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Application of Technology for Drainage System Analysis in Indonesia

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Abstract

Recently, studies for the development of low-lying areas including swamps have become very important not only in Indonesia but also worldwide. Authors focused on drainage problems during heavy rainfall. Among the methods employed, mathematical model simulation of unsteady hydrological and hydraulic phenomena was adopted. This technology can be used not only for analyzing the present conditions of drainage, but also for evaluating plans for drainage improvement. The mathematical model should be modified to analyze hydrological runoff characteristics and operation rule of drainage facilities in Indonesia. The improvement of the drainage system must be performed in collaboration with the farmers and inhabitants. Methods of drainage analysis should be selected according to the respective stages of improvement.

Discipline: Irrigation, drainage and reclamation
Additional key words: low-lying area, runoff, hydraulic phenomena, mathematical model simulation

Introduction

Recently, studies for the development of low-lying areas including swamps have become very important not only in Indonesia but also worldwide. The technology to analyze the present conditions in the area and to assess plans should be developed.

The Research Institute for Water Resources Development (RIWRD) in Indonesia is in charge of the development and diffusion of technology for water resources development projects covering irrigation and drainage, including drainage problems in low-lying areas.

Authors focused their attention on drainage problems during heavy rainfall. Among the methods employed, mathematical model simulation[2–4] of unsteady hydrological and hydraulic phenomena was adopted.

This paper describes a part of the results obtained by the first author who was assigned to RIWRD as a JICA short-term expert during the period November 4 to 29, 1994[5].

Outline of procedure for drainage system analysis

The procedure shown in Fig. 1 is used to carry out drainage system analysis with mathematical model simulation. Mathematical model is based on the following hydrological and hydraulic phenomena:

(1) Runoff from hinterland such as farm land, forest and residential area to drainage canal or river.
(2) Flow in drainage canal or river.
(3) Water movement at gate, pump, syphon, etc.
(4) Plane distribution of inundation.

The model is verified when it can reproduce actual phenomena during heavy rainfall through the

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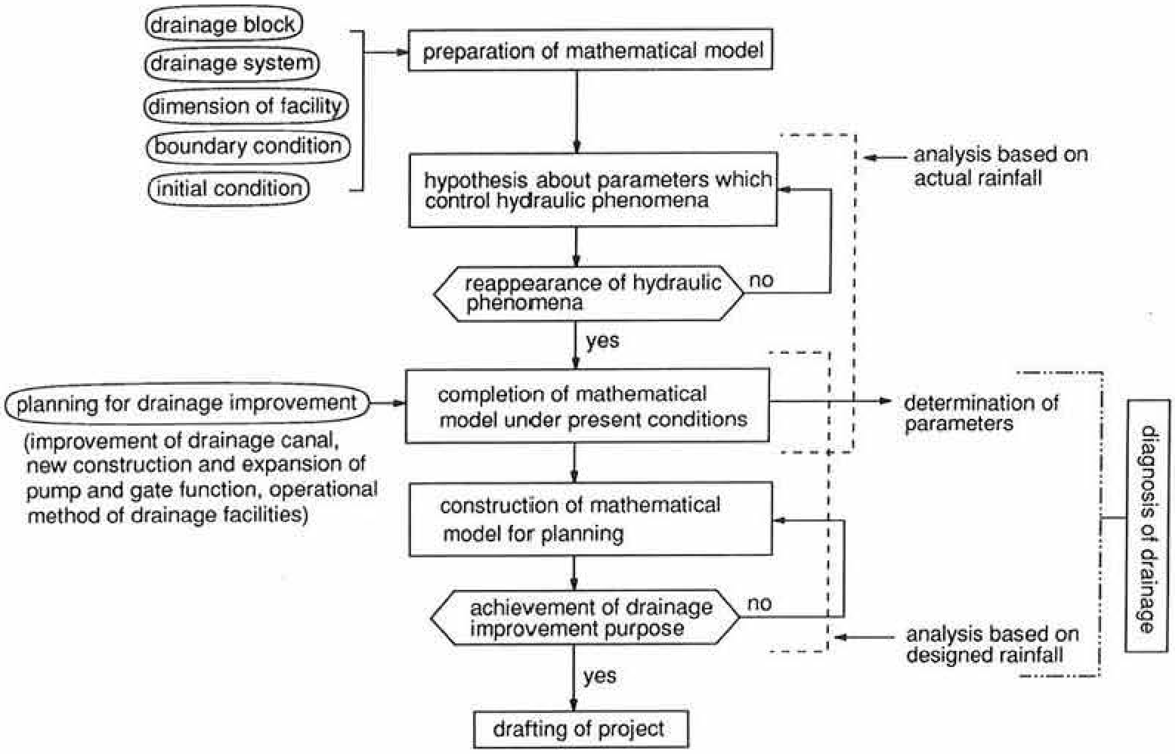

