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Control of Flooding Water and Improvement of Evacuation System for Floodplain Management

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1. INTRODUCTION

Records since the 1960s show that the annual mean flood damage cost (nominal) has increased in proportion to the build up of the social assets in river basin areas, but the frequency of occurrence and the number of deaths and missing people have decreased, thanks to the improvement of levees and flood control facilities such as dams and so on. However, this decreasing probability of disaster makes people less conscious of their need to prepare for disasters, and tends to create a false sense of security. Also, a "Prejudice to normalization" such as the idea of "Nothing will happen to me" is pointed out.

However, a catastrophic disaster by flood like the case of the Great Hanshin Earthquake, for example, can happen, and therefore, measures to minimize the effects of flood disaster must be considered from the viewpoint of risk management.

In this paper, I report, particularly as a flood control measure, how hazard-simulators and evacuation systems should be for prompt, timely and the most appropriate evacuation, and show the flood controlling effects of a network of waterways for inundation drainage as well, considering the floodplain management from viewpoint of risk management.

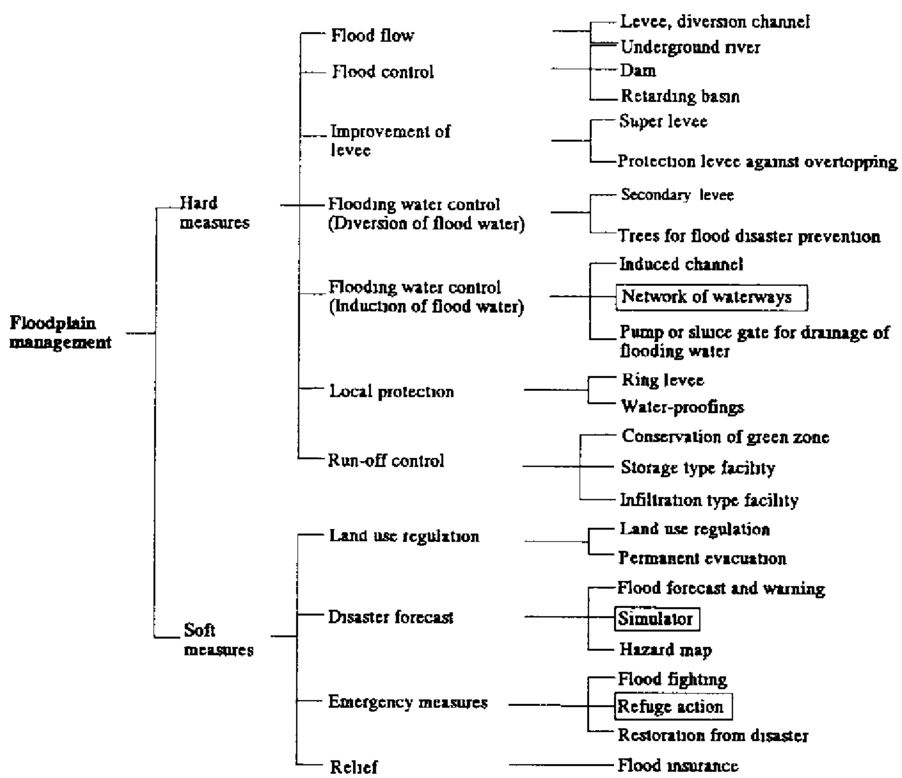

Fig. 1 Floodplain management measures
Note: The boxed are the items considered in this paper.

