THESIS

SOIL EROSION MODELING USING RUSLE AND GIS

ON THE IMHA WATERSHED, SOUTH KOREA

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY HYEON SIK KIM ENTITLED SOIL EROSION MODELING USING RUSLE AND GIS ON IMHA WATERSHE, SOUTH KOREA BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

SOIL EROSION MODELING USING RUSLE AND GIS

ON THE IMHA WATERSHED, SOUTH KOREA

The Imha watershed is located in the northeastern part of the Nakdong River basin, which has major tributaries: the Ban-Byeon Stream and Young-Jun Stream. Most of the Imha watershed is forested and only 15 percent is used for agriculture with paddy and crop fields. This mountainous watershed has steep slopes around 40%. Due to this topographical characteristic, most of the watershed is vulnerable to severe erosion. Soil erosion from steep upland areas has caused sedimentation in the Imha reservoir. It has also deteriorated the water quality and caused negative effects on the aquatic ecosystem.

The Imha reservoir was affected by sediment-laden density currents during typhoon "Rusa" in 2002 and typhoon "Maemi" in 2003. The RUSLE model was combined with GIS techniques to analyze the gross soil loss rates caused by typhoon "Maemi" and the annual average and to evaluate the spatial distribution of soil loss rates under different land uses. The annual average soil loss rate and soil loss rate caused by typhoon "Maemi" were predicted as 3,450 tons/km^2/year and 2,920 ton/km^2/"Maemi" respectively. In addition, the cover management factor for forested areas of the Imha watershed is calibrated using a "Trial and Error method" from the relationship between the annual soil losses and various sediment delivery ratio models. The determined C value for the forested area was 0.03 and is 3 times larger than that of the undisturbed

forested area of Wischmeier and Smith (1978). The sediment delivery ratio was determined to be 25.8% from the annual average soil loss rate and the surveyed sediment deposits in the Imha reservoir in 1997. The trap efficiency of the Imha reservoir was calculated using the methods of Julien, Brown, Brune, and Churchill and ranges from 96% to 99%.

Finally, the life expectancy for dead storage of the Imha reservoir was predicted by comparison between the observed sediment deposits in 1997 and the dead storage capacity of the Imha reservoir. As a result, even though the error of sediment deposits survey is considered, the life expectancy of dead storage might be decreased to half of the design life expectancy of dead storage. Therefore, a recent survey of the sediment deposits of the Imha reservoir is recommended for a better evaluation the life expectancy of reservoir.

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LIST OF SYMBOLS

A	Average annual soil loss (ton·acre^{-1}·yr^{-1})
C	Cover-management factor (dimensionless)
d_{50}	Grain size
d_*	Dimensionless particle diameter
E	Storm energy (ft·tonf·acre^{-1})
EI	Storm erosivity (ft·tonf·acre^{-1}·h^{-1}, or hundreds of ft·tonf·acre^{-1}·h^{-1}). Also a percentage of annual R
EI_{30}	Storm erosivity, interchangeable with EI (hundreds of ft·tonf·acre^{-1}·h^{-1})
g	Gravitational acceleration (m^2/s)
G	Specific gravity
h	Flow depth
I	Precipitation intensity (in··h^{-1})
I_{30}	Maximum 30-min intensity (in··h^{-1})
j	Counter for each year used to produce the average
k	Counter for the number of storms in a year
K	Soil erodibility factor (ton·acre·h·[hundreds of acre-ft·tonf·in^{-1}]
L	Slope length factor (dimensionless)
m	Number of storms n each year
n	Number of year
OM	Organic matter (%)
P	Support practice factor (dimensionless)
q	Unit discharge
Q	Flow discharge
R	Average annual erosivity factor (hundreds of ft·tonf·acre^{-1}·yr^{-1})
S	Slope steepness factor (dimensionless)
SDR	Sediment delivery ratio
SLR	Soil-loss ratio (dimensionless)
T	Temperature
TE	Trap efficiency
V	flow velocity
W	Channel width
X	Reservoir length
Y	Sediment yield
	Greek symbols
α	Slope
β_i	Scaling exponent
Θ	Slope angle
v_m	kinematic viscosity
ω	fall velocity

LIST OF ACRONYMS

ANSWERS	Areal Nonpoint Source Watershed Environmental Resources Simulation
cms	cubic-meter-per-second (m^3/s)
CSU	Colorado State University
DEM	Digital Elevation Model
FAOUN	Food and Agriculture Organization of the United Nations
GIS	Geographical Information System
KINEROS	Kinematic Runoff and Erosion Model
KMA	Korea Meteorological Agency
KOWACO	Korea Water Resources Corporation
ME	Ministry of Environment
mm	millimeter
MOCT	Ministry Of Construction and Transportation
MUSLE	Modified Universal Soil Loss Equation
NIAST	National Institute of Agricultural Science and Technology
NRCS	Natural Resources Conservation Service
NTU	Neuphelometry Turbidity Unit
RUSLE	Revised Universal Soil Loss Equation
SDR	Sediment Delivery Ratio
SS	Suspended Sediment
SEM	Soil Erosion Map
TE	Trap Efficiency
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USLE	Universal Soil Loss Equation
USPED	Unit Stream Power - based Erosion Deposition
WEPP	Water Erosion Prediction Project

Chapter 1: INTRODUCTION

1.1 Overview

The Nakdong River has played an important role throughout Korean history. The river basin has been a favored dwelling-place for as long as people have inhabited the Korean peninsula. The Nakdong River, located in the southeastern part of the Korean Peninsula, is the second largest river in South Korea. It originates from the junction of the Cheolamcheon and Hwangjicheon streams in Dongjeom-dong, Taebaek city, Gangwon province. It has a total length of 511 km, and a drainage area of 23,700 km^2.

There are five multi-purpose dams on the Nakdong River: Andong, Hapchon, Namgang, Milyang along with the Imha Multi-purpose Dam. Figure 1-1 presents the location map of the Nakdong river basin.

The Imha watershed is located in the northeastern part of the Nakdong River basin. Major tributaries are the Ban-Byeon Stream, Dae-Gok stream, and Young-Jun Stream. Imha Multi-purpose Dam was constructed on Ban-Byeon Stream from 1984 to1992. It is located 10km east of the city of Andong, Gyeongbuk province on the Ban-Byeon Stream, and about 350km upstream of the Nakdong River Estuary. It is a rockfill type dam with dimensions of 73 m in height and 515 m in length. Imha reservoir has the flood control capacity of 80 million m^3 among the total storage of 595 million m^3. It supplies water for various purposes that amount to 497 million tons per annum. It also contributes to the water supply for agriculture, industry, and drinking as well as the reduction of flood damage and hydropower production.

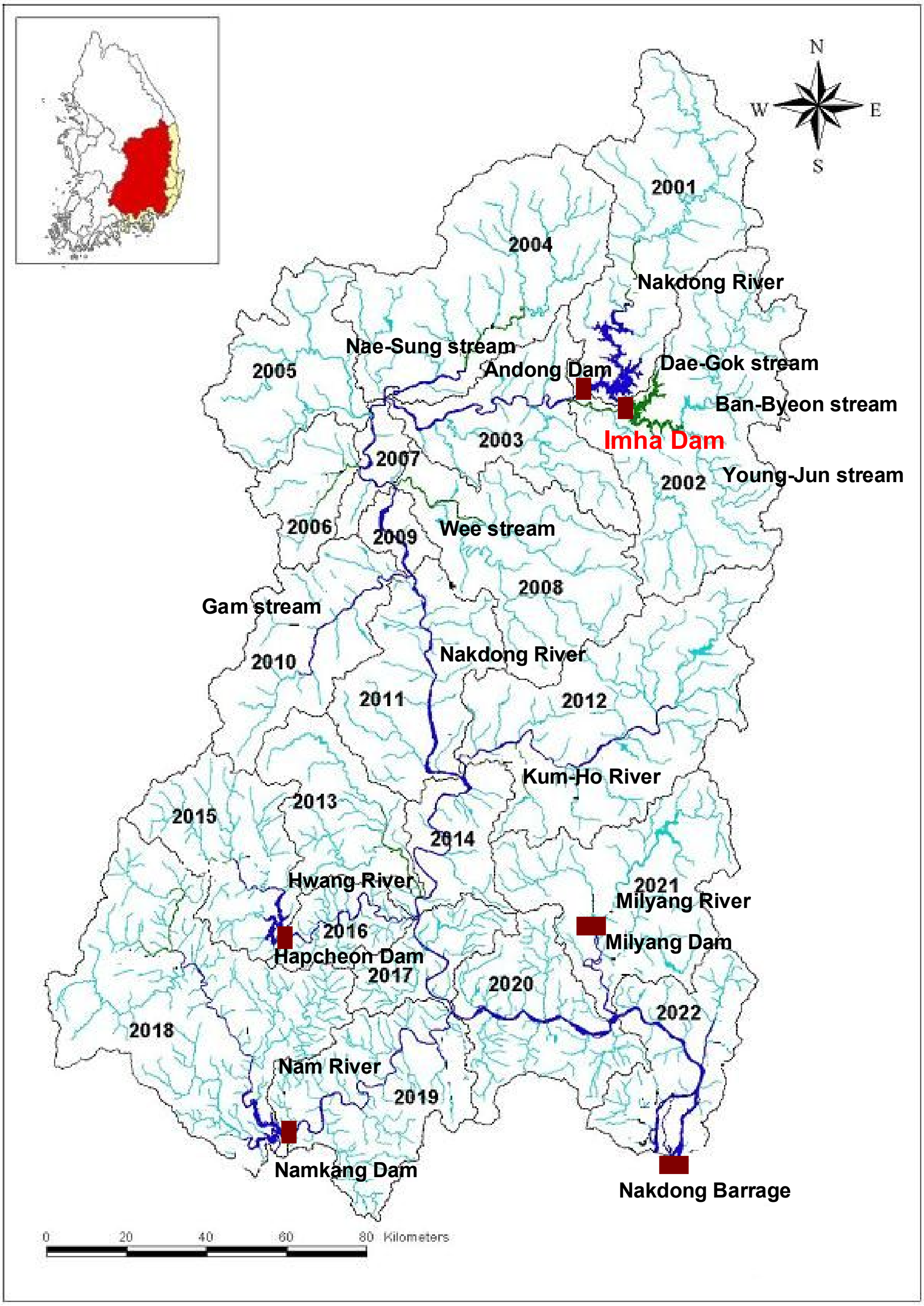


Figure 1.1 – Location map of the Nakdong river basin

a) Imha Multi-purpose Dam b) Downstream of Imha Multi-purpose Dam

Figure 1.2 – Pictures of Imha Multi-purpose Dam (after typhoon "Maemi")

Most of the Imha watershed is forested and only 15 percent is used for agriculture with paddy and crop fields. This mountainous watershed has steep slopes around 40%. Due to this topographical characteristic, most of the watershed is vulnerable to severe erosion. Soil erosion from steep upland areas has caused sedimentation in the Imha reservoir. It has also deteriorated the water quality and caused negative effects on the aquatic ecosystem.

Natural disasters such as floods, typhoons, and snow-melt, in addition to human activities including logging, grazing, agriculture, mining, road building, urbanization, and commercial construction, have often played an important role in creating suspended sediment in streams, rivers, and reservoirs (Lloyd et al., 1987; Newcombe and MacDonald, 1991; Bash et al., 2001). Since Imha reservoir was impounded, it has suffered from continuous turbid water. When the typhoon "Rusa" in 2002 came to the Imha watershed, the turbidity increased to more than 800 NTU (Neuphelometry Turbidity Unit) as shown Figure 1-3. Furthermore, Figure 1-4 shows a level of more than 1200

NTU caused by the typhoon “Maemi” in 2003. Even though turbidity decreased with time, it still remained high three months later.

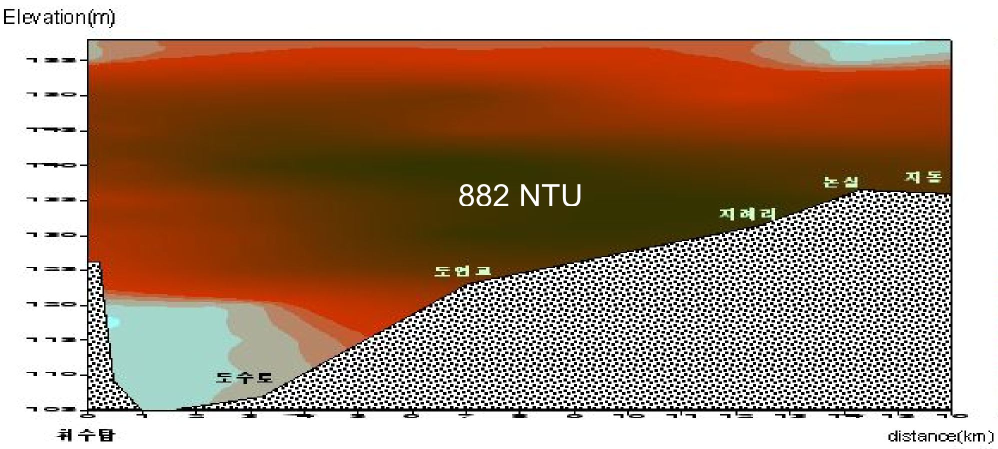


Figure 1.3 – Turbidity variation by typhoon "Rusa" in Sep. 2002 (KOWACO, 2003)

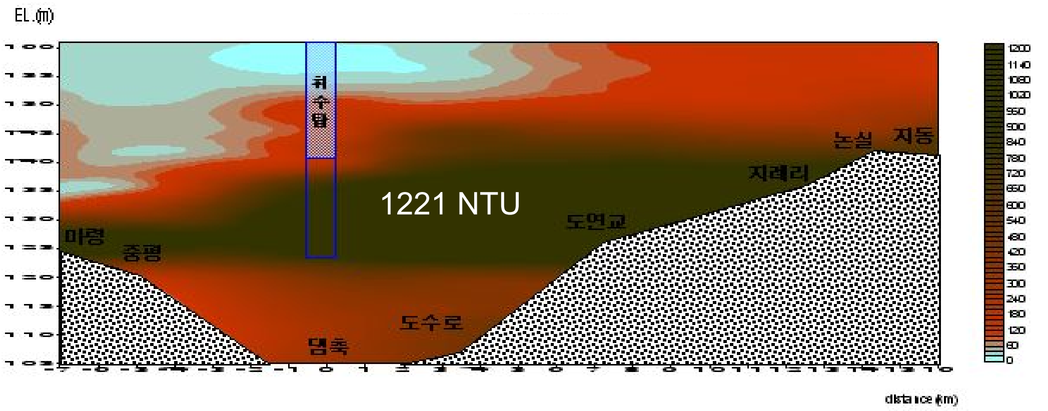
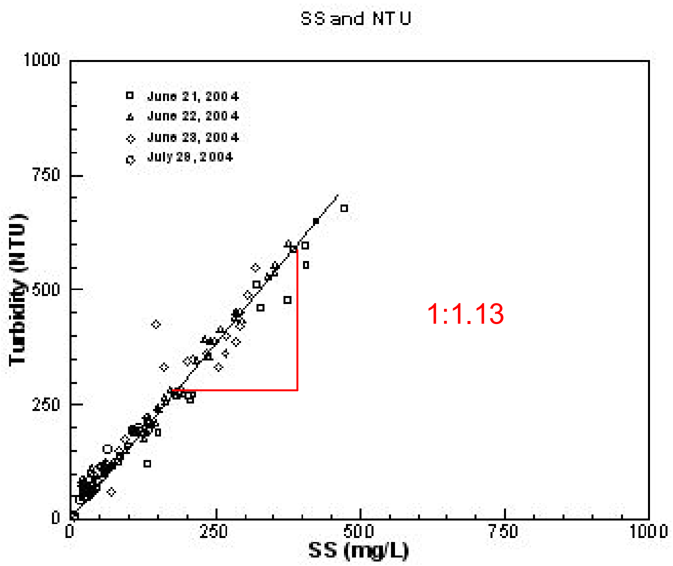
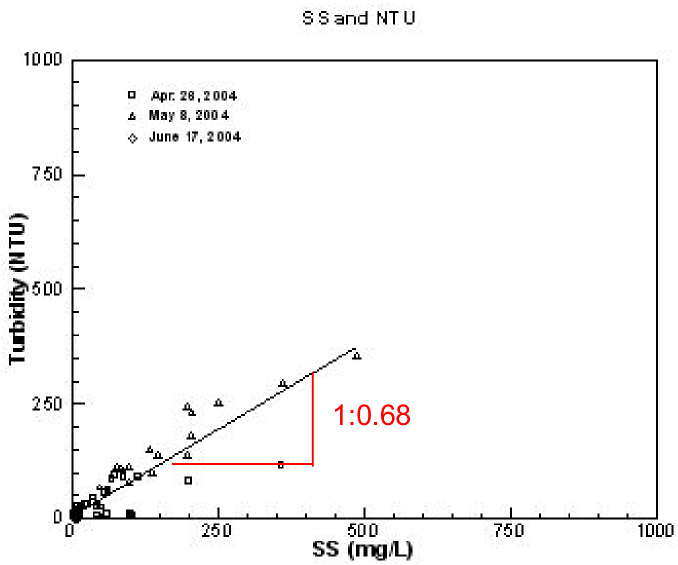


Figure 1.4 – Turbidity variation by typhoon "Maemi" in Sep. 2003 (KOWACO, 2003)

The turbidity was measured both at the Imha reservoir and at the conjunction point of the Imha reservoir and the Ban-Byeon Stream from April 2004 to July 2004 in order to relate turbidity to suspended sediment concentration. Figure 1-5 shows the relationship between turbidity and suspended sediment concentration. As shown in Figure 1-5, the turbidity level is almost the same as the suspended sediment concentration.



a) At the Imha reservoir



b) At the conjunction point of the Imha reservoir and the Ban-Byeon stream

Figure 1.5 – The relationship between turbidity and suspended sediment concentration (KOWACO, 2004)

1.2 Objectives

The objectives of this thesis are:

1) Using the Rainfall, Digital Elevation Model (DEM), Soil Type Map, and Land Cover Map, build the Soil Erosion Map (SEM) and calculate the soil loss rates on the Imha watershed for the following two cases
   a. Annual average soil loss rates
   b. Soil loss rates caused by typhoon “Maemi”
2) Analyze the spatial distribution of soil erosion in the Imha watershed.
3) Using the annual average soil loss rate on the Imha watershed, and sediment deposits surveyed at Imha reservoir in 1997, determine the Sediment Delivery Ratio (SDR) in the Imha watershed.
4) Calculate the Trap Efficiency (TE) at the Imha reservoir.
5) Estimate the life expectancy for the dead storage and whole storage of the Imha reservoir.

Chapter 2: LITERATURE REVIEW

2.1 Introduction

According to the objectives, the following topics are reviewed in this chapter: a) soil erosion modeling using the Revised Universal Soil Loss Equation (RUSLE) and Geographical Information System (GIS), b) Sediment yield calculation in the reservoir using the Sediment Delivery Ratio (SDR), and c) the estimation of the Trap Efficiency (TE) in the reservoir.

2.2 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster and Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998). The major forces originate from raindrop impact and flowing water.

Figure 2-1 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

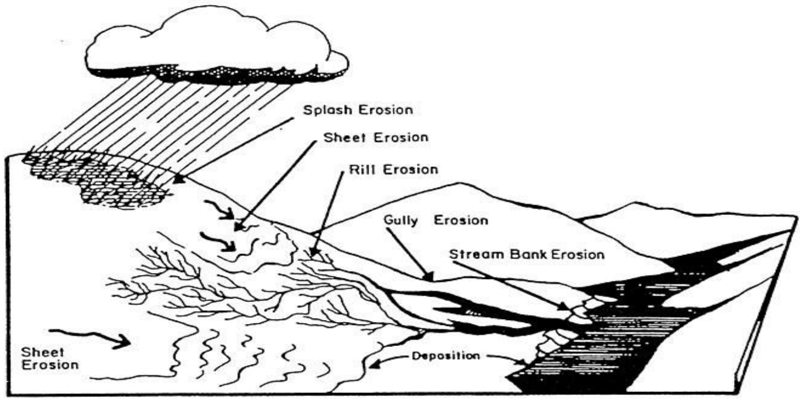


Figure 2.1 – The mechanisms of soil erosion (USACE, 1985)

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by Wischmeier and Smith (1965) in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots.

The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley, 1989) and Unit Stream Power - based Erosion Deposition (USPED) (Mitasova et al., 1996) are based on the USLE and represent an improvement of the former.

In 1996, when the U.S. Department of Agriculture (USDA) developed a method for calculating the amount of soil erosion under soil conditions besides pilot sites such as pastures or forests, RUSLE was announced to add many factors such as the revision of the weather factor, the development of the soil erosion factor depending on seasonal changes, the development of a new calculation procedure to calculate the cover vegetation factor, and the revision of the length and gradient of slope.

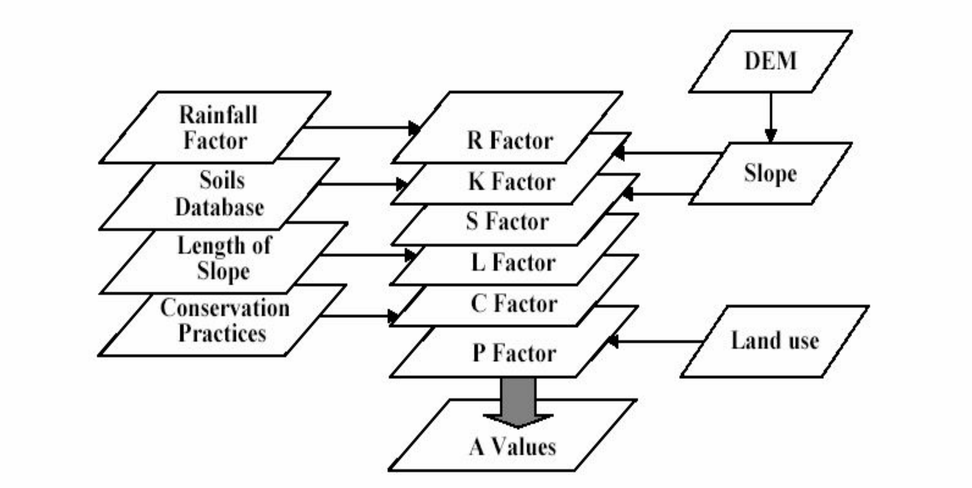


Figure 2.2 – Procedures of RUSLE implementation in GIS

The use of the USLE and its derivatives is limited to the estimation of gross erosion, and lacks the capability to compute deposition along hill slopes, depressions, valleys or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS.

USDA developed the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995) to replace the USLE family of models and expand the capabilities for erosion prediction in a variety of landscapes and settings. This model is a physically based, distributed parameter, single-event simulation erosion prediction model. Processes within the model include erosion, sediment transport and deposition across the landscape and in channel via a transport equation.

The KINEROS model (Woolhiser et al., 1990) is also a physically based, single-event simulation erosion model, which uses the infiltration model and the kinematic wave approximation to route overland flow and sediment.

The two dimensional soil erosion model CASC2D-SED was developed at Colorado State University (CSU) to simulate the dynamics of upland erosion during single rainstorms. This model is based on the raster-based surface runoff calculations from CASC2D. CASC2D-SED (Julien and Saghafian, 1991; Julien et al., 1995; Ogden, 1997a, 1997b; Johnson, 1997; Johnson et al., 2000) is a physically based, distributed, raster, hydrologic and soil erosion model that simulates the hydrologic response of a watershed subject to a given rainfall field.

2.3 Sediment Delivery Ratio

The Sediment Delivery Ratio (SDR) is defined by Julien (1998) as the ratio of the sediment yield at a given stream cross section to the gross erosion from the watershed upstream from the measuring point. It compensates for areas of sediment deposition that become increasingly important with increasing catchment area, and therefore, determines the relative significance of sediment sources and their delivery (Hua Lu et al., 2003).

Since the 1940's, many equations have been developed to predict mean annual sediment yield or reservoir sediment accumulation in small watersheds. Often they are statistically derived from regional data for the purpose of transferring information from gauged to ungauged basins in the same region (Gottschalk, 1946; Gottschalk and Brune, 1950; Glymph, 1954; Anderson, 1954; Hadley and Schumm, 1961). At a regional scale, the most widely used method to estimate SDR is the SDR-area power function equation:

$$SDR = \alpha A^{\beta} \qquad \text{(Eq 2.1)}$$

Where:

A = *catchment area* (km^2)

α = *constant*

β = *scaling exponent*

The constant α and a scaling exponent β are empirical parameters (Maner, 1958; Roehl 1962). Field measurements suggest that β ranges from 0.01 to –0.025 (Walling, 1983; Richards 1993), which means that the SDR decreases with increasing catchment area. The scaling exponent β contains key physical information about catchment sediment transport processes and its close linkage to rainfall-runoff processes. Richards (1993) suggests that β decreases with increasing aridity. Ferro and Minacapilli (1995) found the lower value of β to be up to –0.7. Figure 2-3 is based on field data and indicates that the relationships between SDR and drainage area change considerably between different catchments around the world.

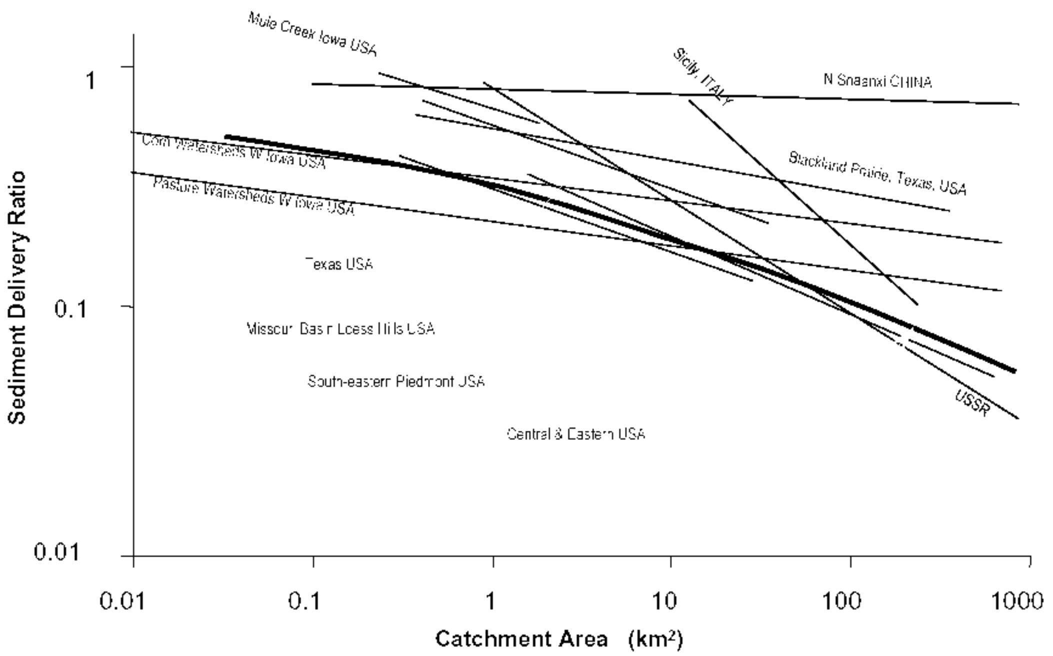


Figure 2.3 – SDR vs Catchment area relationships obtained from different areas around the world (Hua Lu et al., 2003)

Boyce (1975) shows the relationships between SDR and drainage area in Figure 2-4. He noted that the observed decrease in delivery ratio with increasing watershed size appears to violate Playfair's law because it implies continual floodplain deposition. Rather than accept this as the true explanation, he concluded that downstream, low-slope portions of larger watersheds are not adequately represented by standard delivery ratio vs. drainage area curves.

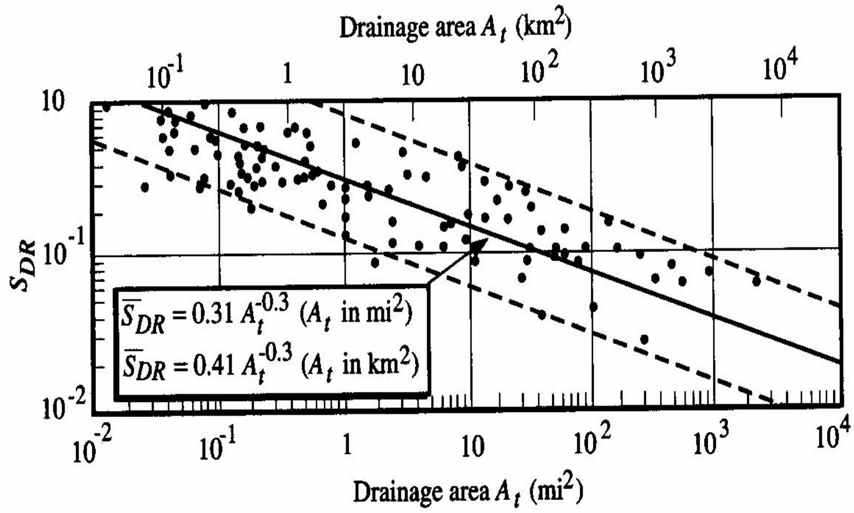


Figure 2.4 – Sediment delivery ratio (modified after Boyce, 1975)

Vanoni (1975) developed the data from 300 watersheds throughout the world to develop an equation by the power function. This equation is considered a more generalized one to estimate SDR.

$$SDR = 0.42A^{-0.125} \qquad \text{(Eq 2.2)}$$

Where:

A = catchment area (mile^2)

To estimate Sediment Yield (SY) from hillslopes and small sub-areas to the channel, Wischmeier (1976) emphasized the fact that "soil loss must be distinguished from field sediment yield." Roehl (1962) states that for catchments with similar area, field data show the values of α and β are also different in different regions. This is the reason why the SDR – area relationship does not take into account local descriptors, such as rainfall, topography, vegetation, land use and soil characteristics. Richards (1993) states that there are some limitations of SDR methods.

1) SDR methods cannot explicitly predict the locations and rates of sediment deposition in the lowland phases.

2) SDR has the problem of temporal and spatial lumping and lack of physical basis.

However, SDR is a very useful concept to model regional scale sediment delivery processes.

2.4 Reservoir Trap Efficiency

Trap Efficiency (TE) is the percent of inflowing sediment that remains in the reservoir. Some proportion of the inflowing sediment leaves the reservoir through the outlet works. The proportion remaining in the reservoir is typically estimated based on the trap efficiency.

Heinemann (1981) suggests that the single most informative attribute of a reservoir is its trap efficiency. Figure 2.5 presents a capacity-annual inflow ratio (C/I) to predict TE (Brune,1953). Brune (1953) used data from 40 ponded reservoirs, which are completely filled by water and have their outlet at the top of the embankment, and 4 other types of reservoirs. The curves produced by Brune are the ones most widely used.

USDA-SCS (1983) had transformed envelope curves into curves for predominantly coarse-grained sediments, as shown in Figure 2.5.

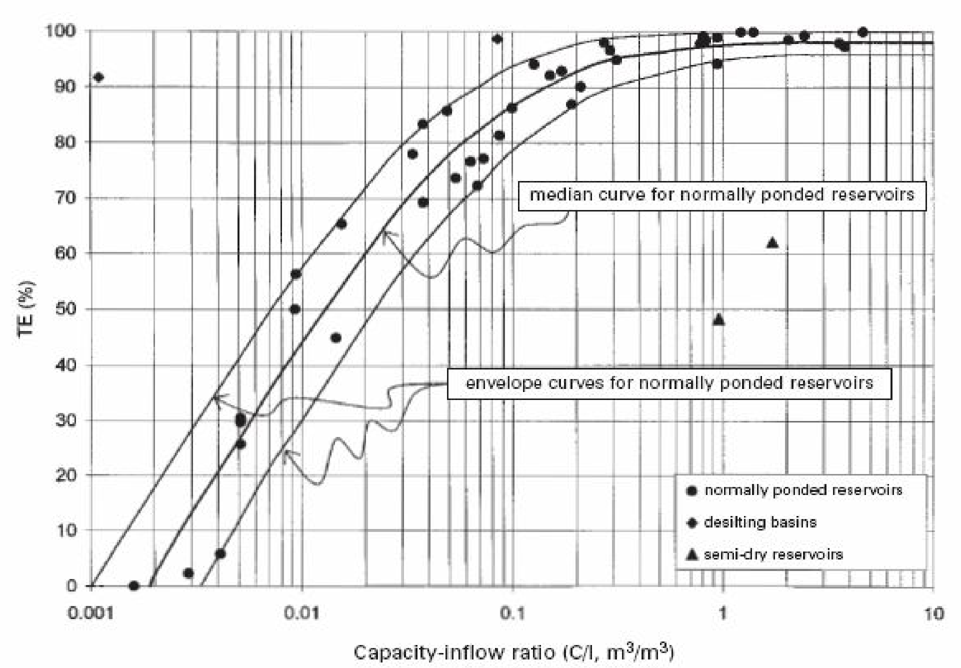


Figure 2.5 – Trap efficiency related to capacity / annual inflow ratio (Brune, 1953)

The USDA-SCS (1983) also suggests that TE should be lowered by 5% for sandy sediments and by 10% for predominantly fine-textured sediments for dry reservoirs. However, this lowering could lead to an overestimation of dead storage, making a planned pond more expensive, because this is not to be based on available field data.

