ESCAP/WMO
Typhoon Committee

TECHNICAL REPORT OF TC WGH PROJECT ON ASSESSMENT SYSTEM
OF FLOOD CONTROL MEASURES ON SOCIO-ECONOMIC IMPACTS

GUIDELINES FOR STRUCTURAL FLOOD CONTROL MEASURES ASSESSMENT

MANUAL FOR ASSESSMENT OF FLOOD CONTROL MEASURES (ASFCM)

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Reviewed by Jinping LIU (TCS).

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FOREWORD

Every year, the majority of the Members of Typhoon Committee have suffered flood disasters frequently. Especially, according to many recent studies, the South-East Asian countries have experienced maximum flood events and are becoming highly vulnerable to the consequent damages.

Although the extend of socio-economic damage cost caused by flood disasters differ with countries, all the Members concur with the necessity of appropriate guidelines and a systematic manual to respond to flood.

The actual damage cost is mainly due to socio-economic factors including rapid urbanization, unsustainable development, constant population growth, lack of proper infrastructures, and absence of reasonable policies. Therefore, it is very important to consider these factors in a comprehensive way when estimating and assessing flood damage. In addition flood damage directly affects the national economy, thus economic analysis should be conducted when establishing flood control policies.

There have been existing flood control measures based on experiences in the past and national preferences regarding economic level and social recognition, however it is true that a critical assessment on flood control measures and the selection procedures for an optimal measure is sometimes absent despite its importance.

In this regard, at its 40th Session held in Macao, China in 2007, Typhoon Committee launched the project on Assessment System of Flood Control Measures (ASFCM) which was proposed by the Working Group on Hydrology (WGH) with the following objectives: to develop the evaluation system for various types of flood control measures, which are implemented for basin wide integrated flood control policy such as river levees and storage facilities,
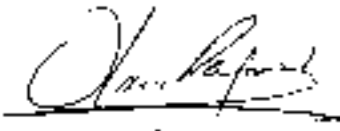
etc.; and to assist and determine the priorities of investment for disaster prevention related project and construction of infrastructures.

The project on ASFCM was performed in the period from 2008 to 2014. The Han River Flood Control Office (HRFCO), in cooperation with Korea Institute of Civil Engineering and Building Technology (KICT) and K-water, made great efforts and highly contributed to this project. Four workshops were held under this project and three events of field survey were conducted in the pilot Members, namely Lao PDR, Philippines and Thailand. The project on ASFCM has achieved the expected goals: (1) a system was developed for the economic assessment of structural flood control with basic inputs including topographic data, asset data and flood damage status in a target area; (2) the HEC-RAS (River Analysis System) model is imported into the system by flood stage estimation; (3) the flood damage cost estimation and the economic analysis using B/C ratios are used as reference information in the establishment of structural measures by estimating flood inundation area; and (4) finally, the optimum alternative regarding economic analysis is suggested.

This technical report is divided into two parts including *Guidelines for Structural Flood Control Measures Assessment and Manual for Assessment System of Flood Control Measures (ASFCM)* which guide you to understand the mechanism of structural flood control measures assessment including flood damage cost estimation and the assessment procedure as well as the practical application of ASFCM step by step.

I do believe that this report will help decision-makers and engineers to examine the optimal flood control measure according to socio-economic circumstances and support TC Members when establishing national/ regional/ local strategies responding to flood in practical practices. I would like to express my sincerest appreciation to all experts of HRFCO, KICT and K-water of Republic of Korea and all related hydrologists of TC Members for their kind cooperation and contribution to this successful project during past 7 years. Also I would like to take this opportunity to thank TCS staff for their

great efforts on the coordination of the project implementation.

ESCAP/WMO Typhoon Committee
Secretary
December 2014

PART A. GUIDELINES FOR STRUCTURAL FLOOD CONTROL MEASURES ASSESSMENT

CHAPTER 1. INTRODUCTION

Flood control measures are defined as measures that minimize damage caused by flood by maintaining flowing and repairing function of basin by controlling flood in stream for protection against flood, maintaining flood control facilities in basin and having flood discharge and urban runoff as the result of basin development smooth from the perspectives of national land conservation, development, use, and environment protection (MOCT, 2001a).

Flood control measures for mitigating flood damage are classified into structural measures and non-structural measures. Regarding structural measures, there are ways to construct various mitigation facilities and operate them so that flood can be prevented without overflow through river or artificial waterway and to detain rainfall temporarily in various detention facilities and drainage it after flood without damage to downstream. Regarding non-structural measures, there are improvement of flood control facility operation system, establishment of flood forecast and warning system, regulation/management of vulnerable areas to flood by varied system devices and establishment of strategies to mitigate flood damage by enhancing public awareness on disaster prevention by education/publicizing.

Fig. 1-1 shows the classification of structural measures and non-structural measures respectively. Reservoirs and retarding structures detain peak flow, stream improvement increases flood passing capability, and bank prevents the overflow of flood to developed areas.

Non-structural measures prevent damage on human lives and property by having people evacuate in advance by way of forecast, alarm, and information transmission on weather and flood. Also they include lifesaving, first aid, and establishing/enforcement of emergency recovery plan on by flood damage investigation.
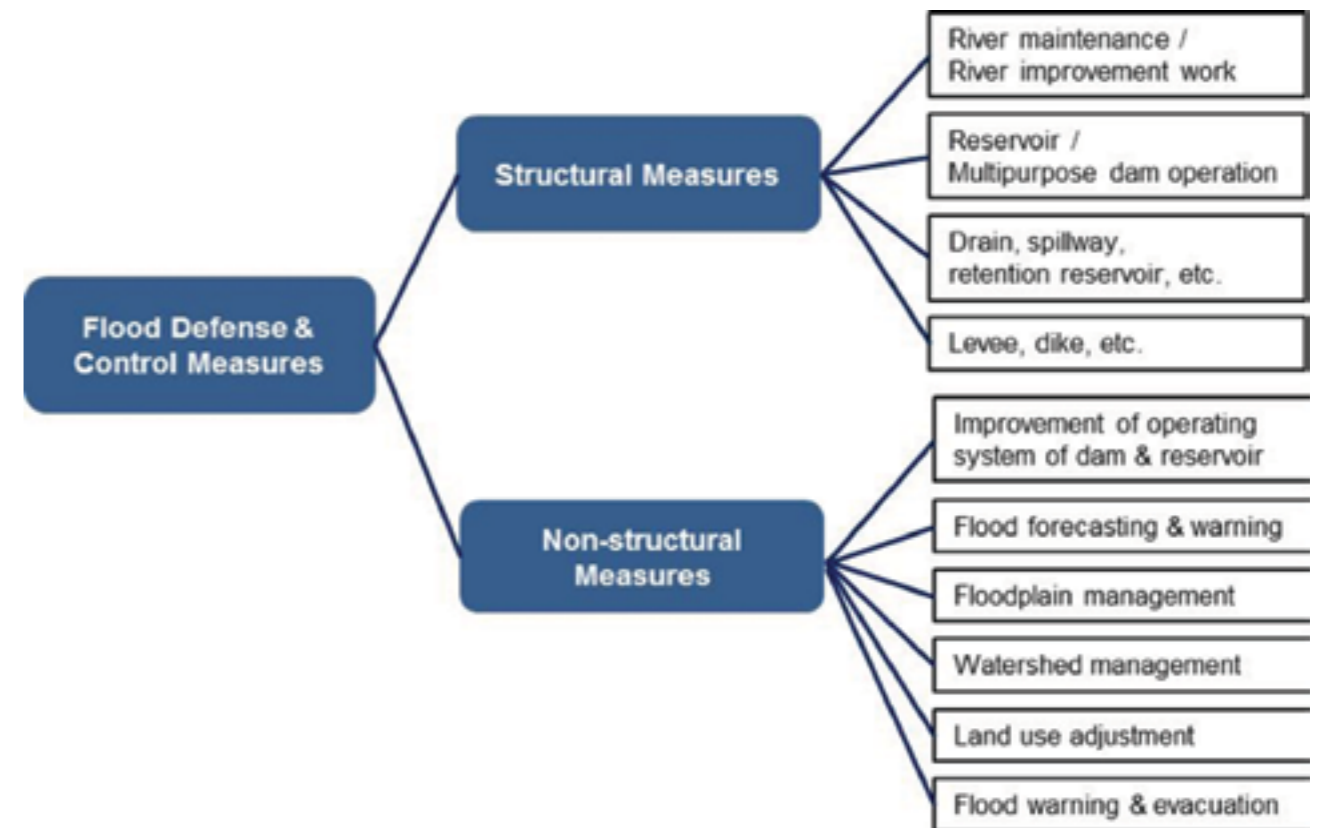
Fig. 1-1 Classification of flood control measures (MOCT, 2004)

1.2 Economic Analysis of Flood Control Measures

There can be many flood control measures to mitigate flood damage. However, government financial resource is limited; therefore, objective criteria in optimizing investment scale, verifying project feasibility and determining the order priority are required. Economic analysis of flood control measures is evaluating and analyzing the benefit and maintenance/management cost of flood control measures.

In an economic analysis of flood control measures, the expected damage cost in a flood damage expected area when a flood control measure would be enforced and when the flood control measure would not be enforced are estimated respectively and the difference between the two becomes the benefit while the estimated project cost becomes the cost. The benefit and cost, then, is compared for economic analysis.

Fig. 1-2 shows the relationship between basic elements and results of economic analysis model for the estimate of flood control benefit. Regarding elements for engineering analysis, there are flood hydrograph by frequency, reservoir operation simulation data, flood track record in stream, stage-discharge curve, discharge-frequency curve, inundation depth and flood damage situation of inundated area, estimated data in dredged sediment and channel improvement cost. Regarding economic elements, there are asset value of flooded areas, stage-damage curve, and indirect flood losses.
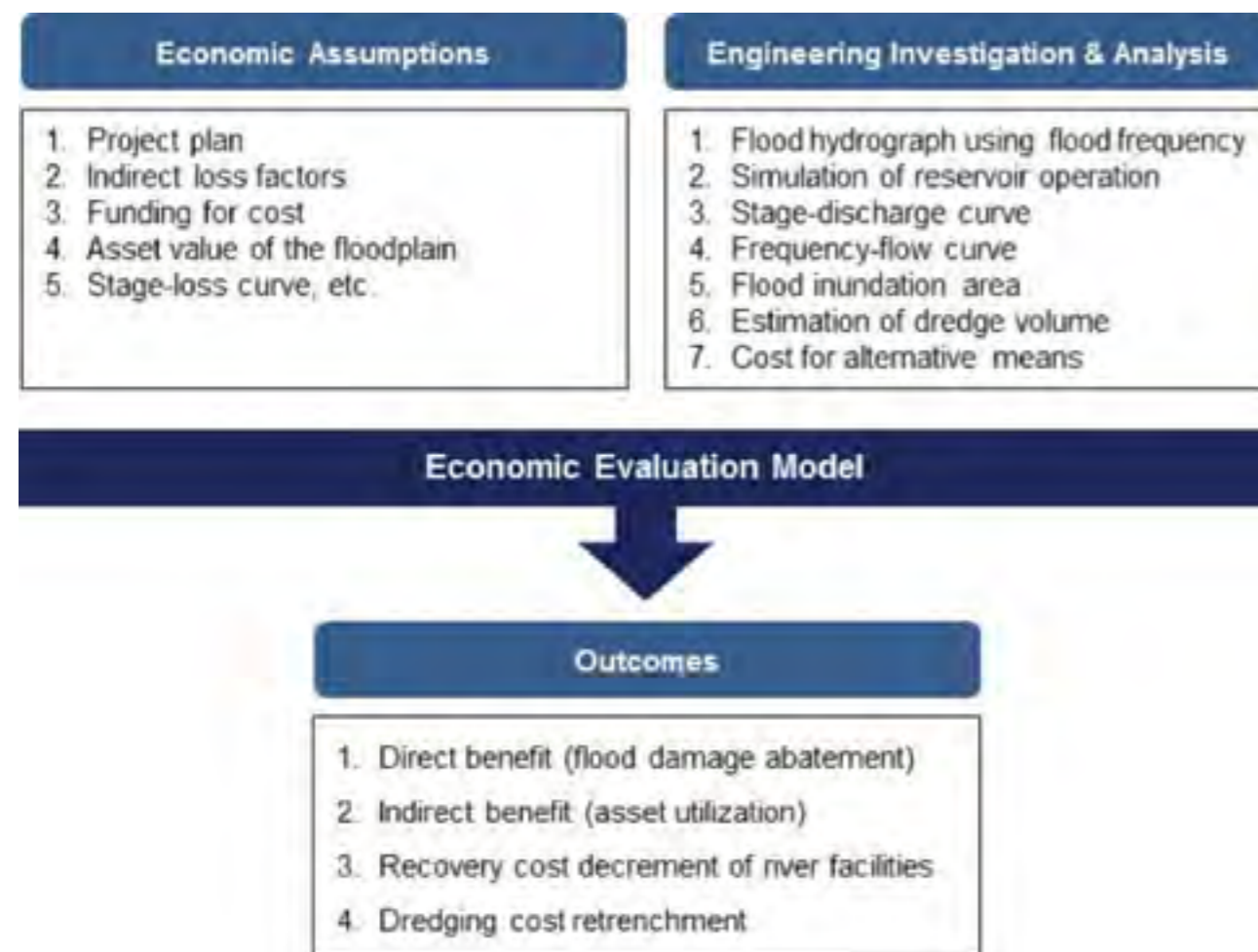
Economic Assumptions

1. Project plan
2. Indirect loss factors
3. Funding for cost
4. Asset value of the floodplain
5. Stage-loss curve, etc.

Engineering Investigation & Analysis

1. Flood hydrograph using flood frequency
2. Simulation of reservoir operation
3. Stage-discharge curve
4. Frequency-flow curve
5. Flood inundation area
6. Estimation of dredge volume
7. Cost for alternative means

Economic Evaluation Model

Outcomes

1. Direct benefit (flood damage abatement)
2. Indirect benefit (asset utilization)
3. Recovery cost decrement of river facilities
4. Dredging cost retrenchment

Fig. 1-2 Basic elements in an economic model for flood control benefit estimation (KWRC, 1998)

CHAPTER 2. ECONOMIC ANAYSIS OF FLOOD CONTROL MEASURES

In general, benefit-cost analysis (BCA), sometimes called cost-benefit analysis (CBA), is used in the economic analysis of flood control measures. This method was used for the first time when the U.S. Army Corps of Engineers applied the benefit-cost analysis concept of the United States Flood Control Act on flood prevention investment analysis in 1936. In 1950, the "Green Book" (original title: Proposed Practices for Economic Analysis of River Basin Projects) was completed in the United States, which was a guideline in benefit-cost analysis. The Green Book provided the bases for economic analysis in the decision making process of public investment projects. Since the 1960s, its application scope was gradually expanded from the United States to countries worldwide. At present, it is being used in the evaluation of a wide range public investment planning, such as water resources, ports, railroad, urban redevelopment, agriculture, education, and pollution-prevention. The Green Book is now used a guideline in the evaluation of investment project feasibility in most agencies in the United States and in many international fields.

The economic analysis should be done on the whole project based on the detail plan on optimum scale and whether the benefit following the construction and operation of investment project would exceed the cost during durable years or not is judged. Regarding concrete standard or index for benefit-cost analysis, methods like benefit-cost (B/C) ratio, net present value (NPV), and internal rate of return (IRR) are being used. Each of them has merits and demerits, depending on the purpose and characteristics of investment project of application. These evaluation methods are not mutually exclusive concept and they can be used in the evaluation of investment projects as complementary standards.

This benefit-cost analysis method can be also used an evaluation method on investment plan for the profit maximization of a private company. The benefit and cost at this time, however, means the benefit and cost of that private company. Benefit and cost should be applied after being converted to the same comparison criteria so that the total benefit and total cost can be made into present value. However, since the durable years of auxiliary structure and facilities are different from each other, it is general to use annual equivalent cost and annual equivalent benefit. The annual equivalent cost and annual equivalent benefit are obtained by discounting all costs and benefits during the project period to the present values as of the standard year, adding them up and let them occur equivalently during the whole period.

Consequently, an economic analysis means the process consisting of evaluating the difference in result for the investment project based on the evaluation of total cost, such as construction cost and maintenance/repair cost, during the economic life of investment project and total benefit achieved by project enforcement and by selecting the best alternative among multiple alternatives. On the other hand, a financial analysis is different from an economic analysis based on market price or actual cost of relevant business and considering the applied interest rate, loan repayment period, tax, government subsidy, and investment fund financing.

2.1 Estimation of Benefits

2.1.1 Direct benefit and indirect benefit

The benefit of flood control measures can be classified into direct benefit and indirect benefit. Direct benefit means the social and economic effects that are earned by decreased flood damage in the area by flood control measures. Decrease in damage of building, durable assets, farming land, crops and industrial assets, decrease in service loss in marketing, transportation, communication and cost saving required for evacuation, and recovery also belong to direct benefit.

Indirect benefit means the decrease in loss of production activities and service in marketing, transportation and communication, and saving in evacuation and recovery cost. In addition, the benefit of social and economic activities, which are expected to increase as the result of flood control measures, also belongs to indirect benefit. When constructing a dam for flood control purposes, the reduction in loss of human lives and mitigation of damages on buildings, household

goods, farming land and crop, industrial assets, and public facilities become direct benefit; while the mitigation effect of indirect damage, such as various service loss and transportation cutoff by flood, become indirect benefit. In case of multipurpose dam, the sum of water supply, flood control effect, power generation by hydropower, and agricultural production increase by irrigation would become direct benefit.

Indirect benefit is benefit induced by or generated from investment project. It has the meaning of induced effects or linkage effects. It includes the benefit that results from the investment project that gives influence to the whole economy and increases economic activity. Livelihood stabilization of local residents, change in living pattern, and increase in employment cannot be expressed in monetary amount. However, they are also indirect benefit as contribution effects on national economy, which include induced effects in public-interest related social convenience, production, labor, and added value. For instance, in addition to current damage mitigation by flood control, decrease in damage possibility and increase in land value following future population increase or economy growth also become indirect benefit. Like this, indirect benefit is more important than direct benefit in certain cases. Therefore, it should be analyzed in detail and be reflected in the evaluation.

The items for benefit and cost of investment project are different depending on the project. Even when some projects are of the same kind, their benefits and costs can be different depending on investment location and scale.

Regarding items of direct benefit of a multipurpose dam, before flood control, living/industrial water supply, irrigation supply, and waterpower generation were considered as benefits in domestic reports or feasibility studies, as shown in Fig. 2-1, the new benefits, depending on the use of a multipurpose dam, such as recreation, water quality improvement at downstream, emergency water supply, and inland transportation by ship, can be also considered.
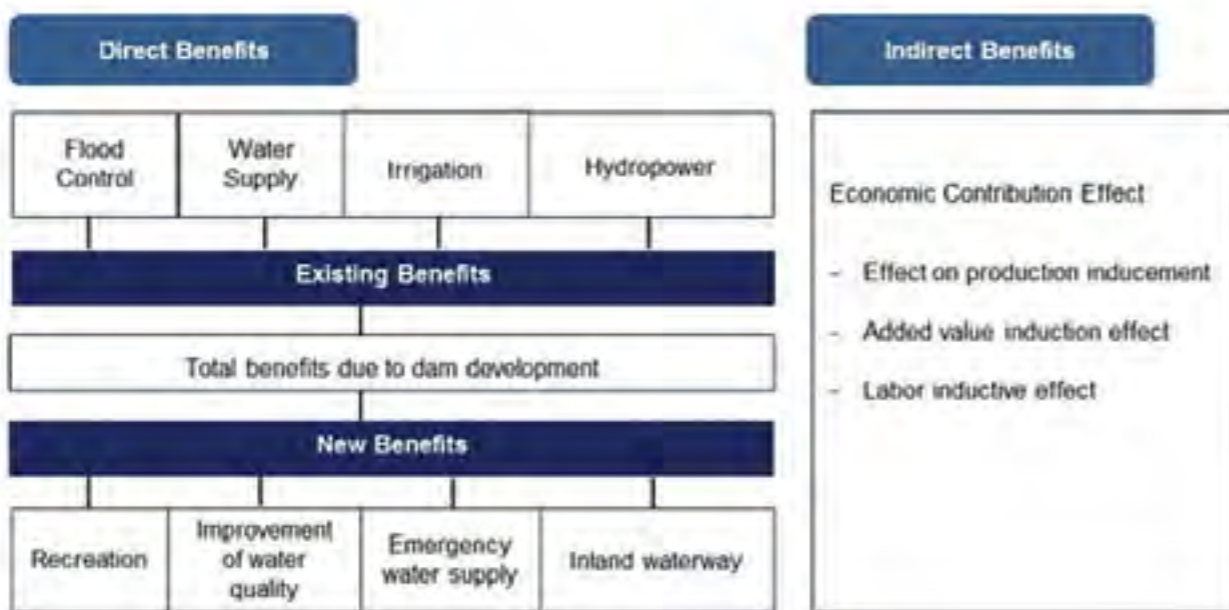

Fig. 2-1 Benefits of estimation for multipurpose dam (MOCT, 2003)

Benefit and cost are classified into tangible and intangible, depending on whether it can be expressed in currency in a market. In general, benefit is more difficult than cost to estimate because benefits are mostly intangible and difficult to measure. Tangible benefits mean measurable benefits which can be assessed in common market.