2. FLOODPLAIN MANAGEMENT

In 1991, the United States published a report entitled "Floodplain Management in the United States; An assessment Report"[1] twenty-five years after their first floodplain management measure was implemented. In the report, various methods for floodplain management were evaluated, and their future flood protection strategies were introduced. Though the U.S. Army Corps of Engineers, state governments and residents had been rather critical about the floodplain management methods at first, the philosophy and technologies were gradually recognized by establishing a floodplain management program through a pilot program conducted by TVA and setting up a united national program for floodplain management, people then began to understand "Controlled floodplain occupation can reduce flood disasters".[2][3]

The concept of floodplain management is not well known in Japan. In this report, the floodplain management measures being presently implemented or expected to be implemented are listed in Fig. 1, by defining the concept in wider sense of flood control measures including comprehensive flood disaster prevention measures. Floodplain management measures can be divided into hard measures using structural bodies and soft measures. What make these measures so different from the conventional flood control methods based on the idea of confining the design flood inside the river course or controlling outflow of flood water from the river basin are primarily forecasting various flooding and overflowing modes and their abilities that make possible of coping with floods and overflows that exceed the planned scale. Full functions as a means of "risk management" can only be achieved if the floodplain management measures are effectively utilized.

Of the floodplain management measures, introduced below are some of the methods which have a distinct feature:

<u>Trees for flood disaster prevention</u>: Trees and a land fill built on the upstream side of a house or houses to weaken the force of flooding and keep the houses not destroyed by flooding flow. An example is the "Funagata Yashiki" or ship-shaped premises such as found in the Ohi River basin.

<u>Floodplain pump and sluice gate</u>: A pump or a sluice gate is normally installed at the junction of a waterway or river and the river into which the flooding water is drained. However, in a closed area of a river basin or an area where the ground level is particularly low, one possible solution may be to install these facilities regardless of the location of the waterway or river, to drain the inundating water from inland.

<u>Permanent evacuation of town</u>: One example was the permanent evacuation of 44 houses in 1976 from the Kuromori and Ishinazaka areas including an adjacent risk zone in Kuroishi city, Aomori prefecture for recovery from the disaster under the Permanent Evacuation Promotion Project for Disaster Prevention of the National Land Agency, when a flooded river destroyed 29 houses totally or partially in these two areas. As the subjected areas were located on a low ground of a dissected valley bottom, a terrace plain 200m distant was selected as an area not prone to flood damage.[4]

Among the floodplain management measures, disaster forecast technologies such as a hazard simulator, flood hazard mapping and emergency measures such as flood fighting, evacuation system are being studied in our division, in addition to river-networking, which is one of the measures for controlling flooding water.

3. AVOIDANCE OF INUNDATION BY MEANS OF RIVER-NETWORK

(1) Modeling of river-network

The solutions for preventing dyke-break or overtopping have relied mainly on levees and dams until today. Also, the emergency measures have been limited as much as draining the water by means of driving channels and pumping (measures for inner water) and positive measures using structures such as controlling and inducing flooding water have not been taken so far. There are some areas among the castle towns, such as Toyama, Takayama, Kurashiki, Saga and Yanagawa where a network of waterways consisting of small rivers, waterways and urban sewers are closely arranged in the river basin. These waterways may constitute a possible way for avoiding inundation.

In this paper, I report the results of a flood simulation made on modeled basin areas in order to assess the flooding water draining effects depending on the difference of the density of waterways. The studied areas were rectangular model river basins of 1 km by 2 km, and each was divided into 10 m × 10 m meshes which made it possible to handle the waterway and floodplain together as one model (PWRI type two-dimensional unsteady flow model). The interval time for the calculations was fixed at Δt=0.1 sec.

The model consists of the equation of continuity and the equation of motion given below:

[Equation of continuity]

$$\frac{\partial h}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0 \text{....(1)}$$

[Equation of motion]

$$\frac{\partial M}{\partial t}+\frac{\partial(uM)}{\partial x}+\frac{\partial(vM)}{\partial y}=-gh\frac{\partial H}{\partial x}-\frac{\tau_{xb}}{\rho} \text{......(2)}$$

$$\frac{\partial N}{\partial t}+\frac{\partial(uN)}{\partial x}+\frac{\partial(vN)}{\partial y}=-gh\frac{\partial H}{\partial y}-\frac{\tau_{yb}}{\rho} \text{......(3)}$$

$$\tau_{xb}=\frac{\rho g n^2 u\sqrt{u^2+v^2}}{h^{1/3}},\ \tau_{yb}=\frac{\rho g n^2 v\sqrt{u^2+v^2}}{h^{1/3}} \text{......(4)}$$

Here, H and h are water level and depth respectively; u and v are velocity in the x and y directions, respectively; g and ρ are gravitational acceleration speed and water density, respectively; M and N are flow flux per unit width in the x and y directions, respectively(M=uh, N=vh); and τ_{xb} and τ_{yb} are shear stresses at bed in the x and y directions, respectively (Manning type expression).