Brune's relationship between TE and the C/I ratio for small agricultural ponds is modified by Heinemann. He utilized 20 normally ponded surface discharge reservoirs data with catchment areas ranging from 0.8 to 36.3 km^2. He concluded that the curve produced by him predicted a lower TE for a selected reservoir than the one of Brune (1953). Figure 2.6 shows the revision of Brune's curve by Heinemann for small agricultural reservoirs.

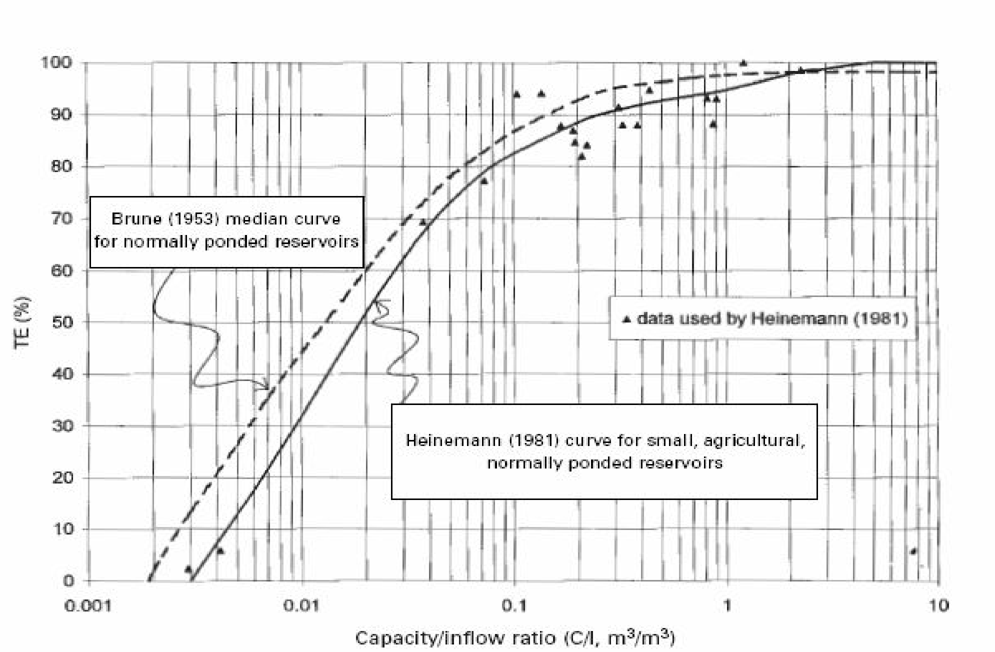


Figure 2.6 – Revision of Brune's (1953) curve by Heinemann (1981) for small agricultural reservoirs

Churchill (1948) suggests that there is a relationship between the amounts of sediments passing through the reservoir and a sedimentation index based on suspended sediment measurements taken near reservoirs in the Tenessee Valley (USA). Figure 2.7 represents this relationship between the amounts of sediments passing through the reservoir and a sedimentation index. The sedimentation index can be estimated as the retention time divided by the mean flow velocity through the reservoir. Therefore, this relationship describes in more detail the hydraulic activity of a reservoir and may be a more appropriate method for estimating TE.

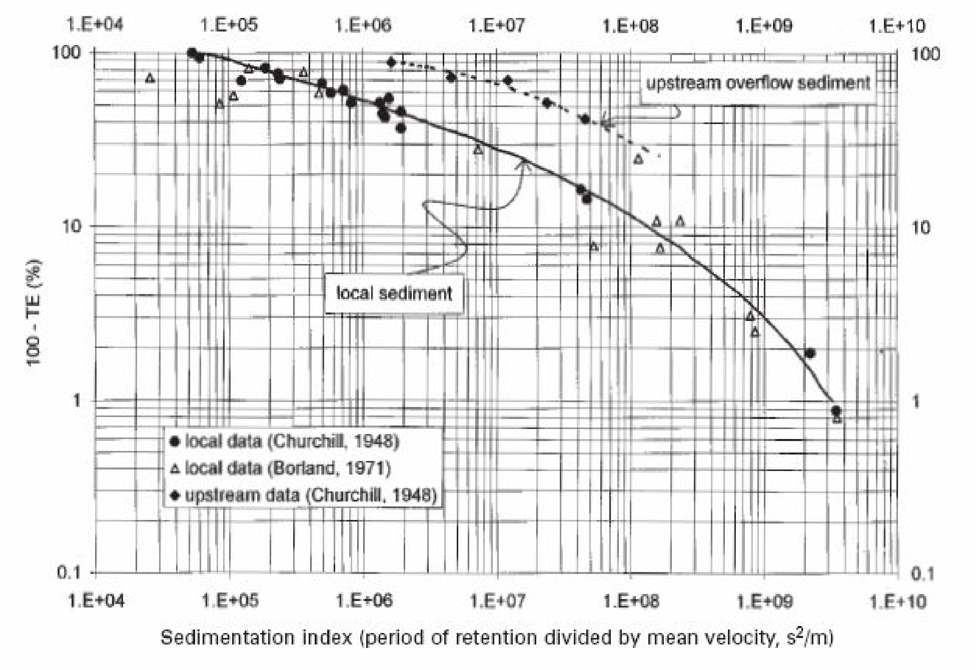


Figure 2.7 – Churchill's (1948) curves for local and upstream sediment, relating TE to a sedimentation index

Trimble and Carey (1990) compared both the Churchill curves (1948) and the Brune curves (1953) for 27 reservoirs in the Tennessee River Basin. They estimated the sediment yield based on the two TE curves and sediment accumulation data for these reservoirs. The estimated TE values used by Brune's curve (1953) were estimated equal to or higher than the TE values used by Churchill's curves (1948).

To compute the trap efficiency, a new method developed by Borland (1971) is introduced using the fraction of material and the settling velocity;

$$TE = 1 - e^{\frac{-1.055 L\omega}{Vh}} \quad \text{(Eq 2.2)}$$

Where:

TE = Trap efficiency;
L = total length of the reservoir;

ω =fall velocity of the sediment;
V = mean velocity of flow;
h =flow depth;

Julien (1998) also developed the trap efficiency equation, which is defined as the percentage of sediment fraction i that settles within a given distance X:

$$TE = 1 - e^{\frac{-X\omega_i}{Vh}} \qquad \text{(Eq 2.3)}$$

Where:
TE = Trap efficiency;
X = total length of the reservoir;
ω =fall velocity of the sediment;
V = mean velocity of flow;
h =flow depth;

He states that, when calculating the trap efficiency of silt and clay particles, careful consideration must be given to density currents and possible flocculation.

2.5 Geographic Information System and Soil Erosion Modeling

A Geographic Information System (GIS) is an arrangement of computer hardware, software, and geographic data that people interact with to integrate, analyze, and visualize data; identify relationships, patterns, and trends; and find solutions to problems. The system is designed to capture, store, update, manipulate, analyze, and display studied data and used to perform analyses (ESRI, 2005). GIS have been used in various environmental applications since the 1970s; however, extensive application of GIS to hydrologic and hydraulic modeling and flood mapping and management did not begin until the early 1990s (Moore et al., 1991; Vieux and Gauer, 1994; Maidment and Djokic, 2000). The ability to represent elevation in terms of topographic surfaces is central to geomorphological analyses and thus to the importance of representing topography using DEM. It is through the distribution of soil that the land surface changes over the long term and so the ability to link sediment transfer with DEM changes (Schmidt et al., 2000). The redistribution of sediment will drive the long-term landscape change, which in turn will affect the hydrological processes acting within and over individual hillslopes (Brooks and McDonnell, 2000).

Soil erosion is affected by the spatial topography, vegetation, soil properties, and land use. A GIS is a very useful tool to deal with the large number of spatial data and the relationship from various sources in the erosion modeling process.

There are some advantages of linking soil erosion models with a GIS such as the following:

1) The possibility of rapidly producing input data to simulate different scenarios. A GIS provides an important spatial/analytical function performing the time-consuming georeferencing and spatial overlays to develop the model input data at various spatial scales (Sharma et al., 1996).

2) The ability to use very large catchments with many pixels, so the catchment can be simulated with more detail (De Roo, 1996).

3) The facility of displaying the model outputs. Visualization can be used to display and animate sequences of model output images across time and space. Therefore, visualization enables objects to be viewed from all external perspectives, and to invoke insight into data through manipulable visual representations (Tim, 1996).

In soil erosion prediction, GIS application is increasing more and more. There are several examples for the integration of GIS with erosion models: De Roo et al. (1989) combined ANSWERS with GIS technology; Mitchell et al. (1993) linked AGNPS with GIS.

The USLE was originally developed to predict long term average annual erosion. In order to determine the slope length factor for a cell dose, Kinnell (2000) points out what procedures are available. Julien and Frenette (1987) studied the Chaudiere basin in Canada to examine the applicability of the USLE to a large area. They used a correction factor to the large watershed to extend the applicability of the USLE.

Molnár and Julien (1998) compared soil loss erosion to different grid cell size. They concluded that large grid cell sizes underestimate soil losses because of the terrain slope effects. They suggest that a correction factor is needed to solve the underestimation of soil loss in the macroscale.

Chapter 3: SITE DESCRIPTION AND DATA SET

3.1 Introduction

This chapter describes the Imha watershed site, along with the various data needed to analyze sediment erosion in the Imha watershed. The Imha watershed, topography, soil types, landuse types, runoff, and precipitation are illustrated for the application of soil erosion modeling. Precipitation data will be used to estimate the rainfall-runoff erosivity factor and soil and landuse type data will be used to predict the soil erodibility factor and cover management factor, respectively. In order to calculate the slope length and slope steepness factor, DEM will be used. Surveyed sediment data will be used to analyze the SDR in the Imha watershed.

3.2 Imha Multi-purpose Dam Watershed

The Nakdong River is located in the southeastern part of the Korean Peninsula and is the second largest river. Drainage area of the Nakdong River is about 23,700 km^2 and total length is about 511 km.

The Imha watershed is located in the northeastern part of the Nakdong River basin, which is between 36° 09' 42" ~ 36° 50' 08"N and 128° 43' 22" ~ 129° 18' 00"E. It includes Andong city, Pohang city, Chungsong-gun, and Yongyuang-gun of the Gyeongsangbuk-do province. Figures 3-1 and 3-2 present the location map of the Imha Multi-purpose Dam, which is near the Andong Multi-purpose Dam. Major tributaries are the Dae-Gok Stream, the Ban-Byeon Stream and Young-Jun Stream. The area of the Imha watershed is 1,361 km^2, which covers 8% of the Nakdong River basin.

Figure 3.1 – The Imha Multi-purpose Dam site

The average elevation of the Imha watershed is 388 m and average watershed slope is 40.26%. Average annual temperature is between 11°C and 12°C, and annual precipitation has been 1,037 mm since recordings have been taken. The variation of annual precipitation is very high. About two thirds of annual precipitation is concentrated in three months, between July and September. The average flow rate is 19.8 m^3 sec^{-1} or about $1{,}700\times10^3$ m^3 d^{-1}.

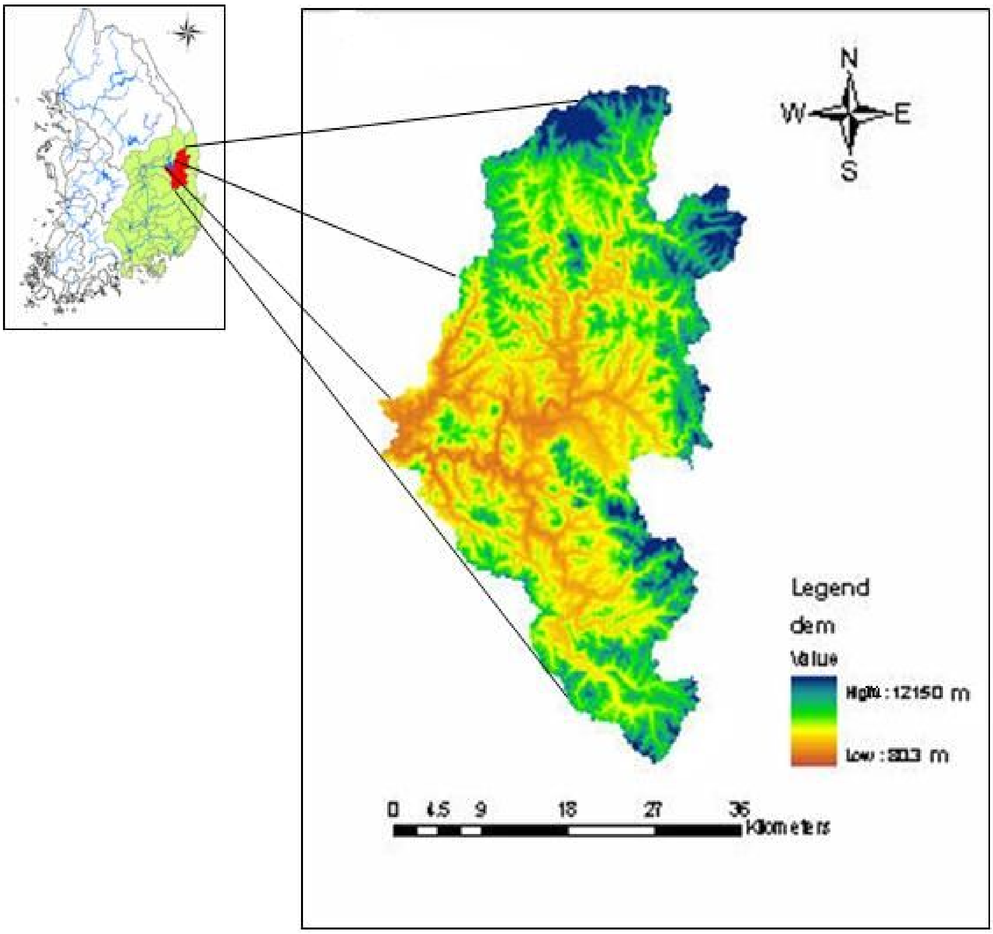


Figure 3.2 – The location map of the Imha watershed area

3.3 Data Set of the Imha Watershed

Soil erosion is influenced by a variety of factors such as rainfall intensity and distribution, soil types, topography of watershed, land use types, etc. These factors are presented very well with the temporal and spatial type using GIS technique. GIS application is increasing more and more to predict soil erosion in the watershed.

In order to predict the soil erosion, sediment delivery ratio, and trap efficiency in the Imha watershed, the following spatial and temporal data are used:

1) Digital Elevation Model (Data source: MOCT, cell size: 30 by 30m)

2) Soil types map (Data source: NIAST, vectorized map)

3) Land cover type map (Data source: MOCT, cell size: 30 by 30m)

4) 13 years of hourly and daily precipitation data (Data source: MOCT, KOWACO)

5) Sediment Deposition survey report in the Imha reservoir (Data source: KOWACO, 1997)

6) Sediment Transportation survey report in the Imha station (Data source: KOWACO and FAOUN, 1971)

The Imha watershed has a database of precipitation and runoff data from 1992 to 2005. It also has some thematic maps, including a hydrologic units map, land cover map, soil type map, population density map, etc. This database is available at the web site (WAMIS) ; http://www.wamis.go.kr

3.3.1 Digital Elevation Model

The DEM of the Imha watershed is presented in Figure 3.3. This DEM was newly created using the digital contour map (scale 1:5000) as a part of "The Nakdong River Basin Survey Project (MOCT and KOWACO, 2005)." This project was done by the Ministry of Construction and Transportation (MOCT) and Korea Water Resources Corporation (KOWACO) from 2002 to 2005. The terrain elevation of the Imha watershed ranges from EL. 80m to EL. 1215m, with average elevation EL. 388m. Using the DEM, the following watershed and river characteristics can be predicted;

1) Watershed characteristics: drainage area, basin perimeter, effective basin width, form and shape factor, drainage density, channel segment frequency, basin average elevation, basin slope, etc.

2) River characteristics: basin length, total stream length, channel slope, stream order, stream length ratio, bifurcation ratio, etc.

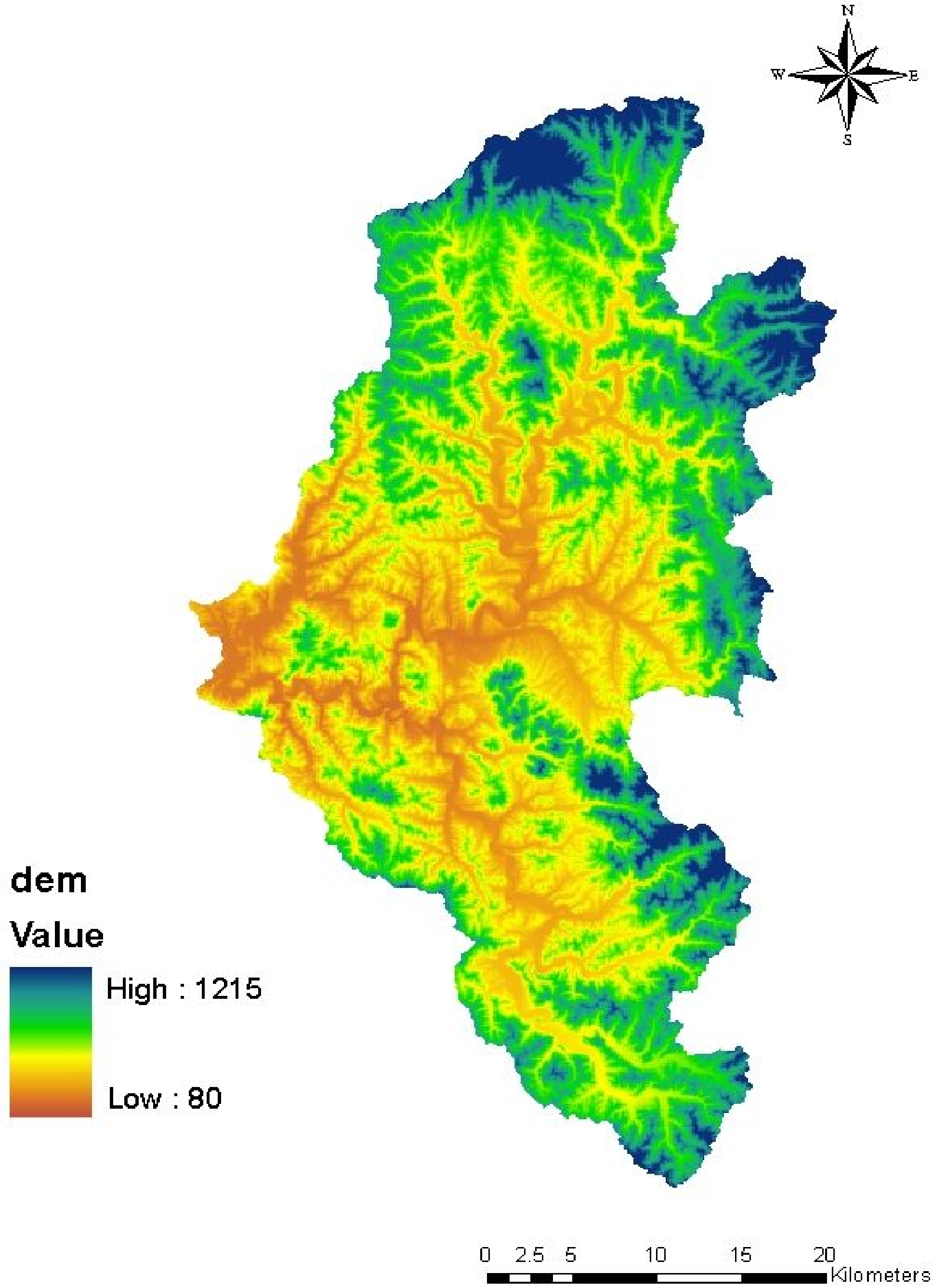


Figure 3.3 – The digital elevation model of the Imha watershed

3.3.2 Soil Classification Map

Soil classification of South Korea had been carried out as a part of "The Nakdong River Basin Survey Project (1971)" by MOCT and KOWACO with the aid of the Food and Agriculture Organization of the United Nations (FAOUN). During this project, soil classification of the Nakdong River basin was divided into 47 soil types as shown in Table 3.1. Detailed soil classification can be found in Appendix A. Soil characteristics include the soil type, unit area, hydrologic condition, and hydrologic soil groups: A, B, C, and D based on the index of the USDA Soil Conservation Service (SCS).

Table 3.1 – The soil classification of the Nakdong river basin

Location	Soil Classification
Coastal area	Fma, Fmb, Fmc, Fmd, Fmg, Fmk
Floodplain area	Afa, Afb, Afc, Afd
Inland area	Apa, Apb, Apc, Apd, Apg
Valley area	Ana, Anb, Anc, And
Low mountain area	Roa, Rob, Roc, Rod, Rea, Rla, Rlb, Rsa, Rsb, Rsc, Rva, Rvb, Rvc, Rxa
High Mountain Area	Maa, Mab, Mac, Mla, Mlb, Mma, Mmb, Msa, Msb, Mua, Mub, Mva, Mvb, Ro

The soil classification map of the Imha watershed is divided into 35 kinds of soil types such as Afa, Ana, Apa, Rea, Maa, Ro, etc. The National Institute of Agricultural Science and Technology (NIAST) published the soil paper map with 1:50,000 scales in 1973. Based on this paper map, a digital soil map was produced with the ARC/INFO coverages of the 1:25,000 scales. Figure 3.4 represents the soil classification in Imha watershed using the published digital soil map. As shown in Figure 3.4, rocky silt loam

(Msb) is widespread, covering about 50% of the Imha watershed. The sandy loam is especially prevalent around the Imha reservoir and Ban-Byeon Stream.

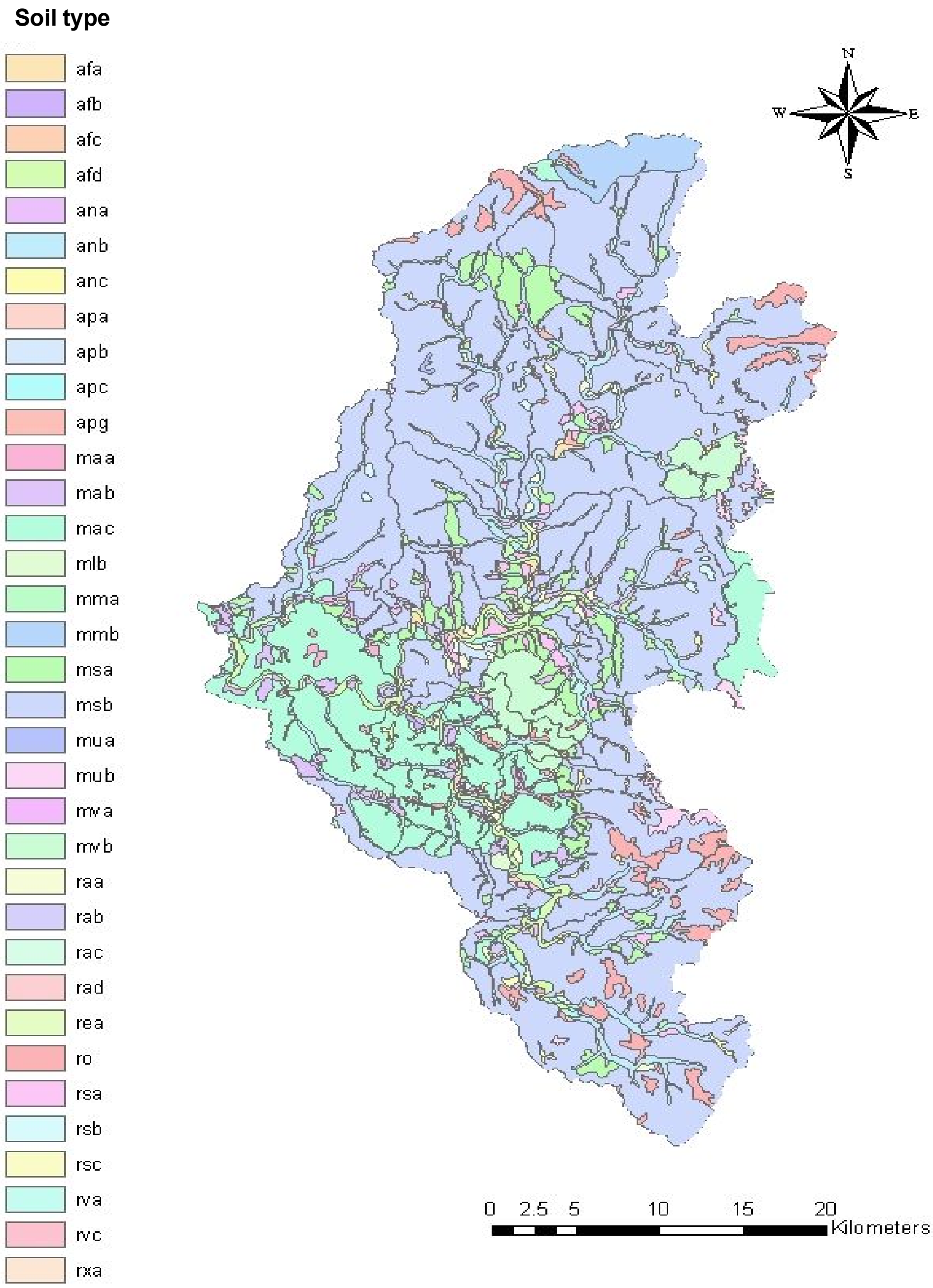


Figure 3.4 – The soil classification map of Imha watershed

3.3.3 Land Cover Map

The Ministry of Environment (ME) created the land cover classification system of South Korea in 1999 to analyze the spatial and temporal variation of land use and to estimate the pollutant load of watershed and upland soil erosion. This system consists of three classes, which are first classification (7 types), second classification (23 types), and third classification. The land cover classification system can be found in Appendix B. Based on this system, the Ministry of Construction and Transportation published the land cover classification map as part of “The Nakdong River Basin Survey Project (2005)” every 5 years from 1975 to 2000. This map was built from the LANDSAT Satellite images. Figure 3.5 represents the land cover classification condition of the Imha watershed in 2000. This land cover classification has six classes (Water, Urban, Wetland, Forest, Crop field, and Paddy field). As shown in Figure 3.4, Crop field, the main source of upland soil erosion, prevails around the Imha reservoir and is widespread around every tributary stream and forest area in the Imha watershed.

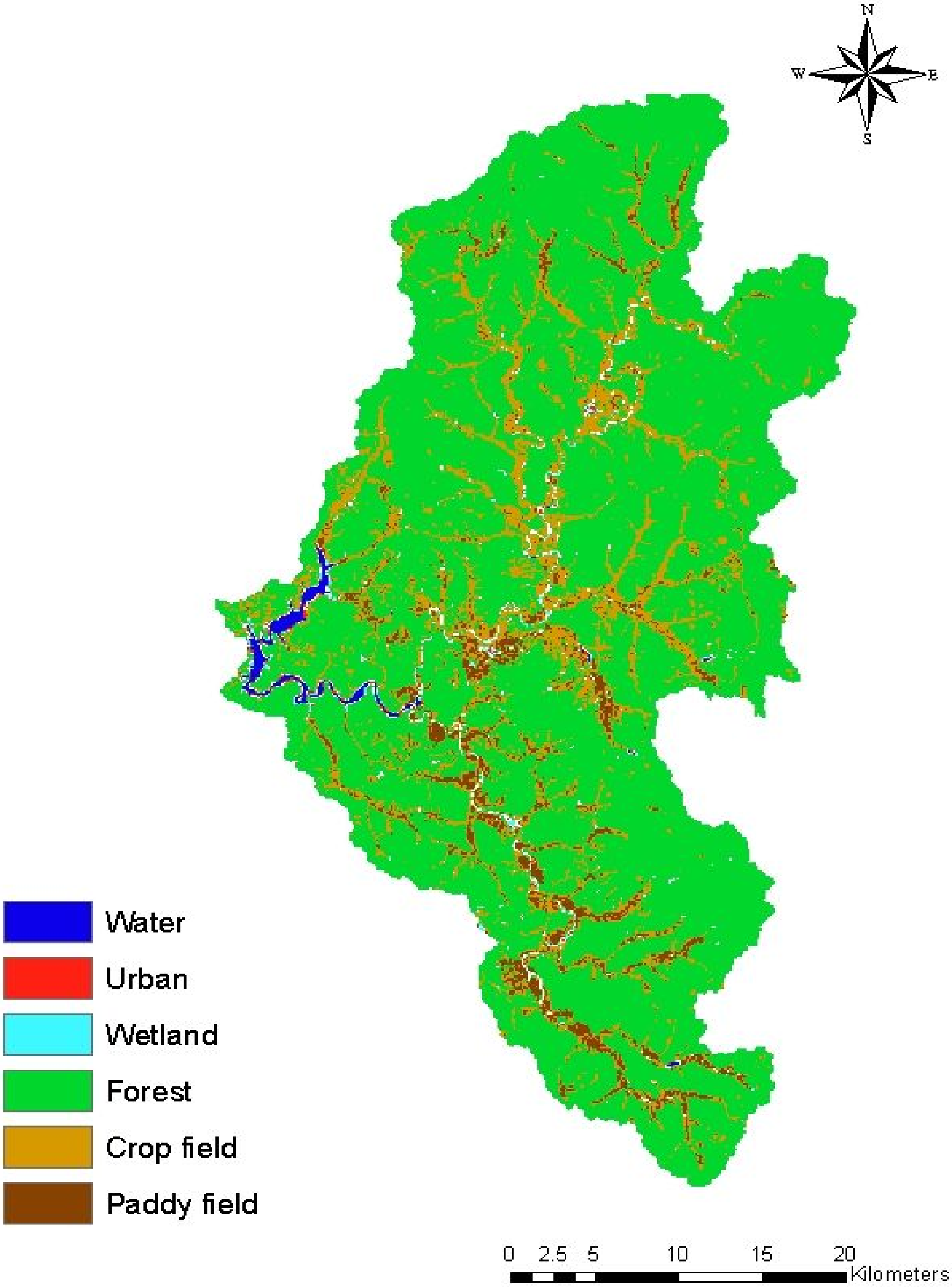


Figure 3.5 – The land cover classification map of Imha watershed

3.3.4 Precipitation and Runoff Data

Table 3.2 presents station name, location, and beginning of observation of 9 rainfall gauge stations in the Imha watershed. One of them is managed by MOCT and the others are managed by KOWACO. Hourly rainfall and runoff records are available for 13 years of data from 1992. Wischmeier and Smith (1978) recommended that at least 20 years of rainfall data should be used to accommodate natural climatic variation. Therefore, the Imha watershed has a kind of limitation to calculate the rainfall runoff erosivity factor of RUSLE.