Regarding the tangible benefits of multipurpose dam construction project, there are supply of water on various purposes, increase in agricultural products and flood damage prevention on farming land and buildings. The values of these benefits are relatively easy to estimate and they can be expressed in monetary term by objective method. Meanwhile, it is difficult to express intangible benefits in monetary term. Regarding intangible benefits in dam construction, there is a decrease in human damage by flood prevention, creation of water-friendly environment, and improvement in river function. These abstract benefits are difficult to assess in monetary term. The following are some examples of intangible benefits:

- Life damage prevention
- Creation of water-friendly environment and improvement of river function
  - Improvement of landscape, beautification of surrounding environment
- Improvement of income and expenditure in farming (stabilization of rural society)
- Advance effects of construction and related industries
  - Accumulation of civil construction technology, domestic production of equipment
- Improvement of public health and sanitation
  - Expansion of water supply, improvement of sanitation level during rainy season
  - Increase in general welfare, pollution prevention (air pollution decrease)
- Contribution in national economy
  - Vitalization of economic growth, use of renewable energy, saving of resources
- Improvement in security (society stabilization effects)

Since most intangible benefits do not have market price, it is difficult to assess them in money. However, various measurement methods are being developed now and efforts to include them in the public investment project economic evaluation are being exerted. It is possible to reflect intangible benefit up to certain extent by measuring the benefit and cost by shadow price.

Cost is the entire resource cost that occurs during investment project on real-time basis. It is required to include external cost caused by the project in addition to direct and indirect cost of investment project. Compared to the concept of benefit, cost has simpler concept and the estimating method is much easier.

Investment on flood control measures project earns benefits. If there would be negative influence on ecological change in environment or a socioeconomic issue, they should be estimated in monetary term and be included in benefit-cost analysis. If a water-friendly space was created and recreation was developed by dam construction or river maintenance, the operation cost of these facilities and the waste contamination by users should also be included in the cost.

Like benefit, cost can also be classified into direct cost, indirect cost, tangible cost, and intangible cost. Direct cost is directly spent on the construction, operation, and management of investment project. Indirect cost are items that investment project interferes with public welfare in monetary terms. Indirect cost may not be spent directly but can sometimes be included in an economic feasibility study. Intangible costs, which mean costs that are difficult to express in money, can occur both in direct cost and indirect cost. Depending on the investment project plan or evaluation purpose, costs can be classified into project cost and maintenance/repair cost.

The annual cost of these converted into annual equivalent cost consists of capital cost and OM&R (operations, maintenance, and repair) cost. Project cost includes costs for construction, land

purchasing/compensation, investigation, design, supervision, project auxiliary items, rental and service fee. When evaluating economics, interest during construction period is also included in project cost. OM&R cost is cost required to have structure or facility to perform normal function during economic life, or, as it is defined, the annual equivalent amount of this cost. Capital cost is the total project cost for the construction project, or the annual equivalent cost, which is obtained by multiplying annual equivalent coefficient to the project cost.

Economic cost means economic loss, which should be considered in the public project feasibility study although it may not be paid by the project owner like an indirect cost. Opportunity cost is the benefit of other investment project, which has been lost because the project fund was invested in this investment project. Therefore, the concept of opportunity cost becomes the basis for interest rate application as comparison criteria for a project feasibility study.

2.3 Economic Evaluation

2.3.1 Benefit-cost analysis concept

The resource allocation constitution within an economy changes when a public project is enforced. Usually, there is a group who gets profit and a group that suffers loss. If the value of profit is bigger than the value of loss and total profit of profit-earning persons minus compensation to loss-suffering persons would still be positive, this can be judged as the increase in overall welfare. This concept is called "compensation principle". The investment purpose of public projects is to enhance the living quality of life. Therefore, it would satisfy this compensation principle by efficiently allocating limited resources. The conformity of benefit-cost analysis is also based on this compensation principle.

In general, the investment plans of public projects differ, therefore, objective criteria to optimize investment and to determine the priority is the economic analysis on which policies would be

determined. The benefit-cost analysis, BCA, is a theoretical analysis technique that evaluates whether it is required to enforce the project or not, how much net welfare would be increased by the investment, what the optimum scale of investment is, and determining the priority of investment among multiple alternatives. In other words, it is a practical method that helps the selection of an investment plan among multiple investment plans when fund is limited.

Benefit-cost analysis, also called cost-benefit analysis or CBA, can be defined as a technical method that draws optimum alternative among various alternatives, which can be conceived to achieve public objective determined on state level by measuring comparing and evaluating costs and benefits.

2.3.2 Evaluation criteria of BCA

A general criterion is required in order to select an investment plan among multiple ones and perform economic evaluation on the facility, which has been determined as optimum scale. This criterion is called evaluation criteria, evaluation indicator, or investment criteria and net present value (NPV), benefit-cost ratio (B/C) ratio, and internal rate of return (IRR) are mainly used.

(1) Net present value (NPV)

Net present value is the sum of future net benefits from the investment project converted to present value. Net present value is a compound word where net and present are added as prefixes. Here, "net" means the remainder obtained by subtracting cost from income. In economic analysis, it means net benefit, which is obtained by subtracting cost from benefit. For salaried people, net income means net receiving money, which is the gross income deducted of tax, medical insurance premium, and payment for future pension. In economic terminology, net profit is defined as the "remainder of profit after deduction of cost". Net profit is used in the calculation of various profitability ratios such as price earning ratio and earning by share.

"Present" means that a value in different timing is converted to present. A proper discount rate is

an important issue in the conversion to present value. If there is no announced discount rate, examples in foreign countries or loan discount rate of commercial banks are used. This will be explained in more detail in the latter part of this paper. Consequently, "net present value" is calculated by discounting future annual net benefits to present value. It can be expressed as follows.

$$\text{NPV} = \frac{B_0 - C_0}{(1+r)^0} + \frac{B_1 - C_1}{(1+r)^1} + \cdots + \frac{B_n - C_n}{(1+r)^n}$$
$$= \sum_{t=0}^{n} \frac{NB_t}{(1+r)^t}$$

Here,
B_t: benefit occurring in year
NB_t: net benefit of net value (= $B_t + C_t$) occurring in year t
n: analysis period
r: discount rate

If there would be residual value of an asset left after the investment analysis period has been finished, it should be also considered. Therefore, the NPV is calculated as follows.

$$\text{NPV} = \sum_{t=0}^{n} \left[\frac{NB_t}{(1+r)^t} \right] + \frac{S_n}{(1+r)^n}$$

Here, the residual value () is determined by considering the depreciation. Depreciation is a process of conserving the decreasing portion of asset value when a fixture or facility is being used. A similar terminology with depreciation is depletion, which is cognizing the decreased portion of value for an asset that has depletion nature. The difference is that the depreciation is the decrease in the potential of asset service while depletion is vanishing of quantity.

Tangible assets are usually depreciated while depletion is applied on depletion asset or depleting asset such as mine, oil field, or forest.

(2) Benefit-cost (B/C) ratio

B/C ratio is the ratio of total benefit and total cost discounted to present. NPV has an issue of advantage to large-scale projects because it gets relative difference. However, B/C ratio has merit in comparing multiple projects from objective perspective. Usually, total discounted cost and total discounted benefit within the same analysis period are used. If the durable years of auxiliary facilities or replacing facilities are different like dam project, annual equivalent installment of discounted total amount is compared for convenience and the B/C ratio also has same value. This B/C ratio can be expressed as follows.

$$B/C \text{ ratio} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}$$

(3) Internal rate of return (IRR)

Internal rate of return means the discount rate (r) when the B/C ratio becomes 1. It also means the discount rate when the net present value becomes 0 when it is evaluated by the net present value.

$$\frac{B_1 - C_1}{(1+r)^1} + \frac{B_2 - C_2}{(1+r)^2} + \cdots + \frac{B_t - C_t}{(1+r)^t}$$
$$= \sum_{t=0}^{n} \frac{NB_t}{(1+r)^t} = 0$$

In the above formula, when it would be regarded that there is no benefit in the first year and the "r", which makes the sum of net benefit discounted from the next year 0, the value becomes the expected rate of profit for that investment project. When considering English terminology, it would be better to say "rate of return" than "rate of profit". In other words, it means discount rate that makes complete repayment of invested cost. Meanwhile, it can be also seen as an expected rate of return when minimum "breakeven" situation would be kept by collecting total cost.

Anyhow, this method is applied when the discount rate that would be applied is not clear or is difficult during NPV or B/C ratio acquisition. A project

developer sets up a minimum rate of return and it would not participate in an investment project if the IRR would not reach minimum rate of return. When the discount rate has the same value with the minimum rate of return, if B/C ratio is smaller than 1, the principle is that the project plan would be dropped. A project is more advantageous when IRR is bigger. Therefore, the magnitude of IRR is directly compared when determining priority of projects.

(4) Other criteria

Regarding other criteria, there are payback (PB) period method and average rate or return (ARR) method. Both methods have demerits of not being able to reflect the temporal value of money. In addition, they are known as insufficient in providing proper economic evaluation information and decision making criteria.

1) Payback period (PB) method

It estimates how soon the invested amount would be paid back in a currency with absolute value. In other words, the period required to pay back all costs of the project. Among multiple alternatives, an alternative with shortest the PB would be chosen as highest priority while potential profit in Let us compare two projects requiring project cost of 100 in the beginning as shown in Table 1. Project A has net benefit of 110 on the first year but Project B does not have any net benefit. Although Project B would have net benefit of 1,000 in the second year, still Project A would be selected in PB method. Therefore, PB method commits clear error in this case.

Table 2-1 Return period calculation example of the law

Project	C0	B1-C1	B2-C2
A	100	110	10
B	100	0	1000

2) Net average rate of return (NARR)

NARR is obtained by dividing the sum of net benefits during whole project period by number of project years. As seen in Table 2-2 below, Project

A has NARR of 114, which is higher than Project B, but it does not explain the temporal value of money because it does not discount the future value of benefit and cost. Since the project period is an important variable, this criterion is difficult to apply on public projects in which benefit occurs for a long period.

Table 2-2 Example of calculation of the average yield

Project	C0	B1-C1	B2-C2	NARR
A	100	115	-	115
B	100	114	114	114

2.3.3 Comparison of evaluation criteria

NPV analysis enables the determining priority by calculating all feasible economic data in one batch. It calculates future value in the net benefit flow into present value using proper discount rate. In general, a project plan is dropped when NPV is 0 or less. When there is no limitation in budget, a project with the highest NPV would get top priority. Even when budget is limited, a project with the highest NPV within the budget limitation receives the highest evaluation.

B/C ratio analysis is a single calculation analysis method like NPV analysis. However, the analysis is not enough with B/C ratio analysis only because the magnitude of actual cost and benefit are not expressed. In the determination of feasible project scale, it is possible to increase NPV and B/C ratio up to a certain extent, depending on the increase in project scale. In this case, the project scale can be determined as the point where NPV is at maximum.

When making a decision using IRR, a project is dropped when the IRR of the project is less than the rate of return used in the project evaluation. This method is used when it is not clear or it is difficult to apply certain discount rate in getting NPV or B/C ratio. However, it cannot be used independently for the evaluation determining investment priority because it does not reflect

project scale information. The merits and demerits of economic evaluation methods are shown in Table 2-3.

Table 2-3 Characteristic of economic analysis methods (HRFCO, 2012)

Method	Characteristics and merits	Demerits
NPV	• Easy to apply • Used when evaluating alternatives with similar result or scale • If economic analysis results of multiple methods are different from each other, the result of NPV analysis would be taken as higher priority	• When investment project is bigger, NPV becomes bigger • Efficiency of capital investment is not expressed
B/C ratio	• Easy to apply • Used when evaluating alternatives with similar result or scale	• Difficult to compare project scale with relativity • When a project has its benefit occur later, B/C ratio becomes lower
IRR	• Possible to determine expected rate of return for investment project • Used when discount rate is not clear for NPV or B/C ratio application	• A project with shorter period can have its profitability exaggerated • A project with later occurrence of benefit has disadvantage

2.3.4 Economic evaluation

In the economic evaluation on flood control projects, total cost and total benefit from that investment are compared. The three evaluation criteria mentioned before — net present value, B/C ratio, and internal rate of return are used for comparison.

It is possible to evaluate by B/C ratio criteria on the same flood control project. There is limitation in evaluation when the independent form of bank project and river flow improvement project, together with combination of alternatives, are the objects of alternative evaluation from the perspective of comprehensive basin flood control plan. Therefore, the evaluation criteria would be selected as the most rational one, depending on the evaluation criteria of each flood control project.

CHAPTER 3. ESTIMATION OF FLOOD DAMAGE COST

Flood damage estimation is estimating actual damage cost caused by flood. In the flood control economic analysis, expected damage cost is estimated by assuming certain extent of damage by certain scale of flood based on past data although actual flood does not happen. In general, expected damage cost is estimated by using empirical relationships derived from existing flood damage investigation and investigating assets in the flood vulnerable area. Since which factors would be included is important, it is required to understand the content and issues in this regard.

The basic method in flood damage cost estimation is a simple method, which is estimating cost of farming land damage, public facilities damage, and indirect damage cost in relation to agricultural crop damage cost in the project area. An improved method (regression analysis method) was suggested after a simple method. It uses basic unit method of a simple method for the human damage, flood victims, and agricultural crop damage cost while the building damage cost, farming land damage cost, public facilities damage cost, and other damage costs are obtained by the relationship between inundated area and damage loss based on disaster statistical yearbook.

However, an improved method still has limitation in regarding the status of asset in the target area and changing economy status because it only considers the relationship between inundated area by city type and damage cost based on disaster statistical yearbook information. Especially, when flooded area is small, the constant term value in the regression function works as a dominating factor and it creates an issue in which the B/C ratio is expressed relatively bigger. When multi-regression function was induced by considering local characteristics, the result suggested that there is a trend in which the damage cost in the area classified as mountainous area had relatively bigger damage cost than the damage cost in other areas. Even the issue related to constant term would be improved, still the accuracy issue of disaster statistical yearbook remains. Therefore, there is limitation in drawing rational result. In addition, it does not properly consider inundation depth and flood frequency.

In order to resolve these issues, the multidimensional flood damage analysis (MD-FDA) was suggested as the way to estimate direct damage cost by obtaining damaged asset in flooded area and multiplying damage ratio, which fits with inundation depth.

3.1 Benefit Factors in the MD-FDA

The MD-FDA considering inundation depth estimates direct damage cost by obtaining damaged asset in flooded area and multiplying damage ratio which fits with inundation depth. The direct damage cost is classified into seven categories, which are human damage cost, building damage cost, building content damage cost, farming land damage cost, agricultural crop damage cost, business place tangible/inventory asset damage cost, and public facilities damage cost. The five damage costs, excluding human damage cost and public facilities damage cost, are estimated based on assessed amount of general assets. The direct damage cost was estimated in principle by estimating recovery cost or repurchasing cost close to amount people actually spend because people who start living again in the damaged area mostly repurchase housing or furniture after flood disaster.

3.2 Basin Constitution of the MD-FDA

Regarding public facilities, the ratio of public civil facilities damage to general asset damage was estimated by deriving the relationship between general asset damage cost and past damage data. Indirect damage cost was excluded. Fig. 3-1 is the conceptual diagram of the MD-FDA.

3.2.1 Properties in general asset damage estimation

Movable assets and real estate, accumulated and kept by men for living and perform economic activities, such as farming, manufacturing, or service business, are used for general asset damage estimation. In other words, buildings, building contents, farming land, agricultural crop, and business place tangible/inventory assets belong here.
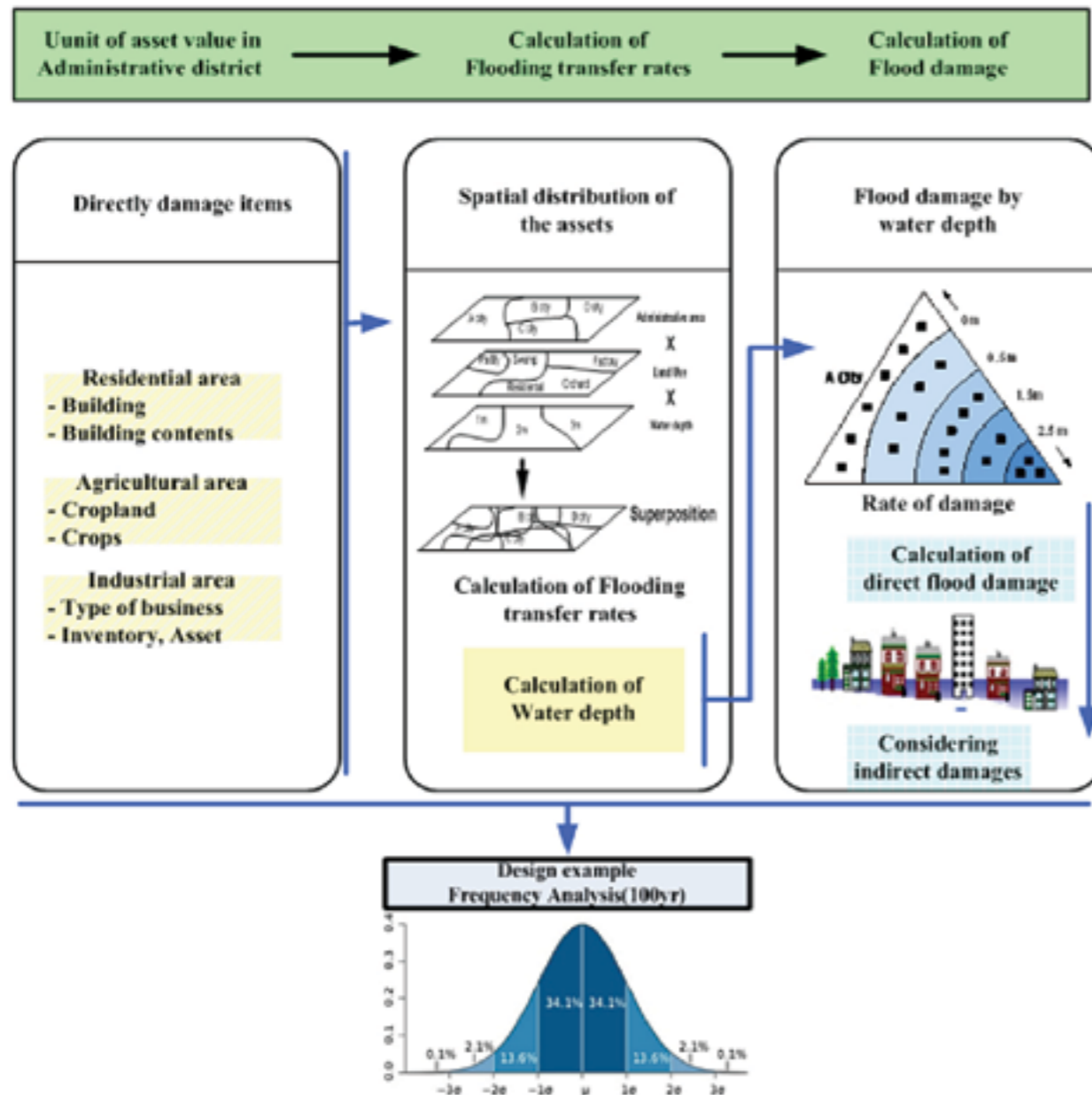
Fig. 3-1 Conceptual diagram of MD-FDA (MOCT, 2004)

3.2.2 Basic unit in general asset damage estimation

In order to estimate the influence of spatial flooding range on flood damage cost concretely, the flooding range was set up as the administrative district. Of course, it is possible to enhance accuracy of damage cost estimation if the unit would be smaller. However, it is more efficient to regard the realistic units that can meet reasonable characteristics of damage cost estimation method such as precision, feasibility, convenience, and simplicity.