What differentiates these models from other conventional ones is that the roughness coefficient on floodplain is made up of ① roughness due to houses, ② roughness due to farming lands n_1, ③ roughness by roads n_2 and ④ roughness due to other land utilities n_3. As for ①, the roughness for the percentage of land occupation by houses (area coverage of houses /mesh area × 100%) is determined as given below[5]:

$$n^2=n_0^{\,2}+2\times10^{-2}\times\frac{\theta}{100-\theta}\times h^{4/3} \text{......(5)}$$

Here, n is equivalent roughness coefficient (s/m$^{1/3}$), n_0 is the roughness coefficient for bottom (s/m$^{1/3}$), θ is the ratio occupied by houses (%) and h is inundation depth (m).

Further, n_0^2 is expressed as a surface area weighted average of n_1^2 - n_3^2, and the respective roughness coefficients, were determined by the result of previous experiments and calculations as:

$$n_0^{\,2}=\frac{n_1^{\,2}A_1+n_2^{\,2}A_2+n_3^{\,2}A_3}{A_1+A_2+A_3} \text{......(6)}$$

Here, n and A are roughness coefficient and surface area, respectively. The suffixs 1, 2 and 3 respectively represent farmland, road/street, and other land uses. The roughness coefficients for each land use are n_1=0.060, n_2=0.047, and n_3=0.050, respectively.

For this computation, θ=25% and n_0 =0.05 are employed presuming a population density of 7,500 persons/km^2.

(2) Conditions for calculation

The model basin areas, as shown in Fig. 2, incline to the right at a slope of 1/3000 and to the downstream at 1/1000 having two different waterway densities; low density (L=500 m) and high density (L=130 m) expressed as the average access distance L*. The case of the higher density is equivalent to the waterway density in the central area of Yanagawa city in Fukuoka prefecture. The scale is of a ditched waterway of size 10 m (W) × 1 m (D) (This depth is specified, raising the bottom by 1 m assuming that 1 m of the 2 m depth is already filled with the water of antecedent rainfalls), having a roughness coefficient at bed of n_w=0.025.

The conditions for calculation are given in Table 1. The specified flooding types are overtopping and breaking of dyke, and, as shown in Fig. 3, a triangular hydrograph of 50m^3/s peak flow rate for the overtopping and 200 m^3/s for the breaking of dyke were given as the flooding discharge. The volume of flooding is 900,000 m^3 and 7,200,000 m^3, respectively.

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* The mean access distance L is the average distance from a random point to a nearby waterway, and is approximated as L=A/(2× ΣL), where L is the overall length of the waterways and the A, the subject catchment area. In case of the center area of Yanagawa city, L=130 m for waterways and ditches having a width of 10 m or more, and L=60 m for all waterways and ditches combined.