Table 3.2 – Rainfall Gauge Stations

No.	Stations	Location		Beginning of Observations	Remark
		Longitude	Latitude		
1	Cheong Song	129-02-38	36-25-42	Sep-87	KOWACO
2	Bu Dong	129-08-42	36-22-34	Jan-00	KOWACO
3	Bu Nam	129-04-19	36-19-47	Sep-87	KOWACO
4	Seok Bo	129-08-36	36-32-33	Sep-87	KOWACO
5	Jin Bo 2	129-04-17	36-31-28	Jan-00	KOWACO
6	Young Yang	129-06-32	36-39-01	Sep-87	KOWACO
7	Su Bi 2	129-12-15	36-41-40	Jan-00	KOWACO
8	Il Wol	129-05-19	36-44-54	Jun-92	KOWACO
9	An Dong	128-48-46	36-42-40	Jan-68	MOCT

Figure 3.6 presents the location map of rainfall guage stations. As shown in Tables 3.3 and 3.4, annual average precipitation of Imha watershed is 1,038mm and average flow rate is 19.8 cms from 1992 to 2004. This database is available at the web site managed by MOCT; http://www.wamis.go.kr

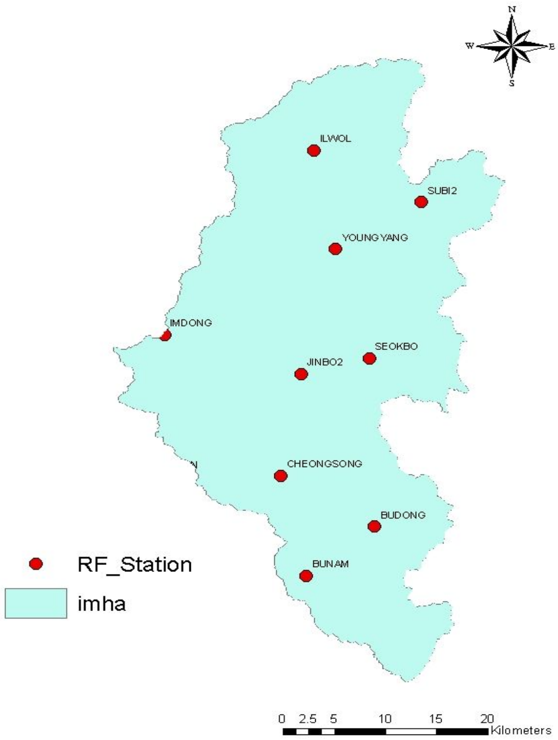


Figure 3.6 – Rainfall gauge stations of the Imha watershed

Table 3.3 – Annual precipitation records

Units: mm

Yr./Mon.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Sum
1992	19.9	9.0	27.0	75.0	46.0	23.0	163.8	211.8	105.8	12.3	9.4	31.0	734.0
1993	33.3	41.9	30.7	37.6	169.4	145.9	281.6	380.0	73.4	26.2	51.0	9.4	1280.4
1994	15.4	7.3	18.5	31.4	107.7	116.1	84.9	95.8	26.5	98.4	19.3	4.9	626.2
1995	24.6	12.8	42.1	64.6	54.6	86.3	127.5	229.9	29.3	26.4	7.9	1.7	707.7
1996	14.8	0.0	114.8	36.1	98.0	279.2	108.2	112.9	26.0	32.1	39.3	26.0	887.4
1997	20.3	17.7	15.2	56.1	146.2	145.9	326.9	142.9	44.5	5.1	117.5	43.8	1082.1
1998	23.8	22.9	25.6	116.1	74.6	140.5	229.7	359.9	114.1	27.8	19.2	1.6	1155.8
1999	2.4	3.1	61.6	76.4	121.4	172.8	114.9	290.0	322.1	59.1	11.7	0.5	1236.0
2000	10.6	0.2	23.7	36.1	40.0	132.9	149.3	184.7	236.2	19.5	50.6	1.6	885.4
2001	30.1	46.7	10.2	13.6	21.5	198.1	85.4	62.8	148.3	81.3	6.4	18.1	722.5
2002	70.5	0.0	40.5	151.1	102.1	24.5	180.7	672.4	74.7	54.4	2.5	41.5	1414.9
2003	16.3	27.5	44.3	179.6	166.4	158.3	341.3	284.6	250.7	11.1	66.5	12.1	1558.7
2004	2.2	26.8	11.9	74.2	85.9	277.0	222.0	287.6	159.3	2.7	35.6	14.4	1199.6
Aver.	21.9	16.6	35.9	72.9	94.9	146.2	185.9	255.0	123.9	35.1	33.6	15.9	1037.7

Table 3.4 – Annual runoff records

Units: cms

Yr./Mon.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Ave.
1992	6.0	3.8	18.6	10.5	5.1	1.2	26.5	39.8	17.4	5.5	1.2	1.8	11.5
1993	4.2	16.6	9.6	7.3	57.7	19.6	108.0	175.7	19.7	3.3	4.6	4.5	36.3
1994	3.4	2.5	5.2	5.5	14.3	6.6	25.8	4.9	1.7	9.8	3.5	1.4	7.1
1995	0.8	1.4	6.3	10.6	4.7	6.2	17.4	32.3	10.9	2.5	1.6	1.4	8.1
1996	1.5	1.5	11.3	5.3	7.9	70.9	27.9	5.0	3.4	2.0	1.8	1.8	11.7
1997	1.0	0.9	2.2	8.1	23.3	19.1	130.6	23.8	2.8	1.2	7.2	18.6	20.2
1998	8.4	13.1	10.0	49.5	11.1	17.0	84.8	169.5	14.7	22.0	4.5	1.8	34.2
1999	0.9	0.9	9.6	28.2	14.5	35.6	21.4	89.4	171.8	15.7	5.9	1.8	32.9
2000	2.5	1.6	2.0	3.9	1.8	15.4	27.4	36.7	110.6	6.0	4.8	3.4	18.0
2001	3.6	5.9	13.7	2.7	1.0	25.5	15.2	4.4	22.1	14.2	4.2	2.1	9.5
2002	19.1	4.4	5.8	28.0	56.8	3.9	26.9	264.8	66.4	12.8	2.5	6.9	42.0
2003	2.4	7.4	23.9	61.9	62.2	55.6	156.8	103.1	159.0	5.4	10.2	5.2	54.6
2004	1.6	3.2	4.3	10.6	23.9	98.0	108.6	89.2	49.3	5.7	3.2	2.5	33.5
Aver.	2.9	4.9	7.8	13.4	15.2	24.0	50.9	60.2	39.7	8.5	4.2	4.1	19.8

3.3.5 Sediment Survey Data

Two sediment surveys were completed at the Imha water-level gauge station. Table 3.5 presents the sediment transportation data surveyed before the Imha multi-purpose dam was constructed. The Food and Agriculture Organization of the United Nations (FAOUN) and KOWACO surveyed the area to determine the designed dead storage of the Imha multi-purpose dam from 1969 to 1970. The average sediment transportation based on the survey is 378 tons/km^2/year.

In 1997, KOWACO carried out the sediment deposits survey of the Imha reservoir using equipment such as a theodolite, plane table, sounding rods, echo-sounders and slow moving boats, etc. Based on the “Sediment Deposits Survey Report of the Imha reservoir (KOWACO, 1997)”, the surveyed sediment deposition was about 890 ton/km^2/year (680 m^3/ km^2/year) on the Imha reservoir.

Table 3.5 – Sediment Transportation data

Place	Year	Annual Precipition (mm)	Total sediment transportation (ton/km2)	Sampling num.
Yean	1969	1086	178	13
	1970	1057	240	7
Imha	1969	1232	389	19
	1970	1253	366	22
Dongcheon	1969	1328	408	22
	1970	1345	603	22
Changri	1969	1661	1596	12
	1970	1373	516	37

3.4 Summary

Chapter 3 demonstrates the Imha watershed site description and data set: topography, soil and land use characteristics, precipitation, runoff, and sediment survey data. Precipitation and runoff data are needed to estimate the rainfall runoff erosivity factor (R). DEM, with 30m grid cell size, is needed to analyze the slope length (L) and slope steepness (S). A soil map based on vectorized feature data is used to estimate the soil erodibility (K) and transformed into the raster data file with 30m grid cell size. A land cover map, extracted from LANDSAT images, is used to predict the cover management factor (C), which is one of the most sensitive factors in analyzing the soil loss rates of the RUSLE model.

Chapter 4: METHODOLOGY AND PARAMETER ESTIMATION

4.1 Introduction

This chapter describes the basic concepts, the procedure of the RUSLE model, in addition to the methodology to estimate six parameters, and parameter prediction of the RUSLE model. Based on the rainfall storm events, DEM, soil type map, and land cover map, six parameters of the RUSLE model will be estimated and verified as to the reasonability of the parameter estimation results.

4.2 RUSLE Parameter Estimation

The extent of erosion, specific degradation, and sediment yield from watersheds are related to a complex interaction between topography, geology, climate, soil, vegetation, land use, and man-made developments (Shen and Julien, 1993). The USLE is the method most widely used around the world to predict long-term rates of interill and rill erosion from field or farm size units subject to different management practices. Wischmeier and Smith (1965) developed the USLE based on many years of data from about 10,000 small test plots throughout the U.S. Each test plot had about 22m flow lengths and they were all operated in a similar manner, allowing the soil loss measurements to be combined into a predictive tool. RUSLE was developed to incorporate new research since the earlier USLE publication in 1978 (Wischmeier and Smith, 1978). Agriculture Handbook 703 (Renard et al., 1997) is a guide to conservation planning with the RUSLE.

The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation must also occur during the receding portion of the hydrograph as the flow rate decreases. The basic form of the RUSLE equation has remained the same, but modifications in several of the factors have changed. Both USLE and RUSLE compute the average annual erosion expected on field slopes and are shown in equation 3.1

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(Eq 4.1)}$$

Where:

A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in ton· acre^{-1}· yr^{-1}, but other units can be selected (that is, ton· ha^{-1} · yr^{-1});

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt (100ft·tonf·acre^{-1}·yr^{-1});

K = soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow;

L = slope length factor – the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions;

S = slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow

P = support practice factor – the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

L and S factors stand for the dimensionless impact of slope length and steepness, and C and P represent the dimensionless impacts of cropping and management systems and of erosion control practices. All dimensionless parameters are normalized relative to the Unit Plot conditions, as described in Agriculture Handbook 703. Over the years, the USLE and RUSLE became the standard tool for predicting soil erosion not only in the U.S., but also throughout the world (Meyer, 1984). Widespread use has substantiated the usefulness and validity of RUSLE for this purpose.

4.2.1 Rainfall-Runoff Erosivity Factor (R)

Wischmeier and Smith (1958) derived the rainfall and runoff erosivity factor from research data from many sources. The rainfall – runoff erosivity factor is defined as the mean annual sum of individual storm erosion index values, EI_{30}, where E is the total storm kinetic energy and I_{30} is the maximum rainfall intensity in 30 minutes. To compute storm EI_{30}, continuous rainfall intensity data are needed. Wishmeier and Smith (1978) recommended that at least 20 years of rainfall data be used to accommodate natural climatic variation.

Renard et al. (1997) states that the numerical value used for R in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain. The rainfall runoff erosivity factor (R) derived by Wischmeier appears to meet these requirements better than any of the many other rainfall parameters and groups of parameters tested against the plot data.

Wischmeier and Smith (1965) found that the best predictor of rainfall erosivity factor (R) was:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right] \quad \text{(Eq 4.2)}$$

Where:

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt (100ft·tonf·acre^{-1}·yr^{-1});

E = the total storm kinetic energy in hundreds of ft-tons per acre;

I_{30} = the maximum 30-minute rainfall intensity;

j= the counter for each year used to produce the average;

k= the counter for the number of storms in a year;

m= the number of storms n each year;
n= the number of years used to obtain the average R.

The calculated erosion potential for an individual storm is usually designated EI. The total annual R is therefore the sum of the individual EI values for each rainfall storm event. The energy of a rainfall storm is a function of the amount of rain and of all the storm's intensity components. The median raindrop size generally increases with greater rain intensity (Wischmeier et al., 1958), and the terminal velocity of free-falling waterdrops increases with larger drop size (Gunn and Kinzer, 1949). Wischmeier also found that the rain kinetic energy (E) relationship, based on the data of Laws and Parsons (1943), is expressed by the equation;

$$E = 916 + (331)\log_{10}(I), \quad I \leq 3.0 \text{ in/hr} \qquad \text{(Eq 4.3)}$$

$$E = 1074, \quad I \geq 3.0 \text{ in/hr} \qquad \text{(Eq 4.4)}$$

Where:
I = the average rain intensity;
E= the kinetic energy in ft-tons per acre inch of rain

As shown in Eq. 4.3, the rainfall runoff erosivity factor is only dependent on rain intensities alone.

Based on the Wischmeier method, rainfall runoff erosivity factors for two cases, which are the average annual rainfall erosivity factor, and the rainfall erosivity factor caused by typhoon "Maemi", are estimated in the Imha watershed. Table 4.1 presents the rainfall runoff erosivity factors for two cases. As examples, the trends of annual rainfall runoff erosivity and rainfall runoff erosivity factors based on each storm event can be found in Appendix C.

Table 4.1 – Rainfall-runoff erosivity factor

No.	Stations	Rainfall-Runoff Erosivity Factor		Beginning of Observations
		Annual average	Typhoon Maemi”	
1	Cheong Song	146.2	21.4	Sep-87
2	Bu Dong	251.8	96.5	Jan-00
3	Bu Nam	184.8	54.2	Sep-87
4	Seok Bo	197.1	164.0	Sep-87
5	Jin Bo 2	203.0	34.9	Jan-00
6	Young Yang	154.0	31.6	Sep-87
7	Su Bi 2	186.6	151.3	Jan-00
8	Il Wol	179.6	90.0	Jun-92
9	An Dong	162.2	20.8	Jan-68

Related to the rainfall runoff erosivity factor for these two cases, these values represent the data point of each rainfall gauge station in the Imha watershed. Each data point needs to be interpolated spatially to make the same grid cell size as the other thematic maps: DEM, Soil Map, Land use map, and Topographic map. The method of Interpolation used in this process was the Ordinary Kriging interpolation method supported in the Geostatistical Analyst, one of the tools in ARC GIS. Figure 4.1 presents isoerodent maps for two cases of the Imha watershed. In the case of the average annual rainfall runoff erosivity factor, the maximum value is 251.8 at Bu Dong rainfall gauge station and the minimum value is 146.2 at Cheong Song station. When the typhoon “Maemi” came to the Imha watershed, rainfall runoff erosivity values ranged from 21 to 164. Furthermore, R values of Seok Bo and Su Bi2 stations located in the eastern area are over 80% of the annual average rainfall runoff erosivity value.

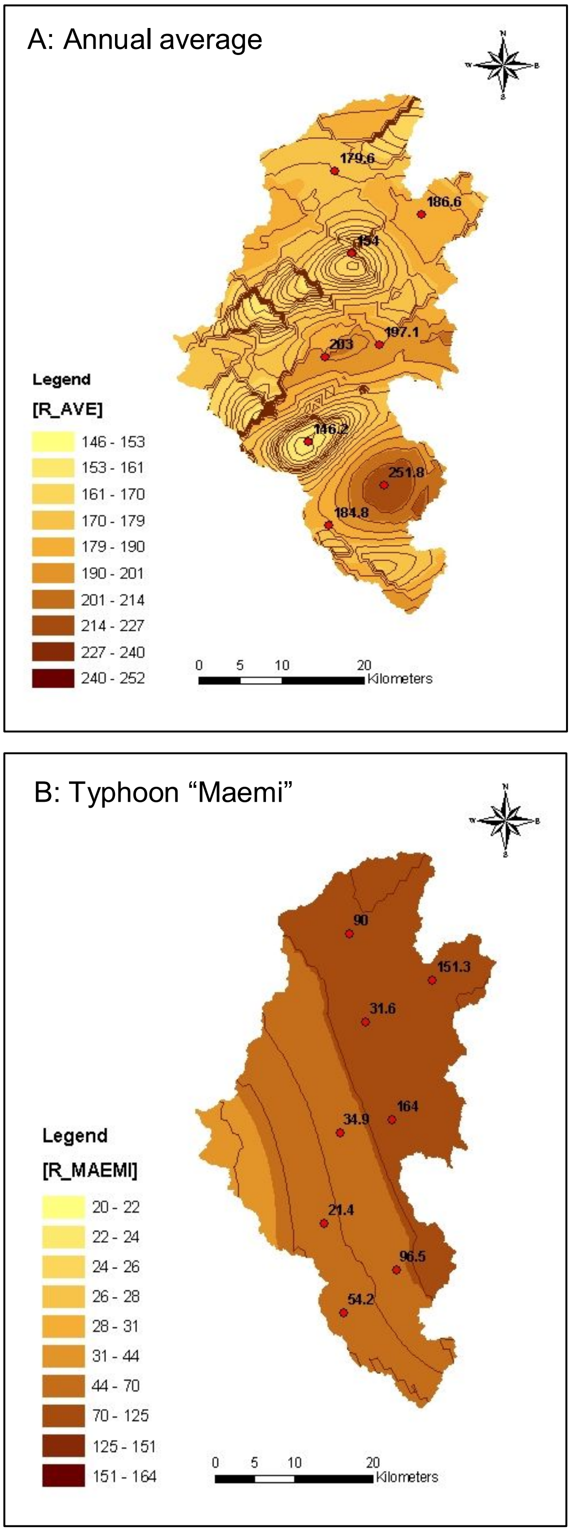


Figure 4.1 – Isoerodent maps of the Imha watershed (A: annual average, B: Typhoon "Maemi")

Computed R values of the Imha watershed are verified for reasonability before using the RUSLE model. Sixty values, taken from the state of Ohio, Illinois, and North Carolina in the U.S.A., were used for verifying reasonability. These sixty R values were taken from the Climate City Database of USDA Natural Resources Conservation Service (NRCS). The reason that the sixty R values from these three states were chosen is the similar annual average precipitation and climatic patterns compared to the the Imha watershed. Figure 4.2 presents the comparison between computed R values of Imha watershed and sixty R values from the Climate City Database of USDA Natural Resources Conservation Service (NRCS). As shown in Figure 4.2, computed R values of the Imha watershed have similar values with the sixty R values from the three states.

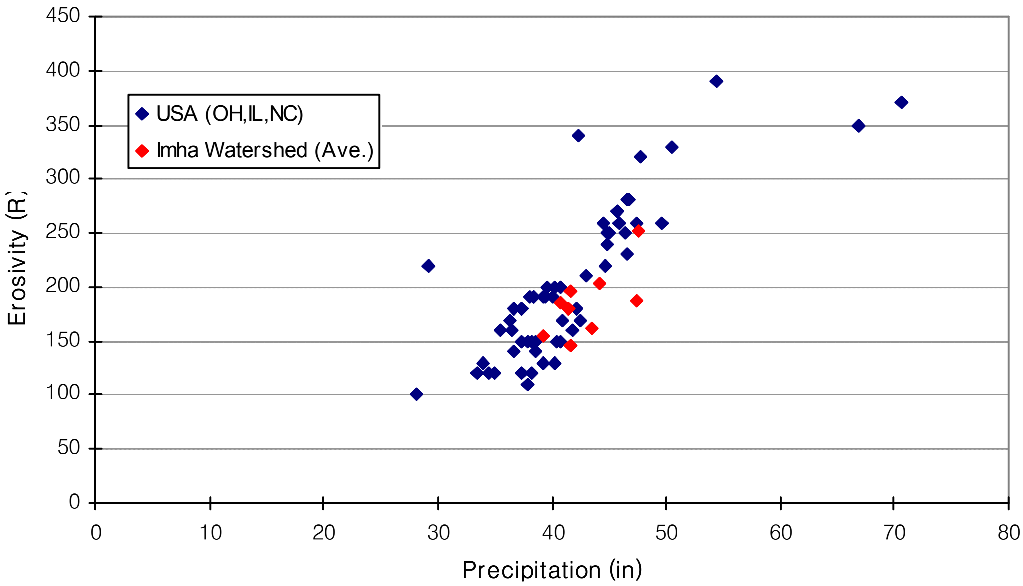


Figure 4.2 – Comparison of Erosivity (R) between USA and Imha rainfall stations

Jeong et al. (1983) predicted R values at 51 meteorological stations managed by the Korea Meteorological Agency (KMA) using the hourly data from 1960 to 1980. As Figure 4.3 shows, R values of this study in Imha watershed range from 260 to 320 (Units: 10^7J/ha ·mm/hr). Hyun (1998) also estimated the R values with the research center of Missouri University and this result is slightly smaller than Jeong’s R values. Figure 4.3 presents two isoerodent maps of South Korea.

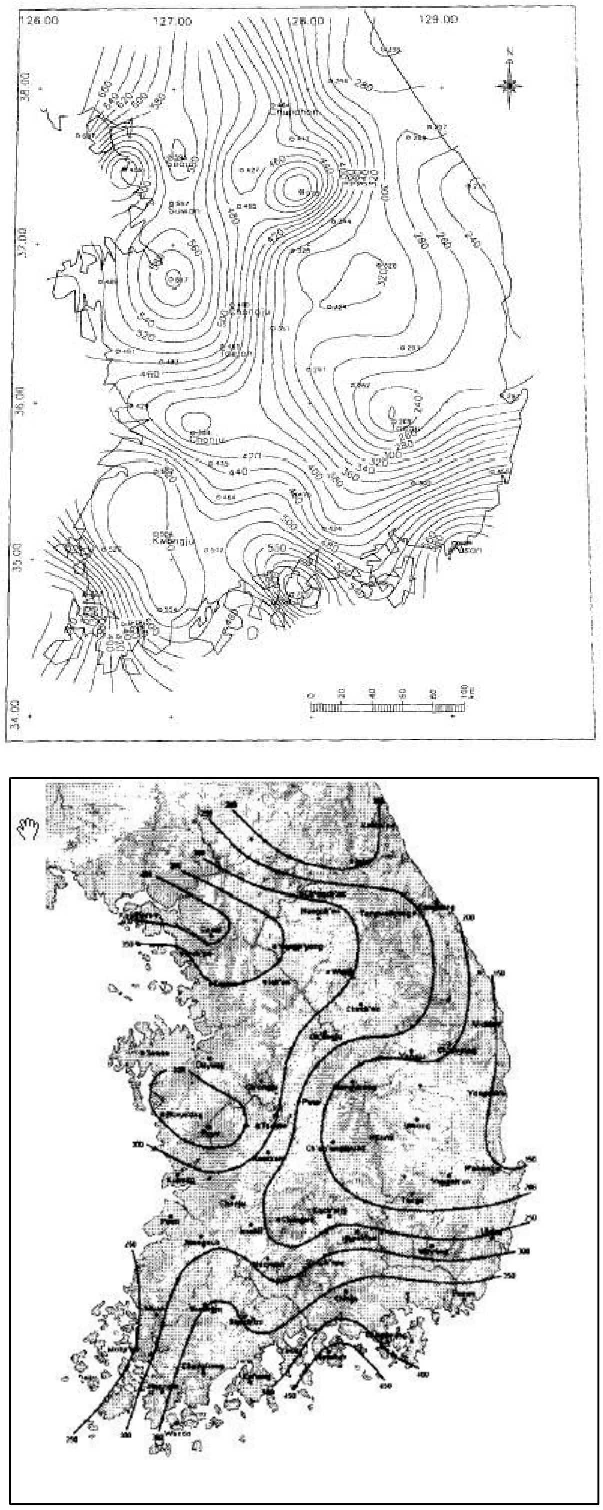


Figure 4.3 – Isoerodent Maps (Above: Jeong et al., 1983, Below: Hyun, 1998)

4.2.2 Soil Erodibility Factor (K)

Soil erodibility (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input, as measured under a standard condition. The standard condition is the unit plot, 72.6ft long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hillslope (Weesies, 1998). K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. Soil erodibility factors (K) are best obtained from direct measurements on natural runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Romkens 1985). For satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years (Loch et al., 1998). Therefore, considerable attention has been paid to estimating soil erodibility from soil attributes such as particle size distribution, organic matter content and density of eroded soil (Wischmeier et al., 1971). Figure 4.4 represents the nomograph used to determine the K factor for a soil, based on its texture; % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability.

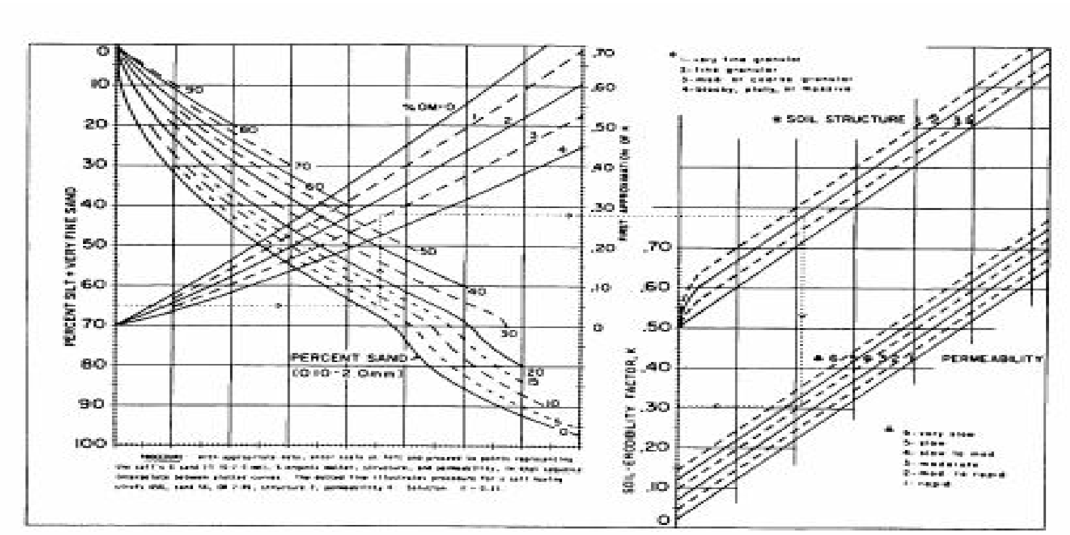


Figure 4.4 – Soil erodibility nomograph (after Wischmeier and Smith, 1978).

The relationship of soil erodibility to the grain size distribution was presented as the Unified Soil Classification System, ASTM D 2487, which can be found in Appendix D. Erickson completed this diagram with some supplements. The only reliable way to establish local values for K is to use runoff plots under the standard conditions of bare fallow. It is commonly assumed that once the K value has been established for a soil, it is regarded as permanent.

Soil classification of the Imha watershed is divided into 35 types of soil with varying soil characteristics. In this study, Soil erodibility (K) of the Imha watershed can be defined using the relationship between soil texture class and organic matter content proposed by Schwab et al. (1981). The organic matter content is assumed to be 0.5% because there is no organic matter content survey data in the Imha watershed. Table 4.2 presents the soil erodibility factor (K) based on the soil texture class by Schwab et al. (1981).

Table 4.2 – Soil Erodibility Factor (K) (Schwab et al., 1981)

	Organic Matter Content (%)	
Textural Class	0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy very fine sand	0.44	0.38
Sandy loam	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay loam	0.28	0.25
Silty clay loam	0.37	0.32
Silty clay	0.25	0.23

Based on Table 4.2, the Soil Erodibility Factor (K) of the Imha watershed is determined for each soil texture class. Table 4.3 presents the results of K values in the Imha watershed. They range from 0.0 in rock land to 0.48 in silt loam area. Figure 4.5 represents the soil erodibility (K) map of the Imha watershed.

Table 4.3 – Soil type of Imha watershed (KOWACO, 2004)

Num	Soil type	Soil Characteristics	K factor by Schwab.
1	afa	loamy fine sand, 0-2 percent slopes.	0.44
2	afb	silt loam, 0-2 percent slopes	0.48
3	afc	loamy fine sand, 0-2 percent slopes	0.44
4	afd	loamy fine sand, 0-3 percent slopes	0.44
5	ana	silt loam, 2-7 percent slopes	0.48
6	anb	sandy loam, 0-2 percent slopes	0.27
7	anc	sandy loam, 7-15 percent slopes.	0.27
8	apa	silty clay loam, 0-2 percent slopes	0.37
9	apb	silty clay loam & silt loam, 0-2 percent slopes	0.42
10	apc	sandy loam, 0-2 percent slopes	0.27
11	apg	sandy loam, 0-2 percent slopes	0.27
12	maa	silt loam & silt clay loam, 15-30 percent slopes	0.43
13	mab	sandy loam, 15-30 percent slopes	0.27
14	mac	sandy loam, 30-60 percent slopes	0.27
15	mlb	silt loam, 30-60 percent slopes	0.48
16	mma	Rocky loam, 30-60 percent slopes	0.27
17	mmb	Rocky loam, 15-30 percent slopes	0.27
18	msa	stony silt loam, 30-60 percent slopes	0.48
19	msb	rocky siltloam & silt clayloam,30-60 percent slopes	0.43
20	mua	stony loam, 7-15 percent slopes	0.27
21	mub	rocky loam, 15-30 percent slopes	0.27
22	mva	rocky loam, 15-30 percent slopes	0.27
23	mvb	rocky loam, 15-30 percent slopes	0.27
24	raa	silty clay loam, 2-7 percent slopes	0.37
25	rab	sandy loam, 15-30 percent slopes	0.27
26	rac	cobbly loam, 7-15 percent slopes	0.27
27	rad	gravelly loam, 7-15 percent slopes	0.27
28	rea	sandy loam, 15-30 percent slopes	0.27
29	ro	Rock land	0.00
30	rsa	stoney silt loam, 30-60 percent slopes	0.48
31	rsb	silt clay loam & silt loam, 7-15 percent slopes	0.43
32	rsc	silt loam, 15-30 percent slopes	0.48
33	rva	cobbly silty clay loam, 30-60 percent slopes	0.37
34	rvc	rocky loam, 15-30 percent slopes	0.27
35	rxa	loam, 2-7 percent slopes	0.27

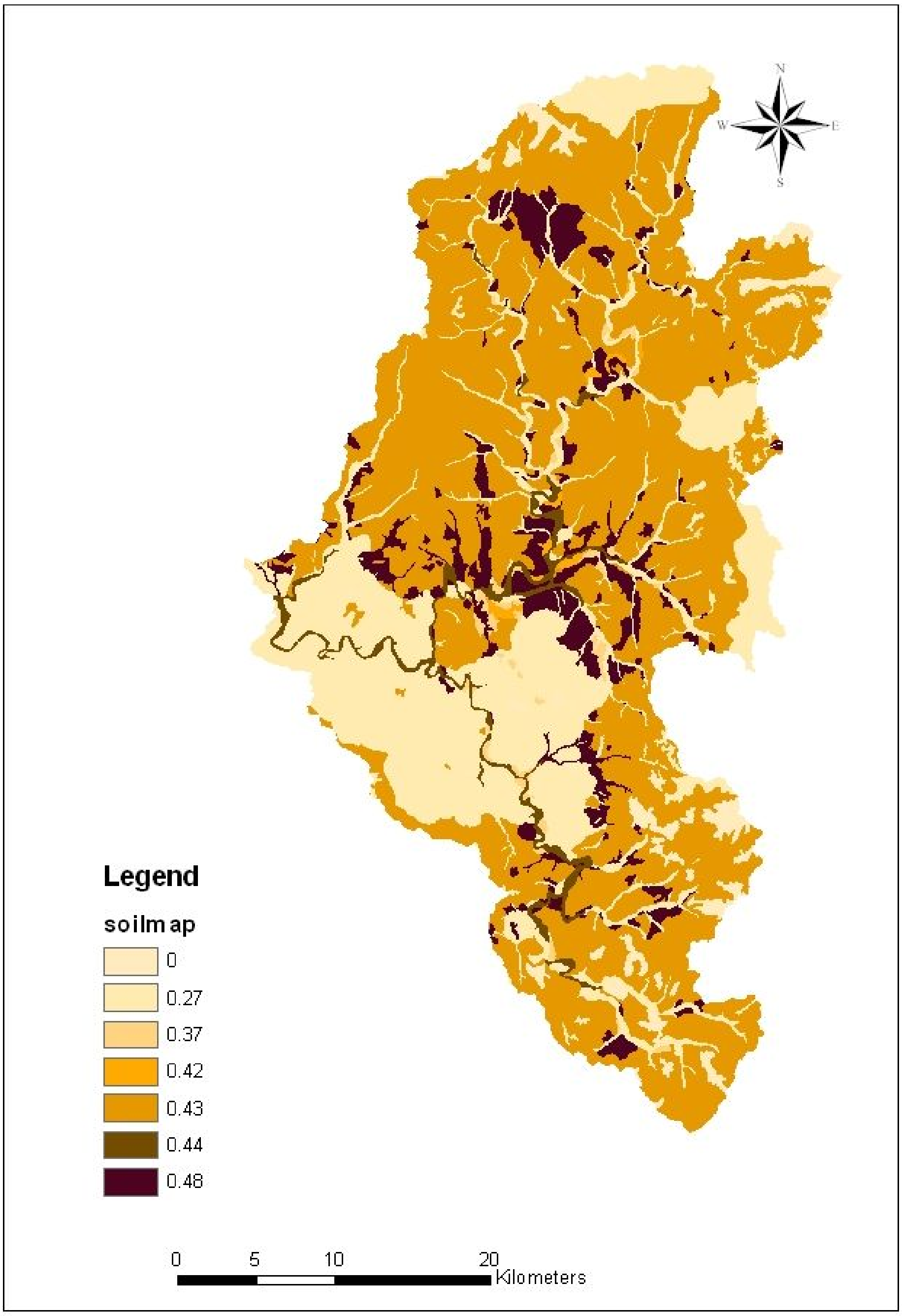


Figure 4.5 – Soil erodibility (K) map of the Imha watershed

4.2.3 Slope Length and Steepness Factor (LS)

The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of a slope length factor, L, and a slope steepness factor, S. In general, as slope length (L) increases, total soil erosion and soil erosion per unit area increase due to the progressive accumulation of runoff in the downslope direction. As the slope steepness (S) increases, the velocity and erosivity of runoff increase.

Slope length (L) is defined as the ratio of soil loss from the field slope length to that from a 72.6 ft length under otherwise identical conditions. Figure 4.6 presents the profile of slope length. For cropping land, L is evaluated by the equations used in RUSLE (McCool et al., 1987; McCool et al., 1997; Renard et al., 1997) with

$$L = (X_h / 72.6)^m \qquad \text{(Eq 4.5)}$$

Where:

X_h = the horizontal slope length in ft

m = a variable slope length exponent.

m is related to the ratio ϵ of rill erosion to interrill erosion by the following equation:

$$m = \varepsilon / (1+\varepsilon) \qquad \text{(Eq 4.6)}$$

ϵ is calculated for conditions when the soil is moderately susceptible to both rill and interrill erosion using the following equation:

$$\varepsilon = \frac{\sin\theta}{0.0896 \times \left[3.0 \times (\sin\theta)^{0.8} + 0.56\right]} \qquad \text{(Eq 4.7)}$$

Where:

Θ = the slope angle.