3.2.3 Input data for general asset damage estimation

The following data are required for concrete estimation of direct damage cost:

1. Data on assets which suffered direct damage
2. Relationship between inundation depth and damage ratio

3. Data on inundation depth in the target area

Actual flood damage cost is estimated by preparing information in 1 and 2 and setting up the relationship in advance and information in 3 will be substituted to the direct damage cost estimation function when certain flood would actually occur.

3.3 Asset Investigation by Administrative District

Table 3-1 shows concrete asset estimation method reflecting local characteristics by administrative district. Local characteristics are first classified into residential characteristics, farming characteristics, and industrial characteristics. How these local characteristics are reflected in the flood damage cost estimation will be explained below. Information regarding these local characteristics can be obtained from data of public agencies like the National Statistical Office.

3.3.1 Residential characteristics

(1) Building assets

Building asset value is estimated by multiplying the building unit price to the total building space in target area. Because the value is estimated by limiting the object building to residential buildings and business buildings are not included, there is a concern for under-assessment. However, business buildings are included in the tangible fixed asset item in industrial area. A method to separate business buildings in detail is required for more accurate asset estimation.

> **Asset value of building** (KRW) = building price per unit area for each building type (KRW/square metre) x ratio of gross area (square metre/number of building) x number of household x construction deflator in the base year

Here, the total area by building type is estimated by number of household based on city/county statistical yearbook. If there is no such statistical information, national average data can be used.

Table 3-1 Direct damage assets and damage cost estimation (MOCT, 2004)

Local characteristics	Classification		Data	Estimation method
Residential Characteristics	Buildings	Detached house	① Total building area and number of housing by building type	Estimate by multiplying building unit price to average of relevant administrative district (① x ② x ④, ③ is for consideration)
		Apartment	② Building unit price by building type	
		Row house	③ Number of stories for apartment and row houses	
			④ Number of housing by administrative district and by building type	
	Building contents		① Distribution ratio and average price of household goods	Estimate by multiplying assessed unit price to number of household (② x ③, ① is for consideration)
			② Assessed cost of household good by district	
			③ Number of household by administrative district	

Farming Characteristic	Farming land / Rice pad	Field	① Damage cost by buying and loss ② Area of field and rice pad by administrative district	Directly estimate when buying or loss has occurred (① x ②)
	Agricultural crop / Rice pad	Field	① Assessed unit price for agricultural crop by unit farming area ② Ares of field and rice pad by administrative district ③ Kinds of agricultural crop by administrative district	Estimate agricultural crop asset by multiplying assessed agricultural crop unit price per unit area by district to area of rice pad and field (① x ②, ③ is for consideration)
Industrial Characteristics	Tangible assets / Intangible assets		① Tangible and intangible assets of business per one employee by industry classification ② Number of employee by industry classification by district	Estimate tangible and intangible assets of business by multiplying assessed unit price per person to number of employee by high-level industry classification (① x ②)

In order to estimate building asset value of project evaluation reference year, the nominal increment by price increase should be removed from statistical values expressed in monetary terms. For this, construction business deflator correction factor for reference year in divisor form was introduced (refer to Table 3-2).

Table 3-2 Annual construction deflator correction exponent (Korea) (MOCT, 2004)

Year	Construction deflator
1997	100.00
1998	104.74
1999	104.02
2000	106.02
2001	109.61
2002	114.44
2003	122.36

(2) Building content

Asset value of building content is estimated by following function.

> **Asset value of building content** (KRW)
> = Assessed amount of household goods (KRW/number of household) x number of household x consumer price index

Here, the assessed amount of household goods was estimated as minimum amount and maximum amount by multiplying distribution ratio and average price by each household good item to distribution ratio and average price of household goods as of the end of 1997 in National Wealth Statistics (1999) in Korea. Number of household can be obtained from city/county statistical yearbook of relevant year.

In practical analysis, it would be more convenient to use average value or representative value for assessed amount for household goods.

3.3.2 Farming characteristics

Farming characteristics are measured by agricultural crop or area of field and rice pad in administrative district units. It is possible to obtain the data for the last few years and area of field and rice pad in district units from city/county statistical yearbook of relevant year.

(1) Farming land

Data for past years on farming area by field and rice pad are collected from city/county statistical yearbook. Even a farming land would be inundated; there is little damage down to certain inundation depth. When there is burying or loss, damage cost would be directly estimated.

(2) Agricultural crop

Agricultural crop asset value is estimated by multiplying assessed agricultural crop unit price per unit area by city, county, and district to area of rice pad and field, as shown in Function.

> **Agricultural crop asset value** (KRW)
> = assessed agricultural crop unit price per unit area (KRW/ha) x area of rice pad and field (ha) x consumer price index

When assessing agricultural crop asset, production quantity of representative crop and special crop of field and rice pad would be assessed as follows. For rice pad, production quantity of rice would be taken. For field, average harvest quantity during recent three years excluding maximum harvest and minimum from city/county statistical yearbook would be taken as ordinary year harvest for application.

Assessed unit price of crop per unit area was set up based on production cost. In addition, if information related to "assessed unit price of crop" per unit area would be available in city/county, it would be used.

$$c = \frac{\sum P_i \cdot x_i}{\sum A_i}$$

Here,
c: assessed agricultural crop unit price per unit area
i: kind of agricultural crop from field and rice pad in relevant area
x: average harvest quantity
P: price
A: Farming area

The basic quantity, farming area of agricultural crop is obtained from the administrative district data from city/county statistical yearbook for relevant year.

3.3.3 Industrial characteristics

Tangible and fixed assets of business are estimated by multiplying assessed unit price per person to number of employee by high-level industry classification.

Assessed amount of tangible/inventory assets per employee by industry classification was obtained by dividing tangible/inventory assets of business by industry classification given in the National Wealth Statistics (1999) by the National Statistical Office by total number of employees by industry classification and shown by city/province considering deviation by region. The number of employee by business can use city/county statistical yearbook for district units for relevant year.

> **Asset value in industrial area** (KRW)
> = assessed amount of tangible/inventory assets per one employee by industry classification (KRW/person) x number of employee by business (persons) x consumer price index

3.4 Estimation of Inundated Inclusion Ratio

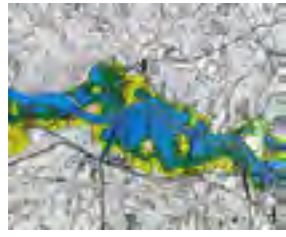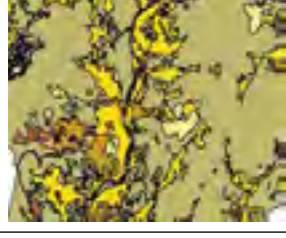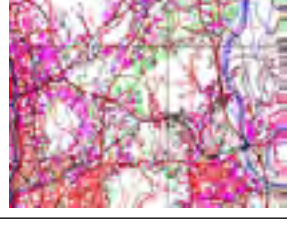Existing flood damage estimation method classified damaged area into five areas of metropolitan cities, small and medium cities, garden cities, agricultural areas, and mountainous areas. It calculated damage cost in one-dimensional method, which multiplies weight value by characteristic or attribute value to inundated area. This existing method has minimum classification unit as city/county/

district; therefore, the accuracy is low and it does not reflect the asset value of damaged area in correct manner because it only takes population as a single independent variable for representative characteristic of the region. In addition, because it digitally estimates inundated area without spatial definition on inundated area, it does not consider inundation depth. It also has demerit that it does not reflect the difference in damage cost estimation method within the damaged area, such as land use type or population concentration.

In order to complement existing demerits, this study linked the spatial information of damaged area, such as administrative district, inundated area, inundation depth and land use status to geographical information system (GIS) and estimates inundated inclusion ratio by residential, farming, and industrial areas, depending on inundation depth of inundation damaged area within administrative district.

Table 3-3 Classification and utilization of spatial data (MOCT, 2004)

Classification	Contents	Utilization
	< Inundation Map > Digital map containing information on expected flood inundation in flood damage area such as flood return period (frequency), inundation depth, inundated area	Obtain spatial information such as inundated area by frequency and inundation depth
	< Administrative District Map > Digital map showing administrative districts controlled by local self-governing bodies in city/county/district unit	Basic unit that shows human, social, and economic status of inundation damaged area
	< Land Cover Map > A map with 1/50,000 scale made in high-level classification system based on Landsat TM image. Available for Korean peninsula at the end of 1980s and end of 1990s	Obtain spatial information such as farming land distribution and its area
	< Land Use Map > Digital map and prepared by investigating ground coverage and land use status and its printout	Obtain spatial information such as farming land distribution and its area
	<Digital Topographical Map> A map in uniform scale for whole national land widely used as a basic map for maps prepared by state, other theme maps, and special maps	Obtain information of residential area and industrial area distribution

In order to draw spatial attribute values of damaged area, inundation map by overflow analysis, administrative district map, land cover map and land use map showing land use status were utilized. Table 3-3 shows the classification and contents of spatial information data to be used.

(1) Inundation map

There are several names for flood related theme maps, depending on purpose. However, there is no uniform definition and its kinds are various, depending on the viewpoint on disaster. A map prepared to prevent flood damage in advance by forecasting inundation scope has multiple names, such as flood occurrence map, flood forecast map, flood hazard map and flood risk map.

Among them, the flood occurrence map is prepared by investigating inundation occurrence on the area that received frequent damage from inundation during past floods and marking those on a map. Flood forecast map, flood hazard map, and flood risk map are maps on which expected magnitude of flood and inundation scope are marked. Therefore, flood occurrence map has its purpose on publicizing the danger of flood to residents and providing with information on inundation and evacuation so that evacuation system when there would be a flood would be built in advance. The purposes of flood forecast map, flood hazard map and flood risk map are closer to disaster prevention using engineering means such as structural measures to cope with disaster.

(2) Administrative district map

This study used administrative district digital map following the classification system of Ministry of Public Administration and Security in Korea.

(3) Land use map and land cover map

1) Land use map
In Korea, land use map is prepared in 1/25,000 scale by editing/overlapping the road, river and railroad layers drawn from 1/37,500 map made from aerial photograph and 1/5,000 digital topographical map and complementing items investigated locally: 414 land use status maps out of total 769 maps were made, which covers 55% of whole national land. Table 3.4 shows the basic attribute information of land use map.

Table 3-4 High-level, middle-level, and detail-level classification items in land use map (MOCT, 2004)

High-level	Middle-level	Detail-level classification
Farming land	Rice pad	Rice pad readjusted / rice pad not readjusted
	Field	General and special crops / orchard and others
Forest land	Grassland	Natural grassland / pasture land
	Forest	Needle leaf tree forest / broad leaf tree forest / mixed tree forest
	Others	Golf course, cemetery, amusement park
Cities and residential land	Residential and commercial use land	General residential land / high-rise residential land / commercial/business land / bare empty lot and artificial green land
	Traffic facility facilities	Road, railroad and surrounding area/ airport, seaport
	Industrial area	Industrial use land / industrial use bare land and others
	Public facilities	Power generation facility / treatment facility / education or military facility / public use land
	Other facilities	Quarry / fish farm, breeding ground / reclaimed land / mineral spring land

Water system	Wetland	Mudflat / saltpan
	Rivers	River
	Lakes	Lake / dam
	Others	Sand beach and others

2) Land cover map

In Korea, Ministry of Environment makes and distributes land cover map using satellite image. It is distributed with classification on high level, middle level, and detail level.

High-level ground coverage map is a map with 1/50,000 scale based on high-level classification system based on Landsat TM image (resolution: 30 m x 30 m). It covers the Korean peninsula at the end of 1980s and at the end of 1990s. Middle level ground coverage map is a map with 1/25,000 scale and ground resolution 5 m consisting of 23 classification items, such as residential, industrial, commercial areas, and traffic facility area detailed from high-level classification items made by using IRS satellite image. Detail level ground coverage map is a map with 1/5,000 scale and ground resolution of 1 m, consisting of 48 classification items, such as detached house, row house, and apartment detailed from middle-level classification for the areas that represent the classification characteristic of high-level classification made by using high-resolution IKONOS satellite image and aerial photograph. Detail level ground coverage map is made for six model areas. Table 3-5 shows the items and codes by classification of land cover map.

Table 3-5 High-level / middle-level / detail-level items and codes for land cover map (MOCT, 2004)

High-level		Middle-level		Detail-level classification	
Urbanized dry area	100	Residential area	110	Detached house	111
	100		110	Row house	112
	100		110	Apartment	113
	100	Industrial area	120	Industrial are	121
	100	Commercial area	130	Commercial, business area	131
	100		130	Mixed use area	132
	100		130	Gas station, LP gas station, oil storage area	133
	100	Entertainment facility area	140	Entertainment and recuperation facility	141
	100		140	Game arena	142
	100	Traffic facility area	150	Airport	151
	100		150	Seaport	152
	100		150	Railroad	153
	100		150	Road	154
	100		150	Other traffic, communication facilities	155
	100	Public facility area	160	Environment infrastructure facility	161
	100		160	Power generation facility	162
	100		160	Education, correctional, military facilities	163
	100		160	Other public facilities	164
Farming area	200	Rice pad	210	Rice pad readjusted	211
	200		210	Terraced rice pad without readjustment	212
	200	Field	220	Field	221
	200		220	Field in mountainous area	222
	200	Vinyl house cultivation area	230	Vinyl house cultivation area	231
	200	Orchard	240	Orchard	241
	200	Other cultivation area	250	Horticulture, landscaping, plantation, nursery (seedbed)	251
	200		250	Farm, ranch, cattle farm	252
Forest area	300	Broad leaf tree forest	310	Natural broad leaf tree forest	311
	300		310	Planted broad leaf tree forest	312
	300	Needle leaf tree forest	320	Natural needle leaf tree forest	321
	300		320	Planted needle leaf tree forest	322
	300	Mixed tree forest	330	Mixed tree forest	331
Green land	400	Natural green land	410	Natural green land	411
	400	Golf course	420	Golf course	421
	400	Other green land	430	Cemetery park	431
	400		430	Roadside tree	432
	400		430	Other green land	433
Wetland	500	Inland wetland	510	Inland wetland	511
	500	Coastal wetland	520	Mudflat	521
	500		520	Saltpan	522
Bare land	600	Mining area	610	Mine	611
	600		610	Quarry	612
	600		610	Other mineral mines	613
	600	Other bare land	620	Seacoast	621
	600		620	Riverbank	622
	600		620	Other bare land	623
Water area	700	Inland water	630	River	631
	700		630	Lake	632
	700	Sea water	640	Sea water	641

(4) Digital topographical map

Digital topographical map is a computerized map with three-dimensional coordinates on topography and features on earth prepared by the National Geography Information Institute in Korea. It is digital geography information expressing various natural and artificial features on earth, such as road, railroad, building, river, mountain, rice pad, and field in three-dimensional location coordinates and graphics (signs).

Digital topographical map is state basic map made by state with uniform scale on national land. It is used as base data in making other theme maps and special maps for development and utilization of national land.

3.4.2 Selection and utilization of spatial information

After the asset values by residence, farming, and industry on administrative district units are

drawn, inundated inclusion ratios of inundated area in residential, farming, and industrial areas are estimated by utilizing GIS. Total damage cost of inundated area is obtained by multiplying inundated inclusion ratio to asset value by administrative district.

GIS data required for the estimation of flood damage cost can be classified into river data, human/social/economic data and geography data. Therefore, inundation map, administrative district map, land cover map, land use map, and digital topographical map can be the frames for it.

Table 3-6 Framework data item selection for flood damage cost estimation (MOCT, 2004)

Type	Attribute items	Remarks
Inundation map	• Inundated area boundary and area by frequency • Inundated area boundary and area by inundation depth	Existing data and inundation analysis result
Administrative district map	• Administrative district unit boundary and area • Asset value within administrative district • Value of industry tangible asset and inventory asset • Value of farming land and agricultural crop in farming area	The map should contain latest information on administrative district unit. Asset value within district unit was illustrated
Land cover map	• Framing: high-level and middle-level classification items • Industry: industrial, commercial, entertainment area in middle-level classification items	When National Geography Information Institute, Korea, would complete land use map, using it would be proper
Digital topographical map	• Building layer (code 4) which is high-level classification item • Residential: detail-level classification code 4112, 4113, and 4115 • Industry: middle-level classification code 43, 44, and 45	Use 1/5,000 scale digital topographical map from National Geography Information Institute, Korea. For area not covered, use 1/25,000 digital topographical map

Inundation map uses digitized information, such as flood occurrence map, flood forecast map, flood hazard map, or flood risk map. It is also possible to estimate inundated area by separate inundation analysis.

Regarding digital maps on geography information, there are land use map, land cover map, and digital topographical map as mentioned before. These spatial data overlapped with inundation map divide the asset value by residential, farming, and industrial characteristics, depending on

inundation depth.

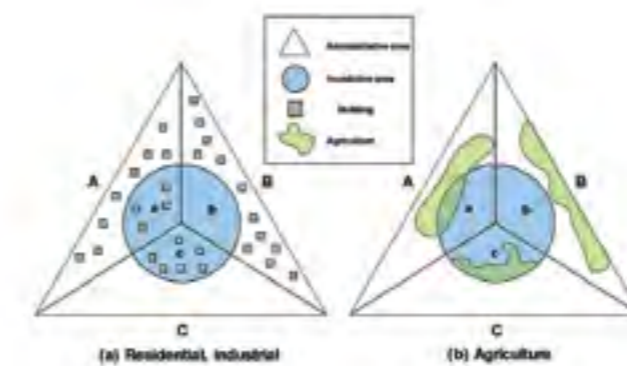### 3.4.3 Estimation of inundated inclusion ratio

Inundated inclusion ratio is used in the conversion of total asset value of local characteristic elements such as residential, industrial, and farming within administrative district into asset value for actual inundated area. The position information of spatial

objects, which is geographical element, are overlapped by inundation depth and expressed in ratio to whole by local characteristic element.