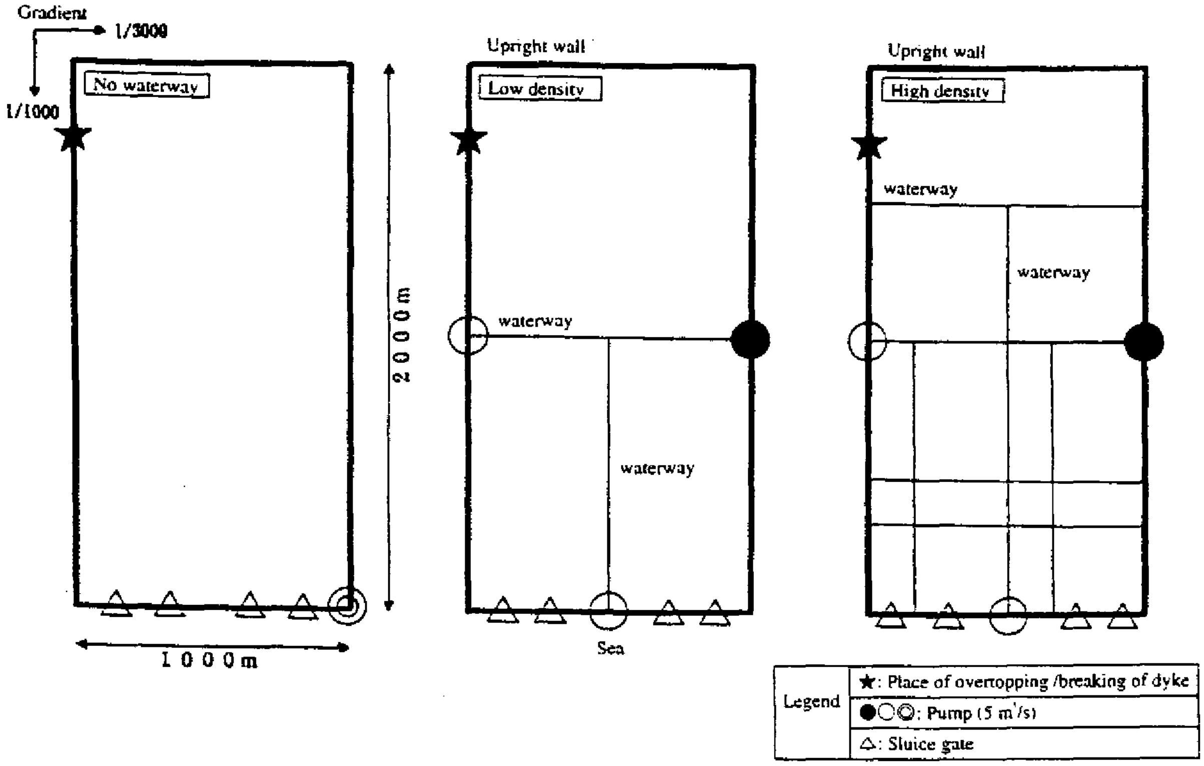

Fig. 2 Model basin of waterway network

Table 1 List of calculated cases

Case	Type of flooding	Peak flooding discharge	Conditions for drainage		
			waterway	pump	sluice
1	Broken dyke	200	H. density	15	4
2	Broken dyke	200	L. density	15	4
3	Broken dyke	200	None	5	4
4	Overtopping	50	H. density	5	4
5	Overtopping	50	L. density	5	4
6	Overtopping	50	None	5	4

Note: The unit for the peak flooding discharge and pump drainage discharge is m^3/s.

The drainage conditions are specified as: $5m^3/s$ pumping at the place indicated with a small black circle (●) for overtopping (the black star (★) shows the place of overtopping or broken dyke), and $5m^3/s$ pumping at each place marked with a black (●) or white circle (O) for breaking of dyke. Where no waterway exists in the area, drainage is done by a 5 m^3/s pump at the double circles (◎) where the ground level is the lowest, for both overtopping and breaking of dyke.

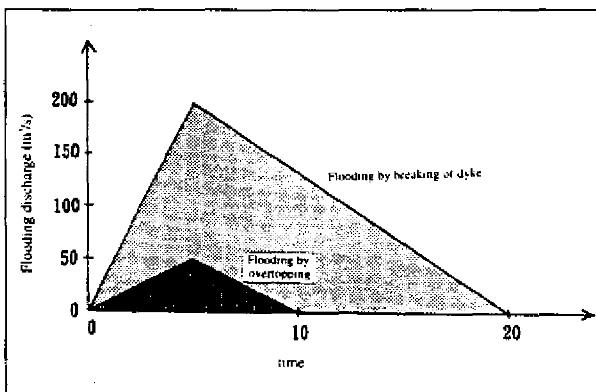

Fig. 3 Flood hydrograph

No drainage is made from places having no pump at the end of the waterway, and the water is just left to flood from the waterway. Other than those pumps, four sluice gates (1 m(w) × 1 m(h) at ground level) are arranged presuming some openings into the sea on the downstream side.