Fig. 1. Procedure for drainage analysis

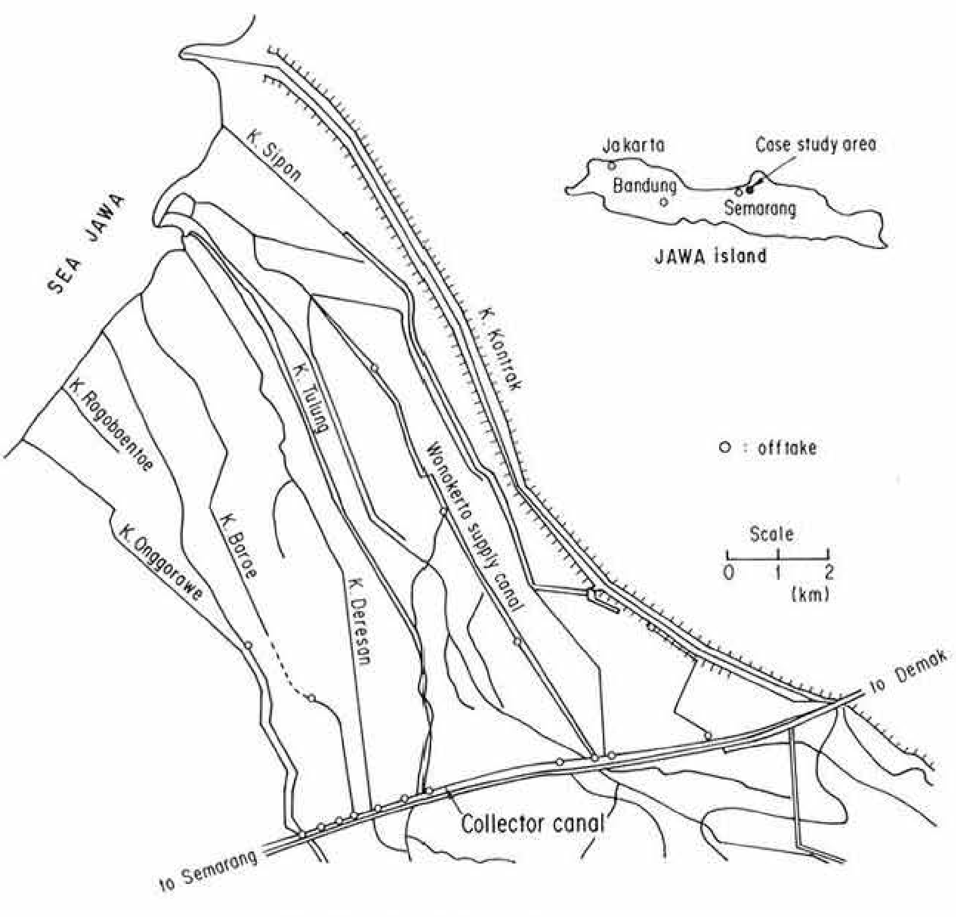

Fig. 2. Description of study area

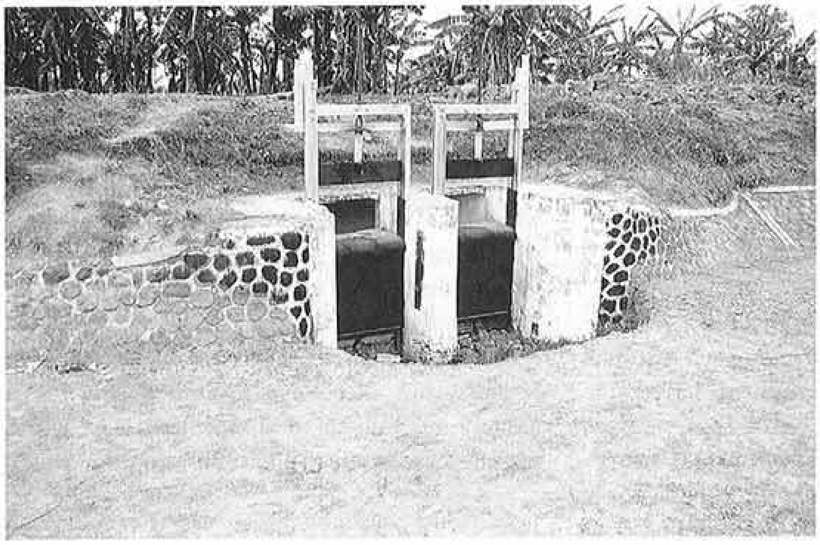

Plate 1.
Offtake at collector canal

Plate 2.
Sedimentation in collector canal

Plate 3.
Wonokerto supply canal connected to drainage canal

determination of several parameters. The model can be used to estimate hydraulic phenomena for optional rainfall, and to develop suitable plans for drainage, including the management of drainage facilities.

Case study

1) Description of case study area

A part of the Jratun Seluna project area was selected as a case study area. The name of Jratun Seluna is derived from the combination of 5 rivers: Jragung, Tuntang, Serang, Lusi and Juana.

The case study area which is located near Semarang is surrounded by K. Kontrak, collector canal, K. Onggorawe and the sea as shown in Fig. 2. K. Deresan, K. Tulung and K. Wonokerto penetrate into the area. Total area is about 4,200 ha.

There are some offtakes (outlets) at the collector canal shown in Plate 1 and foregoing large rivers. Two big weirs which control both water resources and drainage are installed: one between the collector canal and K. Onggorawe and the other between the collector canal and K. Kontrak. The former was not effective due to sedimentation. Some part of the collector canal and almost all parts of K. Onggorawe have lost their flow capacity by sedimentation as shown in Plate 2. On the other hand, K. Deresan has been improved. It has a syphon system to cross both the road and the collector canal.