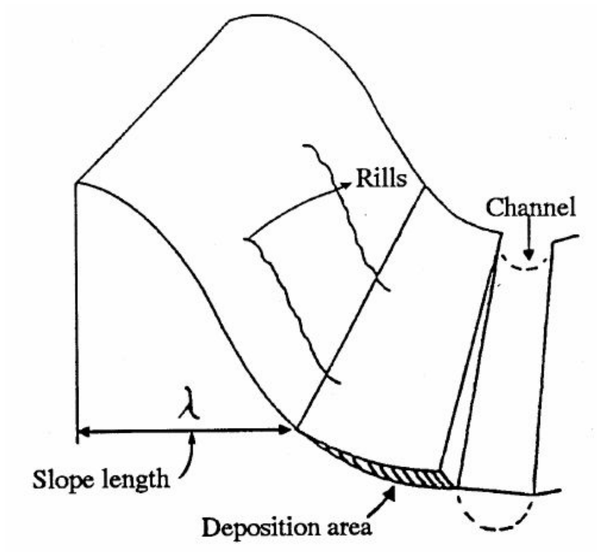


Figure 4.6 – Schematic slope profiles of RUSLE applications (Renard et al., 1997)

The slope steepness (S) is defined as the ratio of soil loss from the field slope gradient to that from a 9% slope under identical conditions. The RUSLE slope steepness equation is the following (McCool et al., 1987; McCool et al., 1997; Renard et al., 1997):

$S=10.8 \times \sin\Theta + 0.03 \qquad \sigma\leq9\%$ (Eq 4.8)

$S=16.8 \times \sin\Theta - 0.50 \qquad \sigma>9\%$

Where:

Θ = the slope angle;

σ = the slope gradient in percentage.

The slope length and slope steepness (S) can be defined from the Digital Elevation Model (DEM) (Hickey et al., 1994; Van Remortel et al., 2001) using equations 4.5 ~ 4.8. DEM is currently available in 30 meter resolution for the Imha watershed. The LS factor layer is calculated using an Arcinfo AML using the method of Van Remortel et al. (2001) (visit http://www.yogibob.com/slope/slope.html for more information). Figures 4.7 and 4.8 represent the slope length (L), slope steepness (S), and LS factor, respectively.

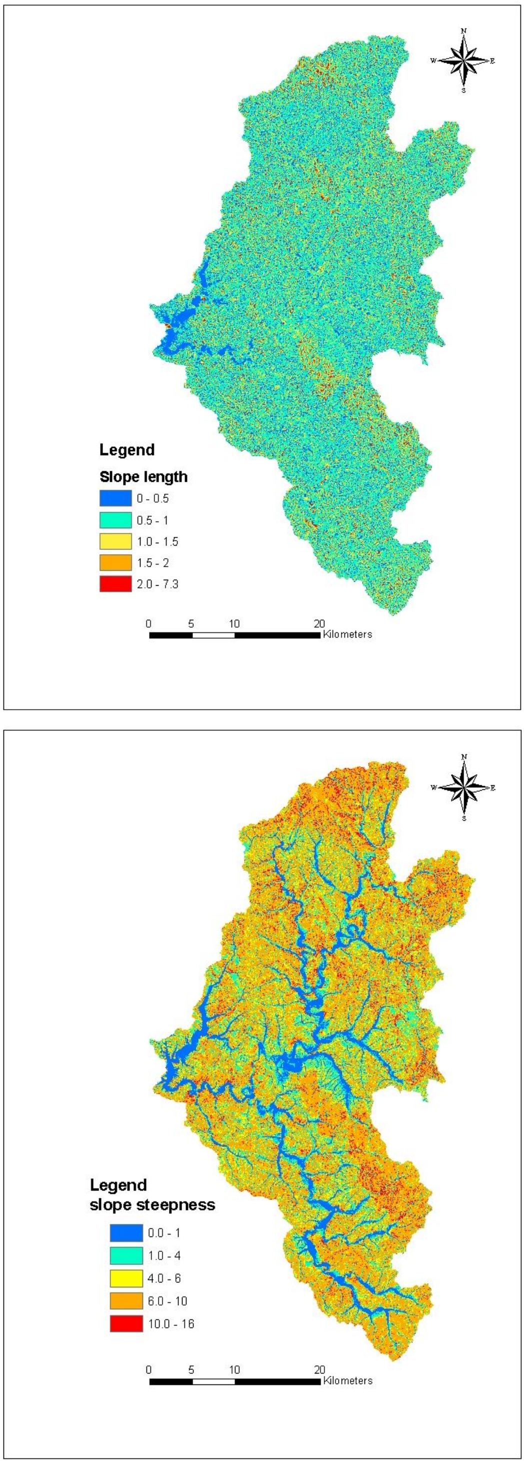


Figure 4.7 – Slope Length (Above) and Slope Steepness (Below) map

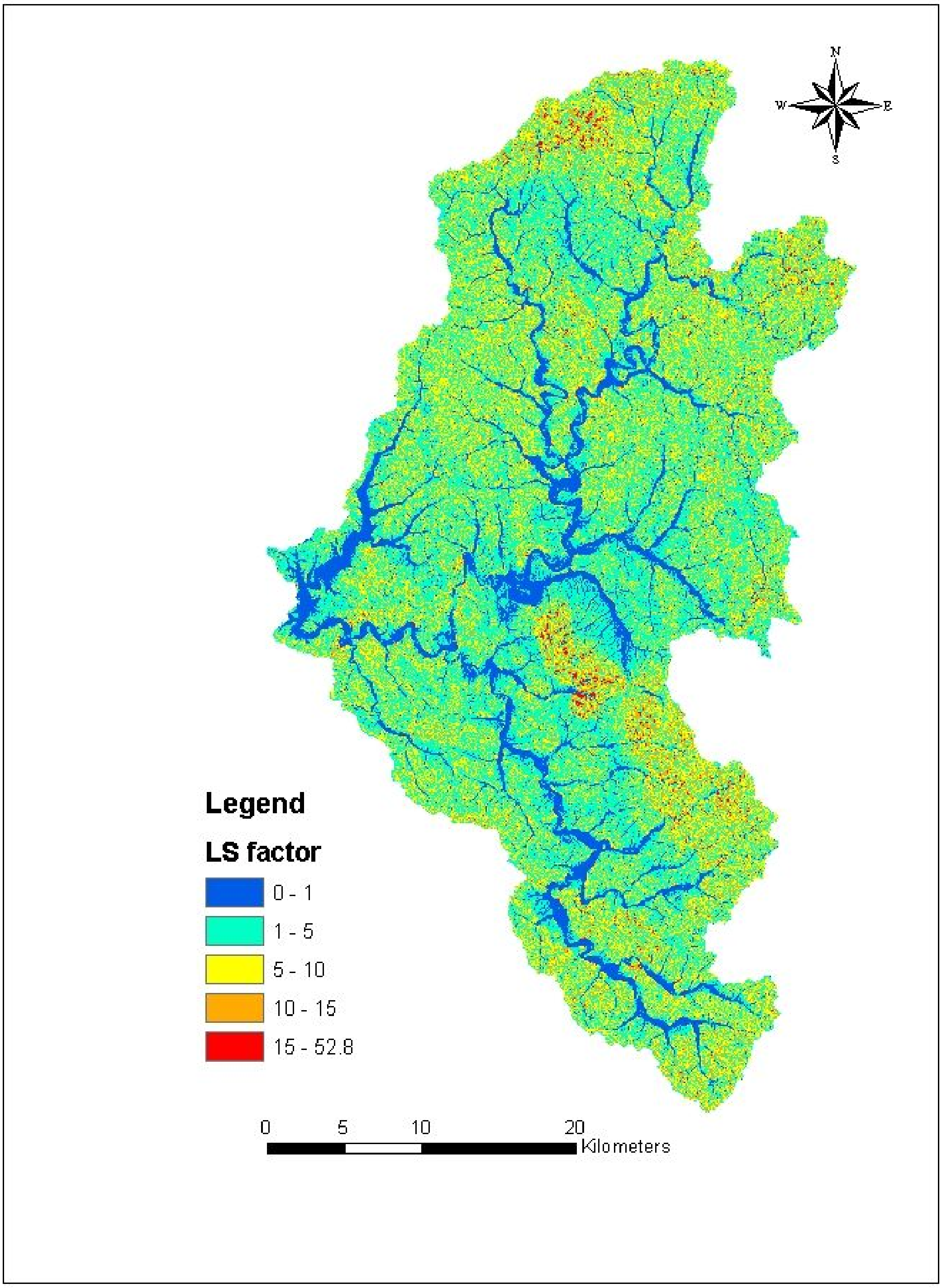


Figure 4.8 – Slope Length and Steepness (LS) map of the Imha watershed

4.2.4 Cover Management Factor (C)

The cover management factor (C) represents the effects of vegetation, management, and erosion control practices on soil loss. As with other RUSLE factors, the C value is a ratio comparing the existing surface conditions at a site to the standard conditions of the unit plot as defined in earlier chapters.

RUSLE uses a sub factor method to compute soil loss ratios (SLR), which are the ratios of soil loss at any given time in the cover management sequence to soil loss from the standard condition. The sub factors used to compute a soil loss ratio value are prior land use, canopy cover, surface cover, surface roughness, and soil moisture.

There are two C factor options in RUSLE, a time invariant option and a time variant option (Kuenstler, 1998). In the case of South Korea, about two thirds of annual precipitation is concentrated in the summer season, between July and September due to Monsoon effects. Due to the precipitation pattern of South Korea, a time invariant option is applied to the Imha watershed.

Based on the "Nakdong River Basin Survey Project, (MOCT and KOWACO, 2005)", the land cover of the Imha watershed is classified with six land cover classifications: Water, Urban, Wetland, Forest, Crop field, and Paddy field. The National Institute of Agricultural Science and Technology (NIAST) had studied the cover management factor with crop coverage based on the Lysimeter experiments from 1977 to 2001 and proposed the cover management factor about the Crop land. Basically, Wischmeier and Smith (1978) proposed that the cover management factor (C) ranges from 0.0001 to 0.009 in undisturbed forest area (Table 4.4).

Table 4.4 – Cover management factor (C) for forest (after Wischmeier and Smith, 1978)

Percentage of area covered by canopy of trees and undergrowth	Percentage of area covered by duff at least 2 in. deep	Factor C
100 - 75	100 – 90	0.0001 - 0.001
70 - 45	85 – 75	0.002 - 0.004
40 - 20	70 – 40	0.003 - 0.009

However, forested area of Imha watershed has been already disturbed due to the Imha multi-purpose dam construction and the development of the surrounding area such as road construction, restaurant and hotel construction, and agricultural area development. Furthermore, the density of forested area is much less than that of the U.S. Due to these uncertain reasons, the cover management factor of forested area in the Imha watershed is calibrated using the "Trial and Error method" from a relationship between the annual soil loss rate and SDR in order to determine the appropriate C value. The estimation process of the appropriate C value of forested area will be mentioned in detail in Chapter 5.2.1. The estimated C value of forested area is 0.03.

Table 4.5 represents C factors of the Imha watershed applied according to the land cover classification.

Table 4.5 – Cover management factor (C)

Num	Land cover type	Cover Management Factor (C)	Applied method
1	Water	0.00	
2	Urban	0.01	Urban density
3	Wetland	0.00	
4	Forest	0.03	Trial and Error
5	Paddy field	0.06	Kim, 2002
6	Crop Land	0.37	NIAST, 2003

Figure 4.9 presents the cover management factor (C) of Imha watershed. Of the land cover classifications, forest prevails and covers about 82%.

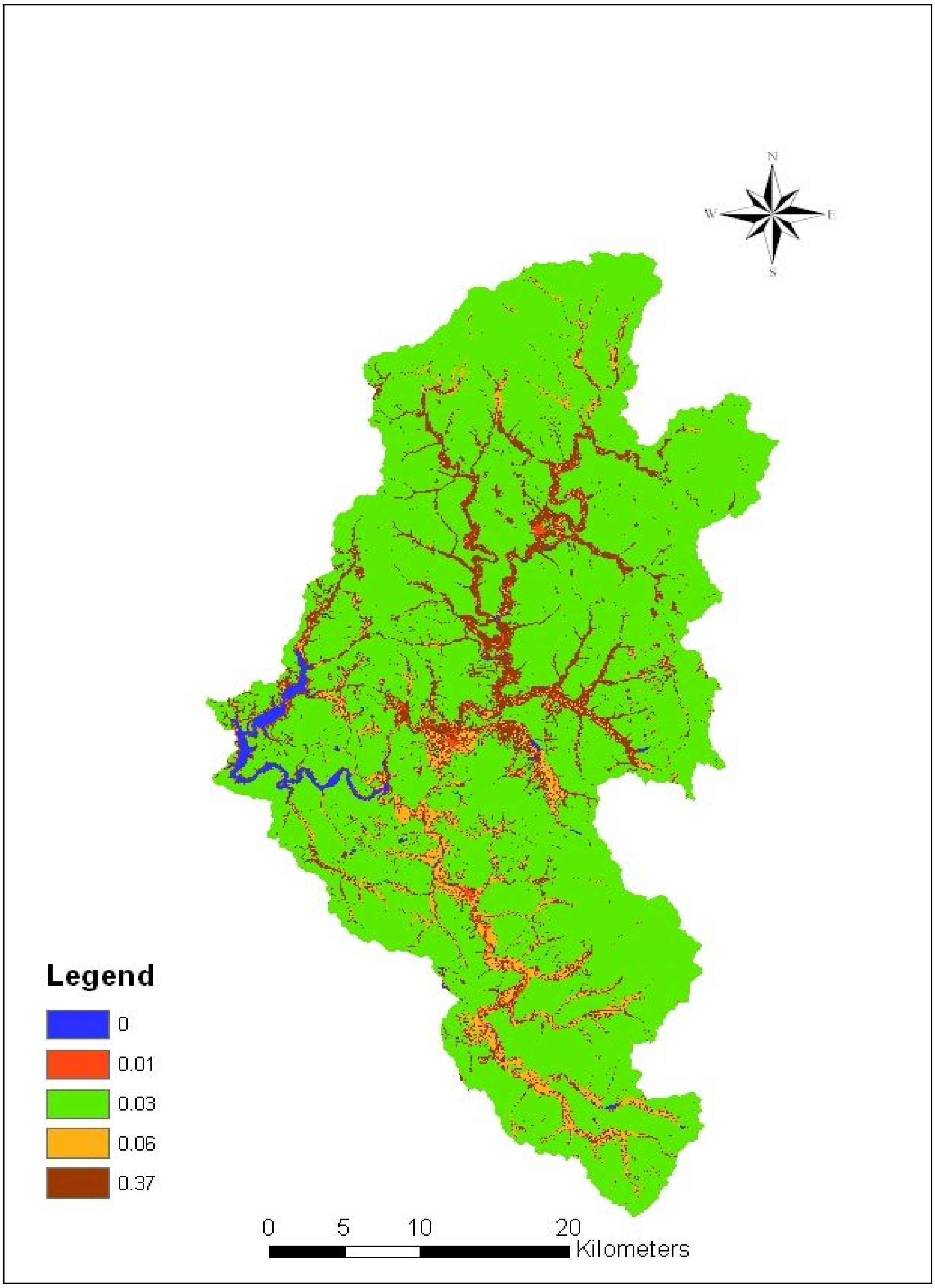


Figure 4.9 – Cover Management (C) map of the Imha watershed

4.2.5 Support Practice Factor (P)

The Support Practice Factor (P) in RUSLE is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage. The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The supporting mechanical practices include the effects of contouring, stripcropping, or terracing.

Most of the Imha watershed is forested and only 15 percent is used for agriculture with paddy and crop fields. Table 4.6 represents the value of support practice factor according to the cultivation method and slope (Shin, 1999)

Table 4.6 – Support practice factor (p)

Slope (%)	Contouring	Strip Cropping	Terracing
0.0 - 7.0	0.55	0.27	0.10
7.0 - 11.3	0.60	0.30	0.12
11.3 - 17.6	0.80	0.40	0.16
17.6 - 26.8	0.90	0.45	0.18
26.8 >	1.00	0.50	0.20

The support practice factor is calculated based on the relation between terracing and slope in the paddy field areas and is estimated according to the relation both contouring and slope in the crop field areas. Figure 4.10 presents the support practice factor (P) of Imha watershed.

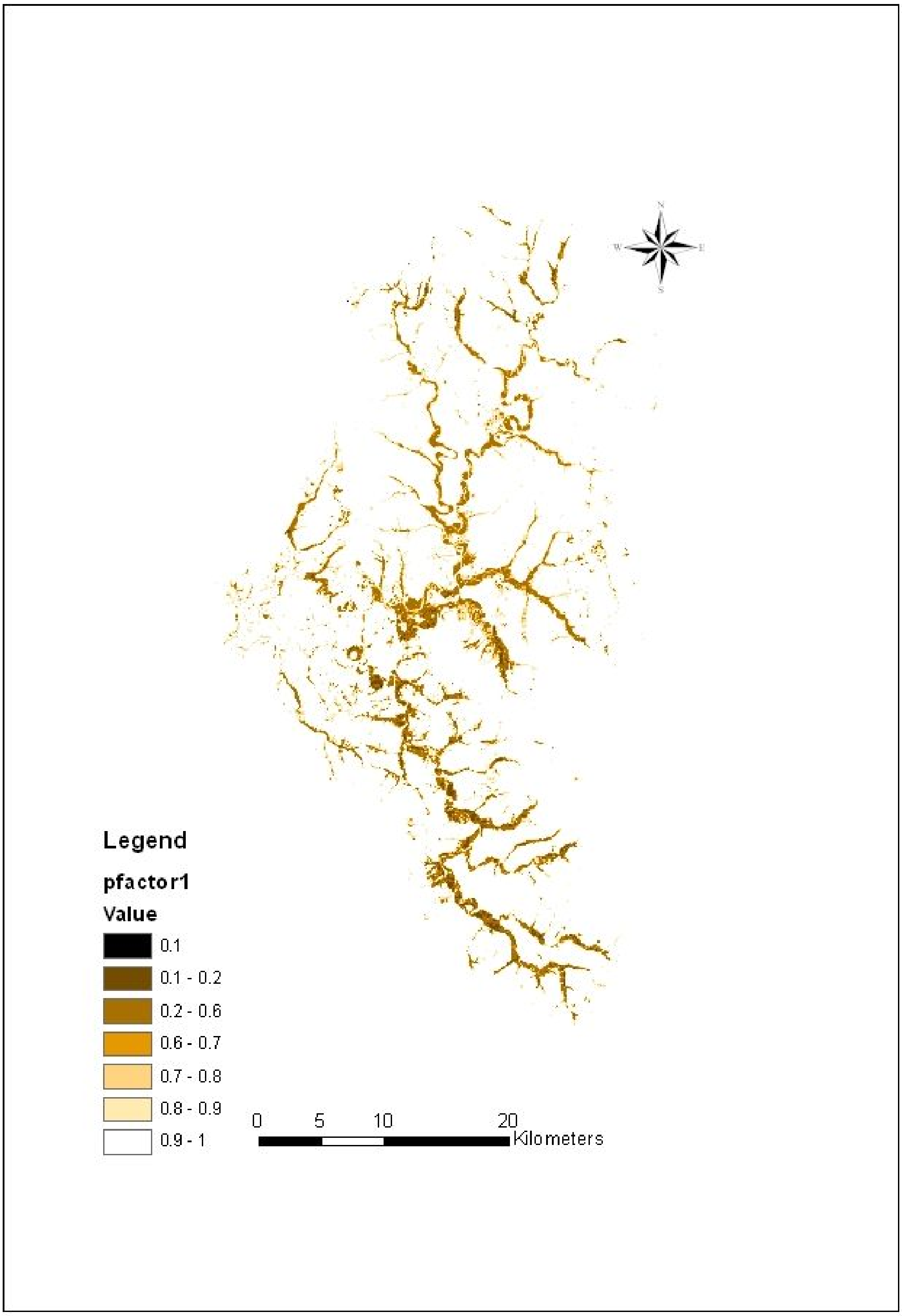


Figure 4.10 – Support Practice (P) map of the Imha watershed

4.3 Summary

Chapter 4 presents the procedure and methodology of the RUSLE parameter estimation. RUSLE has six parameters, which are rainfall erosivity (R), soil erodibility (K), slope length and steepnees (LS), cover management (C), and support practice factor (P).

In the Imha watershed, the annual average R values range from 154 to 251 based on the location of rainfall stations. Bu Dong rainfall station located in the southeastern part of the watershed presents the maximum R value of 251. Based on the soil classification and organic matter, soil erodibility (K) is estimated and varies from 0 to 0.48. Slope length and steepness (LS) is predicted using the DEM and Arcinfo AML developed by Van Remortel et al. (2001). LS values range from 0 to 53. The cover management factor (C) is calculated based on the C factor of NIAST (2003), Wischmeier and Smith (1987), and Kim (2002). Forested area C value is estimated using a "Trial and Error method" from the relationship between the annual soil losses and various sediment delivery ratio models. The determined C value for forested area was 0.03 and is 3 times larger than that of the undisturbed forested area of Wischmeier and Smith (1978). C values range from 0 to 0.37. The support practice factor (P) is calculated according to the cultivating method and slope.

Chapter 5: APPLICATION AND RESULTS

5.1 Introduction

This chapter deals with the application and results of two cases of the RUSLE model; the annual average soil loss rate, and soil loss rate by typhoon "Maemi" in the Imha watershed. The results of these two cases will be analyzed and compared based on the spatial and temporal variation. Based on the land cover in Imha watershed, the spatial distribution pattern of soil loss rate will be analyzed.

The basic concept of the Sediment Delivery Ratio (SDR) will be described and SDR will be estimated in the Imha reservoir using the "Sediment deposit survey report in Imha reservoir (KOWACO, 1997)" and total soil loss rate in the Imha watershed.

Finally, chapter 5 presents the basic concepts and influence factors of Trap Efficiency (TE). TE also will be determined in Imha reservoir using the length, width, annual average runoff, and settling velocity of particle size of Imha reservoir.

5.2 Events Simulation of Soil Loss Rate

In order to simulate upland erosion at Imha watershed, three cases will be modeled. In performing this analysis, each thematic map, which is the same grid cell size and coordination, will be used. The rainfall runoff erosivity factor (R) varies spatially and temporally throughout the Imha watershed. In contrast, the soil erosivity factor (K), the slope length and steepness factor (LS), the cover management factor (C), and support practice factor (P) are considered to be constant throughout the Imha watershed.

Computed annual average soil loss rate will be used to estimate the SDR at the Imha reservoir as representing the relationship between annual average soil loss rate and surveyed sediment deposits.

5.2.1 The Annual Average Soil Loss Rate

The occurrence of soil erosion has a close relationship with the status of land use and the situation of farmland management along with topographical characteristics such as slope length and steepness.

As mentioned previously in chapter 4.2.4, the cover management factor of forested area is calibrated using the "Trial and Error method" through the relationship between the annual soil loss rate and SDR in order to find the most appropriate C value. Table 5.1 presents the results of the annual soil loss rate and SDR estimated according to the variable C values of forested area. Figure 5.1 represents the relationship graph between the annual average soil loss rate and SDR including the observed sediment deposits and SDR values estimated using the basin characteristics. Based on the SDR values estimated by Renfro (1975), Williams (1977), and Roehl (1962), and surrounding development situations of the Imha watershed, the appropriate C value range for forested area can be chosen as 0.03 in this study.

Table 5.1 – Soil loss rate based on the Land cover at the Imha watershed

C value of Forest	Gross erosion(A_T) by RUSLE		SDR (%)	Remarks
	(tons/acre/yr)	(tons/km^2/yr)		
0.0001	4.9	1210.8	73.5	
0.005	6.4	1581.5	56.3	
0.010	7.9	1952.1	45.6	
0.020	10.9	2703.3	32.9	
0.030	14.0	3449.6	25.8	Chosen
0.040	17.0	4200.8	21.2	
0.085	30.6	7561.4	11.8	
0.100	35.2	8698.1	10.2	

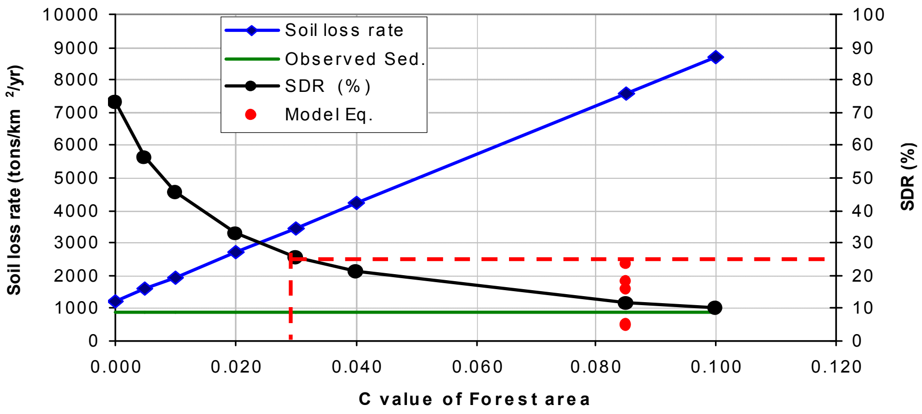


Figure 5.1 – Annual average soil loss rates map of the Imha watershed

In order to predict the annual average soil loss rate in the Imha watershed, six parameters of the RUSLE model are multiplied using the raster calculator function tool of the ARC GIS. Figures 5.2-3 represent the annual average soil loss rate map of the Imha watershed and histogram for annual average soil loss rate, respectively. The maximum soil loss rate, which is 750 tons/acre/year, occurs at the dried crop field and annual average soil loss rate is predicted to be 14 tons/acre/year (3,450 tons/km^2/year).

Table 5.2 shows the annual average soil loss rate based on the land cover type. The total annual average soil loss rate of the Imha watershed is about 2.7million tons /year. Of this soil loss rate, Forested area covers primarily 93% of total annual average soil loss rate and crop field area is the second order.

Table 5.2 – The annual average soil loss rate based on the Land cover

Land cover type	Area (km2)	Portion of area (%)	Soil loss rate (tons/km^2/year)	Soil loss rate (tons/year)	Portion of soil loss rate (%)
Water	15.0	1.1	0.0	0.0	0.00
Urban	9.9	0.7	0.003	0.03	0.00
Wetland	4.2	0.3	0.0	0.0	0.00
Forest	1122.4	82.5	2248.6	2523940.9	93.49
Paddy field	61.9	4.5	19.8	1222.8	0.05
Crop Land	147.6	10.8	1181.2	174382.3	6.46
Total	1361.0	100.0	3449.6	2699546.0	100.0

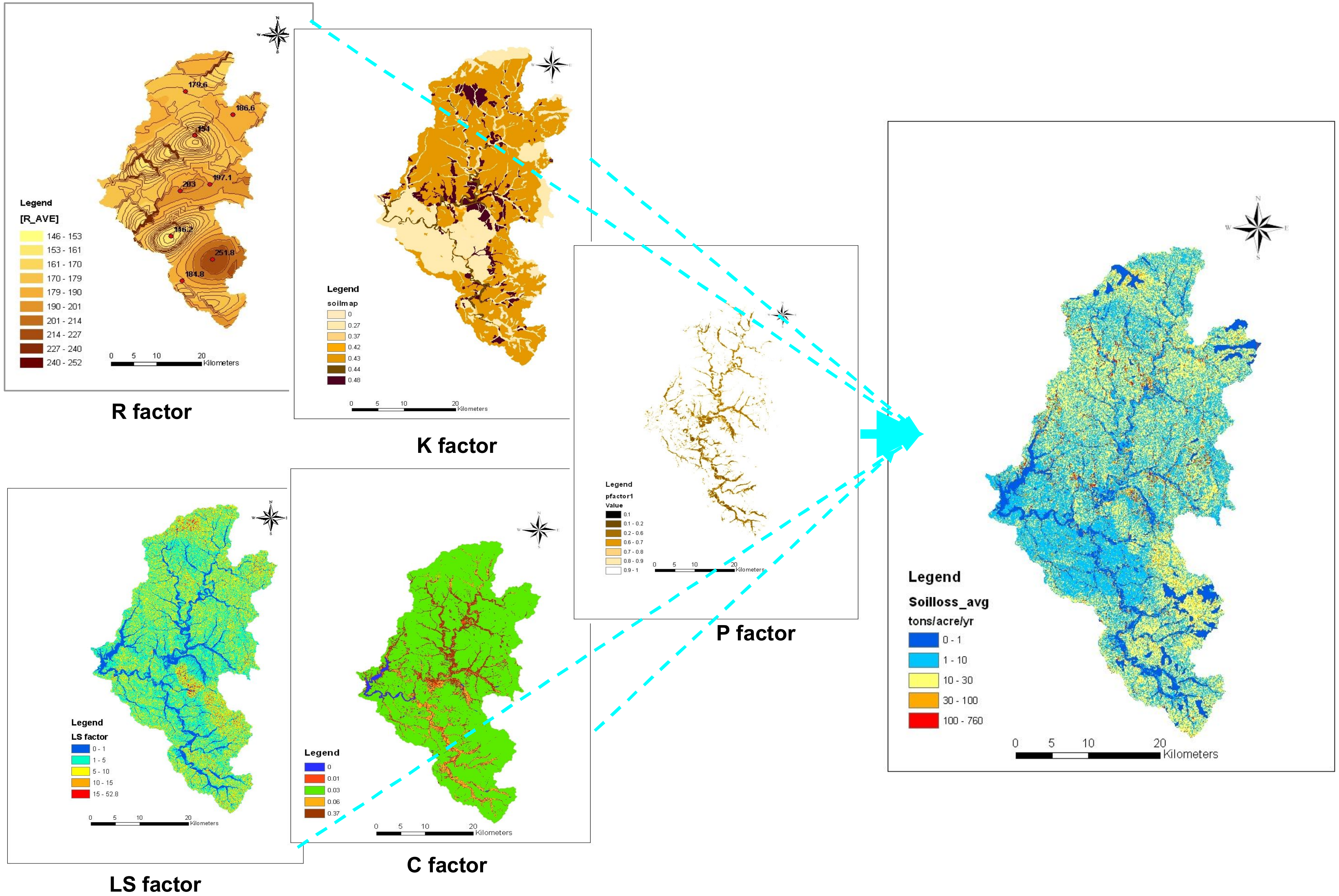


Figure 5.2 – Annual average soil loss rate map of the Imha watershed

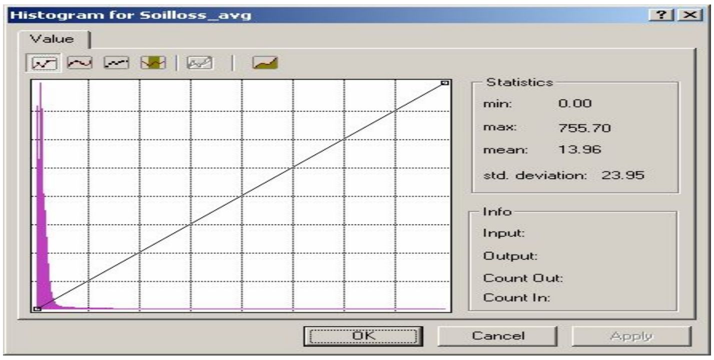


Figure 5.3 – Histogram for annual average soil loss rate

5.2.2 The Soil Loss Rate by Typhoon "Maemi"

Typhoon Maemi struck the South Korea Peninsula on the evening of September 12, 2003, dumping 432mm of rain and triggering massive floods and landslides. It is reported that at least 110 people lost their lives, some 25,000 people were evacuated from their homes, and 1.4 million households were left without power. "Maemi" was the worst typhoon to hit South Korea for more than a decade. Figure 5.4 shows the passage (TRC, 2003) and GOES-9 1km image (KMA, 2003) of typhoon "Maemi".