Therefore, inundated inclusion ratio is estimated by administrative district. It is estimated by inundation depth included in the three local characteristic elements: residential, industrial, and farming. The sum of inundated inclusion ratios is always 1. Fig. 3-2 shows the concept of spatial information overlapping in the estimation of inundation inclusion ratio. Fig. 3-3 shows the representative pattern of overlapped spatial information.
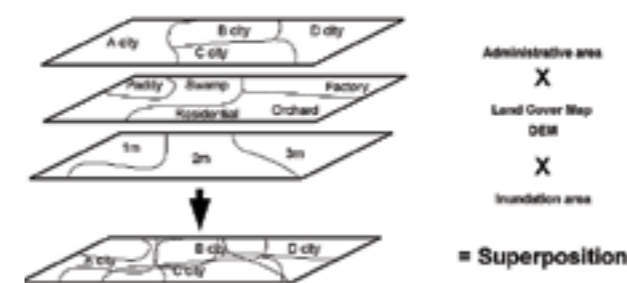
Fig. 3-2 Overlapping of spatial information for estimation of inundated inclusion ratio (HRFCO, 2012)

Fig. 3-3 Conceptual diagram of overlapped spatial information for estimation of inundated inclusion ratio (MOCT, 2004)

Let us assume that, in Fig. 3-3(a), the triangle means administrative zone consisting of A, B, and C three units, and the internal circle means inundated area. If a portion of A, B, C three units has been inundated. The Fig. 3-3(a) shows three cases: (1) buildings are evenly distributed

in inundated area and dry area (as A unit), (2) buildings are not inundated (as unit B), and (3) all buildings are inundated (as unit C). Likewise, in Fig. 3-3(b), the farming land inundation shows three cases.

In Fig. 3-3(a), the inundated inclusion ratio of "A" unit residential area or industrial area is 0.67 when inundation depth is 0 m and 0.33 when inundation depth is bigger than 0 m. The inundated inclusion ratio of "B" unit is 1 when inundation depth is and 0 when inundation depth is bigger than 0 m. "C" unit is opposite of "B" unit.

Likewise, the inundated inclusion ratio of farming can be estimated by area ratio of farming area as shown in Fig. 3-3(b).

Since this inundated inclusion ratio considers only the spatial distribution of local characteristic elements, the number or area of graphic information does not have to agree with statistical data.

The inundated inclusion ratios with multiple step inundation depth like Fig. 3-4 are estimated at 0.3, 0.2, 0.25, 0.1, and 0.15 when inundation depths are 0 m, 0–0.5 m, 0.5–1.5 m, 1.5–2.5 m, and 2.5 m+, respectively, depending on the number distribution of building graphic.
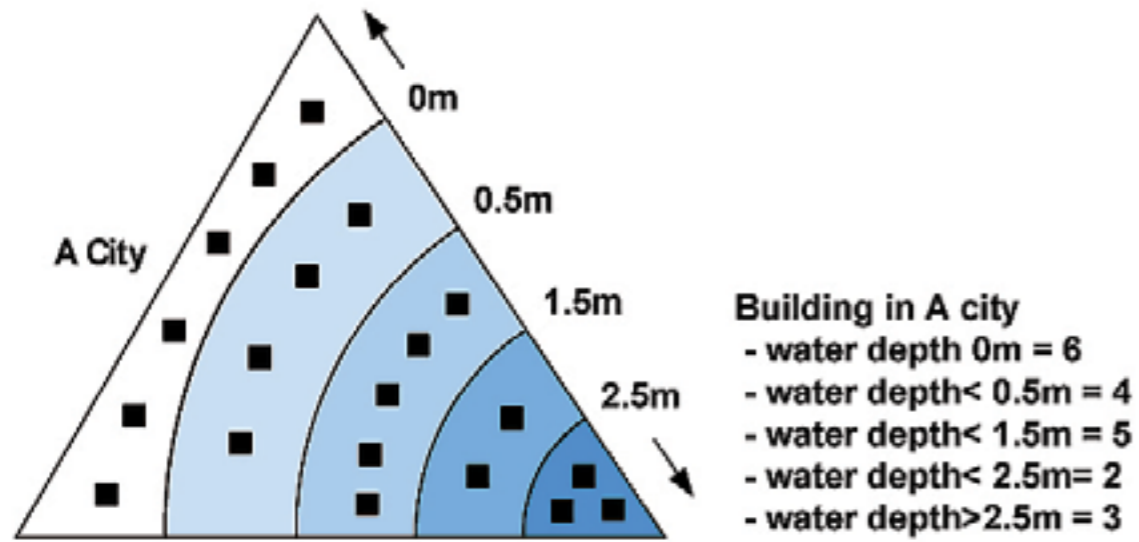
Fig. 3-4 Inundated inclusion ratio according to various inundation depth (MOCT, 2004)

3.5 Estimation of Inundation Damage Cost

Inundation damage cost should be estimated by multiplying inundated inclusion ratio and inundation damage ratio to asset value by item in target area. However, it is difficult to directly estimate public facility damage from public facility asset; it would be estimated from the relationship with general asset damage cost.

3.5.1 Damage cost by residential characteristic inundation depth

(1) Estimation of building damage cost

1) When inundation damage of underground space cannot be considered

Building damage cost is estimated by multiplying damage ratio, depending on estimated inundation depth to building asset value by equal ground height zone. However, the asset damage ratio is estimated from the building damage ratio suggested in Table 3-7 under the assumption that the number of floors shall be considered. The asset damage ratio, though, is not related to residential type.

Building damage ratio (KRW)
= building asset value (KRW) x residential area inundated inclusion ratio x inundation damage ratio of building by inundation depth index

Table 3-7 Building damage ratio by inundation depth (unit: %) (MOCT, 2004)

Inundation depth	0–0.5 m	0.5–1.0 m	1.0–2.0 m	2.0–3.0 m	3.0 m above
Detached house	15	32	64	95	100
Apartment	$15/n_1$	$32/n_1$	$64/n_1$	$95/n_1$	$100/n_1$
Row house	$15/n_2$	$32/n_2$	$64/n_2$	$95/n_2$	$100/n_2$

n_1: number of apartment stories, n_2: number of row-house stories

Building asset value and building inundated inclusion ratio are estimated by object asset investigation by administrative district and the method suggested in the inundated inclusion ratio estimation.

High-rise housing (apartment, row house) has possibility of excess assessment in damage because of wrong estimation in which all households in the building are assumed to have suffered inundation damage. In general, when inundation depth is less than a few meters, the third floor above would be ignored. It is recommended to have building asset be corrected by building average coefficient (average number of floor).

2) When inundation damage at underground space can be considered

Depending on the level of investigation and local situation, it is possible to estimate inundated inclusion ratio by classifying the building type in more detail considering the use of building underground space and facilities.

However, such analysis should be determined after judgment of necessity that fits with overall accuracy of investigation level.

If there is information on use of underground space and facility, it is possible to estimate by building damage ratio in Fig. 3-5 and Table 3-8. However, in case of detached house, it is possible to assume that there is no underground space. In case of apartment, it is possible to consider damage weight values for underground parking, electrical facilities and heating facilities. For row house, it is possible to consider the residential use ratio of underground space.
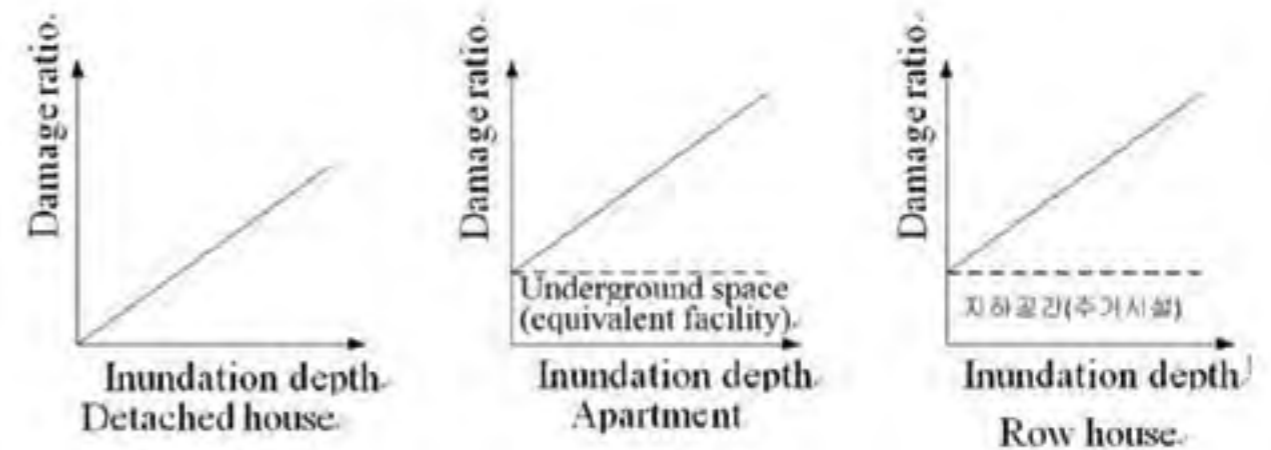

Fig. 3-5 Damage ratio, depending on inundation depth by housing type considering underground space (MOCT, 2004)

Table 3-8 Building damage ratio by inundation depth (considering underground space facilities) (MOCT, 2004)

(Unit: %)

Inundation depth	0–0.5 m	0.5–1.0 m	1.0–2.0 m	2.0–3.0 m	3.0 m above
Detached house	14.5	32.6	50.8	92.8	100
Apartment	$14.5/n_1+\alpha$	$32.6/n_1+\alpha$	$50.8/n_1+\alpha$	$92.8/n_1+\alpha$	$100/n_1+\alpha$
Row house	$14.5/n_2+100\cdot\beta$	$32.6/n_2+100\cdot\beta$	$50.8/n_2+100\cdot\beta$	$92.8/n_2+100\cdot\beta$	$100/n_2+100\cdot\beta$

n_1: number of apartment stories, n_2: number of row-house stories, α:

(2) Estimation of damage cost for building content

The estimation was done by multiplying damage ratio, depending on assumed inundation depth to building content asset value by equal ground height zone. It is estimated by the building content damage ratio in Table 3-9 based on the assumption that it is not related to residence type

> **Building content damage cost** (KRW)
> = asset value damage cost (KRW) x residential area inundated inclusion ratio x building content inundation damage ratio of building by inundation depth

and the damage ratios of assets are all same.

Table 3-9 Building content damage ratio by inundation depth (HRFCO, 2012)

(Unit: %)

Inundation depth	0–0.5 m	0.5–1.0 m	1.0–2.0 m	2.0–3.0 m	3.0 m above
Damage ratio	14.5	32.6	50.8	92.8	100

(1) Estimation of farming land damage cost

Same standard is applied on the damages on field and rice pad, depending on inundation depth. The threshold of flood damage will be set up as inundation depth 1 m. It is assumed that farming land will be buried and lost when inundation depth is 1 m or above. The damage cost is estimated based on commonly used average damage cost caused by farming land burial and loss. Farming land damage cost is estimated by the following function. Table 3-10 shows the damage ratio of farming land.

> **Farming land damage cost** (KRW)
> = average damage cost caused by burying and loss (KRW) x farming area inundated inclusion ratio x farming land inundation damage ratio by inundation depth

Table 3-10 Farming land damage ratio by inundation depth (MOCT, 2004)

Inundation depth damage ratio	1 m below	1 m above	Remark
Damage content	Inundation	Burying, loss	• Use average value of burying and loss
Farming land — Rice pad	0 %	100 %	• Burying Buried area (m²) × 0.1(m) × 2,940 (KRW)/m³
Farming land — Field	0 %	100 %	• Loss Lost area (m²) × 0.2 (m) × 5,660 (KRW)/m³

(2) Agricultural crop damage cost

Damage cost is estimated by simplifying the farming type as general cultivation and vinyl house cultivation. However, if more detail classification would be possible, it can be added to damage cost estimation using the same method.

1) General cultivation case

Same standard is applied on the damages on field and rice pad, depending on inundation depth. The threshold of flood damage will be set up as inundation depth 1 m. It is assumed that farming land will not suffer damage when inundation depth is 1 m or below. However, there will be damage in agricultural crop. Agricultural crop damage is estimated by the following function. Table 3-11 shows the damage ratio of farming land.

> **Agricultural crop damage cost** (KRW)
> = asset value of agricultural crop (KRW) x farming area inundated inclusion ratio x agricultural crop inundation damage ratio by inundation depth

2) If vinyl house cultivation can be considered

Recently, the agricultural cultivation is changing to crops with high added value and special crop cultivation using vinyl house in city suburbs and areas nearby river is increasing. This characteristic also affects damage cost estimation. Therefore, a damage cost estimation method limited to flowering plant and facility vegetable mainly cultivated in vinyl houses is suggested.

If the damaged area has been doing vinyl house cultivation during the last 3~5 years and if it will be continued in the future, it is possible to add agricultural crop damage cost by estimating damage cost for facility and crop as shown in Table 3-12.

Table 3-11 Agricultural crop damage ratio by inundation depth (MOCT, 2004)

Inundation depth damage ratio		1 m below				1 m above
Agricultural crop	Inundation period (day)	1 day below	1–2	3–4	5–6	7 days above	
	Rice pad	14 %	27 %	47 %	77 %	95 %	100 %
	Field	35 %	51 %	67 %	81 %	95 %	100 %

Table 3-12 Damage cost on facility and crop for vinyl house cultivation (MOCT, 2004)

Classification	Cultivation kind	Specification	Unit	Unit price
Facility	Vinyl house	Steel structure PET greenhouse	m^2	80,120
	Vinyl house	Steel structure glass greenhouse	m^2	104,156
	Vinyl house	Automated vinyl house	m^2	28,000
	Vinyl house	Steel pipe house (A–G type)	m^2	7,940
	Vinyl house	Steel pipe house (H–K type)	m^2	9,400
	Vinyl house	Steel pipe house (A–I type)	m^2	3,330
	Vinyl house	Steel pipe house (B–I type)	m^2	3,550
	Vinyl house	House made of wood	m^2	3,420
	Vinyl house	House made of bamboo	m^2	2,280
Agricultural crop	Facility vegetable	Green vegetable	ha	2,120,000
	Facility vegetable	Garden fruits	ha	2,800,000
	Flowering plant	Lily	ha	20,232,000
	Flowering plant	Gypsophila paniculata	ha	9,400,000
	Flowering plant	Rose	ha	10,800,000
	Flowering plant	Chrysanthemum	ha	7,836,000
	Flowering plant	Cactus	ha	15,261,000
	Flowering plant	Carnation	ha	32,939,000
	Flowering plant	Gladiolus	ha	13,990,000
	Flowering plant	Cymbidium	ha	19,780,000

3.5.3 Damage cost dependent on industry characteristic and inundation depth

The damage dependent on industry characteristic and inundation depth of administrative district units is classified into tangible asset damage and inventory asset damage as shown in Table 3-13. The damage cost is estimated by multiplying the damage ratio depending on inundation depth to the values of business tangible asset and inventory asset.

> **Tangible / inventory asset damage cost** (KRW)
> = tangible / inventory asset value (KRW) x industrial area inundated inclusion ratio x tangible / inventory asset inundation damage ratio by inundation

Table 3-13 Damage cost dependent on industry characteristic and inundation depth (MOCT, 2004)

(Unit: %)

Inundation depth damage ratio	0–0.5 m	0.5–1.0 m	1.0–2.0 m	2.0–3.0 m	3.0 m above
Tangible asset	23.2	45.3	78.9	96.6	100
Inventory asset	12.8	26.7	58.6	89.7	100

3.6 Estimation of Total Damage Cost

Total damage cost is obtained by adding human life / victim damage cost and public facilities damage cost to general asset damage cost in residential, farming, and industrial areas.

3.6.1 Human life damage cost

(1) Human life loss

Human life damage and loss are estimated by the following function.

> **Human life loss damage cost** (KRW)
> = number of lost human lives per inundated area (person/ha) x loss basic unit (KRW/person) x inundated area (ha)

Here, the loss basic units of death 250 million KRW per person and injury 20 million KRW person at 1998 fixed price were applied. Number of lost human lives per unit inundated area was drawn from the last 30 years' data and suggested as in Table 3-14.

(2) Victim damage loss

Victim damage loss amount is estimated by the following function.

Here, days of evacuation was assumed as average 10 days by referring to disaster yearbook of the recent 10 years. Daily average national income was estimated at 27,000 KRW by dividing 1998 national income by 365 days. Number of victim occurred per unit inundated area was suggested in Table 3-15 by the average of the last 30 years' data.

> **Victim damage loss** (KRW)
> = number of victim occurred per inundated area (person/ha) x days of evacuation (days) x daily average national income (KRW/person, day) x inundated are (ha)

Table 3-14 Damage cost dependent on industry characteristic and inundation depth (MOCT, 2001)

(Unit: person/ha)

Classification	Metropolitan	Small and medium city	Garden city	Farming city	Mountainous city
Death	0.004	0.004	0.001	0.002	0.002
Injury	0.002	0.002	0.001	0.001	0.002

(Unit: person/ha)

Classification	Metropolitan	Small and medium city	Garden city	Farming city	Mountainous city
Number of victim	1.85	1.17	0.27	0.37	0.98

3.6.2 General asset damage cost

Damage cost for building, building content, farming land, agricultural crop, and business tangible asset and inventory asset are estimated by the following function by adding the values obtained by method suggested in MD-FDA.

General asset damage cost (KRW)

$= \sum_{i}^{n}=1[RD_i$(building, building content, inundation depth) $+ AD_i$ (farming land, agricultural crop, inundation depth) $+ ID_i$ (business tangible asset and inventory asset)]

RD_i, AD_i, ID_i are the functions of inundation depth - damage cost. However, at present, there is little data to draw the functions. Therefore, damage cost functions were expressed by investigating assets by general asset damage item at residential, farming and industrial areas by the method suggested in MD-FDA and multiply the damage ratio depending on inundation depth to them.

3.6.3 Damage ratio of public facilities

Direct damage cost estimation of public facilities in inundation expected area is generally done by using the damage cost ratio of public civil facilities to general asset damage cost when it is not possible to estimate the scope and scale. Table 3-16 is the ration of public facilities damage cost to general asset damage cost drawn by analyzing public facility items appearing in disaster yearbook. Estimation is done in each item after excluding public facilities which do not exist in damaged area.

3.6.4 Basic function in direct damage cost estimation method

By summarizing estimation methods till now, the following function for direct damage cost can be obtained.

Direct damage cost (KRW)

$= (1 + \alpha)$ general asset damage cost + human life damage cost

---

Here, α: the ratio of public facilities damage cost to general to general asset damage cost

Public facility items	Road, bridges	River	Streams	Water & sewage	Seaport facilities	Fishing port facilities	Schools
Damage ratio	1.38	0.87	0.58	0.18	0.02	0.01	0.03
Determining coefficient	0.99	0.47	0.80	0.99	0.40	0.01	0.92

Public facility items	Railroad	Irrigation facility, bank	Erosion control, forest road	Military facility	Small scale facility	Other facility	Total
Damage ratio	0.23	0.54	0.28	0.42	0.69	0.80	6.01
Determining coefficient	0.95	0.73	0.93	0.92	0.91	0.94	

3.7 Comparison of Improved Assessment Method and the MD-FDA

MD-FDA (multidimensional method) estimates flood damage cost more accurate and more rational by complementing the issues in improved assessment method. The detail comparison of two methods is shown in Table 3-17.

MD-FDA estimates 100 % damage scale by general asset investigation (building, building content, farming land, agricultural crop, business tangible asset, and inventory asset) of expected damage area and estimates expected flood damage cost by applying damage ratio, depending on inundation depth condition. Different from existing inundated area - damage cost regression analysis method, MD-FDA estimates damage cost focusing on statistics yearbook of each area (city and county). Therefore, it can reflect local characteristics and the estimation can consider the spatial distribution of inundated area by linking to GIS.

Flood damage cost estimation using MD-FDA is an advanced method than the existing estimation method that estimates the average flood damage cost by administrative district based on past flood damage cost. It is expected that it would contribute in more accurate and more concrete estimation of flood damage cost by reflecting the local characteristics of inundation expected area.

However, in order to perform more accurate estimation, more precise flood inundation map should be built in advance and recent statistical data should be available. It is believed that accurate damage cost estimation on inundated area would be possible if the MD-FDA would be used in organic linking with projects, such as ongoing basin investigation and flood map preparation.