There are many leaks which reach the sea. The topography is quite flat. Gradient is about 1/6,000. Field elevation is less than 2.0 m above sea level. There are villages along the canals. Main crops are rice, banana, coconut, etc. Banana is cultivated by raising soils up 0.5 m. There are many fish ponds near the sea area.

Tidal influence reaches the confluence point of the collector canal and K. Deresan, although it does not reach the following confluence points: the collector canal and K. Wonokerto, the collector canal and K. Kontrak.

As for the drainage system, supply canals which have offtakes along the collector canal change their function to drainage, especially downstream. Drainage from the fields during heavy rainfall discharges into them. Upstream of K. Deresan, K. Wonokerto and K. Kontrak, there is no lateral inflow from hinterland. In the Wonokerto supply canal that is finally connected to the drainage canal as shown in Plate 3 and reaches the sea, there are lateral inflows from hinterland.

2) Fundamental model

Fundamental model was constructed based on the results of field survey and assumptions based on technical experience.

Daily rainfall data observed in Buyaran station which was the nearest rainfall observation station were used. Daily rainfall amounted to 99, 113 and 90 mm during the period of February 22–24, 1991. Each daily rainfall event was smaller than the designed rainfall of 170 mm occurring once every 5 years, but successive rainfall events for 3 days, namely 302 mm in total, seemed to be worth using for the case study. Sherman equation was used to