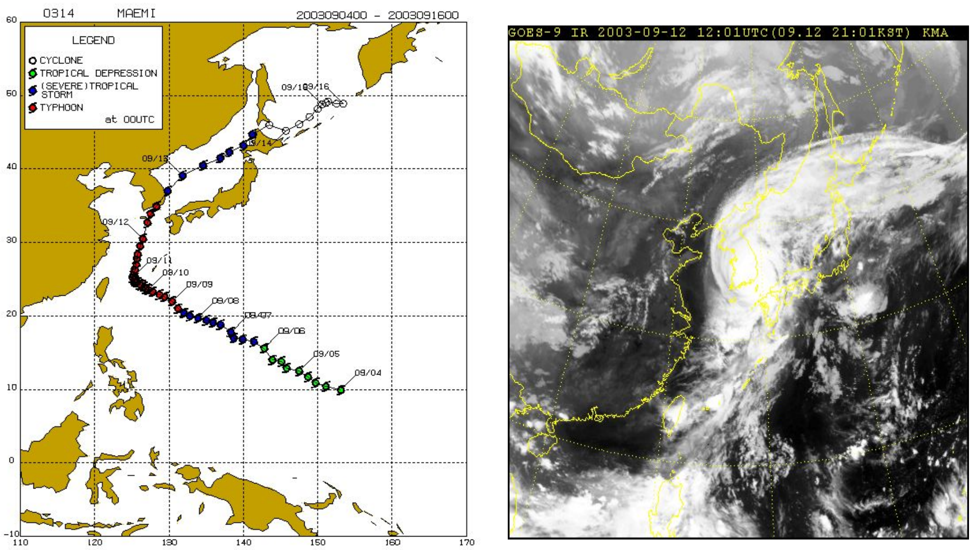


Figure 5.4 – Passage of typhoon "Maemi" (left; TRC, 2003) and GOES-9 image (Right; KMA, 2003)

During the strike of the typhoon "Maemi", the total precipitation of the Imha watershed was recorded to be about 184 mm and the maximum inflow discharge was 6665 cms. Detailed discharge and precipitation data and hydrograph are shown in Table 5.3 and in Figure 5.5 respectively.

Table 5.3 – Detailed discharge and precipitation data at the Imha watershed

From ~ to	Inflow Discharge		Outflow Discharge		Precipitation	
	Max (cms)	Total (m^3)	Max (cms)	Total (m^3)	Max. Intensity (mm/hr)	Total (mm)
Sept.12 01:00 ~ Sept.14.24:00	6664.5	2.79E+08	1630.6	1.05E+08	26.9	183.5

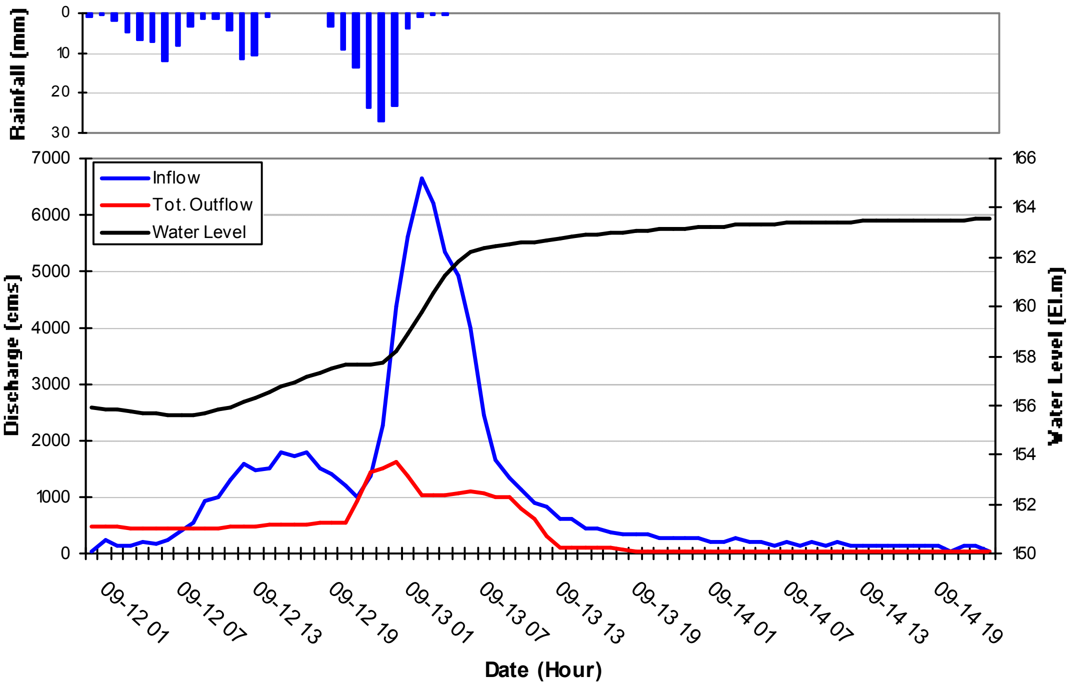


Figure 5.5 – Hydrograph of the Imha reservoir for typhoon "Maemi"

Due to the storm event of the typhoon "Maemi", the average soil loss rate of the Imha watershed is estimated about at 5.4 tons/acre/Maemi (1330 ton/km^2/Maemi) and is around 39 percent of the annual average soil loss rate of 14.0 tons/acre/year. Figure 5.6 shows the spatial distribtution of the soil erosion at the Imha watershed. The soil loss rate by typhoon “Maemi” occurs until the maximum 329 tons/acre/Maemi at the part of the crop field area.

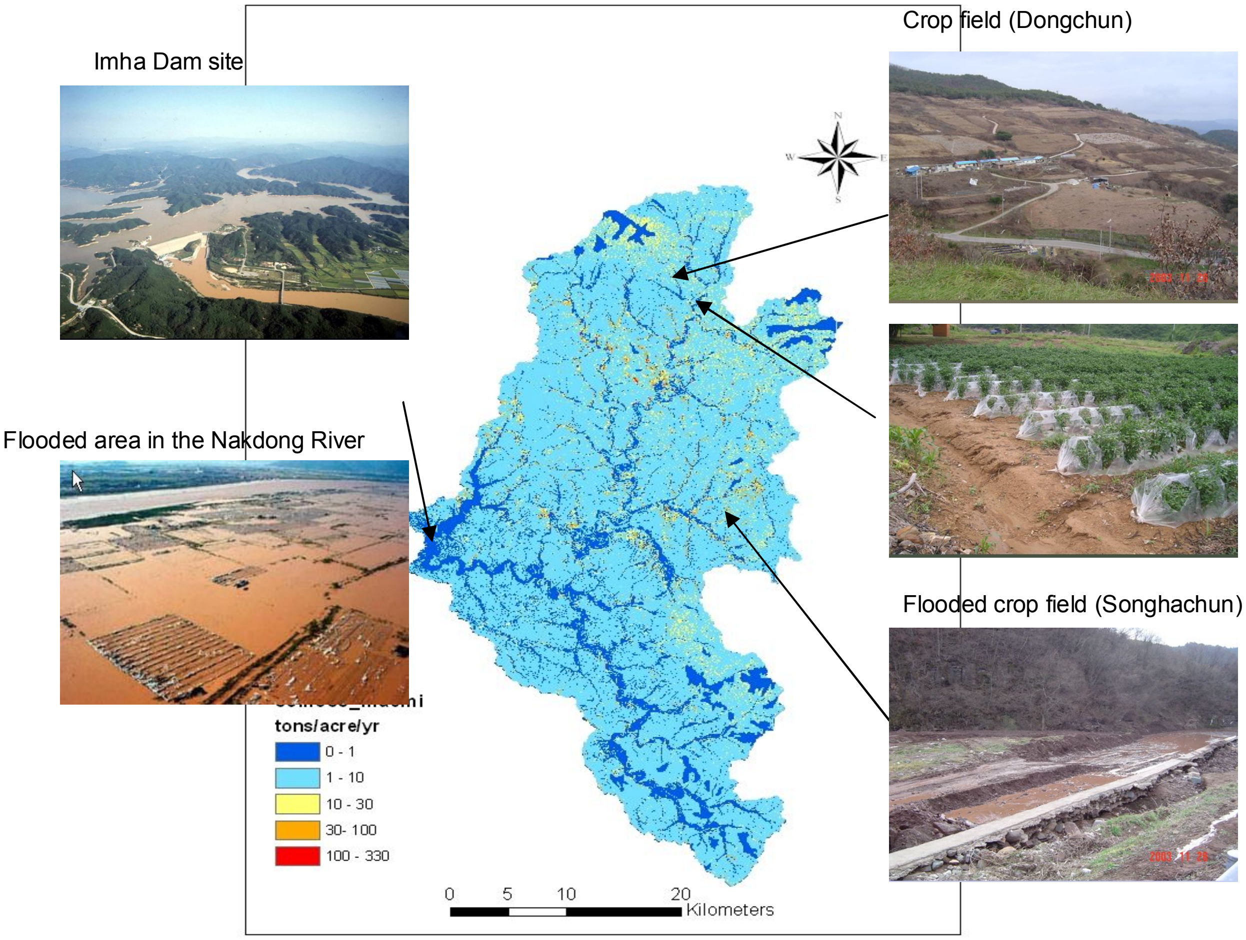


Figure 5.6 – Soil loss rates map by typhoon “Maemi” of the Imha watershed

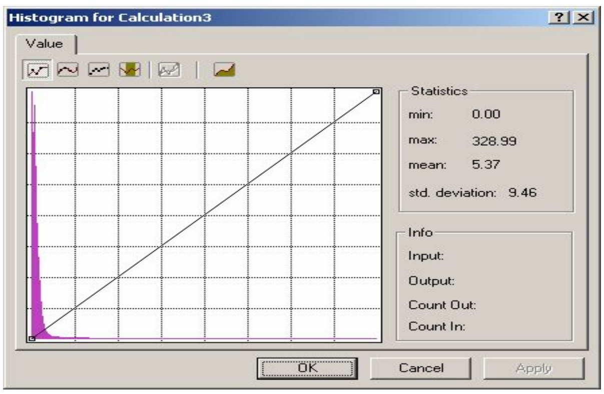


Figure 5.7 – Histogram for soil loss rates by typhoon “Maemi”

5.3 Sediment Delivery Ratio

The sediment delivery ratio (SDR) denotes the ratio of the sediment yield Y at a given stream cross section to the gross erosion A_T from the watershed upstream from the measuring point (Julien, 1998). In terms of the definition of sediment delivery ratio, the expression for computing sediment delivery ratio can be written as follows:

$$S_{DR} = \frac{Y}{A_T} \qquad \text{(Eq 5.1)}$$

Where:

Y = sediment yield;

A_T = gross erosion per unit area above a measuring point;

SDR =sediment delivery ratio.

There is no precise procedure to estimate SDR, although the USDA has published a handbook in which the SDR is related to drainage area (USDA SCS, 1972). SDR can be affected by a number of factors including sediment source, texture, nearness to the main stream, channel density, basin area, slope, length, land use/land cover, and rainfall-runoff factors. The relationship established for sediment delivery ratio and drainage area is known as the SDR curve. For example, a watershed with a higher channel density has a higher sediment delivery ratio compared to the same watershed with a low channel density. A watershed with steep slopes has a higher sediment delivery ratio than a watershed with flat and wide valleys. In order to estimate sediment delivery ratios, the size of the area of interest should also be defined. As shown in the following two equations, the larger the area size, the lower the sediment delivery ratio because large areas have more chances to trap soil particles.

Vanoni (1975) $$SDR = 0.42A^{-0.125} \qquad \text{(Eq 5.2)}$$

Boyce (1975) $$SDR = 0.31A^{-0.3} \qquad \text{(Eq 5.3)}$$

Where: A = catchment area ($mile^2$)

Roughly speaking, SDR is closely related to the power of -0.1 and -0.3 to the drainage area. The drainage area method is most often and widely used in estimating the sediment delivery ratios in previous research.

On the other hand, Maner (1958) suggests that SDR is better correlated with relief and maximum length of a watershed expressed as relief-length ratio (R/L) than with other factors. Renfro (1975) modified the equation as follows:

$$\log(SDR) = 2.94259 + 0.82362\log(R/L) \qquad \text{(Eq 5.4)}$$

Where:
R = relief of a watershed, defined as the difference in elevation between the maximum elevation of the watershed divide and the watershed outlet
L = maximum length of a watershed, measured approximately parallel to mainstream drainage.

Williams (1977) suggests that the sediment delivery ratio is correlated with drainage area, relief-length ratio, and runoff curve numbers. He developed an equation based on the sediment yield data for 15 Texas basins as follows:

$$SDR = 1.366 \times 10^{-11} \times Area^{-0.0998} \times ZL^{0.3629} \times CN^{5.444} \qquad \text{(Eq 5.5)}$$

Where: *Area = the drainage area (Km^2);*
ZL = the relief-length ratio in m/km;
CN =the long-term average SCS curve number.

Roehl (1962) developed the relationship for the SDR using data acquired from field investigations in the southeast Piedmont region of the United States as follows:

$$\log SDR = 4.5 - 0.23\log(10 \times Area) - 0.51\log(\frac{L}{R}) - 2.79\log B \qquad \text{(Eq 5.6)}$$

Where: *Area = the drainage area (miles^2);*
L/R = the dimensionless basin length-relief ratio (watershed length, as measured essentially parallel to the main drainageway divided by elevation difference from drainage divide to outlet);

B = the weighted mean bifurcation ratio (Bifurcation ratio is the ratio of the number of streams of any given order to the number in the next higher order).

KOWACO carried out the sediment deposits survey at the Imha reservoir in 1997. Based on the "Sediment Deposits Survey Report of the Imha reservoir (KOWACO, 1997)", the observed sediment deposition is about 890 tons/km^2/year at the Imha reservoir. The annual average soil erosion predicted by the RUSLE model is 3,450 tons/km^2/year. Table 5.4 presents the SDR predicted from the relationship between the annual soil erosion estimated by the RUSLE model and the observed sediment deposits and the estimated relationship established for sediment delivery ratio and drainage area; Boyce (1975) and Vanoni (1975).

Table 5.4 – Results of SDR in the Imha watershed

Imha basin Area	Observed Deposits(1997)	Soil loss rate by RUSLE		SDR (%)		
(km^2)	(ton/km^2/yr)	(tons/acre/yr)	(tons/km^2/yr)	Boyce	Vanoni	Observed
1,361	890	14.0	3449.6	5.6~10.1	20.6~26.3	25.8

Table 5.5 shows results of SDR predicted from the relief-length ratio, drainage area, Curve Number, and Bifurcation ratio using the Renfro (1975), Williams (1977), and Roehl (1962) model.

Table 5.5 – Results of SDR using watershed characteristics

Sub Water-shed	Max Elev.	Min Elev.	Leng-th	Area	ZL	CN	Bifur-cation Ratio	SDR(%)		
	El.m	El.m	km	km2				Renfro	Williams	Roehl
Imha	1215	80	96	1361	11.8	68.3	4.18	22.7	15.8	8.5
Ban-byeon	1215	100	75	780	14.9	68.3	4.48	27.4	18.1	8.9
Dae-gok	546	107	15	110	29.3	68.3	4.18	47.8	28.2	24.0
Yongjeon	704	100	53	397	11.4	68.3	4.41	22.0	17.6	9.5

In the Imha watershed, SDR calculated by observed deposits data is 25.8% and represents the highest value compared to the other two sediment delivery ratio and drainage area relationships. The reason that the observed SDR is higher than other methods can be found from several typical basin characteristics of the Imha watershed:

1) The Imha watershed is located within a mountainous area and has steep slope around 40%.

2) Most streams in the Imha watershed have no floodplain.

3) Due to the construction of the Imha multi-purpose dam, areas near the Imha reservoir and major streams are developing continuously.

4) Most crop field areas, one of the main sources causing soil erosion, are located near the reservoir and streams.

5) Due to the flat basin formation of Imha watershed, rainfall runoff and SDR are much faster than other long dendritic basins.

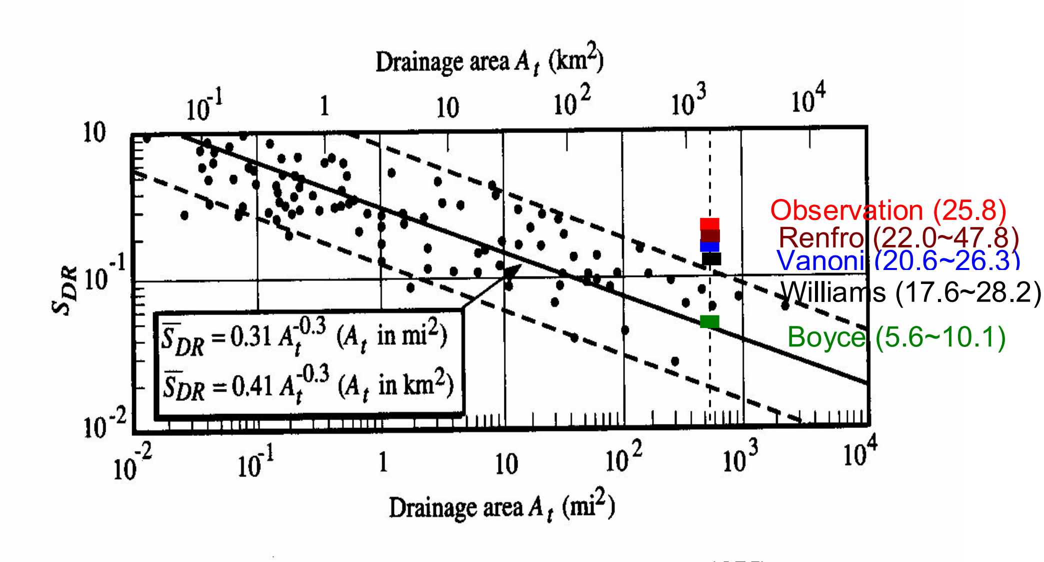


Figure 5.8 – The results of SDR in the Imha watershed.

5.4 Trap Efficiency at the Imha Reservoir

The trap efficiency (TE) of a reservoir can be defined as the percentage of the total inflowing sediment that is retained in the reservoir.

$$TE = \frac{[Y_S(in) - Y_S(out)]}{Y_S(in)} \qquad \text{(Eq 5.7)}$$

Where:

TE = Trap efficiency;

Ys (in) =Sediment yield in weight units (inflow);

Ys (out) =Sediment yield in weight units (outflow);

Trap efficiency is of particular importance when determining the annual sedimentation rate or capacity loss. As sediment is trapped, the reservoir storage capacity is decreased.

There are some factors influencing the trap efficiency of a reservoir. These factors are hydraulic characteristics of the reservoir and sediment characteristics of the inflowing sediment. Figure 5.9 presents the factors influencing the trap efficiency of a

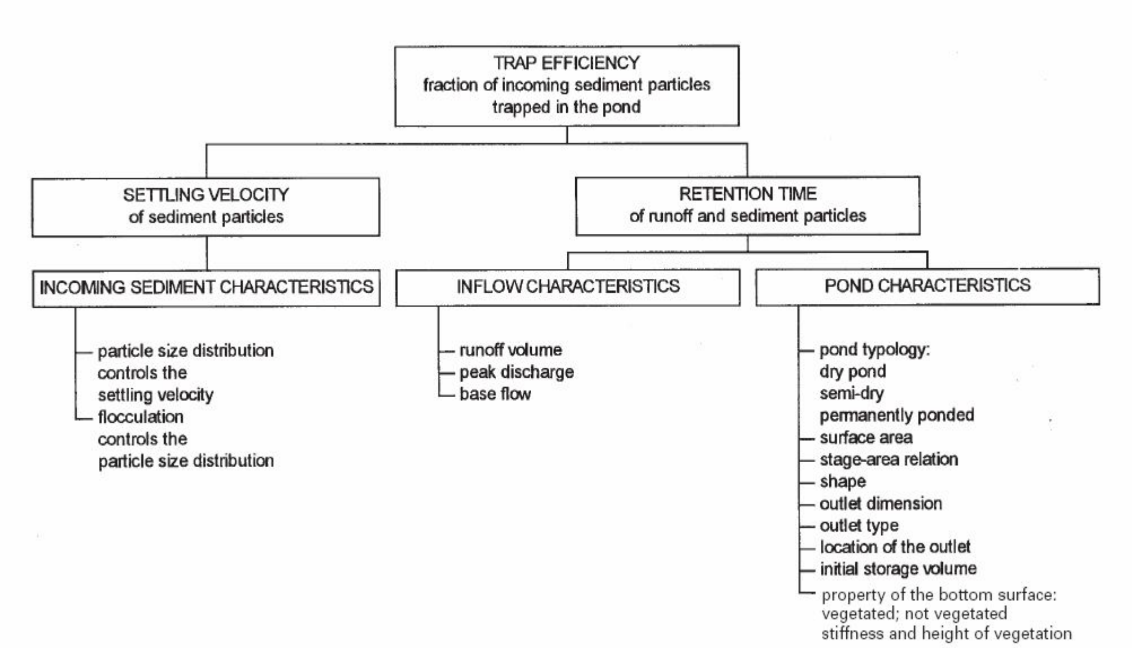


Figure 5.9 – Factors that influence the trap efficiency of reservoirs (Gert, 2000)

In order to estimate the trap efficiency at the Imha reservoir, the TE equation developed by Julien (1998) is applied:

$$TE = 1 - e^{\frac{-X\omega_i}{Vh}} = 1 - e^{\frac{-X\omega_i}{q}} \quad \text{(Eq 5.8)}$$

Where:
TE = Trap efficiency;
X = total length of the reservoir (m);
ω =fall velocity of the sediment (m/s);
V = mean velocity of flow (m/s);
h =flow depth (m);
q= unit discharge (m^2/s);

The fall velocity of the sediment based on the drag coefficient of sand particles can be defined using the following equation (Julien, 1998):

$$\omega = \frac{8\nu_m}{d_s}\left\{\left[1 + 0.0139 d_*^{\,3}\right]^{0.5} - 1\right\} \quad \text{(Eq 5.9)}$$

Where:
ω = fall velocity of the sediment;
v_m = kinematic viscosity (m^2/s);
ds = sediment size ;
d_* = dimensionless particle diameter;

The dimensionless particle diameter is defined with the following equation:

$$d_* = d_s\left[\frac{(G-1)g}{\nu_m^{\,2}}\right]^{\frac{1}{3}} \quad \text{(Eq 5.10)}$$

Where:G = specific gravity;
g = gravitational acceleration (m^2/s);

As mentioned in chapter 3.3.4, the annual average runoff of the Imha watershed is 19.8 cms. After the typhoon “Maemi” came to the Imha reservoir, several measurements were done by KOWACO at the Imha reservoir. Figure 5.10 presents the relationship between water temperature and water depth both at the intake tower and at the Imha dam site. The water temperature, which is needed to calculate the kinematic viscosity, is around 18.5 ^{o}C at water depth 20m. Figure 5.11 shows the particle size distribution at the intake tower of the Imha reservoir. Detailed particle size distribution data can be found in Appendix F. The d_{50} is 3.2 micron (0.0032mm) based on the particle size distribution of suspended solid. The average reservoir width, total reservoir distance from dam, required to estimate the TE, can be acquired from the Figure 5.12.

Based on these surveyed data, trap efficiency at the Imha reservoir is analyzed as being 99.0%, as shown in Table 5.6. Table 5.7 presents the results of TE estimated by the other methods such as Brown, Brune, and Churchill. As shown in Table 5.5-6, TE at the Imha reservoir ranges from 96 to 99%.

Table 5.6 – The result of TE at the Imha Reservoir

d_{50} (mm)	Kinematic viscosity (m^2/s)	Dimensionless particle diam. d*	Fall Velocity (m/s)	Unit Discharge (m^2/s)	Distance of Reservoir (m)	TE (%)
0.0032	1.00E-06	0.081	9.22E-06	0.040	20000	99.0

Table 5.7 – The results of TE estimated the other methods

Reservoir Capacity	Inflow rate	Watershed area	Reservoir length	TE (%)		
acre-ft	acre-ft/year	$miles^2$	ft	Brown	Brune	Churchill
466153.2	506212.2	525.7	65616.0	98.9	96.8	Out of range
			Assume:	K=0.1	median curve	

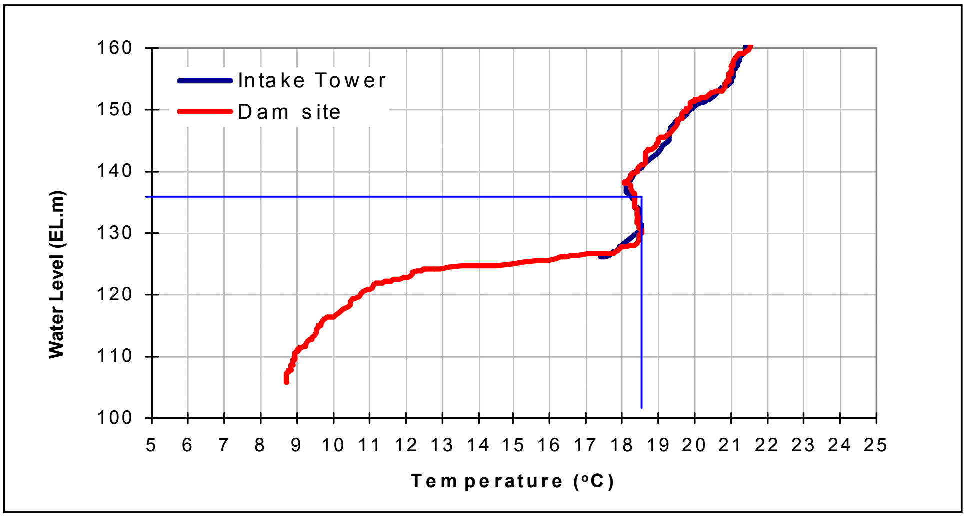


Figure 5.10 – Relationship between Water Temperature and depth

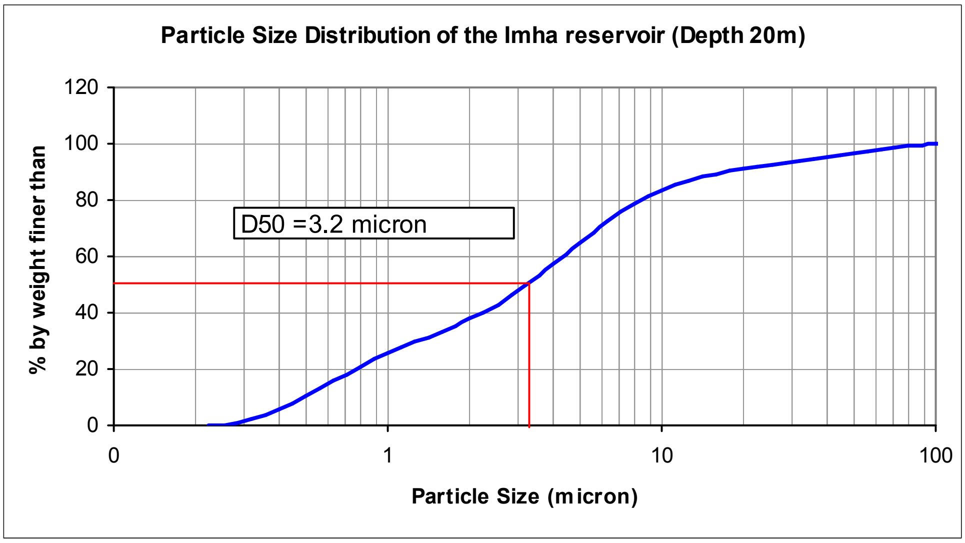
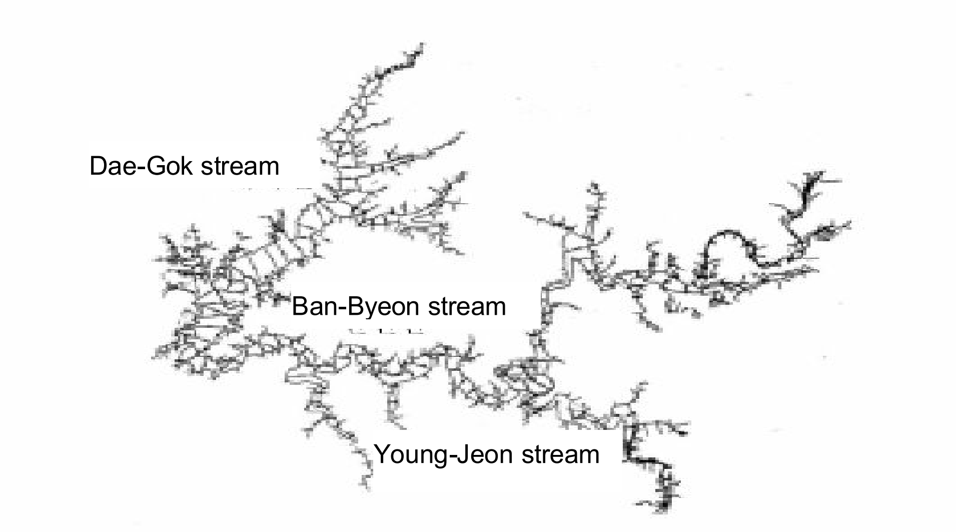
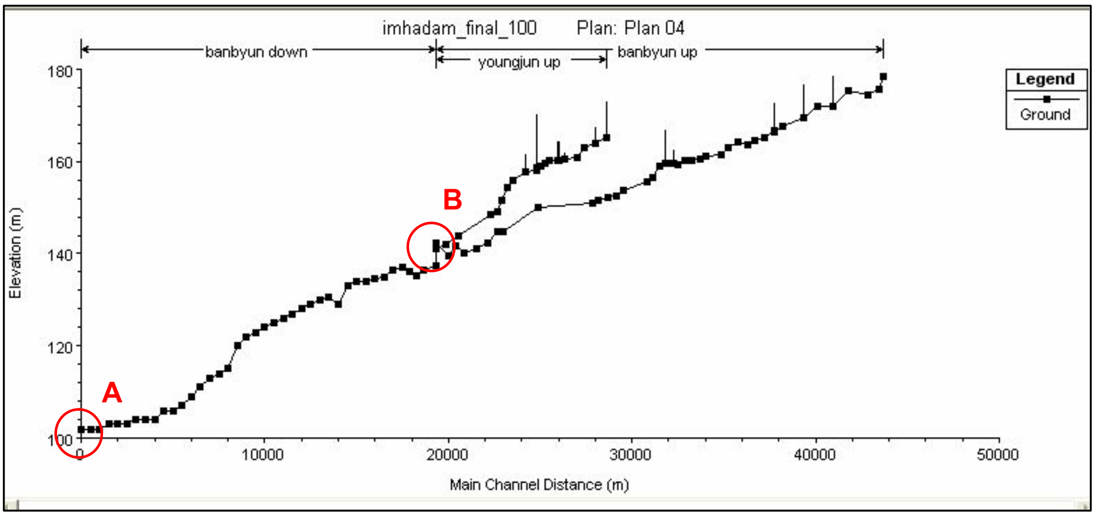


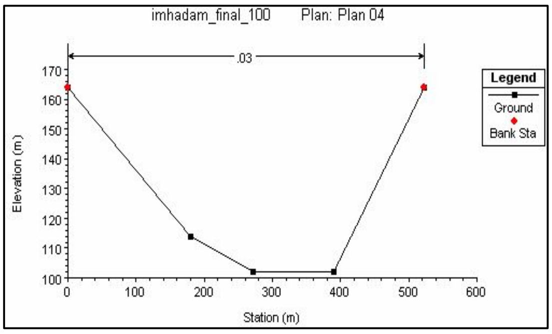
Figure 5.11 – Particle size distribution at Intake tower of the Imha reservoir

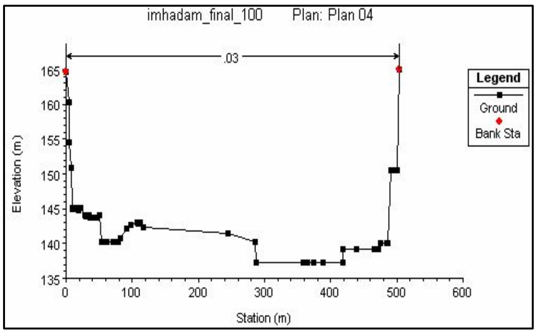


a) The lake boundary of Imha Reservoir



b) The bed elevation profile of the Ban-Byun and theYoung-Jun stream





c) The cross section profiles of the downstream (A) and the conjunction point (B)

Figure 5.12 – Profiles of the Ban-Byeon stream and the Young-Jeon stream

When the Imha multi-purpose dam was constructed, the sediment deposits per unit area of the reservoir were designed to be 300 m^3/km^2/year. Based on these design sediment deposits, the dead storage capacity of the Imha reservoir for sediment deposits is determined to be 40×10^6 m^3 and the life expectancy for the dead storage of the Imha reservoir is determined by 100 years. The sediment deposits of the Imha reservoir were surveyed to be 680 m^3/km^2/year in 1997 and are over twice compare to the design sediment deposits. As a result, even though the error of sediment deposits survey is considered, the life expectancy for dead storage might be decreased compare to the design life expectancy for dead storage. Therefore, a recent survey of the sediment deposits of the Imha reservoir is recommended for a better evaluation the life expectancy of reservoir. In addition, the life expectancy for whole storage of the Imha reservoir is evaluated to be about 670 years.

In order to increase the life expectancy of the Imha reservoir and prevent sediment-laden density currents into the Imha reservoir from upland erosion of the watershed during the flood season, appropriate control measures should be performed as soon as possible. After enormous damages from typhoon “Rusa” and “Maemi”, KOWACO and the government of South Korea have continuously invested in control measures in the Imha watershed. There are several control measures such as watershed control, inflow control, and deposition control, as summarized by Julien (1998). He suggests that control of the watershed may be the most effective sediment control measure, because it reduces the sediment production at the source. Methods of watershed control include proper soil conservation practices and increasing the vegetative cover of a watershed. The control of sediment inflow into a reservoir can be achieved by proper watershed management supplemented with sediment-retarding structures throughout the watershed. There are several methods of controlling sediment laden density currents such as stream channel improvement and stabilization, settling basins, sabo dams, or off-channel reservoirs.