Table 3-17 Comparison of existing improved assessment method and the MD-FDA (MOCT, 2004)

Classification				Existing improved assessment method	MD-FDA	Improved item
Major items				• Function of only inundated area (inundated area-damage cost relationship) • Inundated area - damage cost curve for five city types suggested	• Function of inundated area, inundation depth and frequency • Damage cost estimated by multiplying inundation inclusion ratio and damage ratio by inundation depth to various indicators by administrative district	• Since local characteristics are reflected in asset investigation, classification by city type is not necessary
Benefit estimation concept				Damage cost x inundated area (consider flood damage cycle)	Object asset x inundated area x damage ratio (damage cost is calculated by frequency)	• Since the damage cost estimation unit is small-scale administrative district; local characteristics are reflected in same area
Estimation method by detail benefit	Asset damage	General asset damage cost	Building	Inundated area -damage cost relationship	Building area x damage ratio x building unit price	• Improvement was made on that, if economics would be assessed by project zone, excessive assessment is made at farming land and mountainous area.
			Household goods	Not reflected	Number of household x damage ratio x household goods unit price (classified in 5 kinds for household goods unit price)	
			Farming land	Inundated area damage cost relationship	Farming land inundated area x loss unit price (loss unit price classified into burying and loss)	
			Crops	field and rice pad inundated area x crop unit price	Agricultural crop x damage ratio x agricultural crop assessment unit price	
			Tangible asset and inventory asset	Not reflected	Number of employee x damage ratio x assessment unit price (assessment unit price classified into tangible asset and inventory asset)	
		Public facilities		Inundated area -damage cost relationship	General asset damage cost x fixed ratio	• Automatic improvement was made on that, when inundated area was small, the constant term worked as dominating factor and regression analysis method was not used when the properness of relationship function is low
	Human life damage	Human life loss		Inundated area x human life loss per inundated area x basic unit	Same as left	
		Victims		Inundated area x number of victim per inundated area x average income	Same as left	
	Other benefit			Inundated area -damage cost relationship	Not reflected	• Before, when there is little difference in benefit depending on flood frequency, analysis was not possible. Now, it is possible

4.1 Procedure for Economic Assessment of Structural Flood Control Measures

In the previous chapter, general matters regarding the economic assessment on structural-measure of flood control were discussed. In this chapter, the procedure for economic assessment on structural measure of flood control will be explained (shown in Fig. 4-1 and Fig. 4-2). After estimating the flood stage, we have to check inundation. If flood would be, we'll estimate the flood damage cost using the MD-FDA. Decision-maker can be acquire the optimal alternative for structural flood control measures in economic-social effects.

Information required for each procedure is also summarized again.
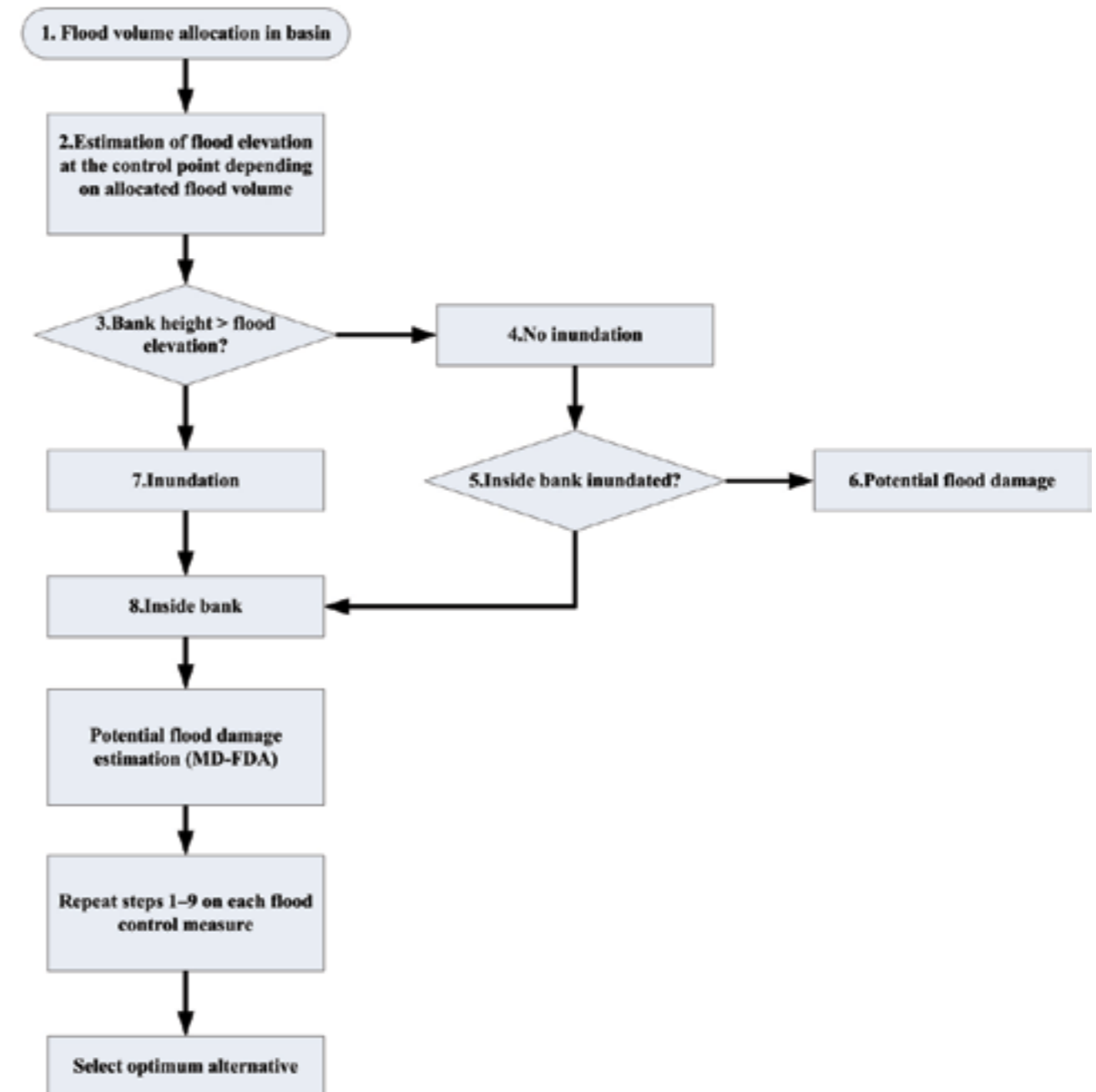

Fig. 4-1 The procedure of economic assessment for structural-measure of flood control (HRFCO, 2012)
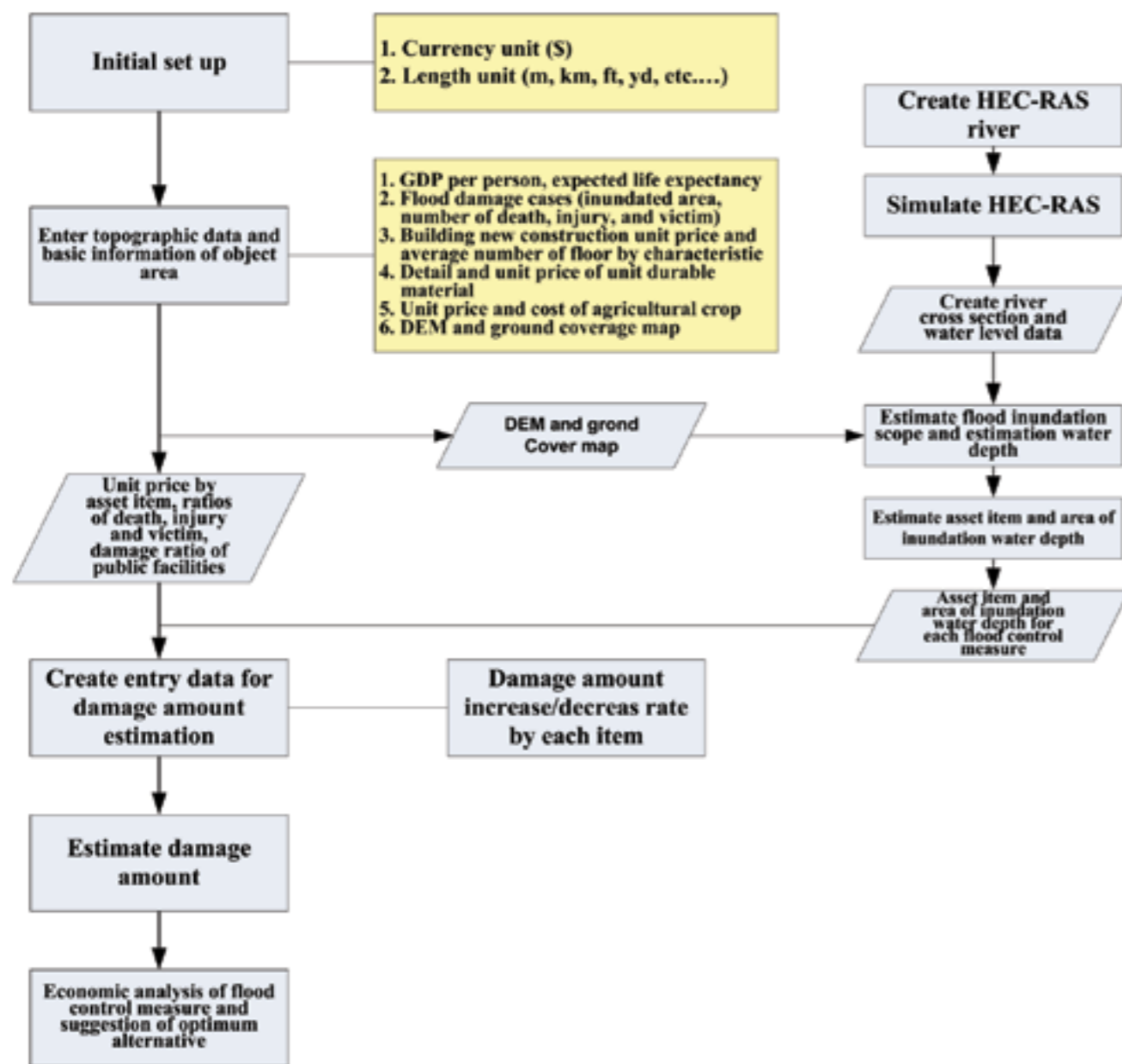
Fig. 4-2 Diagram of Assessment System of Flood Control Measures (ASFCM)

4.2.1 Initial set up

Set up the currency and unit (Syeteme International d'unites or United States Unit) for the target area. Build data required for economic analysis such as GDP per person, population density, and expected life expectancy for the assessment considering socioeconomic elements. Build data on inundated area, number of deaths, number of injuries, and number of flood victims of past flood damage cases. Investigate basic asset data, such as building new construction unit price, detail/unit price of unit durable material and agricultural crop unit price.

4.2.2 Build topographical, hydrological data required

Build basic topographical, hydrological data required for estimation of flood stage and flood inundation area. Build data on target area such as DEM, ground coverage map, river cross-section map, and river length. Estimate flood stage and flood inundation area by flood volume.

4.2.3 Area classification

There is difficulty in standardizing and utilizing data for economic analysis because required asset data are not sufficient and data status are different by area and by country. Therefore, a method to utilize asset value of area, which was entered as default value, is suggested. For this, it is recommended to identify the situation at target area and group them by certain area classification in order to utilize the asset data. Grouping may be done into four groups by way of population density and GDP. Utilize basic asset value relevant to each group.

4.3 Estimation of Flood Stage

There are various hydrological analysis models in one or two dimension for flood stage estimation. Each of one- or two-dimensional programs has merits and demerits. One-dimensional model has small number of entry data; its applicability is good if the river flow is good in one direction. The analysis result is relatively good. In case of two-dimensional model, entry data are variable and detail that would make analysis accuracy high. However, two-dimensional model can produce worse result than one-dimensional model if it is used for a basin with poor data quality like in the case of developing countries. It is recommended to use a program that can produce the best results by analyzing various conditions, including basic basin data.

4.3.1 One-dimensional model

One-dimensional model perform analysis based on assumption that the flow in a target river occurs toward only one direction. There are models like HEC-RAS and MIKE-11.

<Estimation method>
Following general method is used in one-dimensional models without much difference.

1. Input river cross-section data at right angle of focus river

2. Input distance between river cross sections

3. Input other river characteristic data (such as roughness coefficient)

4. Input flood discharge to analyze

5. Estimate flood stage applied of standard sequential method

4.3.2 Two-dimensional model

Two-dimensional model obtains the solution of river flow equation by numerical calculation. It requires more effort and higher technology level in operation than one-dimensional model. Sometimes the stability of calculation is not sufficient.

<Model characteristics>

1. Actual river situation is reflected by inputting river topographic data

2. It is possible to calculate information such as water level, flow quantity and flow velocity at most stream sections

3. Analysis is possible for various conditions such as the impact of structure in river on flow

4.3.3 HEC-RAS and Geo-RAS

1) Flood stage estimation for flood inundation area estimation
Take one-dimensional hydrological model HEC-RAS for flood stage estimation and simulate flood stage. Estimate flood stage by each point along the stream. Import it to ASFCM.

2) Estimation of flood inundation area
Estimate inundation area by GeoRAS using flood stage of each point at stream estimated by HEC-RAS. Compare the DEM data by grid and flood stage data of relevant point. If flood stage data is higher, set the relevant grid area as flood inundation area. The biggest demerit of one-dimensional analysis model is the judgment on flood stage and flood inundation area. For better rationality in selecting grid, comparison was done by expanding the traverse cross section by stream section at maximum using GeoRAS. The estimated flood inundation area is saved at HEC-RAS Project file and imported into ASFCM.

4.4 Estimation of Inundation Area at River

Analysis is done by assuming that an area is inundated area if the elevation of a cell in basin is lower than river stage.

[Application method]

One way is to analyze by calling in hydrological analysis result and basin DEM from Arc-GIS tool Another way is to analyze by calling in basin DEM from hydrological analysis model and comparing it with flood stage inundation result

The results of above two methods do not differ because the programs has become precise recently

There are merits and demerits in inundated area estimation using one-dimensional or two-dimensional analysis model results respectively. As using one-dimensional analysis result, system building and analysis are easy; however, inundation area is exaggerated because the analysis focuses on normal flow. On the other hand, as two-dimensional analysis model result is used, inundation area is relatively accurate because flood stage estimation is more precise with two-dimensional flow direction. Also, damage cost estimation is more accurate because it is in proportion to inundated area. Nevertheless, utilizing two-dimensional model has demerit which is system building and analysis are difficult and requires high-technology level.

4.5 Economic Analysis

Estimate damage scale by general asset investigation (building, building content, farming land, agricultural crop, business tangible asset, and inventory asset on expected damage area. Estimate more objective and accurate expected flood damage cost by applying damage ratio.

[Application method]

• Build input data

  • Asset investigation by administrative district, investigate past flood damage data

  • Estimate inundation damage ratio of damage in target area using GIS

PART B. MANUAL FOR ASSESSMENT SYSTEM OF FLOOD CONTROL MEASURES (ASFCM)

CHAPTER 1. EXECUTION OF ASFCM AND USER ENVIRONMENT (GUI)

Flood control measure assessment system was established for the economic evaluation of structural flood control measures. Basic entry data were established by the initial setting of topographic data, asset data and flood damage status of target area. HEC-RAS was imported into the system by estimating the flood stage at outside of the system. Flood damage amount estimation and the result of economic analysis (B/C ratio) were utilized as reference information in the establishment of structural flood control measures by way of estimating flood inundation area (please refer to Fig. 4-2 of PART A: Diagram of Assessment System of Flood Control Measures).

1.1 Program Installation

Find installation program "fda_setup.exe" and run it as shown in Fig. 1-1. It is recommended to close other programs before running the installation program. If other program uses system file, it is possible that system files would not be copied. In such case, the system should be rebooted.

Fig. 1-1 Program installation of ASFCM

1.1.1 Selecting program installation elements

Fig. 1-2 is the screen of setting the program installation elements. The three elements, which are flood control measures assessment system, sample and short cut to start program, shall be basically installed. Dependent on user preference, it is possible to install by checking '√' in the selection boxes. After selecting, click Next button.
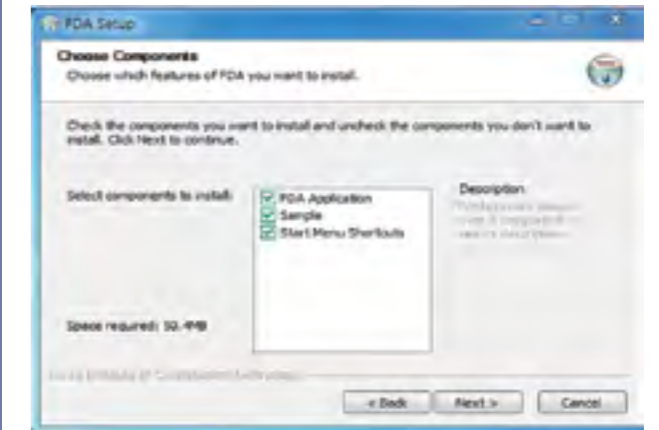
Fig. 1-2 Setting program installation elements

1.1.2 Selecting installation folder

Fig. 1-3 is the screen of setting the directory where the program would be installed. The default value is installation to c:\Program Files\FDA\. If a user wants to install the program in other folder, a user can click Browse button to change the folder location or directly key-in folder name. Click Next button after entering installation folder location.

Fig. 1-3 Setting the directory for program installation

1.1.3 Selecting Start Menu

Fig. 1-4 shows the screen determines the folder name where the Start program will be registered. The default is FDA; however, a user can determine other folder name. After setting folder name, continue by clicking Next button or, a user can return to Save Folder selection by clicking Back. When the Next button is clicked, installation starts by copying the program.