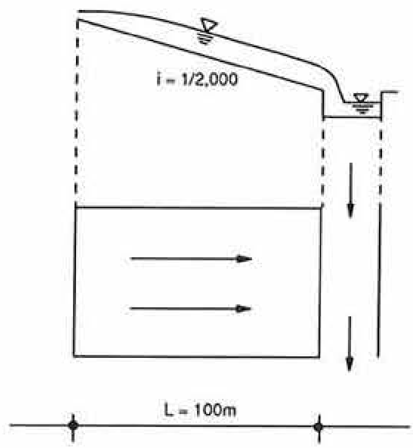

Fig. 3. Field slope

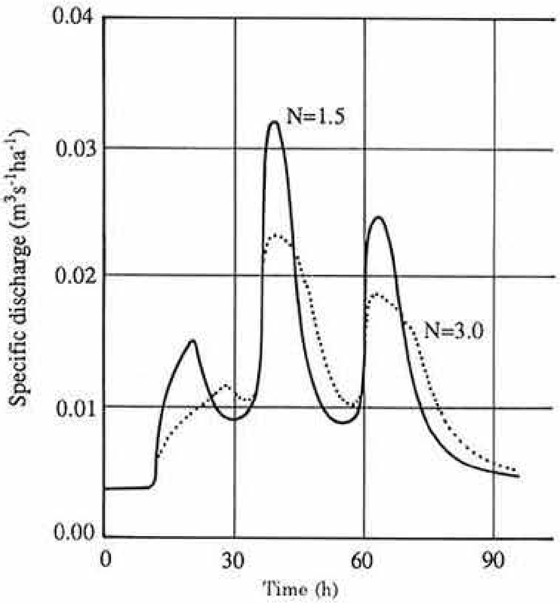

Fig. 4. Runoff analysis

separate each daily rainfall (mm/d) into hourly rainfall (mm/h): $r_t = r_{24} \cdot (t/24)^n$. Here, r_t: rainfall intensity during t hours, r_{24}: daily rainfall, t: time in hour. Parameter n was assumed to be 0.3, considering the intensity of rainfall in Indonesia.

The slope of hinterland was assumed to be uniform as shown in Fig. 3. The following assumptions were made: the slope length; 100 m, the slope gradient; 1/2,000(= 0.0005), maximum loss of rainfall; 40 mm, and base flow; 0.004 $m^3s^{-1}ha^{-1}$. Then, runoff analysis by the Kinematic Wave Method[1] was carried out. The value of the parameter of equivalent roughness N was 1.5 or 3.0. According to the results shown in Fig. 4, the peak specific discharge became 0.032 $m^3s^{-1}ha^{-1}$ for $N = 1.5$ and 0.023 $m^3s^{-1}ha^{-1}$ for $N = 3.0$, respectively.

Procedure for constructing the mathematical model was as follows:

(1) Selecting the canals to be modeled.
(2) Assigning numbers along canals including dummy numbers.
(3) Supplying data related to cross-section, elevation and block catchment area into each block.
(4) Assigning zero velocity as boundary condition.
(5) Supplying information about connection of canals.
(6) Supplying dimension and operation rule of gate and pump if necessary.
(7) Assigning tidal level fluctuation as boundary condition at downstream end.
(8) Assigning runoff discharge as boundary condition at upstream end.