(3) Result of calculation

a) Flooding by overtopping

The distribution of the maximum inundation depth (Fig. 4) shows a tendency that the higher the density of waterways, the more inundated water is drained by the waterways, and the lower the depth of inundation on the downstream side. The inundation which gave a depth of 1 m or more in the area with no waterways gives a depth of less than 50 cm in the area of higher waterway density. This is due to the effect of the drainage by waterways and the storage function inherent in the waterway itself.

Also, as can be seen from the variations of flooding direction and velocity with time in the case of the high density waterway (Fig. 5), the upper right area is inundated by the flood water propagated through the waterways two hours after the start of overtopping and before the larger area begins to be inundated. This phenomenon is observed in actual floods, suggesting that there may be some areas where the damage by inundation temporarily increases because of the existing waterways.

The larger part of the upper half area becomes inundated by the flood water five hours after the start of overtopping. By ten hours after the start of flooding (the overtopping water finishes flowing in) the inundation disappears almost throughout the area, which proves the effectiveness of a network of waterways.

b) Breaking of dyke

Because the total volume of flooding water caused by a break of dyke is 8 times greater than that of overtopping, a considerably larger area will have an inundation depth of 50 cm or more as shown in Fig. 6 (The Distribution of Inundation Depth), while the case of overtopping shows the depth less than 50cm in most of the area. Particularly in the lower right basin area, the depth exceeds 1m. Although the inundation depth of this type is greater compared with that of overtopping, the effectiveness of inundation draining seems to be sufficiently large. Further, of the total volume of flooded water, 82 percent is drained by waterways and 15 percent by pumps, proving the greater draining efficiency of waterways (case 1).

With the results of this calculation, the effectiveness of waterway networks for inundation drainage is now being investigated by modeling them based on the waterway arrangements in actual river basin areas (Fukui city and Kawaguchi city in Saitama prefecture). The study will clarify the practical effect of waterway networks for inundation drainage.

4. DEVELOPMENT OF HAZARD SIMULATOR[6]

A variety of flood risk maps such as Flood Hazard Map have been published so far. However, those maps give information on the state of inundation under certain conditions, and it's difficult to apply it in different situations. We have developed a hazard simulator in our division for the Tsurumi River Basin. This system displays the data of flood computed beforehand on the monitor of a personal computer, and can handle combinations of:

6 flood hydrographs × 50 dyke break locations presumed.*

The calculation model is the same type as the PWRI type two-dimensional unsteady flow model used for waterway networks, but drainage by sewage systems is also taken into account. The basin area is divided into meshes of about 100 m × 100 m, and the following main water hazard preventive information can be displayed: inundation depth of flooded water; flooding velocity and direction; number of people/families who suffer damage; amount of damage at any given time; degree of difficulty of taking refuge corresponding to inundation depth and flooding velocity; and the positions and particulars of shelters and organizations for flood protection.

[Information on inundation]

- -Variation of inundation depth with time (Fig. 7)
- -Inundated area by arrival time of flooding water
- -Flow direction and velocity of flooding water

[Information on damage]

- Number of people / families suffering from damage } (Fig. 8)
- Amount of assets / flood damage cost } (Fig. 8)

* The hydrograph can meet the flood (the wave shape of June, 1966) which corresponds to a rainfall having a probability of excess: 1/30, 1/40, 1/50, 1/100, and 1/150, and the recorded actual flooding in September, 1958. Dyke is assumed to break at every 700 m interval on the levee section managed by the M.O.C.