Fig. 1-4 Choosing Start Menu folder

1.1.4 Installation completion
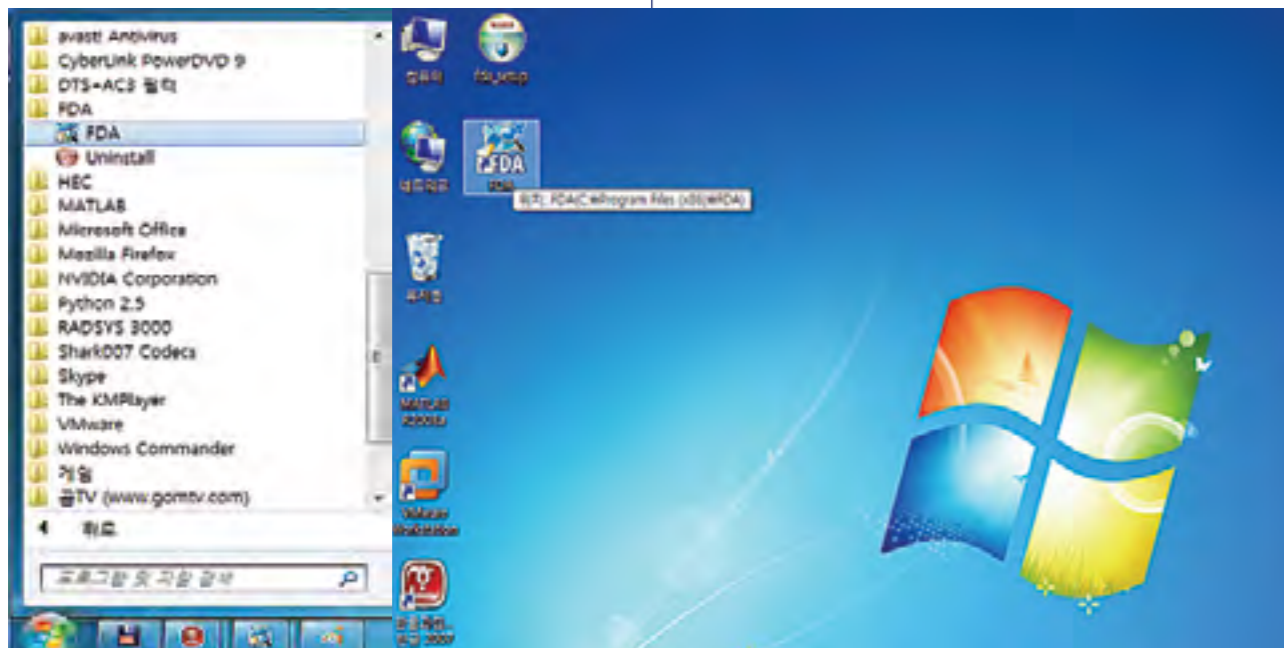
Fig. 1-6 Program execution (ex. Window)

Click Finish when installation has completed as shown in Fig. 1-5. If the program would run without rebooting after the rebooting message pop up window, it is possible that the database would not be generated. Rebooting is recommended because it will clearly complete the program installation.
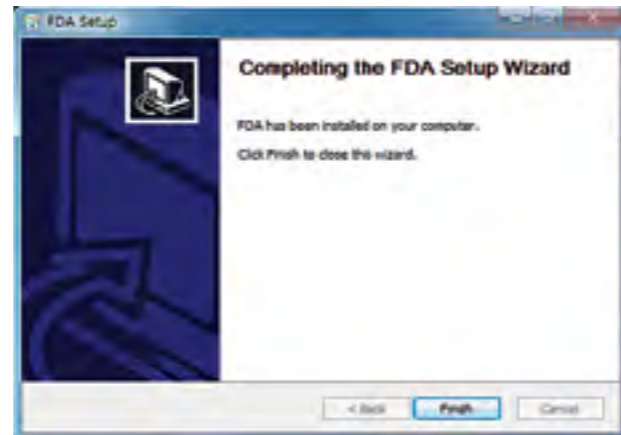
Fig. 1-5. Completion of program installation

1.1.5 Program execution

If the OS is Window, click "Start → All programs → FDA → FDA" in the left-bottom of screen. It is also possible to run the program by double-clicking the shortcut icon on desktop

1.2 Initial Run Screen

The screen consists of title bar at top, menu run collection, toolbar, status bar at bottom, menu tree at left, and map screen at righ
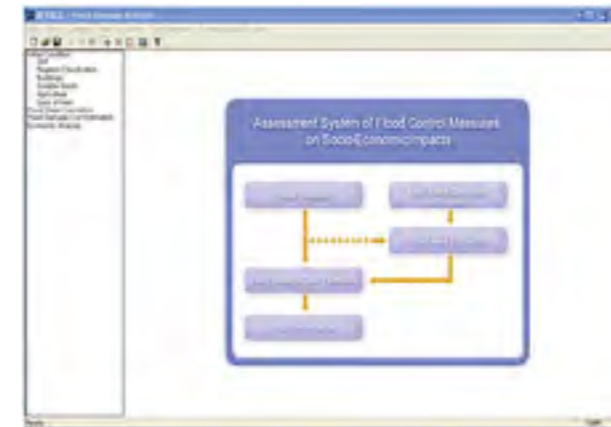
Fig. 1-7 The screen which appears when the program is running for the first time

1.3 Title Bar

"File name-program name" is shown at title bar. If there is no file name, file name will be shown as "no file name". Program name is always "Flood Damage Analysis"

Fig. 1-8 Title bar

1.4 Menu Collection
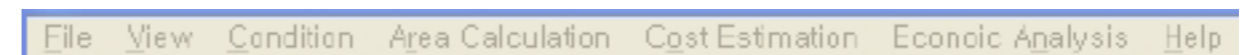
Fig. 1-9 Menu bar

Menu collection consists of seven top menus such as File, View, Condition, Area Calculation, Cost Estimation, Economic Analysis, and Help. They can be used easily by the menu tree in the left.

- **File**: This menu manages files with "fda" extension. It creates, opens, saves, saves as another name, runs recent file and ends program.
- **View**: This menu expands/shrinks map and manages whether to show toolbar or status bar.
- **Condition**: This menu is regarding various conditions when there is flood inundation.
- **Area Calculation**: It opens a window to choose HEC-RAS project file and ground coverage map.
- **Cost Estimation**: It estimates damage amount.
- **Economic Analysis**: Benefit, Cost, B/C, and Ratio value are calculated.
- **Help**: It shows program information.

1.5 Tool Bar

Fig. 1-10 Tool bar

1.6 Menu Tree

Menu Tree makes the use of above menu collection easier. It is possible to open or fold "Initial Condition" and "Flood Stage Calculation" in Menu Tree by double clicking the button.
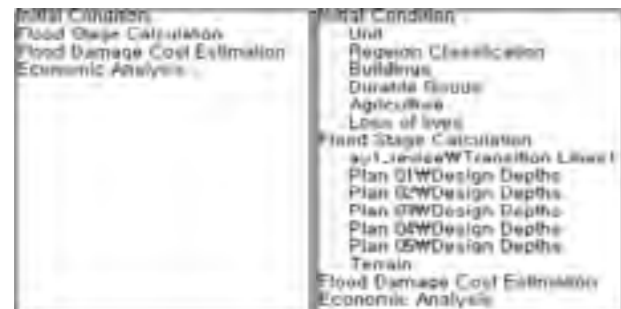
Fig. 1-11 Menu Tree

1.7 Map

Fig. 1-12 Map

Above screen is map-showing screen at the right of main screen. User can visualize the flood inundation content on the screen.

1.7.1 Map manipulation

The map in this system can be manipulated by mouse, toolbar at op and View in menu collection. Mouse is used as follows.

[Mouse wheel to upper side]: Shrink map

[Mouse wheel to down side]: Expand map

[Drag and drop]: (Move mode) move map/ (Expand/ shrink mode) designate scope

View of menu collection and toolbar can be used as follows;

[Zoom All 🔲]: Shows map on full screen

[Pan ➕]: Changes to map-move mode

[Zoom out ✉]: Changes to map-shrink mode

[Zoom in 🔲] : Changes to map-expand mode
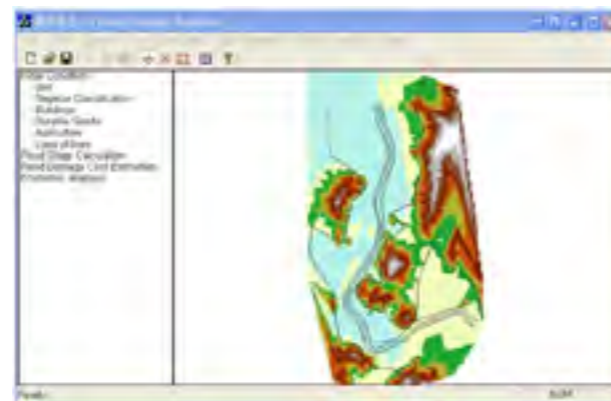
Fig. 1-13 Map manipulation

1.7.2 Map move
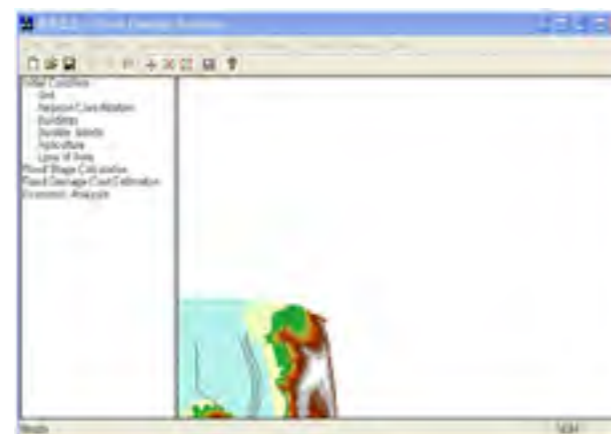
Fig. 1-14 Map move mode

Fig. 1-14 shows moved map by mouse drag and drop. It is possible to know that the screen is in Move mode by seeing lower end of View at menu collection at top or by seeing the toolbar button is pushed in. At this time, it is possible to change the location of map by mouse drag and drop. Above screen is map shrunk by turning mouse wheel to down side.

Above screen is map expanded by turning mouse wheel to upside. The map expands based on the exact center of the map. However, it does not expand anymore after certain limit because there is no content to show with too much expansion.

1.7.3 Map expansion
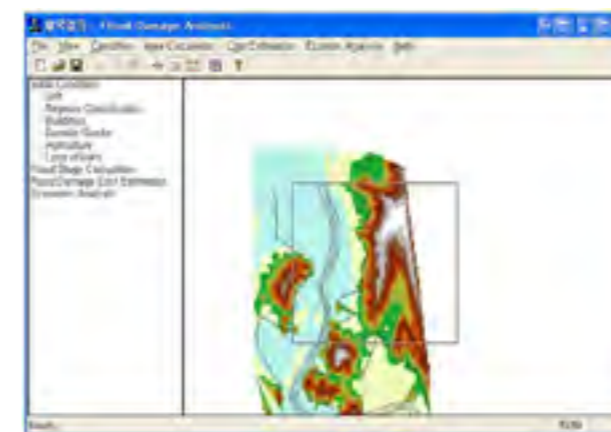
Fig. 1-15 Map expansion mode

When mouse is clicked and dragged in expansion mode, a rectangle zone is indicated. After changing mode by 🔲, select the zone the user wants to see and release the mouse button, the map expands to the extent of selected scope.

It is possible to use the wheel of mouse. Turning mouse wheel to down side makes step-by-step expansion of map with the pointer of mouse as reference. However, it does not expand anymore after certain limit because there is no content to show with too much expansion.

1.7.4 Map shrink
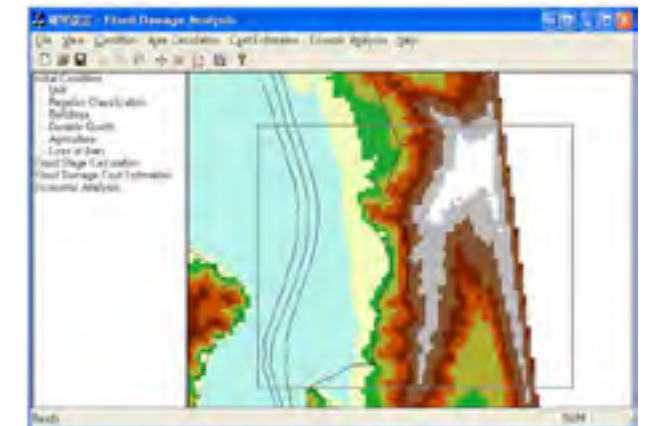
Fig. 1-16 Map shrink mode - designate shrink scope

Fig. 1-16 is expanded screen by designating certain zone. Map shrink mode is selected by an icon. Like expansion, when mouse is clicked and dragged in expansion mode, a rectangle zone is indicated. The map shrinks at the ratio of this rectangle size and whole map size. It is also possible to shrink map by turning mouse wheel to upper side. At this time, the map shrinks with mouse pointer as reference.

1.7.5 Recovering the map to initial status
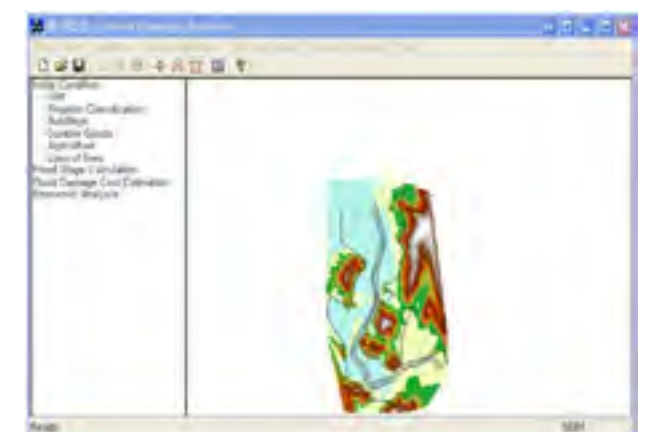
Fig. 1-17 Map expansion mode - result screen

Above screen, Fig. 1-17, is shrunk map by designated certain zone. When going back to initial screen after expanding or shrinking, a button or View-Zoom All of menu collection is used. This button is not selection mode. It returns the map to initial status.

1.8 Damage Estimation Result Screen

Fig. 1-18 Estimated damage

Above screen, Fig. 1-18, is the result of damage amount estimated from flood damage cost. The content of each field is as follows.

Table 1-1 Flood cost

Field name	Content
Flood area	It is inundation location of HEC-RAS and inundation scope based on water level.
Building	It is building damage amount.
Durable	It is durable material damage amount.
Agriculture	It is farming land damage amount.
Crop	It is agricultural crop damage amount.
Death and Injury	It is the estimated number of lost human lives and injured persons per inundated area.
Victim	It is victim human life loss amount per inundated area.
Total	It is total sum of above damage amounts.

1.9 Economic Analysis

Fig. 1-19 Economic analysis

Above screen, Fig. 1-19, is benefit, cost and B/C ratio for each flood control measure. The content of each field is as follows as shown in Table 1-2.

Table 1-2 Economic analysis

Field name	Content
Plan	It means flood control measures. Each flood control measure has benefit value and cost value.
Benefit	It is benefit value estimated for each flood control measure.
Cost	It is loss value estimated for each flood control measure.
B.C. Radio	It is B/C ratio estimated for each flood control measure.

2.1 Unit Setting

The first screen of Assessment System of Flood Control Measures (ASFCM) under execution is the menu tree. Click Initial Condition and then double-click Unit, or, select Unit of Condition in menu bar. Unit setting pop up window will appear. For currency, it is possible to select Korean Won (\) or US$ ($). For length, it is possible to select SI unit (m) or US unit (ft). After selecting units for currency and length, click OK.

Fig. 2-1 Initial screen of executed program

2.2 Area Setting

The next initial setting is area classification by population density and GDP in target area. It is possible by setting the 'Region Classification' of Initial Condition at the menu tree at the left bottom of the screen. Asset information is essential for the economic evaluation in flood control measures assessment system; however, it is difficult to secure sufficient asset information both in Korea and in overseas. Even there would be some data, they are partial data; therefore, domestic data (population density and GDP) by administrative district are saved first as basic data to resolve this. Then a target area is classified and the saved data of relevant area is used. GDP of target area shall be entered into the Per GDP item of Applied Region in the screen and population density is

entered into *Pop. Density item*. Then the area classification is automatically done. The result is indicated in Class item. Region classification is in 4 classes. The standard value for the region classification is identified by the value set at GDP and Pop. *Density of Criteria*. User can revise it. Data by administrative district is entered as base data. If data by administrative district for relevant country or target area is available, the data can be entered. It is possible to run Region Classification in accordance with the data. When above procedure has been completed, click 'OK" and complete area classification. If a user wants future area classification to be done by the data already entered, click 'Save as default' button at the right bottom of screen. Then it will be possible to classify area in the future with the data entered at this time.
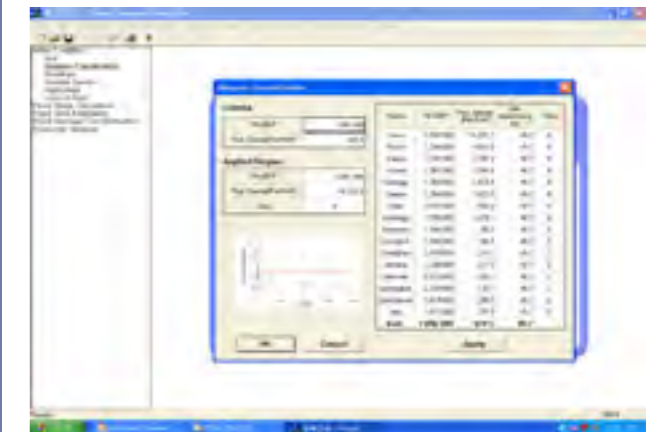

Fig. 2-2 Area setting

2.3 Asset Data Entry

2.3.1 Asset data - building

Initial condition to be set next to area classification is building asset data. Clicking Building button of Initial Condition at menu tree will set building asset data. Unit rates for flood damage recovery and new construction shall be entered in this step. They will become basic data in the estimation of flood damage amount on buildings. This screen consists of Construction Cost, where new building construction unit rates shall be entered, Building Distribution, where building distribution status

shall be entered, and Damage per flood depth (%), which will estimate damage ratio dependent on flood depth.

There are five types of building such as Bricks, Concrete, Shopping mall, Office and Factory. New construction cost by m^2 shall be entered for above five types of building as default values. It is possible to enter more building type up to 10 types. Regarding building distribution type, distribution ratios by building type, which were entered into Construction Cost, shall be entered to each area of residential area, commercial area and industrial area. Building area ratio for all three areas (residential, commercial and industrial) shall be entered into Building area Ratio and distribution ratio by each building type shall be entered.

Damage per flood depth sets the extent of building damage dependent on building flood depth. Building damage ratio by flood depth (m) shall be entered here. Current settings are as following. When flood depth is 0.5m, damage ratio is 15 %. When flood depth is 1.0m, damage ratio is 32 %. When flood depth is 3.0m, damage ratio is 95 %. Like before, if there is data for relevant country or target area is available, enter the data. It is possible to utilize the data in the future by clicking Save as default button at the right bottom of the screen. When all data had been entered, click 'OK" button.
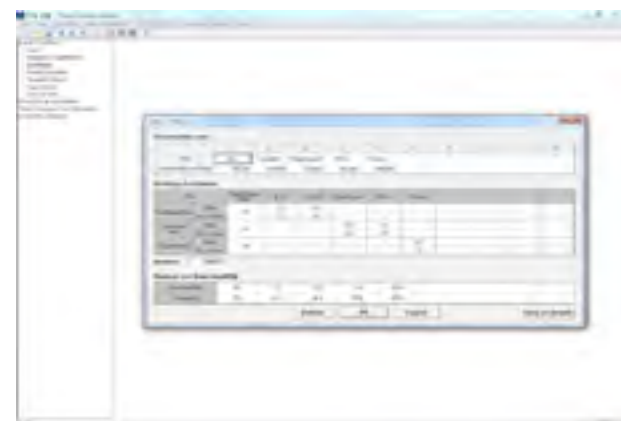
Fig. 2-3 Asset data (1): Building

After entering building unit rates and damage ratio, user shall enter data for the estimation of public facilities damage amount by clicking Public facilities in Initial Condition. It is more difficult to collect data for public facilities than buildings. Damage on public facilities happens in various forms; therefore, fixed rate is multiplied to building damage amount to estimate damage amount for public facilities. Damage ratio for each public facility shall be entered in this screen. 'No. of public facilities' is the number of public facility types. As default, there are five types (Road, River, School, Rail, etc.). In order to revise this, user can enter a number to the blank cell in 'No. of public facilities' and click Apply. Then blank cells would be generated as many as entered number. After entering ratios by country and by area (other than default value), click OK button.
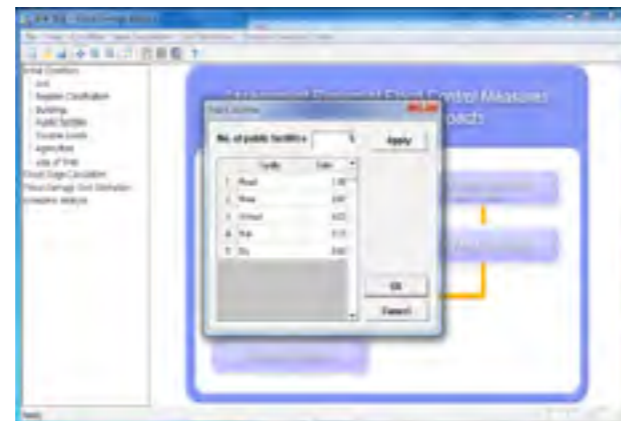
Fig. 2-4 Asset data (2): Public facilities

2.3.3 Asset data - durable goods

Fig. 2-5 is the screen for the entry of durable goods data in Initial Condition. Average area per one building shall be entered into '1 household average area' item. Durable goods item shall be entered into Item in the table at the center of the screen. Durable goods flood damage ratio shall be entered into Penetration rate. Cost per durable goods shall be entered into Unit cost. Then the cost will be automatically estimated dependent on damage ratio. In addition, durable goods damage ratio by residential, commercial and industrial area shall be entered into Ratio of Durable Goods at the right top of the screen. The types

of durable goods are various by area and it is difficult to reflect them; therefore, durable goods in residential area shall be entered and the durable goods damage amount of commercial area and industrial area shall be estimated by entering ratio of area. Damage amount by flood depth shall be entered into Damage per flood depth (%) table at the bottom of screen. After entering data of relevant area and relevant country, click Save as default and OK so that the data can be used as default value later.