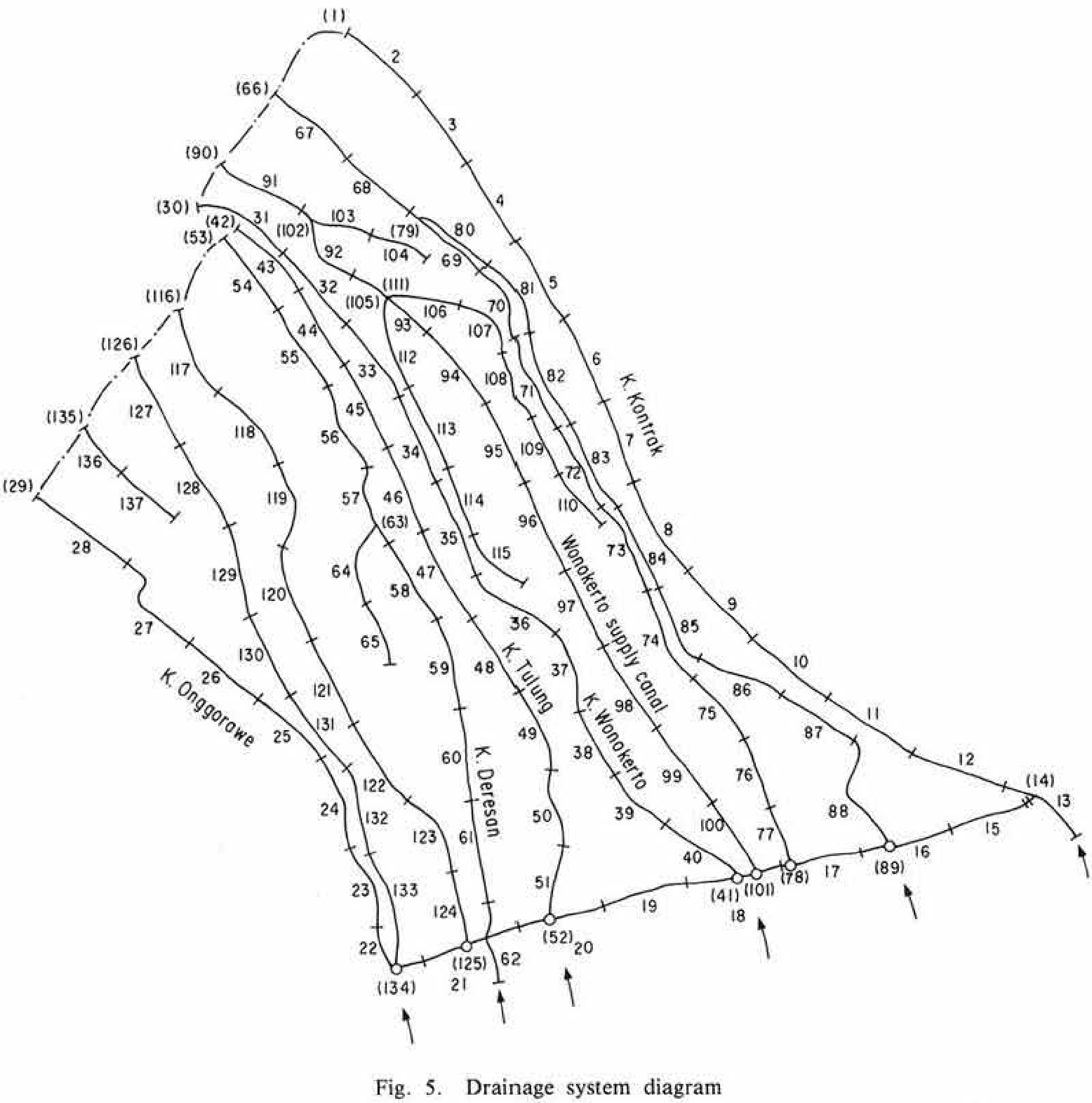

Fig. 5. Drainage system diagram

(9) Supplying specific runoff discharge from hinterland to canal obtained by runoff analysis.
(10) Supplying initial water level.

Drainage system diagram is shown in Fig. 5. Interval length was set at 1,000 m. Number of meshes totaled 137. Tidal fluctuation was presented in meshes nos.1, 29, 30, 42, 53, 66, 90, 116, 126 and 135. Difference in tidal influence depending on the locations was not considered. Inflow discharge was estimated and given in meshes nos.13, 16, 18, 20, 22 and 62 independently. Gate was modeled at velocity point of mesh no.15. It was set up to avoid reverse inflow: from no.13(=no.14) to no.15. Offtake gates along the collector canal were closed by assigning a zero velocity boundary.

Interval of calculation was set at 30 s. About 5 min of computer cpu time were requested to calculate hydraulic phenomena for 96 h using a personal computer. The computer used here was TEXAS personal computer (cpu = 486 DX2, 66 MHz). Microsoft FORTRAN version 5.1 was used as compiler.

3) Calculation cases

Calculation cases were arranged in Table 1. To interpret easily the results, boundary discharge at the upstream end was set at a constant value. Discharge boundary at upstream end was 25 m^3/s (no.13), 15 m^3/s (no.16), 10 m^3/s (no.18), 10 m^3/s (no.20), 12 m^3/s (no.22), 12 m^3/s (no.62), respectively. Tidal water level of type TB was 1.0 m higher than that of TA. Index ○ (circle) denoted that the item was considered. Manning roughness n was modified from 0.03 to 0.022 in case of canal rehabilitation. Initial water level was set at 0.0 m.

Case 1 could be considered to represent the fundamental model. In case 2, influence of the increase in peak specific discharge would have to be estimated. In case 3, effect of canal rehabilitation should be considered. Then, the effect of pump installation should be analyzed in case 4. In case 5, influence of rise in tidal level associated with environmental changes on a global scale in the future should be considered.