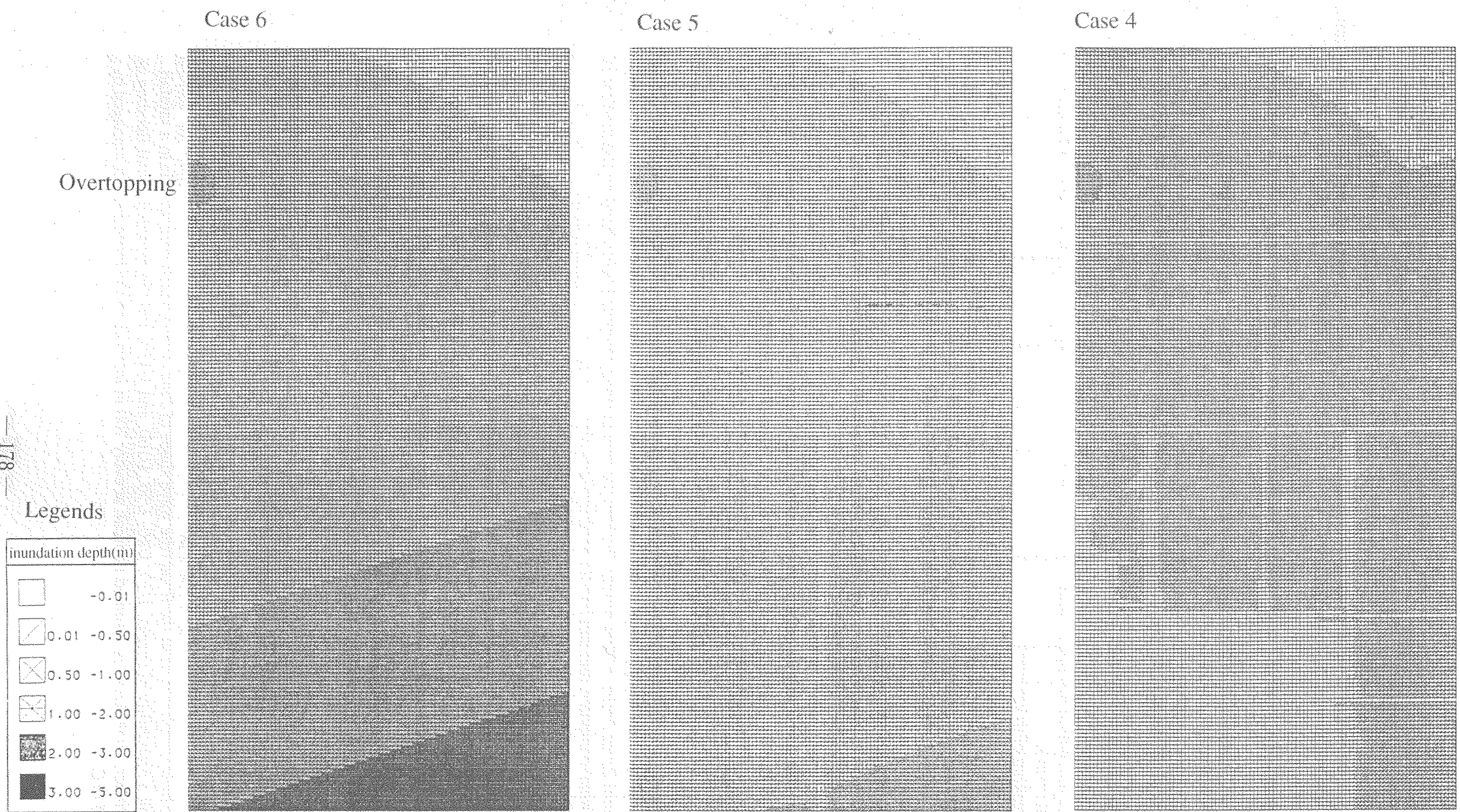

Fig. 4 Distribution of maximum inundation Depth (flood by overtopping)