Fig. 2-5 Asset data (3): Durable goods

2.3.4 Asset data - agricultural crop

Fig. 3.6 is the screen for the entry of agricultural crop asset data. At the top of the screen, cultivation quantity and cultivation cost per 1 ha of agricultural crop and ratio of each crop to whole crop shall be entered. As default, values for paddy, garlic, bean and orchard should be entered. Adding another crop is not possible. Damage ratio by flood depth shall be entered in the center of the screen. After entering data to the two tables, damage amount per m^2 is automatically estimated at 'Damage of Agricultural Land' at the bottom of the screen. After entering data of relevant area and relevant country, click Save as default and OK so that the data can be used as default value later.

Fig. 2-6 Asset data (4): Agricultural crop

2.3.5 Asset data - casualty

The last Initial Condition entry data is casualty information. Casualty status by basin or by administrative district shall be entered. After data entry, casualty status by area will be summarized in the table at the bottom of screen. Casualty data for the target area will estimate casualty damage amount by utilizing casualty status by area classification.
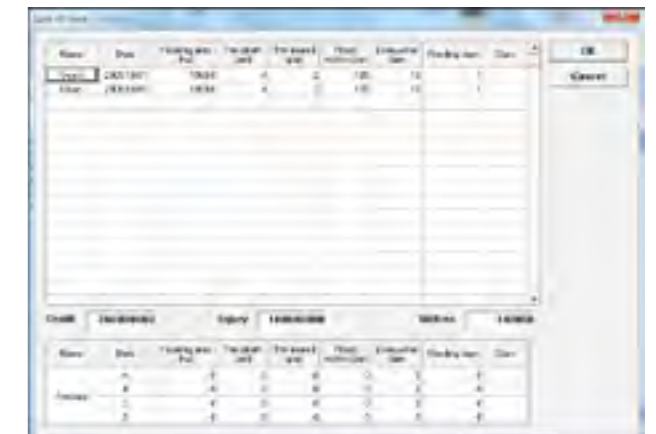

Fig. 2-7 Asset data (5): Casualty

Procedure of flood inundation analysis

(1) Work before analysis
- Build basin TIN
- Build river centerline

(2) Analysis of flood inundation
- Based on TIN of basin perform basic work for the estimation of basin inundation depth using

HEC-GeoRAS module of Arc-GIS (PreRAS work)
• Import HEC-GeoRAS work result at HEC-RAS
• Estimate flood stage by entering flood volume and complementing river cross-section data (entering roughness coefficient)
• Estimate inundation location and area using HEC-RAS GIS-Tool RAS-Mapper (post-RAS)

Program for flood stage analysis

- HEC-GeoRAS (Ver. 10)
: Developed for HEC-RAS model topographic data. An expanded model of Arc-GIS developed by ESRI, who is GIS tool developing company in United States.

: Download program and manual from home page (http://www.hec.usace.army.mil/)

- HEC-RAS (Ver. 4.1)
: Flood stage estimating program

: Developed by Hydrologic Engineering Center of U.S. Army Corps of Engineer

: Download program and manual from home page (http://www.hec.usace.army.mil/)

3.1.1 Constitution of HEC-GeoRAS items

This step is called PreRAS work. The constituents are as follows.
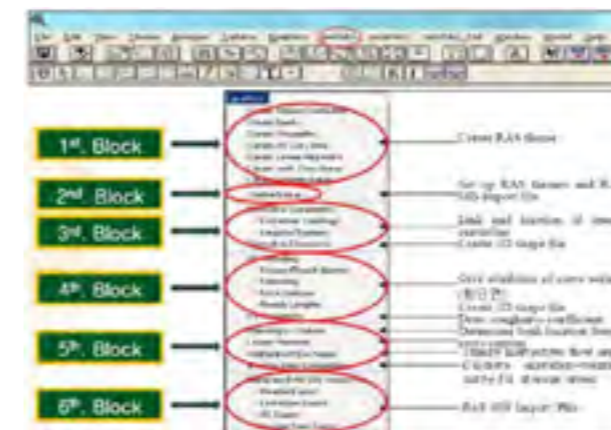
Fig. 3-1 Constitution of PreRAS in HEC-GeoRAS

It is fine to configure data in the sequence of six blocks. However, if the user is familiar with HEC-RAS, it is easier to configure no. 1 block then directly move to no. 6 block and configure remaining data by using HEC-RAS data imported.

Table 3-1 Creating flood inundation map using HEC-RAS and HEC-GeoRAS

Constitution content	Explanation
TIN	As an altitude data file, it does not directly work on HEC-RAS constitution. However, it is required for the altitude entry of other file.
Stream centerline	As the stream centerline, it is classified into upstream and downstream.
Main channel banks	Set up of reference location to provide with bank location of cross section cut lines.

Flowpath centerlines	Provide with Reach length information to cross section cut lines.
Cross Section cut lines	Set up reference line to draw stream cross section information.
Land use-manning table	As a file providing with roughness coefficient, constituted by land use data.
Level Alignment	Provide with information on location where flow is limited by being higher than bank.
Ineffective flow areas	Provide with information on ineffective flow areas of river.
Storage areas	Provide with information on section where river flow is suspended

Source:Creating Flood Inundation Map using HEC-RAS and HEC-GeoRAS, the 20th Hydraulic Engineering Workshop of Korea Water Resource Association

3.1.2 Constitution of first block and its application

- Constitution of first block is as follows.

Fig. 3-2 Constitution sequence of 1st block

(1) Call in TIN of basin to apply

- Constitute basin TIN by high-resolution digital map of that basin. Perform all works based on this data.

Fig. 3-3 Call in TIN of basin to apply

(2) Create stream centerline to apply inundation analysis

- Create stream centerline to apply river inundation analysis. If there is existing basin stream centerline, it can be set up by calling in that stream centerline file (shape file). If there is no existing basin stream centerline, set up stream centerline by sequentially plotting points relevant to stream line from upstream to downstream.

- Set up afterward stream cross section and inundation zone based on the stream centerline

Fig. 3-4 Stream centerline setup method
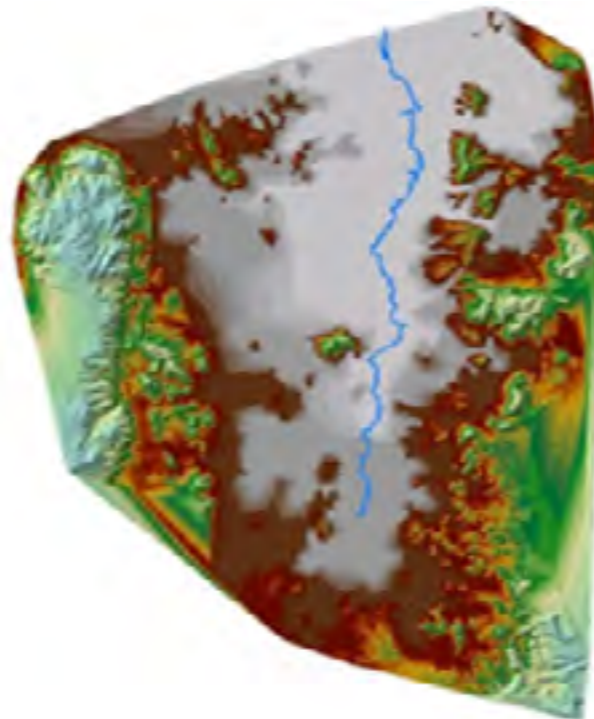
Fig. 3-5 Stream centerline setup result (a case of Hotyai basin in Thailand)

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(3) Set up flow zone to apply inundation analysis (Create Banks)- Set up stream bank (the red line in the left and right of stream centerline in Fig. 4-6).

- Set up reference line to determine stream inundation at left and right. Set the left up first.

Set up stream bank by plotting from upstream to downstream.

- If flood volume flows along the flow cross section within bank line in HEC-RAS analysis, it is judged that there will be no inundation.

(4) Set up stream inundation zone
(Create Flowpaths)

- Set up a zone that can be inundated when stream would flow over bank (the left and right blue lines at outside of river bank line).

- Set up maximum area which can be inundated when there would be stream inundation.

- If flood volume cannot flow along the cross section within bank line in HEC-RAS analysis, estimate flood stage by expanding cross section up to stream inundation zone. There would be no inundation at the location outside inundation zone even the flood volume would be at maximum
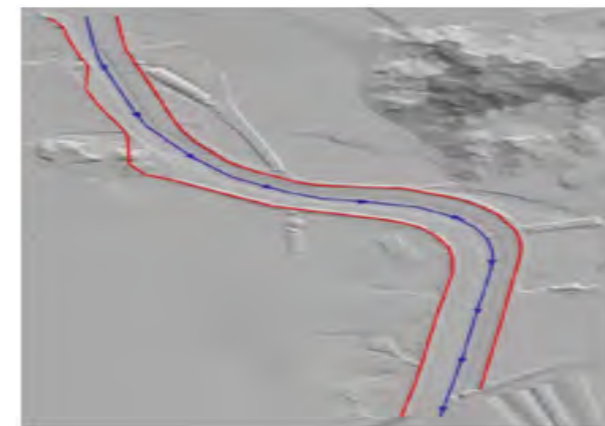
Fig. 3-6 Stream inundation zone set up method

(5) Set up stream cross section (create cross section cut lines)

- Set up stream cross section to perform flood stage analysis at the right angle to stream centerline in sequence from upstream to downstream.

- When setting up to downstream direction, set up cross section from left bank to right bank.

- Cross section for analysis shall be set up to the

outside of inundation zone so that there would not be error when simulating inundation zone.

- Coordinates and altitude information on stream traverse cross section from basin TIN from above.
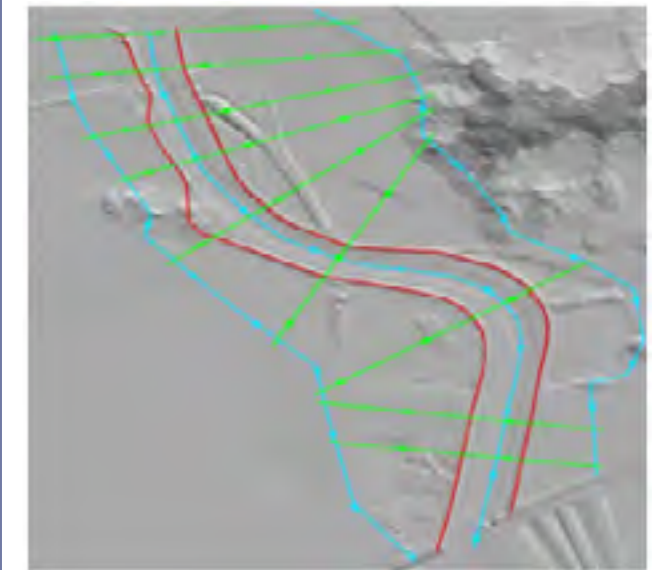
Fig. 3-7 Stream cross section setup method
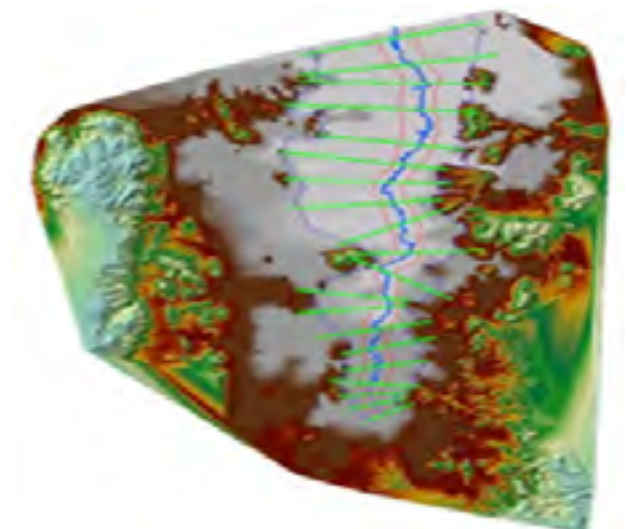
Fig. 3-8 Result of stream cross section setup (a case of Hotyai basin in Thailand)
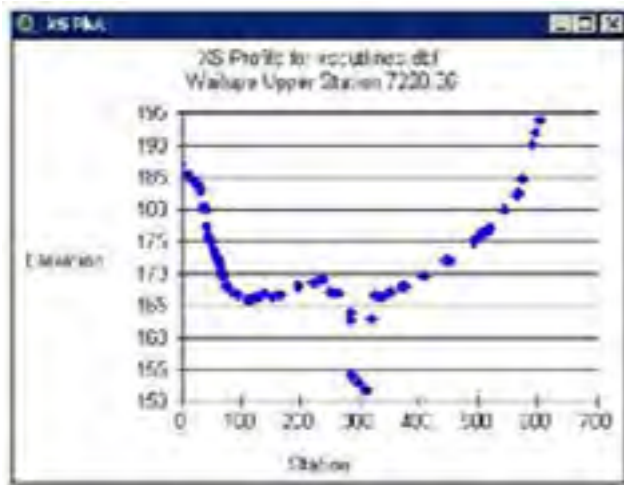
Fig. 3-9 Result of stream cross section drawn (seen at HEC-RAS)

(6) Determination of Levee (Create Levee Alignments)

- Set up Levee to use in flood stage analysis.

- After setting up Levee line, enter Levee altitude.
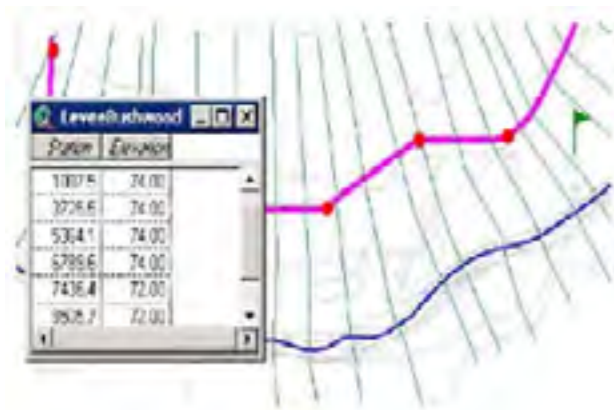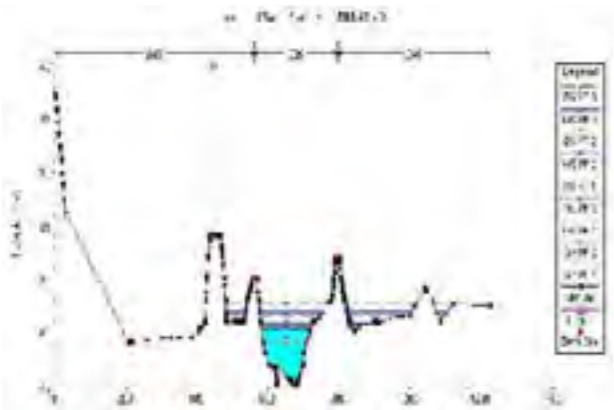

Fig. 3-10 Levee setup method

Fig. 3-11 Result of le (seen at HEC-RAS)

(7) Others

It is easy to set up ineffective flow area (create ineffective flow areas) and storage area (create storage areas) at the drawn HEC-RAS file.

3.1.3 Constitution of second block and its application

This is system summary on the content prepared during 1st block constitution. Check each content. If all are correct, move to the next block.
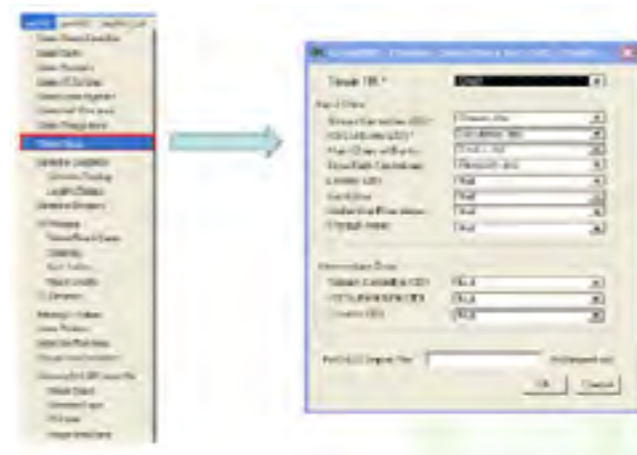
Fig. 3-12 Constitution and content of second block

3.1.4 Constitution of third block and its application

Perform data drawing from the content prepared during the first block constitution. Click one by one and perform relevant content. If an error occurs, check error content and go back to the first block and repeat performance from first block.
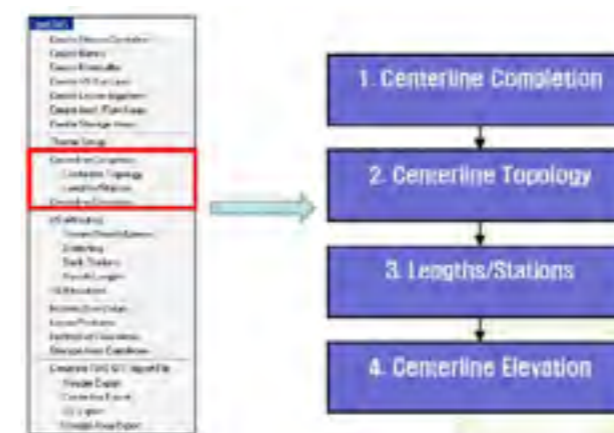
Fig. 3-13 Constitution and content of third block

3.1.5 Constitution of fourth block and its application

- Enter attribute handling of traverse cross section and branch number.

- Click one by one and enter data in sequence.

- Draw altitude data from basin TIN and show result in 3D image.
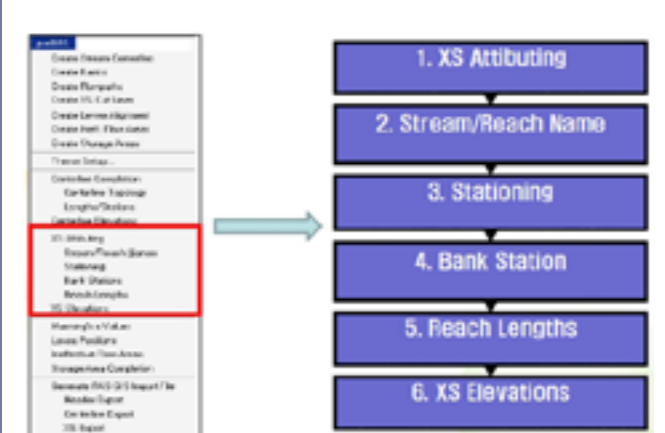
Fig. 3-14 Constitution and content of fourth block

3.1.6 Constitution of fifth block and its application

Enter stream structure and roughness coefficient. It is easier to enter data at HEC-RAS rather than here.