5.5 Spatial Variability of Gross Soil Erosion

The RUSLE model has six parameters such as rainfall runoff erosivity (R), soil erodibility (K), slope length and steepnees (LS), cover management (C), and support practice factor (P). In the Imha watershed, range values for those six parameters are as following.

1) Rainfall runoff erosivity factor (R) : 154 ~ 251 ($100ft{\cdot}tonf{\cdot}acre^{-1}{\cdot}yr^{-1}$)

2) Soil erodibility factor (K) : 0 ~ 0.48 (tons/acre)

3) Slope length factor (L) : 0 ~ 7.3

4) Slope steepness factor (S) : 0 ~ 16.1

5) Cover management factor (C) : 0 ~ 0.37

6) Support practice factor (P) : 0.1 ~ 1.0

Figure 5.13 shows the spatial variability of gross soil erosion in the Imha watershed. The values of 50% and 90% are about 9 tons/acre/year and 11 tons/acre/year, respectively.

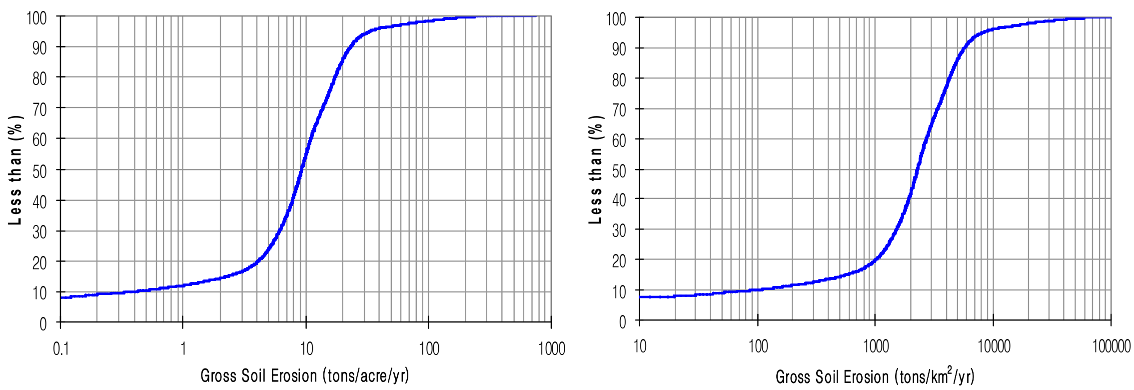


Figure 5.13 – Spatial variability of gross soil erosion

5.6 Summary

Chapter 5 presents results of two cases of RUSLE model application; the annual average soil loss rate and soil loss rate caused by typhoon “Maemi” in Imha watershed. Based on the results of annual average soil loss rate and the sediment deposits observed at Imha reservoir (KOWACO, 1997), SDR is predicted in the Imha reservoir. In addition, some models for SDR were used to compare with the calculated SDR. Finally, the trap efficiency of the Imha reservoir was calculated using the methods of Julien, Brown, Brune, and Churchill.

1) The annual average soil loss rate is predicted to be 14 tons/acre/year (3,450 tons/km^2/year) in the Imha watershed.

2) The soil loss rate caused by the typhoon “Maemi” is analyzed to be about 5.4 tons/acre/”Maemi” (1,330 ton/km^2/”Maemi”). This soil loss rate covers around 39 percent of the annual average soil loss rate.

3) The estimated SDR is 25.8% and is fairly high compared to other SDR models such as Boyce, Vanoni, Roehl, and Williams. There are several reasons why the observed SDR is higher than the other SDR methods, including steep slopes mountain, no floodplain, crop field areas near the reservoir and streams, and flat Imha watershed formation.

4) Based on surveyed data of the Imha reservoir, TE is estimated to be 99.0%. The TE estimated by Brown and Brune ranges from 96 to 98%.

5) The life expectancy of dead storage of the Imha reservoir was predicted by comparison between the observed sediment deposits in 1997 and the storage capacity of the Imha reservoir. As a result, even though the error of sediment deposits survey is considered, the life expectancy of dead storage of the Imha reservoir might be decreased compare to the design life expectancy of dead storage. Therefore, a recent

survey of the sediment deposits of the Imha reservoir is recommended for a better evaluation the life expectancy of reservoir.

Chapter 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The RUSLE model was combined with GIS technique to analyze the gross soil loss rates caused by typhoon “Maemi” and the annual average and to evaluate the spatial distribution of soil loss rates under different landuses. Cover management factor for forested area of the Imha watershed is calibrated using a “Trial and Error method” from the relationship between the annual soil losses and various sediment delivery ratio models. The SDR was calculated from the annual average soil loss rate and surveyed sediment deposits in the Imha reservoir 1997 and was evaluated by the appropriation of SDR through comparison with other SDR models such as Boyce, Vanoni, Renfro, Williams, and Roehl. The trap efficiency of the Imha reservoir was calculated using the methods of Julien, Brown, Brune, and Churchill. The life expectancy for dead storage of the Imha reservoir was also evaluated by comparison between the observed sediment deposits in 1997 and the dead storage capacity of the Imha reservoir.

Specific conclusions are summarized below related to the results of the RUSLE model application, SDR, and TE at the Imha reservoir:

1) To determine the soil loss rate in the Imha watershed, two cases were analyzed.

- Case1: as shown in Figure 5.2, the annual average soil loss rate was analyzed to be 14 tons/acre/year (3,450 tons/km^2/year) and gross annual average soil erosion was about 2.7million tons/year in the Imha watershed. The soil loss rate of forested area was prevailing 93% of gross annual average soil loss rate. In the gross annual average soil loss rate, crop field was placed behind the forested area and paddy field was after crop field.

- Case2: the average soil loss rate caused by the typhoon “Maemi” was analyzed to be about 5.4 tons/acre/”Maemi” (1,330 ton/km^2/”Maemi”) as shown in Figure 5.6. This soil loss rate covers around 39 percent of the annual average soil loss rate.

2) In case of the spatial variability of gross soil erosion of the Imha watershed, the relationship between probability and gross soil erosion is analyzed. The values of 50% and 90% are about 9 tons/acre/year and 11 tons/acre/year, respectively as shown in Figure 5.13.

3) To determine the SDR at the Imha reservoir, the annual average soil loss rate, estimated at 3,450 tons/km^2/year, was compared with the surveyed sediment deposits, 890 tons/km^2/year, in the Imha reservoir in 1997. As a result of analysis, the SDR of the Imha watershed was estimated to be 25.8% as shown in Figure 5.8. This SDR is fairy high compared to the Boyce, Vanoni, Williams, and Roehl models. Several reasons for high SDR were found such as high, steep slopes, no floodplain, many crop field areas near the reservoir and streams, and flat Imha watershed formation.

4) The trap efficiency of the Imha reservoir was calculated using the methods of Julien, Brown, Brune, and Churchill and ranges from 96% to 99% as shown in Table5.6.

5) The life expectancy for dead storage of the Imha reservoir was predicted by comparison between the observed sediment deposits in 1997 and the dead storage capacity of the Imha reservoir. As a result, even though the error of sediment deposits survey is considered, the life expectancy of dead storage of the Imha reservoir might be decreased compare to the design life expectancy of dead storage. Therefore, a recent survey of the sediment deposits of the Imha reservoir is recommended for a better evaluation the life expectancy of reservoir.

6.2 Recommendations for future studies

Recommendations for future studies are summarized below:

1) The Imha multi-purpose dam has been operated for 14 years since it was constructed in 1993. However, whenever managers of Imha multi-purpose dam face the flood season every year, they are suffering from severe turbid water into the reservoir. In order to solve this problem, the turbidity and total suspended solids prediction system, which can analyze spatially and temporally the gross soil erosion rate and sediment transport process in the watershed and channel, is needed for every storm event. In addition, survey for turbidity, temperature, and TSS is necessary for the efficient water resources and sediment management of the Imha multi-purpose dam reservoir.
2) Better prediction can be complemented by accumulating more accurate input data. For example, the accurate C value for forested area, which has been developing continuously, cannot be predicted easily and is not able to apply without verifying the C value applied for forested area of the other countries. Therefore, the appropriate C value for forested area of the Imha watershed should be found.
3) Even though the error of sediment deposits survey is considered, the life expectancy of dead storage of the Imha reservoir might be decreased compare to the design life expectancy of dead storage. Therefore, a recent survey of the sediment deposits of the Imha reservoir is recommended for a better evaluation the life expectancy of reservoir.

REFERENCES

Anderson, H.W. (1954) “Suspended sediment discharge as related to streamflow, topography, soil and land use.” Trans. AGU 35(2): 268-281.

Bash, J., Berman, C., and Bolton, S. (2001). “Effects of turbidity and suspended solids on Salmonids.” Center for Streamside Studies, Univ. of Washington, Seattle, Washington.

Beasley, D.B. (1989). “ANSWERS: a model for watershed planning.” *Transactions of the ASAE*, 23(4), 938-944.

Brooks, S.M., and McDonnell, R.A. (2000). “Research advances in geocomputation for hydrological and geomorphological modeling towards the twenty-first centry.” Hydrological processes, 14(11-12), 1899-1907.

Brune, G.M. (1953) “Trap efficiency of reservoirs.” *Transactions of the American Geophysical Union 34, 407-18*.

Borland, W.M. (1971). “Reservoir sedimentation. In Shen, H.W., editor, *River mechanics. Vol. 2, Fort Collins, CO: Colorado State University.*

Boyce, R.C. (1975). “Sediment routing with sediment delivery ratios. In present and prospective technology for predicting sediment yields and sources, ARS-S-40, USDA-ARS.

Churchill, M.A. (1948). Discussion of analyses and use of reservoir sedimentation data by L.C. Gottschalk. In Proceedings of the federal interagency sedimentation conferference, *Denver, Colorado,* Washington, DC: US Geological Survey, 139-40.

De Roo, A.P.J. (1996). “Soil erosion assessment using GIS.” Geographical information systems in hydrology, Kluwer Academic Publishers, Dordrecht; Boston, 339-356.

De Roo, A.P.J., Hazelhoff, L., and Burroughs, E.R. (1989). “Soil erosion modeling using ANSWERS and Geographical information systems.” Earth surface processes and landforms, 14, 517-532.

ESRI (2005). Environmental Systems Research Institute. http://www.esri.com

Flanagan, D.C. and Nearing, M.A. (1995). “USDA-Water erosion prediction project: Hillslope Profile and Watershed Model Documentation.” *Report No. 10*, NSERL.

Ferro, V. and Minacapilli, M. (1995) Sediment delivery processes at basin scale. *Hydrological Sciences Journal* 40, 703-716.

Foster, G. R. and Meyer, L. D. (1977). “Soil erosion and sedimentation by water – an overview.” Procs. National Symposium on Soil Erosion and Sedimentation by Water, Am. Soc. Of Agric. Eng., St. Joseph, Michigan, 1-13.

Gert, V. (2000) “Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield.” Progress in Physical Geography 24.2 pp. 210-251.

Glymph, L.M. (1954) “Studies of sediment yield from watersheds. IAHS Publ 37:178-191

Gottschalk, L.C. (1946) “Silting of stock ponds in land utilization project area, SD-LU-2, Pierre, So. Dakota. USDA-SCS Special Rpt #9.

Gottschalk, L.C. and Brune, G.M. (1950) “Sediment design criteria for the Missouri Basin Loess Hills. USDA-SCS Tech Paper 97.

Gunn, R., and G.D. Kinzer (1949) “Terminal velocity of fall for water droplets in stagnant air. J. Meterorol. 6:243-248.

Hadley, R.F. and Schumm, S.A. (1961). “Sediment sources and drainage basin characteristics in upper Cheyenne River Basin.” USGS Water Supply Paper 1531-B.

Heinemann, H. G. (1981). “A new sediment trap efficiency curve for small reservoirs. *Water Resources Bulletin 17, 825-30.*

Hickey, R., Smith, A., and Jankowski, P. (1994). “Slope length calculations from a DEM within ARC/INFO GRID. Computers, Environment, and Urban Systems, vol. 18, no. 5, pp. 365-380.

Hua Lu, C.M., Ian P. P., Michael R.R., Jon O., and Cuan P. (2003). “Sheet and rill erosion and sediment delivery to streams: A basin wide estimation at hillslope to medium catchment Scale.” CSIRO Land and Water, Canberra, Technical Report 15/03.

Hyun, B.K. (1998). “The development of soil loss and runoff prediction model in small basin” NIAST,

Jeong, P.K., Ko, M.H., Im, J.N., Yun, G.D., and Choi, D.W. (1983). “The analysis of rainfall runoff erosivity factor for soil loss prediction” SFA, 16(2) , 112-118.

Johnson, B.E. (1997). “Development of a storm-event based two-dimensional upland erosion model” Ph. D. dissertation, Dept. of Civil Engineering, Colorado State Univerisity.

Johnson, B.E., Julien, P. Y., Molnar, D.K., and Watson, C.C. (2000). “The two-dimensional-upland erosion model CASC2D-SED.” *J. of the AWRA*, 36(1) , 31-42.

Julien, P. Y. (1998). “Erosion and sedimentation*”.* Cambridge University Press, Cambridge, New York.

Julien, P. Y., and Frenette, M. (1987). "Macroscale analysis of upland erosion." Hydrological Sci. J. – Journal des Sci. Hydrol., 32(3), 347-358.

Julien, P. Y. and Saghafian, B. (1991). "CASC2D users manual – A two dimensional watershed rainfall-runoff model." *Civil Eng. Report, CER90-91PYJ-BS-12,* Colorado State University, Fort Collins, CO.

Julien, P. Y., Saghafian, B., and Ogden, F.L. (1995). "Raster-Based hydrologic modeling of spatially-varied surface runoff." *Water Resources Bulletin*, 31(3), 523-536.

Kim, C.S. (2002). "Cover management factor (C) in paddy field."

Kinnell, P.I.A. (2000). "AGNPS-M: applying the USLE-M within the agricultural nonpoint source pllution model." Environmental modeling & software, 15, 331-341.

K.M.A (2003). Korea Meteorological Administration, http://www.kma.go.kr

KOWACO, and FAOUN. (1971). "Pre-investment survey of the Nakdong River Basin,

Korea.", Volume 4. Daegu, Korea. 33-55

KOWACO. (1997). "Deposits survey report of Imha reservoir. " Korea Water Resources Corporation.

KOWACO. (2003). "Turbidity variation report caused by typhoon "Maemi".

KOWACO. (2004). "The prediction of turbid water and water quality on the Seongduk reservoir." Korea Water Resources Corporation Report.

Kuenstler, W. (1998). "A guidelines for the use of the Revised Universal Soil Loss Equation (RUSLE). Chapter 5.

Laws, O.J., and Parsons. D.A. (1943). "The relation of raindrop-size to intensity." Trans. AGU 24:452-460

Lloyd, D.S., Koenings, J.P., and LaPerriere, J.D. (1987). "Effects of turbidity in fresh waters of Alaska." *North American Journal of Fisheries Management*, (7): 18-33

Loch, R. J., B. K. Slater., and Devoil, C. (1998). Soil erodibility (Km) values for some Australian soils. Australian journal of Soil Research, 36: 1045-1055.

Maidment, D.R., and Djokic, D (2000) "Hydrologic and hydraulic modeling support with geographic information systems. ESRI Press, Redlands, CA.

Maner, S.B. (1958). "Factors affecting sediment delivery rates in the Red Hills physiographic area. Trans AGU 39(4): 669-675.

McCool, D.K., Brown, L.C. and Foster, G.R., (1987). "Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of the American Society of Agricultural Engineers, 30: 1387-1396.

McCool, D.K., Foster, G.R., and Weesies, G.A. (1997). "Slope length and steepness factors (LS), Chapter 4, pp. 101-141 in Renard et al. (1997).

Meyer, L.D. (1984). "Evolution of the universal soil loss equation. J. Soil and Water Conserv. 39:99-104.

Ministry of Environment (1999) " Land cover classification system"

Mitasova, H., Hofierka, J., Zlocha, M., and Iverson, R. (1996) "Modeling topographic potential for erosion and deposition using GIS." *Int.J. geographical information systems*, 10(5), 629-641.

Mitchell, J.K., Engel, B.A., Srinivasan, R., and Wang, S.S.Y. (1993). "Validation of AGNPS for small watersheds using an integrated AGNPS/GIS system." Geographical information systems and Water Resources, 89-100.

MOCT and KOWACO. (2005). "The Nakdong River Basin survey project. ", Volume(Ⅰ).

Molnar, D.K., and Julien, P.Y. (1998) "Estimation of upland erosion using GIS." Computers & Geosciences, 24(2) 183-192.

Moore, I.D., Grayson, R.B. and Landson, A.R. (1991) "Digital terrain modeling: A review of hydrological, geomorphological and biological applications." Hydrological Processes,5, 3-30.

Newcombe, C.P. and MacDonald, D.D. (1991). "Effects of suspended sediments on aquatic ecosystes." *North American Journal of Fisheries Management*, (11): 72-82.

NIAST, (2003) "Determination of C factor based on Lysimeter experiments. The National Institute of Agricultural Science and Technology.

Ogden, F.I. (1997a). "CASC2D reference manual. Version 1.17." University of Connecticut, Storrs, CT.

Ogden, F.I. (1997b). "Primer:Using WMS for CASC2D data development." Bringham Young University, Provo, UT.

Renfro, G.W. (1975). "Use of erosion equations and sediment delivery ratios for predicting sediment yield. In Present and Prospective technology for predicting sediment yields and sources, Agricultural Resources Services, ARS-S-40, 33-45. US Dept. Agric., Washington, D.C.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder D.C. (1997). "Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)." Agriculture Handbook No.

703. U.S. Department of Agriculture, Agricultural Research Service, Washington, District of Columbia, USA.

Richards, K. (1993). “Sediment delivery and the drainage network, In: Channel Network Hydrology, Eds. Beven, K. and Kirkby, M.J., 221-254.

Roehl, J.W. (1962). “Sediment yield as a function on upstream erosion. In Universal Soil Loss Equation: Past, Present and Future. SSSA Special Publication #8, Soil Science Society of America, Madison, Wisc.

Romkens, M.J.M. (1985). “The soil erodibility factor: A perspective. In S.a. El-Swaify, W.C. Moldenhauser, and A. Lo, eds., Soil Erosion and Conservation, pp. 445-461. Soil Water Conserv. Soc. Am., Ankeny, Iowa.

Schwab, G.O., Frevert, R.K., Edminster, T.W., and Barnes, K.K. (1981). “Soil Water Conservation Engineering (3rd ed.), Wiley, New York.

Sharma, K.D., Menenti, M., and Huygen, A.V. (1996). “Modeling spatial sediment delivery in an arid region using thematic mapper data and GIS.” Transactions of the ASAE, 39(2), 551-557.

Shen and Julien, P.Y. (1993). “Erosion and sediment transport” in Handbook of Hydrology.

Schmidt, J., Hennrich, K., and Dikau, R. (2000). “Scales and similarities in runoff processes with respect to geomorphometry.” Hydrological processes, 14(11-12), 1963-1979.

Shin, G.J. (1999). “The analysis of soil erosion analysis in watershed using GIS”, Ph.D. Dissertation, Department of Civil Engineering, Gang-won National University.

Tim, U.S. (1996). “Emerging technologies for hydrologic and water quality modeling research.” Transactions of the ASAE, 39(2)., 465-476.

Trimble, S.W. and Carey, W.P. (1990). “A comparison of the Brune and Churchill methods for computing sediment yields applied to a reservoir system. *USGS Water Supply Paper 2340, 195-202*.

T.R.C (2003). Typhoon Research Center, http://www.typhoon.or.kr

USDA-SCS. (1972). “Sediment sources, yields, and delivery ratios. National engineering handbook.” Section 3 Sedimentation.

USDA-SCS. (1983). “National engineering handbook (2nd edition).” Washington, DC: US Department of Agriculture.

USACE. (1985). Remedial investigation and risk assessment, Jefferson Proving Ground, Madison, Indiana. Draft, Volume I, Chapter 11.0. U.S. Army Environmental Center, Aberdeen Proving Ground, MD.

Vanoni, V.A. (1975). “Sedimentation Engineering.” Manuals and reports on engineering practice—No. 54,. American Society of Civil Engineers, New York.

Van Remortel, R., Hamilton, M., and Hickey, R. (2001). “Estimating the LS factor for RUSLE through iterative slope length processing of DEM elevation data.” Cartography 30 (1), 27-35.

Vieux, B.E., and Gauer, N. (1994). “Finite element modeling of storm water runoff using GRASS GIS.” Microcomputers in Civil Engineering, 9:4, 263-270.

WAMIS, Water Management Information System, http://www.wamis.go.kr

Weesies, G.A. (1998). “Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE).” Agriculture Handbook No. 703. Washington, District of Columbia, USA.

Williams, J.R. (1975). “Sediment yield prediction with universal equation using runoff energy factor.” Agricultural Research Service report ARS-S-40. U.S. Department of Agriculture.

Williams, J.R. (1977). “Sediment delivery ratios determined with sediment and runoff models. In: Erosion and solid matter transport in inland waters. pp 168-179. IAHS-AISH publication No. 122.

Wischmeier, W.H. (1976) “Use and misuse of the universal soil loss equation. Soil and Water Conservation 31(1):5

Wischmeier, W.H., Smith, D.D., and Uhland, R.E. (1958) “Evaluation of factors in the soil loss equation. Agric. Eng. 39:458-462, 474.

Wischmeier, W.H. and Smith, D.D. (1965) “Predicting rainfall erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices fro soil and water conservation.” U.S. Department of Agriculture handbook No. 537.

Wischmeier, W.H., Johnson, C.B., and Cross, B.V. (1971) “A soil erodibility nomograph for farmland and construction sites. J. Soil and Water Conserv. 26:189-193.

Wischmeier, W.H. and Smith, D.D. (1978) “Predicting rainfall erosion losses –A guide to conservation planning.” U.S. Department of Agriculture handbook No. 537.

Woolhiser, D.A., Smith, R.E., Sharif, H.O., and Goodrich, D.C. (1990). “KINEROS, a kinematic runoff and erosion model: documentation and user manual.” ARS-77, U.S. Department of Agriculture, Agricultural Research Service.

APPENDIX A – Soil Classification of Nakdong River Basin

Soil Classification of Nakdong River basin (KOWACO, and FAOUN,1971)

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Fma	1	Buyong silty clay loam, 0-1 percent slopes.	35	Poor	D
	2	Ginhae silty caly loam, 0-1 percent slopes.	25	Poor	D
	3	Deunggu silt clay loam, 0-1 percent slopes.	5	Poor	D
	4	Deunggu silty clay loam, 0-1 percent slopes.	10	Poor	D
	5	Jeonbug silt loam, 0-1 percent slopes.	10	Poor	D
	6	Haecheog silt loam, 0-1 percent slopes.	5	Poor	D
	7	Bongrim silty clay loam, 0-1 percent slopes.	5	Very Poor	D
	8	Sadu fine sandy loam, 0-1 percent slopes.	5	Imperfect	B
Fmb	1	Haecheog silt loam, 0-1 percent slopes.	30	Poor to Very poor	D
	2	Myeongji very fine sand, 0-1 percent slopes.	25	Well	A
	3	Sadu fine sandy loam, 0-1 percent slopes.	25	Imperfect	B
	4	Deunggu silt loam, 0-1 percent slopes.	10	Poor	D
	5	Deunggu silty clay loam, 0-1 percent slopes.	5	Poor	D
	6	Gyuam silt loam, 0-2 percent slopes.	5	well to imperfect.	B, C
Fmc	1	Sadu fine sandy loam, 0-1 percent slopes.	35	Imperfect	B
	2	Gwanghwal silt loam, 0-1 percent slopes.	35	Very poor	D
	3	Buyong silty clay loam, 0-1 percent slopes.	30	Poor	D
Fmd	1	Gwanghwal silt loam, 0-1 percent slopes.	45	Very Poor	D
	2	Haechecg silt loam, 0-1 percent slopes.	25	Poor to imperfect	D
	3	Haechecg silt loam, 0-1 percent slopes.	20	Poor to Very poor	D
	4	Baeggu silt loam, 0-1 percent slopes.	10	Very poor	D
Fmg	1	Gwanghwal silt loam, 0-1 percent slopes.	80	Very Poor	D
	2	Suggye silty clay loam, 0-2 percent slopes.	10	Poor	D
	3	Jeonbug silt loam, 0-1 percent slopes.	10	Poor	D
Fmk	1	Gimhae silty clay loam, 0-1 percent slopes.	35	Poor	D
	2	Deunggu silt loam, 0-1 percent slopes.	10	Poor	D
	3	Deumggu silty clay loam, 0-1 percent slopes.	20	Poor	D
	4	Haecheog silt loam, 0-1 percent slopes.	20	Poor to Very poor	D
	5	Bongrim silty clay loam, 0-1 percent slopes.	15	Very Poor	D
Apa	1	Honam silty clay loam, 0-1 percent slopes.	20	Imperfect to poor	D
	2	Sinneumg loam, 0-2 percent slopes.	20	Imperfect	C
	3	Hwadong silty clay loam, 0-2 percent slopes.	8	Mod.well	C
	4	Hwadong silty clay loam, 2-7 percent slopes.	10	Mod.well	C
	5	Geugrag silt loam, 0-2 percent slopes.	15	Imferfect	C
	6	Hamchang silt loam, 0-2 percent slopes.	10	Very poor	D
	7	Ihyeon silt loam, 0-2 percent slopes.	7	Well	B
	8	Hwangryong sandy loam, 0-2 percent slopes.	5	excessive	A
	9	Bonryang sandy loam, 0-2 percent slopes.	5	Well	B
Apb	1	Hwadong silty claay loam, 0-2 percent slopes.	15	Mod. well	C
	2	Hwadong silty clay loam, 2-7 percent slopes.	15	Mod. well	C
	3	Geugrag silt loam, 0-2 percent slopes.	25	Imferfect	C
	4	Jisan loam, 2-7 percent slopes.	20	Poor	D
	5	Baegson loam, 2-7 percent slopes.	15	Well	B
	6	Hwangryong sandy loam, 0-2 percent slopes.c	5	Somewhat	A
	7	Subug sandy loam, 2-7 percent slopes.	5	Poor to imperfect	D
Apc	1	Hwangryong sandy loam, 0-2 percent slopes.	20	Somewhat	A

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Apc	3	Bonryang sandy loam, 0-2 percent slopes.	15	Well	B
	4	Sinheung loam, 0-2 percent slopes.	10	Imperpect	C
	5	Gyuam silt loam, 0-2 percent slopes.	10	Mod.well to imp.	B, C
	6	Cobbly riverwash	10	-	A
	7	Hogye gravelly loam, 2-7 percent slopes.	10	Well	B
	8	Honam silty clay loam, 0-2 percent slopes.	5	Imp. To poor	D
	9	Hamchang silt loam, 0-2 percent slopes.	5	Very poor	D
	10	Hwadong silty clay loam, 2-7 percent slopes.	5	Mod.well	C
	11	Geugrag silt loam, 0-2 percent slopes.	5	Imperfect	C
Apd	1	Gangdong loam, 0-2 percent slopes.	20	Very poor	D
	2	Gangdong loam, 2-7 percent slopes.	10	Poor	D
	3	Hamchang silt loam, 0-2 percent slopes.	15	Very poor	D
	4	Sugye silty ciay loam, 0-2 percent slopes.	15	Very Poor	D
	5	Sinheung loam, 0-2 percent slopes.	15	Imperfect	C
	6	Honam silty clay loam, 0-2 percent slopes.	10	Imperfect to poor	D
	7	Geugrag silt loam, 0-2 percent slopes.	5	Imperfect	C
	8	Hwadong silty clay loam, 0-2 percent slopes.	5	Mod.well	C
	9	Bonryang sandy loam, 0-2 percent slopes.	5	Well	B
Apg	1	Hwangryong sandy loam, 0-2 percent slopes.	30	Somewhat	A
	2	Hwangryong gravelly sandy, loam, 0-2 percent slopes.	10	Somewhat	A
	3	Bonryang sandy loam, 0-2 percent slopes.	25	Well	B
	4	Cobbly river wash	15	-	A
	5	Hogye gravelly loam, 2-7 percent slopes.	10	Well	B
	6	Banho silt loam, 2-7 percent slopes.	5	Well	B
	7	Ihyeon silt loam, 0-2 percent slopes.	5	Well	B
Afa	1	Nagdong loamy fine sand, 0-2 percent slopes.	40	Well	A
	2	Ihyeon silt loam, 0-2 percent slopes.	35	Well	B
	3	Gyuam silt loam, 0-2 percent slopes.	10	Mod.well to imp.	B, C
	4	Hwangryong sandy loam, 0-2 percent slopes.	10	Some excessive	A
	5	Hwangryong gravelly sandy loam, 0-2 percent	5	Someexcessive	A
Afb	1	Hamchang silt loam, 0-2 percent slopes.	20	Very poor	D
	2	Jungdong fine sandy loam, 0-2 percent slopes.	20	Well	B
	3	Gyuam silt loam, 0-2 percent slopes.	20	Mod. well to imp.	B, C
	4	Geugrag silt loam, 0-2 percent slopes.	10	Imperfect	C
	5	sindab sandy loam, 0-2 percent slopes.	10	Very poor	D
	6	Hagsan loam, 0-2 percent slopes.	8	Imferfect	C
	7	Hagsan loam, 2-7 percent slopes.	2	Imferfect	C
	8	Hwabong loamy sand, 0-2 percent slopes.	5	Some excessive	A
	9	Sinheung loam, 0-2 percent slopes.	5	Imferfect	C
Afc	1	Sandy riverwash	40		A
	2	Nagdong loamy fine sand, 0-2 percent slopes.	30	Well	A
	3	Ihyeon silt loam, 0-2 percent slopes.	15	Well	B
	4	Hwabong loamy sand, 0-2 percent slopes.	10	Some excessive	A
	5	Sadu fine sandy loam, 0-1 percent slopes.	5	Imferfect	B
Afd	1	Cobbly riverwash.	40		A
	2	Sandy riverwash.	25		A
	3	Nagdong loamy fine sand, 0-2 percent slopes.	20	Well	A
	4	Hwangryong sandy loam, 0-2 percent slopes.	5	Some excessive	A
	5	Hwangryong gravelly sany, 0-2 percent slopes.	5	Someexcessive	A
	6	Ihyeon silt loam, 0-2 percent slopes.	5	Well	B

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Ana	1	Yuga silt loam, 2-7 percent slopes.	25	Imperfect	C
	2	Banho silt loam, 2-7 percent slopes.	15	Well	B
	3	Banho silt loam, 7-15 percent slopes.	5	Well	B
	4	Yongji loam, 2-7 percent slopes.	10	Imp. to Mod.well.	C
	5	Yongji loam, 7-15 percent slopes.	5	Imp. to Mod.well.	B
	6	Jisan loam, 2-7 percent slopes.	10	Poor	D
	7	Jisan loam, 7-15 percent slopes.	5	Poor	D
	8	Iyheon silt loam, 0-2 percent slopes.	5	Well	B
	9	Jangweon gravelly loam, 2-7 percent slopes.	5	Mod. Well to well	C
	10	Subug sandy loam, 2-7 percent slopes.	5	Poor to imferfect	D
	11	Bonryang sandy loam, 0-2 percent slopes.	5	Well	B
	12	Hamchang silt loam, 0-2 percent slopes.	5	Very poor	D
Anb	1	Jisan loam, 2-7 percent slopes.	10	Poor	D
	2	Jisan loam, 7-15 percent slopes.c	5	Poor	D
	3	Hwangryong sandy loam, 0-2 percent slopes.	15	Somewhat	A
	4	Yongji loam, 2-7 percent slopes.	10	Imp.to mod.well	C
	5	Yongji loam, 7-15 percent slopes.	5	Imp.to mod.well	C
	6	Bonryang sandy loam, 0-2 percent slopes.	15	Well	B
	7	Subug sandy loam, 2-7 percent slopes.	10	Poor to imperfect	D
	8	Hogye gravelly loam, 2-7 percent slopes.	10	Well	B
	9	Baegsan loam, 2-7 percent slopes.	10	Well	B
	10	Seogto gravelly loam, 7-15 percent slopes.	5	Well	B
	11	Cobbly riverwash.	5	-	A
Anc	1	Seogto gravelly loam, 7-15 percent slopes.	10	Well	B
	2	Seogto gravelly loam, 15-30 percent slopes.	10	Well	B
	3	Seogto stony loam, 15-30 percent slopes.	5	Well	B
	4	Seogto bouldery loam, 15-30 percent slopes.	5	Well	B
	5	Gaghwa cobbly loam, 7-15 percent slopes,eroded.	10	Well	C
	6	Gaghwa cobbly loam, 15-30 percent slopes, eroded.	5	Well	C
	7	Banho silt loam, 7-15 percent slopes.	10	Well	B
	8	Banho silt loam, 15-30 percent slopes.	5	Well	B
	9	Jisan loam, 7-15 percent slopes.	10	Poor	D
	10	Hogye gravelly loam, 2-7 percent slopes.	5	Well	B
	11	Hogye gravelly loam, 7-15 percent slopes.	5	Well	B
	12	Yongji loam, 7-15 percent slopes.	5	Imp to mod.well	C
	13	Jangweon gravelly loam, 15-30 percent slopes.	5	Mod.wall to well	C
	14	Sangju sandy loam, 7-15 percent slopes.	5	Well	B
	15	Subug sandy loam, 7-15 percent slopes.	5	Poor to imferfect	D
And	1	Sinbul stony loam, 7-15 percent slopes.	15	Well	B
	2	Sinbul stony loam, 15-30 percent slopes.	25	Well	B
	3	Mangsil stony loam, 15-30 percent slopes.	30	Well	C
	4	Taegu rocky silt loam, 7-15 percent slopes, eroded.	5	Well	D
	5	Taegu rocky silt loam, 15-30 percent slopes.	2	Well	D
	6	Taegu rocky silt loam, 15-30 percent slopes.	5	Well	D
	7	Taegu rocky silt loam, 30-60 percent slopes, eroded	3	Well	D
	8	Mudeung rocky loam, 15-30 percent slopes.	7	Well	C
	9	Mudeung rocky loam, 30-60 percent slopes, eroded	5	Well	C
	10	Mudeung rocky loam, 30-60 percent slopes.	3	Well	C
Raa	1	Bancheon silty clay loam, 2-7 percent slopes.	20	Well	C
	2	Bancheon silty clay loam, 7-15 percent slopes.	15	Well	C