4) Example of results

Fluctuations of the water level in case 1 are shown in Fig. 6. Based on the results, the degree of tidal influence depending on the location became clear. The tidal influence was stronger downstream. The upstream water levels became constant, because a constant discharge boundary was used. Since the water level of the collector canal was higher than that of K. Kontrak, gravity drainage was possible

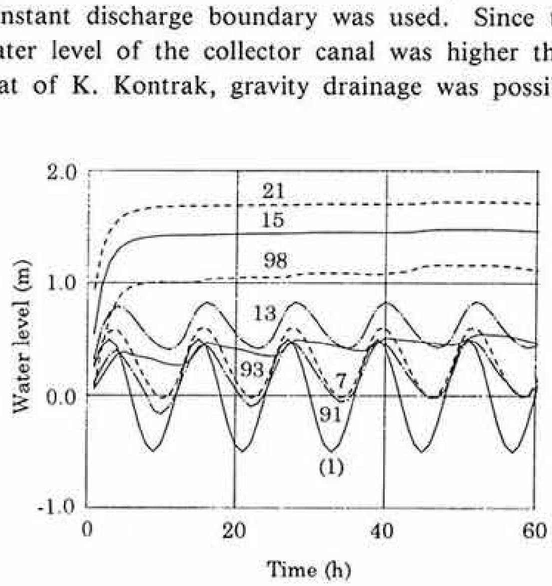

Fig. 6. Fluctuations of water level (Case 1)

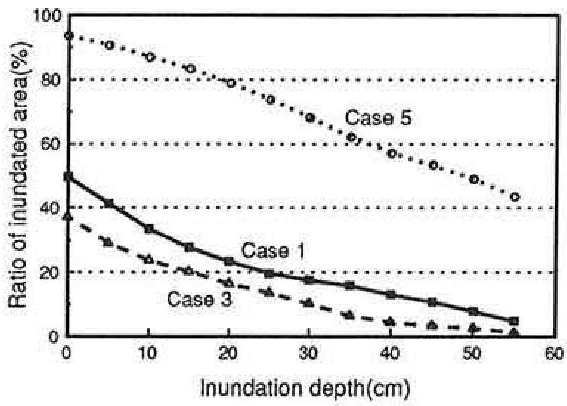

Fig. 7. Comparison of inundation

Table 1. Calculation cases

Case	Equivalent roughness used for runoff analysis	Type of tidal fluctuation	Canal rehabilitation	Pump operation
Case-1	3.0	TA	–	–
Case-2	1.5	TA	–	–
Case-3	3.0	TA	○	–
Case-4	3.0	TA	○	○
Case-5	3.0	TB	–	–

through the gate at mesh no.15. Half of the area was inundated. The ratio of the inundated area in which the inundation depth exceeded 30 cm was 17.6%.

The effect of canal rehabilitation can be evaluated by comparing case 1 and case 3. Influence of tidal rise can be estimated by comparing case 1 and case 5. The above relation for the comparison of the inundation situation is shown in Fig. 7.

Discussion and conclusion

Throughout the case study, the following hydraulic phenomena could be clarified by mathematical model simulation:

(1) Change of water level, velocity and discharge in both time and location.
(2) Influence of tidal water level.
(3) Influence of runoff discharge as boundary condition at upstream end.
(4) Influence of runoff characteristics inside the case study area (= Influence of land use change).
(5) Influence of gate operation.
(6) Effect of canal rehabilitation/improvement.
(7) Effect of pump installation and operation.
(8) Influence or effect of canal network change.

This method can be used not only for analyzing the present condition of drainage, but also for evaluating drainage improvement plans. If the model is once verified by determining parameters such as Manning's roughness n, maximum loss of rainfall and equivalent roughness N in runoff analysis by the Kinematic Wave Method, mathematical model simulation can describe complex hydraulic phenomena occurring during heavy rainfall.

As it is important to analyze the results of both computer simulation and actual hydraulic phenomena, expertise in computer and experience in field survey are necessary. The combination of each technique into one model as total system is essential for mathematical model simulation.

The mathematical model should be modified so as to reproduce hydrological runoff characteristics and operation rule of drainage facilities in Indonesia. Selection of rainfall intensity for the design should be emphasized.

As for the improvement of the drainage system, rapid change may cause more serious damage than before. Development must be promoted in collaboration with the farmers and inhabitants. Methods of drainage analysis should be selected according to the stages of improvement.

Problems such as sedimentation and amendment of peat soils should be addressed from first-hand experience. Assessment and evaluation of achievement may contribute to the design of further improvement plans. Utilization of GIS and development of user-friendly computer system could upgrade the level of analysis.

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