3.1.7 Constitution of sixth block and its application

Export GIS DATA to HEC-RAS file. Take Extract GIS Data of RAS Geometry item and draw in the format of HEC-RAS file.
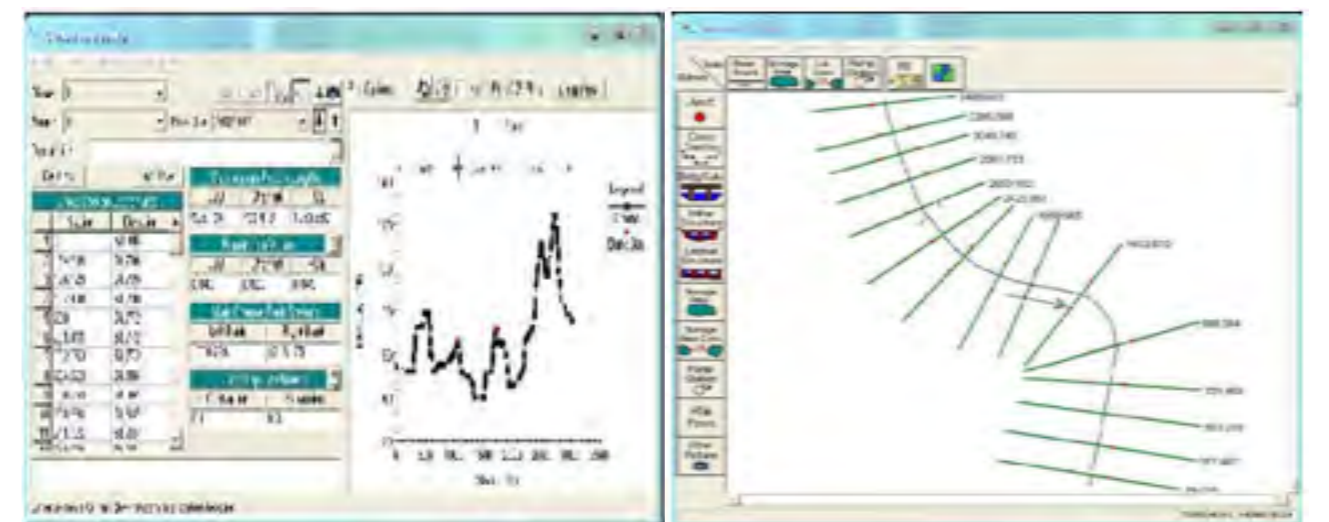
Fig. 3.15 Result of HEC-RAS file creation

3.2 Stream Correction and Flood Stage Analysis Using HEC-RAS

3.2.1 Calling in HEC-GeoRAS analysis file

-Call the file worked at HEC-GeoRAS from HEC-RAS to project. When called in, the following cross-section data are already entered together with cross-section location worked at HEC-GeoRAS

.Fig. 3-16 Calling in HEC-GeoRAS analysis file (a case of Hotyai basin in Thailand)

3.2.2 Complementing cross-section data

Stream cross-section data made by using TIN data at HEC-GeoRAS appear. If there is precise survey data around stream centerline, it is possible to complement stream cross section based on the data. (Enter omitted roughness coefficient and Levee at this time.)
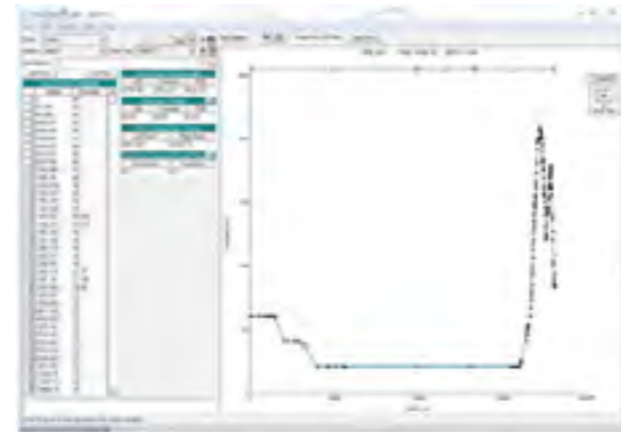
Fig. 3-17 Checking and revising of stream cross section (a case of Hotyai basin in Thailand)

3.2.3 Enter flood discharge data

Enter flood volume to be applied by section. Enter flood volume before and after flood control measure so that flood stage and damaged area before and after flood control measure can be compared and reviewed.
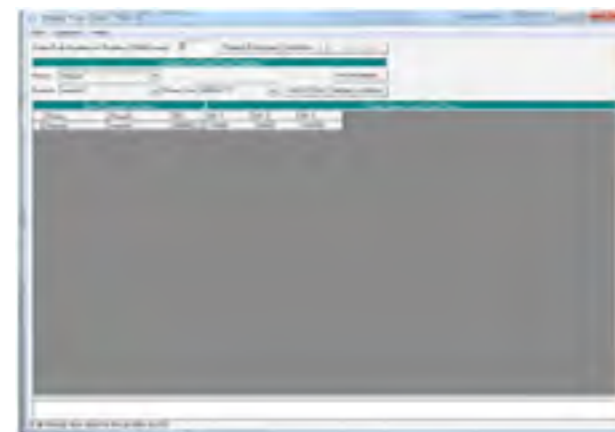
Fig. 3-18 Entering flood volume before and after flood control measure (a case of Hotyai basin in Thailand)

3.2.4 Simulation of flood stage

After complementing cross section and entering flood volume, perform flood stage simulation. It is possible to plot flood stage by each cross section and flood volume in 3D along the stream centerline.

3.2.5 Analysis of flood inundation zone

It is possible to simulate stream inundation zone by using RAS Mapper function in GIS tool item. When basin DEM is entered to RAS Mapper, it automatically estimates stream inundation zone by flood stage.
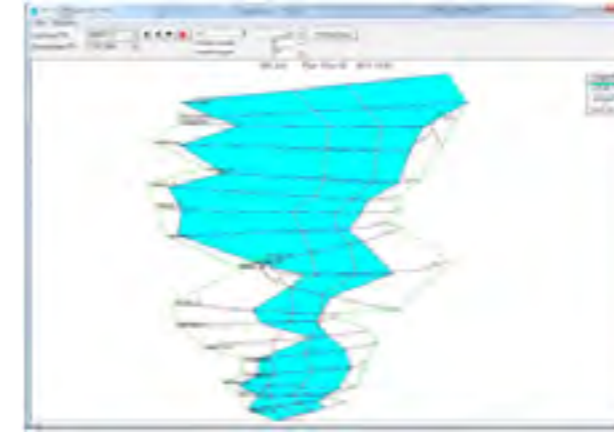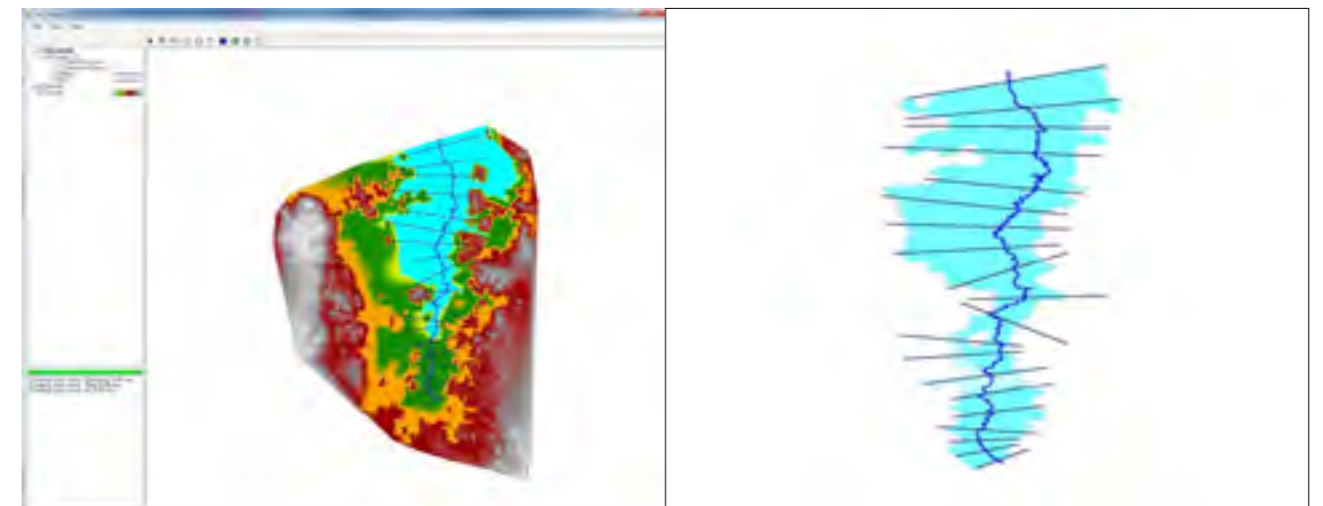

Fig. 3-19 Flood stage simulation result (a case of Hotyai basin in Thailand)

Fig. 3-20 Analysis of flood inundation zone (a case of Hotyai basin in Thailand)

After completing the initial setting of basic data for economic analysis, flood damage area estimation for target area is done. For this, HEC-RAS project file, which performed the flood stage of target area, and land use map file shall be entered into system. When Area Calculation at menu bar is clicked, the 'Import RAS result' pop up window will appear in the center of screen. Browse and select the folder where HEC-RAS project file and land use map are located and click OK. It will import the flood stage simulation result, which the user performed out of system.

used in the estimation of flood damage amount by overlapping flood inundation area with land use map/DEM and identifying asset data and area type of target area.
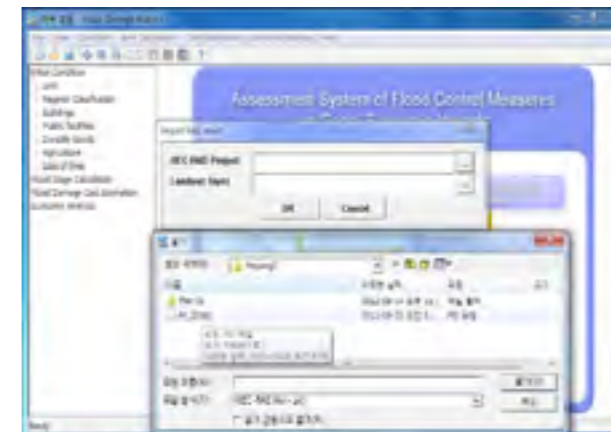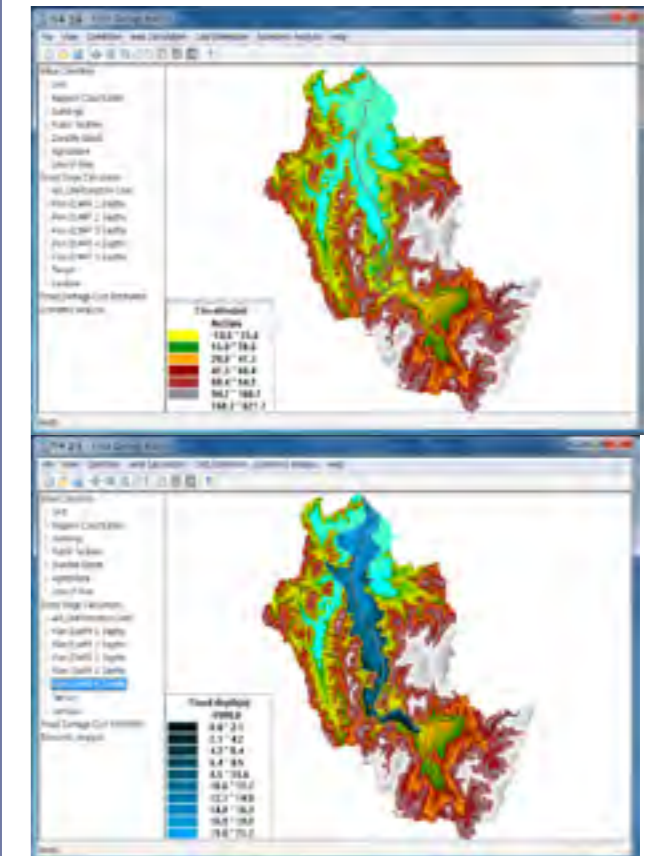

Fig. 4-1 Import of HEC-RAS simulation file

Fig. 4-3 Estimation of the inundation area

Fig. 4-2 Import of landuse data file

Next screen is the result screen after importing the HEC-RAS project file and land use map data into the system. A menu tree is automatically formed at the left of screen for all cases simulated by user at HEC-RAS. In this example, simulation results on five cases were entered. When each case is clicked, flood inundation area of target area is automatically shown in the center of screen. It is

This screen appears when the Legend in the center of screen is clicked. User can change the legend as user likes.

Fig. 4-4 Legend screen
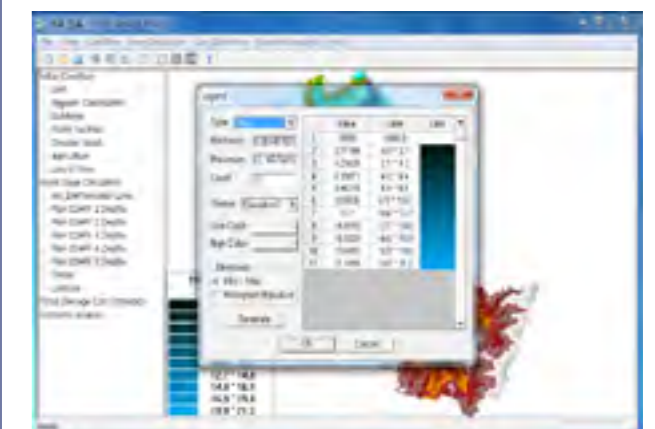
Next screen is land use map of target area. It is possible to see the land use status of target area and residential type of flood inundation area on this screen.
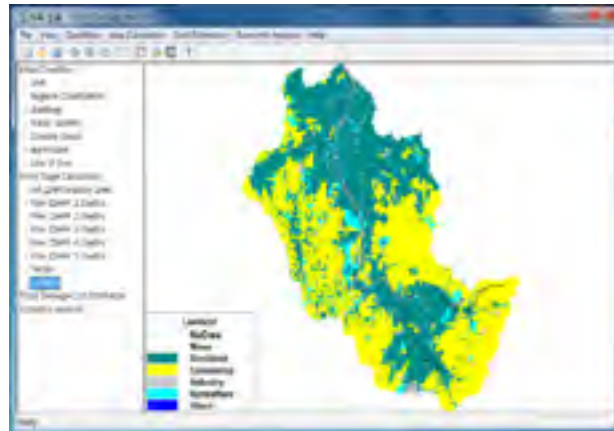

Fig. 4-5 Landuse screen

CHAPTER 5. ESTIMATION OF FLOOD DAMAGE COST

When Flood Damage Cost Estimation in menu tree at the left of screen is clicked, the system shows flood damage amount (total and by item) for each case simulated in HEC-RAS. The content of each field is as following.

Table 5-1 Flood damage cost contents

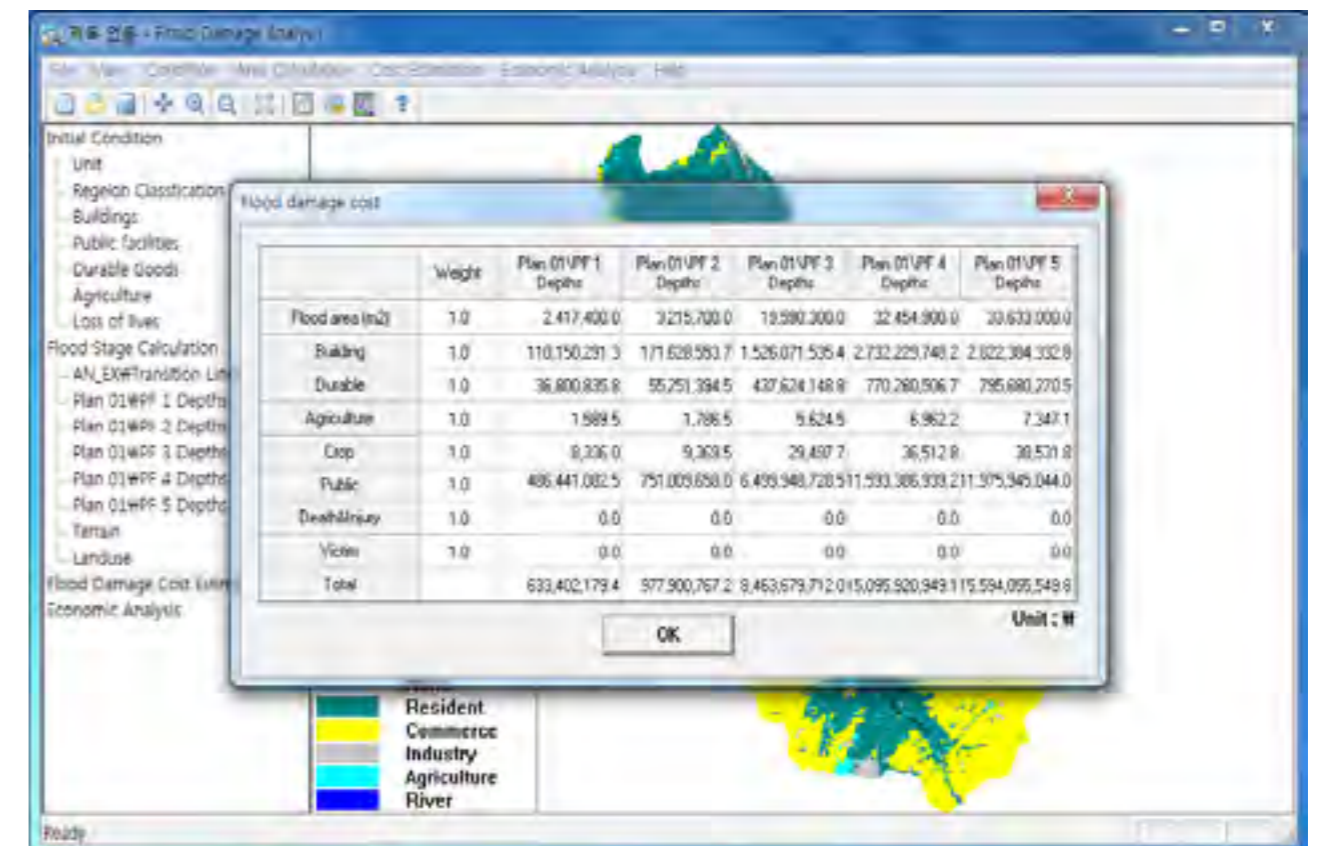| Field name	Content
Flood area	It is inundation location of HEC-RAS and inundation scope based on water level
Building	It is building damage amount
Durable	It is durable material damage amount
Agriculture	It is farming land damage amount
Crop	It is agricultural crop damage amount
Death and Injury	It is the estimated number of lost human lives and injured persons per inundated area
Victim	It is victim human life loss amount per inundated area
Total	It is total sum of above damage amounts

Table 5-1 Estimation of flood damage cost

CHAPTER 6. ECONOMIC ANALYSIS

When Economic Analysis at the left of screen is clicked, it is possible to see the cost, profit and B/C for each measure, which is the result of economic analysis. When the cost is entered by each measure into the pop up window, B/C ratio is automatically calculated.
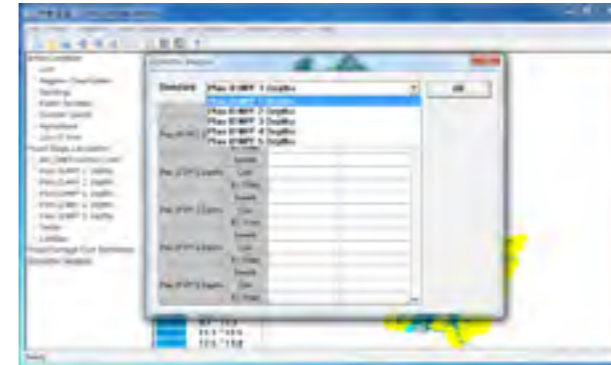

Fig. 6-1 Estimation of economic analysis

Above screen is the result of interest rate, loss and ratio for each flood control measure.
The content of each field is as following.

Table 6-1 Economic analysis content

Field name	Content
Plan	Means flood control measure. Each flood control measure has benefit value and cost value.
Benefit	It is benefit value estimated for each flood control measure
Cost	It is loss value estimated for each flood control measure
B.C. Radio	It is B/C ratio estimated for each flood control measure

ACKNOWLEDGEMENTS

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[2] Ministry of Construction and Transportation (2003). Dam Design Criteria.

[3] Ministry of Construction and Transportation (2004). A study on the Economic Analysis in Flood Control Projects: Multi-Dimensional Flood Damage Analysis.

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[5] Han River Flood Control Office (2012). Establishment of Assessment System for Flood Control Measures.

[6] National Emergency Management Agency (2002). Annals of Korea Disaster