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Raa	3	Baegsan loam, 2-7 percent slopes.	5	Well	B
	4	Baegsan loam, 7-15 percent slopes.	10	Well	B
	5	Baegsan loam, 15-30 percent slopes.	5	Well	B
	6	Hwadong silty clay loam, 2-7 percent slopes.	10	Mod.well	C
	7	Hwadong silty clay loam, 7-15 percent slopes.	5	Mod.well	C
	8	Songjeong loam, 7-15 percent slopes, eroded.	5	Well	B
	9	Songjeong loam, 15-30 percent slopes, eroded.	5	Well	B
	10	Dalcheon silt loam, 7-15 percent slopes, eroded.	5	Well	C
	11	Dalcheon silt loam, 15-30 percent slopes, eroded.	5	Well	C
	12	Jisan loam, 7-15 percent slopes.	5	Poor	D
	13	Yongji loam, 7-15 percent slopes.	5	Imp. to Mod.well	C
Rab	1	Songjeong loam, 7-15 percent slopes, eroded.	15	Well	B
	2	Songjeong loam, 15-30 percent slopes, eroded.	25	Well	B
	3	Samgag sandy loam, 15-30 percent slopes, eroded.	5	Well	B
	4	Samgag sandy loam, 15-30 percent slopes,	15	Well	B
	5	Dalcheon silt loam, 7-15 percent slopes, eroded.	5	Well	C
	6	Dalcheon silt loam, 15-30 percent slopes, eroded.	10	Well	C
	7	Taehwa loam, 15-30 percent slopes, eroded.	10	Well	B
	8	Sinjeong gravelly loam, 15-30 percent slopes,	5	Well	B
	9	Yongji loam, 15-30 percent slopes.	5	Imp. to mod.well	C
	10	Hwadong silty clay loam, 7-15 percent slopes.	5	Mod.well	C
Rac	1	Gaghwa cobbly loam, 7-15 percent slopes, eroded.	15	Well	C
	2	Gaghwa cobbly loam, 15-30 percent slopes, eroded.	20	Well	C
	3	Anyong cobbly loam, 7-15 percent slopes.	10	Well	B
	4	Anyong cobbly loam, 15-30 percent slopes.	20	Well	B
	5	Banho silt loam, 15-30 percent slopes.	15	Well	B
	6	Togye sandy loam, 15-30 percent slopes.	10	Well	A
	7	Iweon stony sandy loam, 15-30 percent slopes.	5	Well	B
	8	Yongji loam, 15-30 percent slopes.	5	Imp. to mod.well	C
Rad	1	Seogto gravelly loam, 7-15 percent slopes.	10	Well	B
	2	Seogto gravelly loam, 15-30 percent slopes.	15	Well	B
	3	Seogto stony loam, 15-30 percent slopes.	10	Well	B
	4	Seogto bouldery loam, 15-30 percent slopes.	5	Well	B
	5	Jangweon gravelly loam, 7-15 percent slopes.	5	Mod.well to wall	C
	6	Jangweon gravelly loam, 15-30 percent slopes.	20	Mod.well to wall	C
	7	Sinbul stony loam, 7-15 percent slopes.	5	Well	B
	8	Sinbul stony laom, 15-30 percent slopes.	10	Well	B
	9	Gaghwa cobbly loam, 15-30 percent slopes.	10	Well	C
	10	Iweon stony sandy loam, 15-30 percent slopes.	10	Well	B
Rea	1	Samgag sandy loam, 15-30 percent slopes, eroded.	5	Well	B
	2	Samgag sandy loam, 15-30 percent slopes, eroded.	15	Well	B
	3	Samgag sandy loam, 15-30 percent slopes, gullied.	5	Well	B
	4	Samgag rocky sandy loam, 7-15 percent slopes.	15	Well	B
	5	Samaga rocky sandy loam, 15-30 percent slopes,	10	Well	B
	6	Samgag rocky sandy loam, 30-60 percent slopes,	10	Well	B
	7	Taehwa loam, 15-30 percent slopes, eroded.	10	Well	B
	8	Taehwa rocky loam, 15-30 percent slopes, eroded.	5	-	B
	9	Songjeong loam, 7-15 percent slopes, eroded.	5	Well	B

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Rea	10	Songjeong loam, 15-30 percent slopes, eroded.	5	Well	B
	11	Dalcheon silt loam, 15-30 percent slopes, eroded.	5	Well	C
	12	Jisan loam, 7-15 percent slopes.	5	Poor	D
	13	Baegsan loam, 15-30 percent slopes.	5	Well	B
Rla	1	Pyeongchang rocky clay loam, 15-30 percent slopes.	45	Well	C
	2	Pyeongchang rocky clay loam, 30-60 percent slopes.	10	Well	C
	3	Jangseong rocky silt loam, 30-60 percent slopes.	25	Well	C
	4	Jangseong rocky silt loam, 30-60 percent slopes,	10	Well	C
	5	Bonggye silty clay loam, 15-30 percent slopes,	5	Well	C
	6	Yongji loam, 7-15 percent slopes.	5	Imp. to mod.well	C
Rlb	1	Pyeongchang rocky clay loam, 15-30 percent slopes.	10	Well	C
	2	Pyeongchang rocky clay loam, 30-60 percent slopes.	25	Well	C
	3	Bonggye siltyclayloam, 7-15 percent slopes, eroded.	5	Well	C
	4	Bonggye siltyclayloam, 15-30 percent slopes, eroded.	10	Well	C
	5	Bonggye cobbly siltyclayloam, 15-30percent slopes,	5	Well	C
	6	Bonggye rocky siltyclayloam, 15-30 percent slopes,	5	Well	C
	7	Bonggye rocky silty clay loam, 15-30 percent	5	Well	C
	8	Jangseong rocky silt loam, 30-60 percent slopes.	15	Well	C
	9	Seogto gravelly loam, 7-15 percent slopes.	5	Well	B
	10	Seogto gravelly loam, 15-30 percent slopes.	5	Well	B
	11	Taehwa loam, 15-30 percent slopes, eroded.	5	Well	B
	12	Sinjeong gravellyloam, 15-30percent slopes, eroded.	5	Well	B
Rsa	1	Taegu rocky silt loam, 7-15 percent slopes.	5	Well	D
	2	Taegu rocky silt loam, 7-15 percent slopes, eroded.	5	Well	D
	3	Taegu rocky silt loam, 15-30 percent slopes.	5	Well	D
	4	Taegu rockysilt loam, 15-30 percent slopes, eroded.	20	Well	D
	5	Taegu rockysilt loam, 30-60 percent slopes, eroded.	5	Well	D
	6	Cheongsim stony silt loam, 30-60 percent slopes.	25	Well	B
	7	Bancheon silty clay loam, 2-7 percent slopes.	5	Well	C
	8	Bancheon silty clay loam, 7-15 percent slopes, eroded.	10	Well	C
	9	Sirye silty clay loam, 7-15 percent slopes, eroded.	5	Well	C
	10	Habin rocky loam, 15-30 percent slopes, eroded.	5	Well	D
	11	Yrga silt loam, 2-7 percent slopes.	5	Imperfect	C
	12	Yongji loam, 7-15 percent slopes.	5	Imp.to mod.well	C
Rsb	1	Bancheon silty clay loam, 2-7 percent slopes.	10	Well	C
	2	Bancheon silty clay loam, 7-15 percent slopes,	30	Well	C
	3	Banho silt loam, 7-15 percent slopes.	5	Well	B
	4	Banho silt loam, 15-30 percent slopes.	20	Well	B
	5	Samam silt loam, 2-7 percent slopes.	25	Well	B
	6	Sirye silt clay loam, 7-15 percent slopes, eroded.	10	Well	C
Rsc	1	Banho silt loam, 7-15 percent slopes.	10	Well	B
	2	Banho silt loam, 15-30 percent slopes.	60	Well	B
	3	Sirye silty clay loam, 7-15 percent slopes, eroded.	10	Well	C
	4	Seogto gravelly loam, 15-30 percent slopes.	5	Well	B
	5	Seogto stony loam, 15-30 percent slopes.	5	Well	B
	6	Yuga silt loam, 2-7 percent slopes.	5	Imperfect	C

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Rsc	7	Saman silt loam, 2-7 percent slopes.	5	Well	B
Rva	1	Bonggye siltyclayloam, 15-30 percent slopes, eroded.	10	Well	C
	2	Bonggye siltyclayloam, 30-60 percent slopes, eroded.	5	Well	C
	3	Bonggye cobbly silty clay loam, 15-30 percent slopes,	5	Well	C
	4	Bonggye cobbly silty clay loam, 30-60 percent slopes,	15	Well	C
	5	Bonggye rocky cobbly silty clay loam, 30-60 percent	5	Well	C
	6	Cheongog sillt loam, 15-30 percent slopes.	5	Well	C
	7	Cheongog silt loam, 15-30 percent slopes, eroded.	5	Well	C
	8	Cheongog bouldery clay loam, 15-30 percent slopes.	5	Well	C
	9	Cheongog bouldery clay loam, 30-60 percent slopes.	5	Well	C
	10	Cheongog bouldery clay loam, 30-60 percent slopes,	5	Well	C
	11	Jeongja rocky loam, 30-60 percent slopes.	10	Well	D
	12	Jeongja rocky loam, 30-60 percent slopes, eroded.	10	Well	D
	13	Mudeung rocky loam, 15-30 percent slopes.	5	Well	C
	14	Mudeung rocky loam, 15-30 percent slopes, eroded.	5	Well	C
	15	Mudeung rocky loam, 30-60 percent slopes, eroded.	5	Well	C
Rvb	1	Bonggye siltyclayloam, 15-30 percent slopes, eroded.	10	Well	C
	2	Bonggye siltyclayloam, 30-60 percent slopes, eroded.	5	Well	C
	3	Bonggye cobbly silty clay loam, 15-30 percent slopes,	5	Well	C
	4	Bonggye cobbly silty clay loam, 30-60 percent slopes,	20	Well	C
	5	Bonggye rocky silty clay loam, 30-60 percent slopse	5	Well	C
	6	Cheongog silt loam, 15-30 percent slopes, eroded.	5	Well	C
	7	Cheongog bouldery clay loam, 30-60 percent slopes.	5	Well	C
	8	Cheongog bouldery clay loam, 30-60 percent slopes,	5	Well	C
	9	Banho silt loam, 7-15 percent slopes.	5	Well	B
	10	Banho gravelly loam, 15-30 percent slopes.	5	Well	B
	11	Sinjeong silt loam, 15-30 percent slopes, eroded.	5	Well	B
	12	Sinjeong gravelly loam, 15-30 percent slopes, eroded.	5	Well	B
	13	Yongji loam, 7-15 percent slopes.	5	Mod.well	C
	14	Yongji loam, 15-30 percent slopes.	5	Mod.well	C
	15	Seogto gravelly loam, 15-30 percent slopes.	5	Well	B
	16	Mangsil stony loam, 15-30 percent slopes.	5	Well	C
Rvc	1	Seogto gravelly loam, 7-15 persent slopes.	5	Well	B
	2	Seogto gravelly loam, 15-30 percent slopes.	15	Well	B
	3	Seogto stony loam, 15-30 percent slopes.	5	Well	B
	4	Seogto bouldery loam, 15-30 percent slopes.	5	Well	B
	5	Mudeung rocky loam, 15-30 percent slopes.	5	Well	C
	6	Mudeung rocky loam, 15-30 percent slopes, eroded.	10	Well	C
	7	Mudeung rocky loam, 30-60 percent slopes.	5	Well	C
	8	Mudeung rocky loam, 30-60 percent slopes, eroded.	5	Well	C
	9	Bonggye silty clay loam, 15-30 percent slopes,	5	Well	C
	10	Bonggye cobbly silty clay loam, 15-30 percent slopes, eroded.	10	Well	C

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Rvc	11	Bonggye, cobbly silty clay loam, 30-60 percent	5	Well	C
	12	Taehwa loam, 15-30 percent slopes, eroded.	5	Well	B
	13	Taehwa rocky loam, 15-30 percent slopes, eroded.	5	Well	C
	14	Yongji loam, 15-30 percent slopes.	5	Mod.well	C
	15	Tongcheon sandy loam, 0-2 percent slopes.	5	Well	B
	16	Mangsil stony loam, 15-30 percent slopes.	5	Well	C
Rxa	1	Jisan loam, 2-7 percent slopes.	15	Poor	D
	2	Jisan loam, 7-15 percent slopes.	15	Poor	D
	3	Yongji loam, 2-7 percent slopes.	10	Mod.well	C
	4	Yongji loam, 7-15 percent slopes.	5	Mod.well	C
	5	Yuga silt loam, 2-7 percent slopes.	10	Imperfect	C
	6	Baegsan loam, 2-7 percent slopes.	5	Well	B
	7	Baegsan loam, 7-15 percent slopse.	5	Well	B
	8	Hamchang silt loam, 0-2 percent slopes.	10	Very poor	D
	9	Gangdong loam, 2-7 percent slopes.	10	Very poor	D
	10	Banho silt loam, 7-15 percent slopoes.	5	Well	B
	11	Sindab sandy loam, 0-2 percent slopes.	5	Very poor	D
	12	Gangdong loam, 0-2 percent slopes.	5	Imperfect	C
Maa	1	Dalcheon silt loam, 15-30 percent slopes, eroded.	10	Well	C
	2	Dalcheon silt loam, 30-60 percent slopes, eroded.	5	Well	C
	3	Dalcheon silt loam, 30-60 percent slopes, severely	5	Well	C
	4	Songjeong loam, 15-30 percent slopes, erodes.	10	Well	B
	5	Songjeong loam, 30-60 percent slopes, erodes.	10	Well	B
	6	Bonggye silty clay loam, 15-30 percent slopes,	5	Well	C
	7	Bonggye cobbly silty clay loam, 15-30 percent	5	Well	C
	8	Bonggye rocky silty clay loam, 30-60 percent slopse	5	Well	C
	9	Samgag sandy loam, 15-30 percent slopes,	5	Well	B
	10	Samgag rocky sandy loam, 30-60 percent slopes,	5	Well	B
	11	Samgag rocky sandy loam, 30-60 percent slopes,	5	Well	B
	12	Mudeung rocky loam, 30-60 percent slopes.	5	Well	C
	13	Mudeung rocky loam, 30-60 percent slopes, eroded.	5	Well	C
	14	Taehwa loam, 30-60 percent slopes, eroded.	5	Well	B
	15	Nagseo rocky loam, 30-60 percent slores, eroded.	5	Well	D
	16	Gwanag rocky sandy loam, 30-60 percent slopes.	5	Well	D
	17	Banho silt loam, 15-30 percent slopes.	5	Well	B
Mab	1	Samgag sandy loam, 15-30 percent slopes,	5	Well	B
	2	Samgag sandy loam, 30-60 percent slopes, gullied.	5	Well	B
	3	Samgag rocky sandy loam, 30-60 percent slopes,	10	Well	B
	4	Samgag rocky sandy loam, 30-60 percent slopes,	10	Well	B

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Mab	5	Nagseo rocky loam, 15-30 percent slopes, eroded.	5	Well	D
	6	Nagseo rocky loam, 30-60 percent slopes, eroded.	10	Well	D
	7	Nageo rocky loam, 60-100 percent slopes, severely	5	Well	D
	8	Gwanag rocky loam, 30-60 percent slopes.	15	Well	D
	9	Gwanag rocky loam, 60-100 percent slopes.	5	Well	D
	10	Mudeung rocky loam, 30-60 percent slopes.	5	Well	D
	11	Mudeung rocky loam, 30-60 percent slopes, eroded.	10	Well	C
	12	Taehwa loam, 30-60 percent slopes, eroded.	5	Well	B
	13	Songjeong loam, 30-60 percent slopes, eroded.	5	Well	B
	14	Dalcheon silt loam, 30-60 percent slopes, eroded.	5	Well	C
Mac	1	Nagseo rocky loam, 15-30 percent slopes, eroded.	5	Well	D
	2	Nagseo rocky loam, 30-60 percent slopes, eroded.	10	Well	D
	3	Nagseo rocky loam, 60-100 persent slopes, severely	5	Well	D
	4	Gwanag rocky sandy loam, 30-60 percent slopes.	15	Well	D
	5	Gwanag rocky sandy loam, 60-100 percent slopes.	5	Well	D
	6	Samgag rocky sandy loam, 30-60 percent slopes,	10	Well	B
	7	Samgag rocky sandy loam, 30-60 percent slopes,	10	Well	B
	8	Mudeung rocky loam, 30-60 percent slopes.	5	Well	C
	9	Mudeung rocky loam, 30-60 percent slopes, eroded.	10	Well	C
	10	Songjeong loam, 30-60 percent slopes, eroded.	10	Well	B
	11	Rock land	10	-	D
	12	Taehwa rocky loam, 30-60 percent slopes, eroded.	5	Well	B
Mla	1	Jangseong rocky silt loam, 30-60 percent slopes.	25	Well	C
	2	Jangseong rocky silt loam, 60-100 percent slopes.	10	Well	C
	3	Jangseong rocky clay loam, 30-60 percent slopes,	10	Well	C
	4	Pyeongchang rocky clay loam, 15-30 percent slopes.	5	Well	C
	5	Pyeongchang rocky clay loam, 30-60 percent slopes.	30	Well	C
	6	Bonggye silty clay loam, 15-30 percent slopes,	10	Well	C
	7	Bonggye cobbly silty clay loam, 30-60 percent slopes, eroded.	5	Well	C
	8	Sinjeong silt loam, 15-30 percent slopes, eroded.	5	Well	B
Mlb	1	Jangseong rocky silt loam, 30-60 percent slopes.	35	Well	C
	2	Jangseong rocky silt loam, 60-100 percent slopes.	20	Well	C
	3	Jangseong rocky clay loam, 30-60 percent slopes,	20	Well	C
	4	Rock land	10	-	D
	5	Rock outcrop	5	-	D
	6	Ryeongchang rocky clay loam, 30-60 percent slopes.	5	Well	C
	7	Mitan gravelly loam, 15-30 percent slopes.	5	Well	B
Mma	1	Nagseo rocky loam, 15-30 percent slopes, eroded.	10	Well	D
	2	Nagseo rocky loam, 30-60 percent slopes, eroded.	25	Well	D
	3	Nagseo rocky loam, 60-100 persent slopes,	5	Well	D
	4	Nagseo rocky loam, 60-100 percent slopes, severely eroded.	5	Well	D

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Mma	5	Mudeung rocky loam, 30-60 percent slopes.	5	Well	D
	6	Mudeung rocky loam, 30-60 percent slopes, eroded.	10	Well	D
	7	Mudeung very rocky loam, 30-60 percent slopes.	5	Well	D
	8	Dalcheon silt loam, 30-60 percent slopes, eroded.	5	Well	C
	9	Dalcheon rocky silt loam, 30-60 percent slopes,	5	Well	C
	10	Gwanag rocky sandy loam, 30-60 percent slopes.	5	Well	D
	11	Songjeong loam, 30-60 percent slopes, eroded.	5	Well	B
	12	Anyong cobbly loam, 15-30 percent slopes.	5	Well	B
	13	Taehwa loam, 30-60 percent slopes, eroded.	5	Well	B
	14	Samgag rocky sandy loam, 30-60 percent slopes,	5	Well	B
Mmb	1	Nagseo rocky loam, 15-30 percent slopes, eroded.	5	Well	D
	2	Nagseo rocky loam, 30-60 percent slopes, eroded.	25	Well	D
	3	Nagseo rocky loam, 60-100 percent slopes, eroded.	5	Well	D
	4	Nagseo rocky loam, 60-100 percent slopes, slopes,	15	Well	D
Mmb	5	Mudeung rocky loam, 30-60 percent slopes, eroded.	10	Well	C
	6	Mudeung rocky loam, 30-60 percent slopes.	5	Well	C
	7	Mudeung rocky loam, 60-100 percent slopes.	5	Well	C
	8	Samgag rocky sandy loam, 30-60 percent slopes,	3	Well	B
	9	Samgag rocky sandy loam, 30-60 percent slopes,	7	Well	B
	10	Gwang rocky sandy loam, 30-60 percent slopes.	5	Well	C
	11	Songjeong loam, 30-60 percent slopes, eroded.	5	Well	B
	12	Anyong cobbly loam, 15-30 percent slopes.	5	Well	B
	13	Taehwa rocky loam, 30-60 percent slopes, eroded.	5	Well	B
Msa	1	Cheongsim stony silt loam, 30-60 percent slopes.	10	Well	C
	2	Cheongsim stony silt loam, 30-60 percent slopes,	15	Well	C
	3	Cheongsim stony silt loam, 30-60 percent slopes,	20	Well	C
	4	Cheongsim stony silt loam, 60-100 percent slopes,	5	Well	C
	5	Taegu rocky silt loam, 15-30 percent slopes, eroded.	5	Well	D
	6	Taegu rocky silt loam, 30-60 percent slopes, eroded.	15	Well	D
	7	Sirye silty clay loam,7-15 percent slopes, eroded.	5	Well	C
	8	Sirye silty clay loam, 15-30 percent slopes, eroded.	10	Well	C
	9	Habin rocky loam, 30-60 percent slopes, eroded.	5	Well	D
	10	Bancheon silty clay loam, 15-30 percent slopes,	5	Well	C
	11	Banho silt loam, 15-30 percent slopes.	5	Well	B
Msb	1	Taegu rocky silt loam, 30-60 percent slopes, eroded.	15	Well	D
	2	Taegu rocky silt loam, 30-60 percent slopes,	5	Well	D
	3	Taegu rocky silt laom, 30-60 percent slopes, gullied.	5	Well	D
	4	Sirye silty clay loam, 15-30 percent slopes, eroded.	15	Well	C

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Msb	5	Habin rocky loam, 30-60 percent slopes, eroded.	10	Well	D
	6	Banho silt loam, 15-30 percent slopes.	5	Well	B
Mua	1	Mangsil stony loam, 7-15 percent slopes.	40	Well	C
	2	Mangsil stony loam, 15-30 percent slopes.	10	Well	C
	3	Chahang loam, 7-15 percent slopes.	10	Well	B
	4	Chahang loam, 15-30 percent slopes.	5	Well	B
	5	Sinbul stony loam, 7-15 percent slopes.	5	Well	B
	6	Sinbul stony loam, 15-30 percent slopes.	5	Well	B
	7	Ungyo cobbly silt loam, 7-15 percent slopes.	5	Well	C
	8	Mudeung rocky loam, 15-30 percent slopes.	5	Well	C
	9	Odae rocky loam, 15-30 percent slopes.	5	Well	C
	10	Mui stony loam, 7-15 percent slopes.	5	Well	B
	11	Imog sandy loam, 2-7 percent slopes.	5	Well	B
Mva	1	Mubeung rocky loam, 15-30 percent slopes.	5	Well	C
	2	Mubeung rocky loam, 30-60 percent slopes.	5	Well	C
	3	Mubeung rocky loam, 30-60 percent slopes, eroded.	10	Well	C
	4	Mudeung very rocky loam, 60-100 percent slopes.	5	Well	C
	5	Odae rocky loam, 15-30 percent slopes.	5	Well	C
	6	Odae rocky loam, 30-60 percent slopes.	15	Well	C
	7	Odae rocky loam, 60-100 percent slopes.	5	Well	C
	8	Ungyo cobbly silt loam, 15-30 percent slopes.	5	Well	C
	9	Ungyo cobbly silt loam, 30-60 percent slopes.	15	Well	C
	10	Mangsil stony loam, 15-30 percent slopes.	15	Well	C
	11	Sinbul bouldery loam, 30-60 percent slopes.	5	Well	B
	12	Imog sandy loam, 7-15 percent slopes.	5	Well	B
	13	Songjeong loam, 30-60 percent slopes, eroded.	5	Well	B
Mva	1	Jeongja rocky loam, 30-60 percent slopes.	10	Well	D
	2	Jeongja rocky loam, 30-60 percent slopes, eroded.	20	Well	D
	3	Mudeung rocky loam, 15-30 percent slopes.	10	Well	C
	4	Mudeung rocky loam, 30-60 percent slopes.	10	Well	C
	5	Sinjeong gravellyloam, 15-30percent slopes, eroded.	5	Well	B
	6	Sinjeong gravellyloam, 30-60percent slopes, eroded.	10	Well	B
	7	Sinjeong gravellyloam, 30-60 percent slopes, gullied.	5	Well	B
	8	Bonggye siltyclayloam, 15-30percentslopes, eroded.	5	Well	C
	9	Bonggye cobbly silty clay loam, 30-60 percent	5	Well	C
	10	Cheongog silt loam, 15-30 percent slopes, eroded.	5	Well	C
	11	Cheongog bouldery silt loam, 30-60 percent slopes.	5	Well	C
	12	Taehwa loam, 30-60 percent slopes, eroded.	5	Well	B
	13	Taehwa rocky loam, 30-60 percent slopes, eroded.	5	Well	B
Mvb	1	Mudeung rocky loam, 15-30 percent slopes.	5	Well	C
	2	Mudeung rocky loam, 30-60 percent slopes.	20	Well	C
	3	Mudeung rocky loam, 30-60 percent slopes, eroded.	10	Well	C
	4	Mudeung rocky loam, 60-100 percent slopes.	5	Well	C
	5	Jeongja rocky loam, 60-100 percent slopes.	5	Well	D, C
	6	Jeongja rocky loam, 60-100 percent slopes, eroded.	15	Well	D, C
	7	Sinjeong gravelly loam, 30-60 percent slopes.	15	Well	B
	8	Sinjeong gravelly sandy loam, 30-60 percent slopes, gullied.	5	Well	B
	9	Taehwa loam, 30-60 percent slopes, eroded.	5	Well	B
	10	Taehwa rocky loam, 30-60 percent slopes,	5	Well	B

Soil type	Num	Soil Characteristics	Area (%)	Hydrologic condition	Hydrologic soil group
Mvb	11	Bonggye cobbly silty clay loam, 30-60 percent slopes, eroded.	5	Well	C
	12	Cheongog bouldery clay loam, 30-60 percent slopes.	5	Well	C
Ro	1	Taegu very rocky silt loam, 30-60 percent slopes, eroded.	15	Well	D
	2	Mudeung very rocky loam, 30-60 percent slopes.	5	Well	C
	3	Mudeung very rocky loam, 60-100 percent slopes.	5	Well	C
	4	Samgag very rocky sandy loam, 30-60 percent slopes, gullied.	5	Well	B
	5	Nagseo very rocky loam, 30-60 percent slopes, eroded.	5	Well	D
	6	Gwanag very rocky sandy loam, 30-60 percent slopes.	5	Well	D
	7	Rock land	45	-	D
	8	Rock outcrop	15	-	D

APPENDIX B – Land Cover Classification System (Ministry of Environment, 1999)

Land Cover Classification System (ME, 1999)

First Classification	Color	Second classification		Color
Urban District 100		Residential Area	110	
		Industrial Area	120	
		Commercial Area	130	
		Recreational Area	140	
		Road area	150	
		Public Facility area	160	
Agriculture 200		Paddy field	210	
		Crop field	220	
		Vinyl house	230	
		Orchard	240	
		Others	250	
Forest 300		Deciduous forest	310	
		Coniferous forest	320	
		Mixed forest	330	
Grass 400		Grass	410	
		Golf course	420	
		Others	430	
Wetland 500		Inland wetland	510	
		Coastal wetland	520	
Barren 600		Mining	610	
		Others	620	
Water 700		Inland Water	710	
		Sea Water	720	

APPENDIX C – Table of Rainfall Runoff Erosivity Factor

C.1 JINBO2 RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	243.7	0.1	0.3	0.6
2	2003041819	2003041907	351.5	0.3	1.0	0.8
3	2003041922	2003042008	229.6	0.2	0.4	0.6
4	2003042305	2003042314	224.5	0.1	0.3	0.6
5	2003042502	2003042519	942.2	0.3	3.0	2.0
6	2003042909	2003042921	679.7	0.4	2.4	1.5
7	2003050618	2003050624	208.4	0.1	0.2	0.5
8	2003050712	2003050803	678.6	0.3	2.1	1.5
9	2003052501	2003052521	769.3	0.2	1.8	1.8
10	2003052924	2003053023	1143.9	0.3	3.6	2.4
11	2003061123	2003061213	287.0	0.2	0.5	0.7
12	2003061906	2003061918	553.5	0.2	1.1	1.3
13	2003062312	2003062318	280.4	0.2	0.6	0.6
14	2003062708	2003062803	1231.9	0.4	4.8	2.4
15	2003070302	2003070311	1714.8	0.6	10.8	2.7
16	2003070824	2003071013	917.2	0.4	4.0	2.0
17	2003071301	2003071310	782.6	0.3	2.5	1.6
18	2003071804	2003071816	548.1	0.2	1.1	1.3
19	2003072207	2003072208	328.3	0.3	1.0	0.6
20	2003072215	2003072306	882.4	0.8	7.3	1.3
21	2003072501	2003072507	569.8	0.5	2.9	1.0
22	2003072823	2003072910	374.1	0.3	1.0	0.8
23	2003080707	2003080712	1149.0	0.9	10.9	1.5
24	2003081101	2003081107	640.2	0.6	4.0	1.1
25	2003081803	2003081914	3827.4	0.9	33.2	6.7
26	2003082020	2003082107	656.4	0.6	3.6	1.2
27	2003083013	2003083109	655.7	0.2	1.3	1.6
28	2003090214	2003090219	358.5	0.4	1.4	0.7
29	2003091201	2003091304	4023.7	0.9	34.9	6.3
30	2003111020	2003111117	449.1	0.2	1.1	1.1
31	2003112717	2003112901	215.7	0.1	0.3	0.6
	sum		25917.5		143.1	49.3

C.2 SUBI2 RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	241.0	0.1	0.3	0.6
2	2003041819	2003041907	359.3	0.2	0.8	0.9
3	2003041922	2003042008	238.1	0.1	0.3	0.6
4	2003042502	2003042519	890.1	0.3	2.5	1.9
5	2003042909	2003042921	1003.5	0.5	4.7	2.0
6	2003050618	2003050624	202.4	0.2	0.3	0.5
7	2003050712	2003050803	1130.2	0.4	4.9	2.2
8	2003052501	2003052521	661.3	0.2	1.3	1.6
9	2003052924	2003053023	817.0	0.2	1.9	1.9
10	2003061123	2003061213	350.5	0.1	0.4	0.9
11	2003061906	2003061918	481.3	0.2	1.1	1.1
12	2003062312	2003062318	384.3	0.3	1.1	0.8
13	2003062708	2003062803	1502.0	0.5	7.1	2.9
14	2003070302	2003070311	740.4	0.4	2.9	1.5
15	2003070824	2003071013	1650.9	0.7	11.0	3.1
16	2003071301	2003071310	549.9	0.3	1.7	1.1
17	2003072207	2003072208	606.8	0.7	4.5	0.8
18	2003072215	2003072306	394.9	0.5	2.0	0.6
19	2003072501	2003072507	749.3	0.7	5.6	1.1
20	2003080707	2003080712	728.0	0.7	5.4	1.0
21	2003081803	2003081914	2613.6	0.5	12.3	5.4
22	2003082714	2003082724	216.0	0.2	0.3	0.6
23	2003083013	2003083109	454.1	0.2	0.7	1.2
24	2003090308	2003090318	283.9	0.3	0.8	0.6
25	2003090906	2003090908	950.3	1.1	10.1	1.1
26	2003091201	2003091304	7841.8	1.9	151.3	9.5
27	2003111020	2003111117	284.8	0.2	0.4	0.7
28	2003112717	2003112901	308.4	0.1	0.2	0.9
	sum		26634.1		236.3	47.0

