee breach. Significant inundation under the floor also occurred even before the breach due to the insufficient drainage. The each time in the answer was averaged in each residential area and set in GIS format for the comparison with our computational results.

## 4 RESULTS AND DISCUSSION

### 4.1 Validation of the computation

The objective area bounded by the Shin River and Shonai River has depressions along the Shin River which collect the rainwater fallen in the area as shown in Fig.(a) The residential areas for the inundation depth comparison are sampled as shown in Fig.(b). The inundation depth for each residential area was obtained by taking average over all the answers in the area.

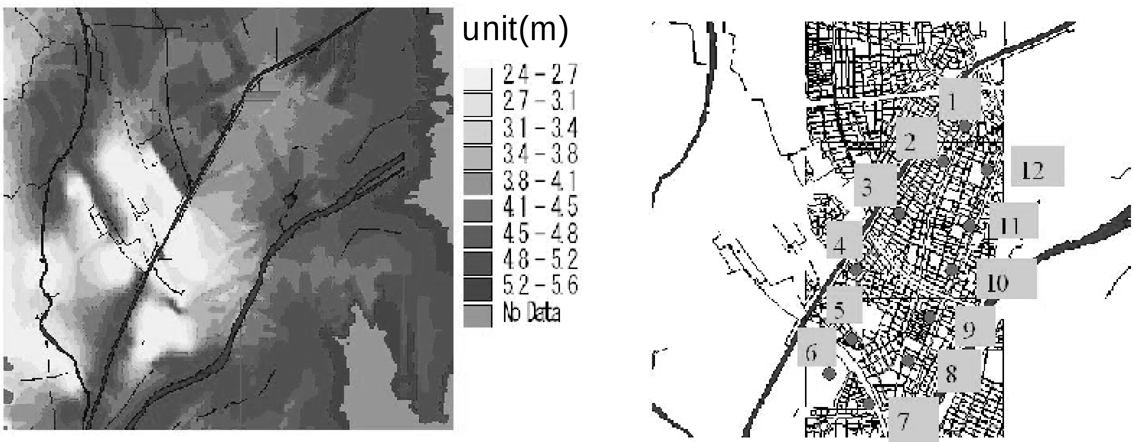


Figure 4. Topography of the area shown by 10m-mesh DEM. The central and broad rivers are the Shin and Shonai rivers respectively. (b) shows the sampling positions for comparison of inundation depth.

Figure 5 show the temporal changes of the inundation depth at Nos. 2 and 8, obtained from the questionnaire survey and computation. The computation considers pumping of the discharge, $30m^3/s$ in the actual operation. Due to the heavy rainfall after 5 hours, the inundation depth increases despite the pumping. It reached about the steady state after 10 hours, however the levee breach at 15.5 h increased the depth rapidly. The computation at both positions reproduces the observed depth. The maximum depth at the lower land at No.2 is deeper than that of No.8.

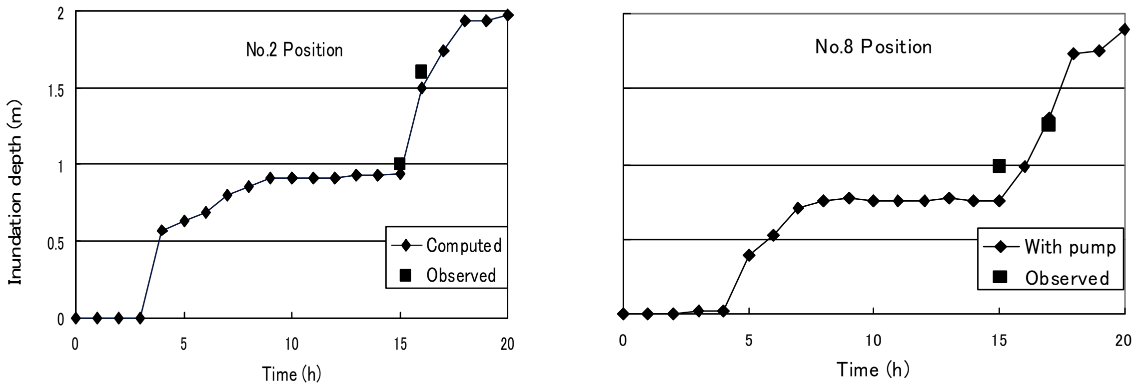


Figure 5. Temporal changes of the inundation depth at No.2 on the left and No. 8 on the right The origin of the time is same as Fig.1.

4.2 Effect of pumping

The effect of the pumping is examined here. Figure 6 compares the inundation depth distributions at 3 h of the computations without and with the pumping of 30m$^3$/s. The effect is obvious for the earlier stage of inundation due to the local rainwater. 1 to 1.5m reduction of the depth was obtained at the depressed region by the pumping.


Figure 6. Computed inundation depth distributions at 3 h without pumping on the left and with the pumping of 30m$^3$/s on the right.

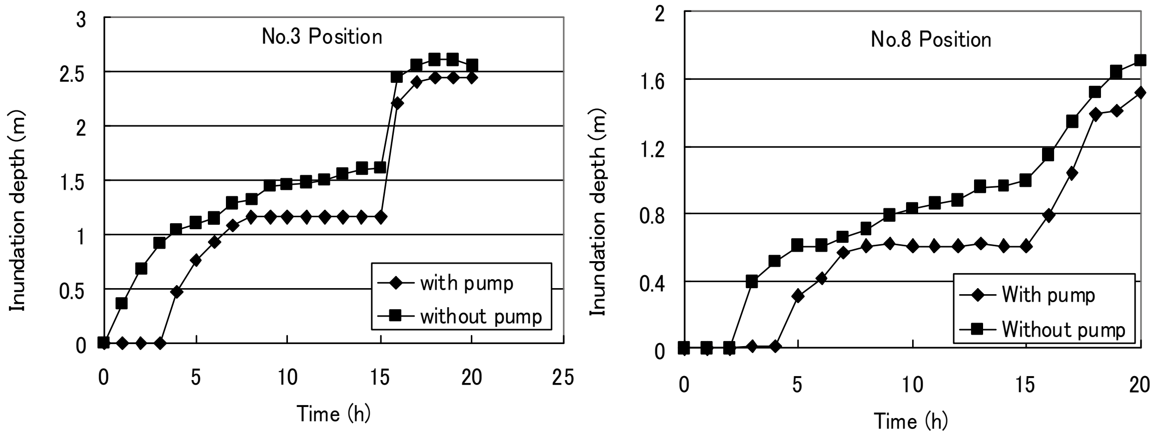


Figure 7. The effect of pumping.

However, rapid increase of the inundation depth after the levee breach diminishes the effect of the pumping. For example, at No.3 Position in Fig. 7, one meter gain in the inundated depth by the pumping decreases to few tens centimeter at the final depth. This is due to the large volume of breached water.

## 5 CONCLUSION

We have proposed the method to construct automatically the mesh cohered with road networks by using the GIS data. The mesh enables the connection with the sewage network. This method was applied to the 2000 TOKAI HEAVY RAIN FLOOD and solved the inundation caused by the levee breach as well as the local rainwater collection. The computed inundation depth was validated by the observed data obtained by the questionnaire survey. The pumping by the sewage system is shown to be effective in the initial stage of the rainwater collecting inundation, however less effective in the latter stage after the levee breach and in the reduction of the maximum inundation depth.

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