C.3 BUDONG RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003030609	2003030623	388.9	0.1	0.5	1.0
2	2003041819	2003041907	363.6	0.2	0.7	0.9
3	2003041922	2003042008	295.5	0.2	0.5	0.7
4	2003042305	2003042314	295.5	0.2	0.5	0.7
5	2003042502	2003042519	784.1	0.3	2.2	1.7
6	2003042909	2003042921	701.3	0.4	2.5	1.5
7	2003050712	2003050803	587.2	0.2	1.4	1.3
8	2003052501	2003052521	880.7	0.2	2.1	2.0
9	2003052924	2003053023	1552.8	0.4	5.5	3.2
10	2003061123	2003061213	458.4	0.2	0.9	1.1
11	2003061906	2003061918	975.6	0.4	3.5	1.9
12	2003062708	2003062803	1108.2	0.4	3.9	2.2
13	2003070302	2003070311	1105.4	0.4	4.8	2.0
14	2003070617	2003070621	429.3	0.2	1.0	0.9
15	2003070824	2003071013	839.2	0.4	3.0	1.9
16	2003071301	2003071310	947.2	0.4	4.1	1.8
17	2003071804	2003071816	498.3	0.2	1.0	1.1
18	2003072015	2003072209	1087.4	0.9	10.3	1.4
19	2003072207	2003072208	499.2	0.6	2.9	0.7
20	2003072215	2003072306	382.1	0.4	1.7	0.7
21	2003072501	2003072507	1131.3	0.8	9.4	1.7
22	2003072823	2003072910	744.8	0.3	2.3	1.6
23	2003080707	2003080712	258.7	0.3	0.8	0.5
24	2003081101	2003081107	284.3	0.2	0.6	0.7
25	2003081803	2003081914	2552.6	0.5	12.1	4.8
26	2003083013	2003083109	622.5	0.2	1.5	1.4
27	2003091201	2003091304	6129.9	1.6	96.5	8.2
28	2003110809	2003110815	235.2	0.2	0.4	0.6
29	2003111020	2003111117	423.4	0.2	0.8	1.1
30	2003112717	2003112901	606.6	0.2	1.2	1.6
	sum		27169.3		178.3	51.0

C.4 CHEONGSONG RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	202.4	0.1	0.2	0.6
2	2003041819	2003041907	274.6	0.2	0.6	0.6
3	2003041922	2003042008	279.4	0.1	0.3	0.7
4	2003042305	2003042314	322.2	0.2	0.6	0.8
5	2003042502	2003042519	1031.3	0.4	3.7	2.1
6	2003042909	2003042921	429.8	0.2	0.7	1.1
7	2003050712	2003050803	666.5	0.3	1.8	1.5
8	2003052501	2003052521	604.2	0.2	1.0	1.5
9	2003052924	2003053023	1330.8	0.3	4.2	2.8
10	2003061123	2003061213	297.7	0.2	0.5	0.8
11	2003061906	2003061918	768.7	0.4	2.7	1.6
12	2003062312	2003062318	346.1	0.3	1.0	0.7
13	2003062708	2003062803	979.1	0.3	3.1	2.0
14	2003070302	2003070311	1521.3	0.7	10.2	2.5
15	2003070617	2003070621	213.5	0.2	0.3	0.5
16	2003070824	2003071013	924.7	0.3	2.9	2.1
17	2003071301	2003071310	913.3	0.3	2.9	1.8
18	2003071804	2003071816	567.9	0.3	1.6	1.3
19	2003072215	2003072306	506.0	0.4	2.2	0.9
20	2003072501	2003072507	1901.3	1.1	20.2	2.4
21	2003072823	2003072910	684.7	0.3	2.2	1.4
22	2003080707	2003080712	562.6	0.4	2.4	0.9
23	2003081101	2003081107	339.6	0.2	0.8	0.7
24	2003081803	2003081914	2994.7	0.5	14.1	5.6
25	2003082020	2003082107	251.2	0.2	0.5	0.6
26	2003083013	2003083109	344.2	0.3	0.9	0.7
27	2003091201	2003091304	3390.4	0.6	21.4	5.6
28	2003111020	2003111117	359.3	0.2	0.8	0.9
	sum		23007.6		103.8	44.8

C.5 SEOKBO RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003041819	2003041907	304.6	0.2	0.7	0.7
2	2003041922	2003042008	254.6	0.1	0.3	0.7
3	2003042305	2003042314	224.5	0.1	0.3	0.6
4	2003042502	2003042519	1036.6	0.3	3.3	2.2
5	2003042909	2003042921	736.7	0.4	3.2	1.5
6	2003050712	2003050803	666.3	0.2	1.6	1.5
7	2003052501	2003052521	563.3	0.2	1.1	1.4
8	2003052924	2003053023	1341.7	0.3	4.2	2.8
9	2003061123	2003061213	369.4	0.2	0.6	0.9
10	2003061906	2003061918	571.1	0.2	1.3	1.3
11	2003062312	2003062318	229.1	0.2	0.5	0.6
12	2003062708	2003062803	1377.1	0.4	4.9	2.7
13	2003070302	2003070311	1532.4	0.6	9.0	2.4
14	2003070824	2003071013	1261.9	0.6	7.9	2.5
15	2003071301	2003071310	931.3	0.4	3.3	1.8
16	2003071804	2003071816	516.6	0.2	1.2	1.2
17	2003072215	2003072306	771.0	0.7	5.8	1.2
18	2003072501	2003072507	695.6	0.7	4.7	1.1
19	2003072823	2003072910	329.9	0.2	0.8	0.7
20	2003080707	2003080712	1048.6	0.7	7.8	1.4
21	2003081101	2003081107	835.3	0.6	4.9	1.4
22	2003081803	2003081914	4396.4	1.0	45.0	7.4
23	2003082020	2003082107	1031.2	0.7	7.7	1.6
24	2003083013	2003083109	659.1	0.2	1.3	1.6
25	2003090214	2003090219	393.7	0.5	1.9	0.7
26	2003091201	2003091304	8010.2	2.0	164.0	9.8
27	2003111020	2003111117	385.7	0.2	0.6	0.9
28	2003112717	2003112901	308.4	0.1	0.2	0.9
	sum		30782.4		288.1	53.5

C.6 YOUNGYANG RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	191.7	0.1	0.2	0.5
2	2003041819	2003041907	371.9	0.2	0.9	0.9
3	2003041922	2003042008	246.1	0.2	0.4	0.6
4	2003042305	2003042314	208.0	0.1	0.2	0.6
5	2003042502	2003042519	827.2	0.4	2.9	1.8
6	2003042909	2003042921	718.5	0.3	2.3	1.5
7	2003050618	2003050624	284.6	0.2	0.4	0.7
8	2003050712	2003050803	721.7	0.2	1.7	1.6
9	2003052501	2003052521	548.7	0.2	1.1	1.3
10	2003052924	2003053023	844.0	0.2	2.0	1.9
11	2003061123	2003061213	248.8	0.1	0.3	0.7
12	2003061906	2003061918	251.7	0.2	0.4	0.6
13	2003062312	2003062318	370.0	0.2	0.9	0.8
14	2003062708	2003062803	1546.5	0.5	7.3	2.8
15	2003070302	2003070311	770.3	0.3	2.4	1.5
16	2003070824	2003071013	1405.3	0.8	11.1	2.6
17	2003071301	2003071310	532.4	0.3	1.5	1.1
18	2003071804	2003071816	661.9	0.2	1.6	1.5
19	2003072207	2003072208	798.0	0.9	7.2	1.0
20	2003072215	2003072306	788.3	0.6	5.0	1.4
21	2003072501	2003072507	1240.7	1.0	12.7	1.7
22	2003072823	2003072910	216.0	0.2	0.3	0.6
23	2003080707	2003080712	1096.7	1.0	11.2	1.4
24	2003081803	2003081914	2550.3	0.5	12.0	5.2
25	2003082020	2003082107	730.9	0.7	4.9	1.2
26	2003083013	2003083109	451.7	0.1	0.5	1.2
27	2003090308	2003090318	247.4	0.3	0.7	0.5
28	2003090906	2003090908	827.2	0.9	7.8	1.0
29	2003091201	2003091304	3341.9	0.9	31.6	5.4
30	2003111020	2003111117	379.6	0.2	0.7	0.9
	sum		23417.9		132.2	44.6

C.7 BUNAM RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	273.9	0.1	0.3	0.7
2	2003041819	2003041907	345.1	0.2	0.5	0.8
3	2003041922	2003042008	314.7	0.2	0.5	0.8
4	2003042305	2003042314	344.4	0.2	0.7	0.8
5	2003042502	2003042519	887.9	0.4	3.1	1.9
6	2003042909	2003042921	632.1	0.4	2.5	1.3
7	2003050712	2003050803	648.8	0.3	1.8	1.4
8	2003052501	2003052521	724.0	0.2	1.4	1.7
9	2003052924	2003053023	1900.4	0.4	7.5	3.7
10	2003061123	2003061213	407.2	0.2	0.6	1.0
11	2003061906	2003061918	879.5	0.3	2.4	1.9
12	2003062708	2003062803	1238.7	0.4	5.4	2.4
13	2003070302	2003070311	1495.0	0.6	8.8	2.5
14	2003070617	2003070621	533.5	0.3	1.5	1.1
15	2003070824	2003071013	1494.4	0.5	7.1	3.0
16	2003071301	2003071310	1066.9	0.4	4.2	2.0
17	2003071804	2003071816	703.7	0.4	2.5	1.5
18	2003072207	2003072208	441.8	0.6	2.6	0.6
19	2003072215	2003072306	500.7	0.5	2.6	0.9
20	2003072501	2003072507	597.5	0.5	3.1	1.0
21	2003072823	2003072910	1806.4	0.7	12.1	2.9
22	2003080707	2003080712	236.7	0.3	0.7	0.5
23	2003081101	2003081107	286.7	0.2	0.6	0.7
24	2003081803	2003081914	3321.0	1.0	32.7	5.6
25	2003082020	2003082107	260.0	0.2	0.6	0.6
26	2003083013	2003083109	671.7	0.3	2.1	1.5
27	2003091201	2003091304	5097.4	1.1	54.2	7.5
28	2003111020	2003111117	382.8	0.2	0.6	1.0
29	2003112717	2003112901	289.7	0.1	0.3	0.8
	sum		27782.6		162.9	52.0

C.8 ILWOL RAINFALL STATION

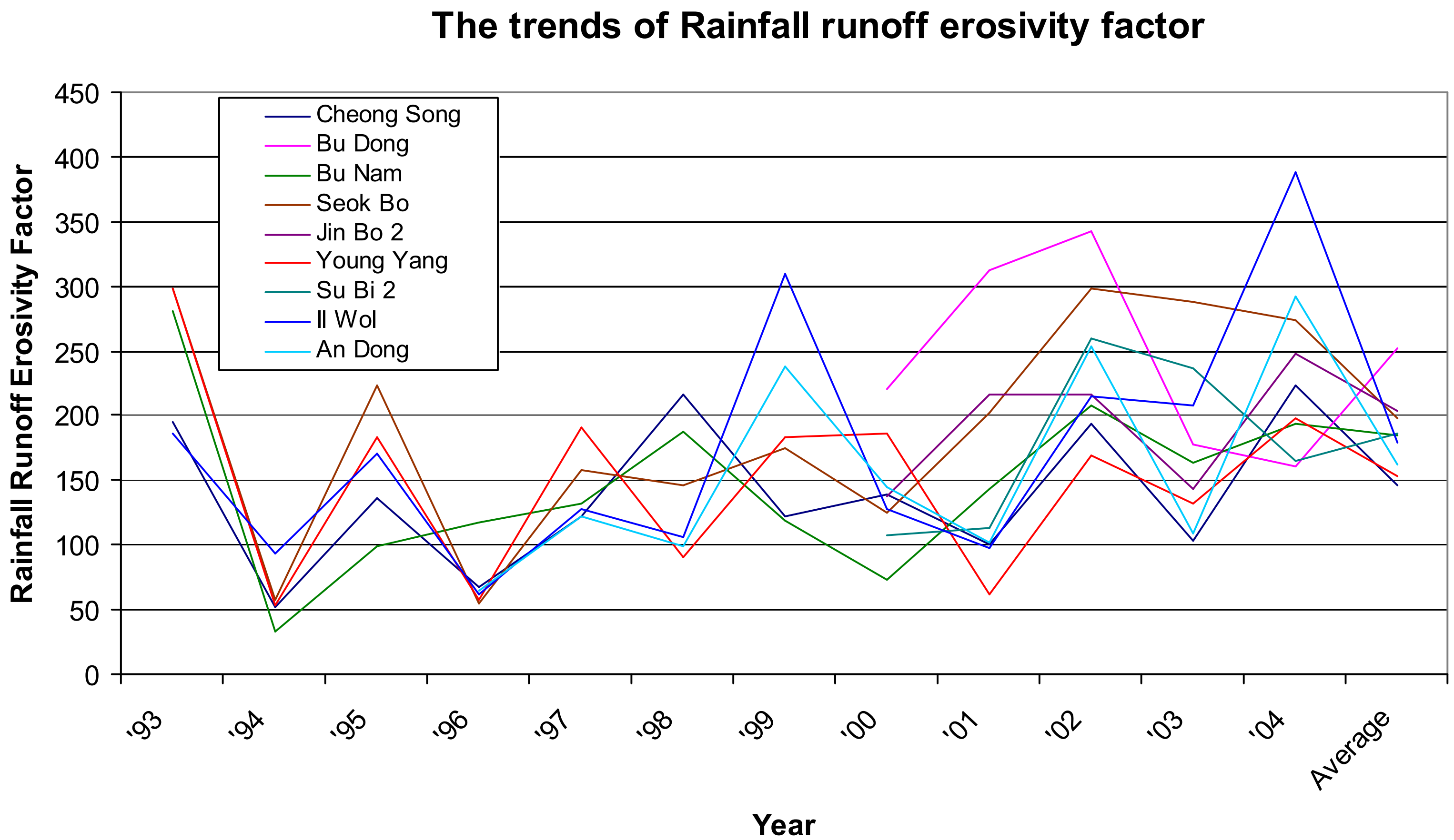
Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003022206	2003022213	250.3	0.3	0.7	0.6
2	2003040723	2003040809	296.0	0.1	0.3	0.7
3	2003041819	2003041907	333.2	0.2	0.7	0.8
4	2003041922	2003042008	235.4	0.1	0.2	0.6
5	2003042502	2003042519	998.1	0.3	3.1	2.2
6	2003042909	2003042921	1120.0	0.4	4.0	2.2
7	2003050712	2003050803	948.4	0.5	4.9	1.9
8	2003052501	2003052521	707.2	0.2	1.7	1.7
9	2003052924	2003053023	790.2	0.2	1.9	1.8
10	2003061123	2003061213	309.4	0.1	0.4	0.8
11	2003061520	2003061523	379.2	0.4	1.6	0.7
12	2003061906	2003061918	213.8	0.1	0.3	0.6
13	2003062312	2003062318	403.7	0.2	0.8	0.9
14	2003062708	2003062803	1915.4	0.5	9.0	3.4
15	2003070302	2003070311	964.5	0.4	4.2	1.7
16	2003070824	2003071013	2985.7	0.7	22.3	5.0
17	2003071301	2003071310	623.1	0.3	2.0	1.3
18	2003071804	2003071816	814.7	0.3	2.6	1.7
19	2003072207	2003072208	327.8	0.5	1.5	0.5
20	2003072215	2003072306	520.7	0.3	1.4	1.2
21	2003072501	2003072507	1387.8	1.3	17.5	1.7
22	2003072823	2003072910	232.0	0.2	0.5	0.6
23	2003080707	2003080712	1132.8	1.2	13.4	1.3
24	2003081101	2003081107	213.5	0.2	0.3	0.5
25	2003081803	2003081914	2696.2	0.5	12.7	5.3
26	2003082020	2003082107	511.8	0.4	2.2	0.9
27	2003082714	2003082724	573.8	0.3	1.8	1.2
28	2003083013	2003083109	487.4	0.1	0.6	1.3
29	2003090308	2003090318	436.5	0.5	2.1	0.7
30	2003090906	2003090908	381.3	0.5	2.0	0.6
31	2003091201	2003091304	5718.0	1.6	90.0	7.8
32	2003111020	2003111117	371.1	0.2	0.7	0.9
33	2003111214	2003111302	208.0	0.2	0.3	0.5
34	2003120522	2003120611	218.7	0.1	0.3	0.6
	sum		29705.6		207.9	54.1

C.9 ANDONG RAINFALL STATION

Storms N.	TIME		Total Energy (ft·ton/acre)	Max. Intensity (in/hr)	Rainfall Energy (ft·ton/acre·in/hr)	Rain depth (in)
	Begin	End				
1	2003040723	2003040809	308.6	0.2	0.6	0.7
2	2003041819	2003041907	318.2	0.2	0.8	0.7
3	2003041922	2003042008	257.3	0.1	0.3	0.7
4	2003042305	2003042314	205.0	0.1	0.2	0.6
5	2003042502	2003042519	1029.7	0.3	3.2	2.2
6	2003042909	2003042921	726.1	0.3	2.0	1.6
7	2003050618	2003050624	320.4	0.2	0.8	0.7
8	2003050712	2003050803	1032.3	0.4	4.1	2.1
9	2003052501	2003052521	535.3	0.2	1.1	1.3
10	2003052924	2003053023	818.0	0.2	1.9	1.9
11	2003061123	2003061213	380.6	0.1	0.4	1.0
12	2003061520	2003061523	407.8	0.3	1.3	0.7
13	2003061906	2003061918	246.6	0.1	0.3	0.6
14	2003062312	2003062318	343.9	0.2	0.7	0.8
15	2003062708	2003062803	1776.3	0.6	10.5	3.1
16	2003070302	2003070311	1112.9	0.6	6.1	1.9
17	2003070824	2003071013	2400.0	0.6	15.1	4.4
18	2003071301	2003071310	542.0	0.3	1.7	1.1
19	2003071804	2003071816	452.4	0.2	1.1	1.1
20	2003072207	2003072208	363.5	0.5	1.7	0.6
21	2003072215	2003072306	994.0	0.7	7.4	1.7
22	2003072501	2003072507	989.2	0.7	7.4	1.6
23	2003072823	2003072910	359.7	0.3	1.0	0.8
24	2003080707	2003080712	378.3	0.5	1.9	0.6
25	2003081803	2003081914	2714.7	0.4	10.7	5.4
26	2003082020	2003082107	271.7	0.2	0.6	0.6
27	2003082714	2003082724	327.9	0.2	0.5	0.8
28	2003083013	2003083109	531.7	0.1	0.6	1.3
29	2003090308	2003090318	317.2	0.4	1.1	0.6
30	2003090906	2003090908	351.1	0.5	1.8	0.5
31	2003091201	2003091304	2641.9	0.8	20.8	4.6
32	2003111020	2003111117	473.1	0.2	1.1	1.1
33	2003120522	2003120611	248.8	0.2	0.4	0.6
	sum		24176.5		109.4	48.2

C.10 The trends of Rainfall Runoff Erosivity Factor

No.	Stations	Rainfall Runoff Erosivity Factor												
		'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	Average
1	Cheong Song	194.4	51.0	136.7	67.0	121.3	216.2	122.3	139.1	101.0	193.4	103.8	223.1	146.2
2	Bu Dong								221.1	311.7	342.4	178.3	161.2	251.8
3	Bu Nam	280.9	33.0	99.6	117.1	131.7	188.0	119.3	73.6	143.8	207.7	162.9	192.9	184.8
4	Seok Bo	298.2	57.9	223.0	54.2	157.2	146.5	175.2	125.3	202.0	298.5	288.1	274.4	197.1
5	Jin Bo 2								137.3	216.0	216.2	143.1	247.3	203.0
6	Young Yang	297.8	52.7	183.5	57.5	190.7	90.6	182.8	187.0	61.0	168.4	132.2	197.2	154.0
7	Su Bi 2								107.3	113.6	259.6	236.3	164.3	186.6
8	Il Wol	186.7	93.0	170.7	61.7	127.4	106.7	309.9	128.0	97.0	214.4	207.9	388.0	179.6
9	An Dong				64.9	121.8	98.9	237.2	145.1	101.7	253.3	109.4	292.0	162.2


The trends of Rainfall runoff erosivity factor
Rainfall Runoff Erosivity Factor
450
400
350
300
250
200
150
100
50
0
Cheong Song
Bu Dong
Bu Nam
Seok Bo
Jin Bo 2
Young Yang
Su Bi 2
Il Wol
An Dong
'93
'94
'95
'96
'97
'98
'99
'00
'01
'02
'03
'04
Average
Year

APPENDIX D – Unified Soil Classification (USC) System (ASTM D 2487)

Unified Soil Classification (USC) System (from ASTM D 2487)

Major Divisions			Group Symbol	Typical Names
Course-Grained Soils More than 50% retained on the No. 200 sieve	**Gravels** 50% or more of course fraction retained on the No. 4 sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands 50% or more of course fraction passes the No. 4 sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-Grained Soils More than 50% passes the No. 200 sieve	**Silts and Clays** Liquid Limit 50% or less		ML	Inorganic silts, very fine sands, rock four, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and Clays Liquid Limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays or high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly Organic Soils			PT	Peat, muck, and other highly organic soils

Prefix: G = Gravel, S = Sand, M = Silt, C = Clay, O = Organic
Suffix: W = Well Graded, P = Poorly Graded, M = Silty, L = Clay, LL < 50%, H = Clay, LL > 50%

APPENDIX E – Determination of C factor based on Lysimeter- experiments (NIAST, 2003)

Cover management factor (C) (NIAST, 2003)

Coverage Crop	C factor	S.D.	Period	Coverage Crop	C factor	S.D.	Period
Soybean	0.19	0.10	1977~1984 1998~2001	Chinese cabbage	0.59	0.24	1998~2001
Red Pepper	0.28	0.09	1981~1982 1994~2001	Orchard grass covered	0.01	0.001	1984~1985 1992
Maize	0.44	0.03	1977~1982				
Upland rice	0.34	0.02	1977~1982	non covered	0.43		1992
Yulmu*	0.18		1986~1987	Grassland	0.003	0.003	1978~1982 1986~1987 1991~1992
Peanut	0.06	0.03	1986~1989	(1st year)	0.47		1977, 1990

* "Yulmu" is the Korean practical name of Coix lachrymajobi var. mayuen

APPENDIX F – Particle Size Distribution at the the Intake tower of the Imha reservoir

Particle size (micron)	Water Depth					
	12m	Cummulative(%)	16m	Cummulative(%)	20m	Cummulative(%)
0.224	0.000	0.000	0.000	0.000	0.000	0.000
0.252	0.043	0.043	0.170	0.170	0.172	0.172
0.283	0.161	0.204	0.769	0.939	0.773	0.944
0.317	0.554	0.758	1.171	2.110	1.164	2.108
0.356	0.928	1.686	1.611	3.721	1.583	3.692
0.399	1.310	2.996	2.010	5.731	1.951	5.643
0.448	1.681	4.677	2.347	8.078	2.249	7.892
0.502	1.976	6.653	2.613	10.691	2.471	10.363
0.564	2.190	8.843	2.798	13.489	2.609	12.972
0.632	2.298	11.141	2.892	16.381	2.658	15.630
0.710	2.308	13.448	2.900	19.281	2.624	18.254
0.796	2.234	15.682	2.831	22.112	2.523	20.777
0.893	2.106	17.789	2.708	24.820	2.375	23.153
1.002	1.963	19.752	2.560	27.380	2.211	25.363
1.125	1.846	21.598	2.423	29.803	2.065	27.428
1.262	1.788	23.386	2.328	32.131	1.964	29.392
1.416	1.816	25.203	2.303	34.434	1.934	31.326
1.589	1.947	27.150	2.361	36.795	1.984	33.310
1.783	2.181	29.331	2.497	39.292	2.109	35.419
2.000	2.519	31.850	2.700	41.993	2.298	37.716
2.244	2.954	34.804	2.956	44.949	2.536	40.252
2.518	3.470	38.274	3.247	48.196	2.808	43.060
2.825	4.049	42.322	3.557	51.753	3.099	46.160
3.170	4.629	46.951	3.849	55.602	3.377	49.537
3.557	5.170	52.121	4.103	59.706	3.625	53.162
3.991	5.590	57.711	4.280	63.986	3.808	56.971
4.477	5.837	63.547	4.360	68.346	3.910	60.880
5.024	5.862	69.409	4.321	72.667	3.912	64.792
5.637	5.651	75.061	4.162	76.829	3.810	68.602
6.325	5.216	80.276	3.886	80.715	3.608	72.210
7.096	4.612	84.888	3.520	84.235	3.326	75.536
7.962	3.890	88.779	3.084	87.319	2.979	78.514
8.934	3.149	91.928	2.626	89.945	2.607	81.121
10.024	2.430	94.358	2.165	92.111	2.226	83.347
11.247	1.803	96.160	1.743	93.854	1.871	85.218
12.619	1.282	97.442	1.369	95.223	1.554	86.772
14.159	0.877	98.319	1.056	96.279	1.287	88.059
15.887	0.582	98.901	0.808	97.087	1.076	89.134
17.825	0.375	99.276	0.617	97.704	0.916	90.050
20.000	0.241	99.517	0.480	98.185	0.808	90.858
22.440	0.156	99.672	0.384	98.569	0.739	91.598
25.179	0.105	99.778	0.322	98.891	0.705	92.303
28.251	0.075	99.853	0.280	99.171	0.694	92.997
31.698	0.055	99.908	0.247	99.418	0.698	93.695
35.566	0.042	99.951	0.219	99.638	0.708	94.404
39.905	0.029	99.980	0.182	99.820	0.717	95.121
44.774	0.017	99.997	0.139	99.959	0.719	95.840
50.238	0.003	100.000	0.041	100.000	0.709	96.549
56.368	0.000	100.000	0.000	100.000	0.685	97.234
63.246	0.000	100.000	0.000	100.000	0.646	97.880
70.963	0.000	100.000	0.000	100.000	0.590	98.470
79.621	0.000	100.000	0.000	100.000	0.520	98.990
89.337	0.000	100.000	0.000	100.000	0.426	99.416
100.237	0.000	100.000	0.000	100.000	0.329	99.745
112.468	0.000	100.000	0.000	100.000	0.229	99.974
126.191	0.000	100.000	0.000	100.000	0.026	100.000

APPENDIX G – Imha multi-purpose dam data during the typhoon "Maemi"

Date	Water Level (El.m)	Inflow Dis. (cms)	Tot. Outflow Dis. (cms)	Power outflow(1)	Spillway outflow(2)	Rainfall (mm)
03-09-12 01	155.90	37.1	476.1	107.2	368.9	1.1
03-09-12 02	155.86	253.4	472.5	107.1	365.4	0.5
03-09-12 03	155.80	140.5	468.6	107.0	361.6	2.1
03-09-12 04	155.74	138.0	465.4	107.0	358.4	4.9
03-09-12 05	155.69	189.7	462.0	107.0	355.0	6.6
03-09-12 06	155.64	187.0	458.8	106.9	351.9	7.2
03-09-12 07	155.60	238.9	456.0	107.0	349.1	12.0
03-09-12 08	155.59	400.9	455.1	106.9	348.2	8.3
03-09-12 09	155.61	563.8	455.3	107.0	348.4	3.6
03-09-12 10	155.70	947.6	458.4	107.0	351.4	1.5
03-09-12 11	155.80	1010.2	464.9	107.0	357.9	1.6
03-09-12 12	155.95	1294.2	472.9	107.2	365.7	4.5
03-09-12 13	156.15	1583.6	482.0	107.4	374.7	11.6
03-09-12 14	156.33	1489.1	491.4	107.5	383.9	10.5
03-09-12 15	156.51	1504.0	500.2	107.5	392.8	1.1
03-09-12 16	156.74	1801.9	510.6	107.6	403.0	0.0
03-09-12 17	156.95	1707.6	519.9	105.9	414.0	0.0
03-09-12 18	157.17	1785.3	532.3	107.9	424.4	0.0
03-09-12 19	157.34	1516.0	541.5	108.0	433.5	0.1
03-09-12 20	157.49	1403.9	539.6	106.3	433.4	3.6
03-09-12 21	157.61	1190.8	539.6	106.3	433.4	9.4
03-09-12 22	157.61	1010.0	945.1	102.0	843.2	13.7
03-09-12 23	157.61	1388.7	1446.6	107.9	1338.7	23.9
03-09-12 24	157.73	2280.0	1524.8	110.8	1414.0	26.9
03-09-13 01	158.20	4387.5	1630.6	111.0	1519.5	23.0
03-09-13 02	158.91	5607.4	1363.2	110.9	1252.3	3.9
03-09-13 03	159.81	6664.5	1024.2	98.4	925.8	0.8
03-09-13 04	160.60	6194.3	1045.4	100.5	945.0	0.7
03-09-13 05	161.24	5342.3	1041.8	102.1	939.7	0.3
03-09-13 06	161.81	4936.6	1076.5	100.5	976.0	0.1
03-09-13 07	162.21	3988.7	1103.9	98.9	1005.0	0.0
03-09-13 08	162.40	2436.0	1082.1	99.3	982.9	0.0
03-09-13 09	162.49	1645.0	999.9	99.6	900.4	0.0
03-09-13 10	162.54	1356.7	997.2	99.4	897.8	0.0
03-09-13 11	162.59	1143.4	783.1	99.8	683.4	0.0
03-09-13 12	162.63	901.9	613.2	100.1	513.1	0.0

Date	Water Level (El.m)	Inflow Dis. (cms)	Tot. Outflow Dis. (cms)	Power outflow(1)	Spillway outflow(2)	Rainfall (mm)
03-09-13 13	162.70	828.1	321.6	99.5	222.1	0.0
03-09-13 14	162.77	621.3	113.3	98.3	15.1	0.0
03-09-13 15	162.84	607.9	98.4	98.4	0.0	0.0
03-09-13 16	162.89	463.2	98.4	98.4	0.0	0.0
03-09-13 17	162.94	464.1	98.5	98.5	0.0	0.0
03-09-13 18	162.98	391.6	98.6	98.6	0.0	0.0
03-09-13 19	163.02	358.6	65.1	65.1	0.0	0.0
03-09-13 20	163.06	342.1	48.1	48.1	0.0	0.0
03-09-13 21	163.10	342.7	48.2	48.2	0.0	0.0
03-09-13 22	163.13	269.4	48.2	48.2	0.0	0.0
03-09-13 23	163.16	269.2	47.7	47.7	0.0	0.0
03-09-13 24	163.19	269.1	47.3	47.3	0.0	0.0
03-09-14 01	163.22	269.3	47.3	47.3	0.0	0.0
03-09-14 02	163.24	195.5	47.3	47.3	0.0	0.0
03-09-14 03	163.26	195.6	47.3	47.3	0.0	0.0
03-09-14 04	163.29	270.0	47.3	47.3	0.0	0.0
03-09-14 05	163.31	196.0	47.3	47.3	0.0	0.0
03-09-14 06	163.33	196.1	47.3	47.3	0.0	0.0
03-09-14 07	163.34	121.8	47.3	47.3	0.0	0.0
03-09-14 08	163.36	196.3	47.3	47.3	0.0	0.0
03-09-14 09	163.37	121.9	47.4	47.4	0.0	0.0
03-09-14 10	163.39	196.5	47.4	47.4	0.0	0.0
03-09-14 11	163.40	122.0	47.4	47.4	0.0	0.0
03-09-14 12	163.42	196.7	47.4	47.4	0.0	0.0
03-09-14 13	163.43	122.1	47.4	47.4	0.0	0.0
03-09-14 14	163.44	122.1	47.4	47.4	0.0	0.0
03-09-14 15	163.45	122.2	47.4	47.4	0.0	0.0
03-09-14 16	163.46	122.2	47.4	47.4	0.0	0.0
03-09-14 17	163.47	122.3	47.4	47.4	0.0	0.0
03-09-14 18	163.48	122.3	47.4	47.4	0.0	0.0
03-09-14 19	163.49	122.4	47.5	47.5	0.0	0.0
03-09-14 20	163.50	122.4	47.5	47.5	0.0	0.0
03-09-14 21	163.50	47.4	47.4	47.4	0.0	0.0
03-09-14 22	163.51	122.4	47.4	47.4	0.0	0.0
03-09-14 23	163.52	122.4	47.5	47.5	0.0	0.0
03-09-14 24	163.52	47.5	47.5	47.5	0.0	0.0