# GIS based DSS for Optimal Erosion Management: A Case Study of the Huai Talupkup Watershed, Thailand

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**Abstract**

*A Geographic Information System based Decision Support System (GIS based DSS) was developed for evaluating the optimal erosion management (which includes soil and water conservation: SWC and crop management system: CMS) alternatives watershed based upon the multi-objectives such as greatest physical effectiveness, cost-benefit return and social benefit acceptance. The system has been developed by integrating the decision element models: erosion model (Universal Soil Loss Equation: USLE, Modified USLE: MUSLE, Potential Nutrient Loss Model), economic model (Cost-Benefit Analysis: CBA), and social benefit model (Net Benefit Index: NBI), with a SWC knowledge based system (SWC-KBS) and multi-objectives optimization approach, into one system, using Arc-View GIS and Visual Basic programming. The application was tested in the Huai Talupkup small watershed, Thailand, an area of 1,550 ha. The selected optimal erosion management for 10 land class units (LCUs), which were based upon the similarity of land management regime which include a variety of terrace practices and suitable crop management systems. The selected optimal erosion management from the system, using a discount rate of 8 % and a project lifetime of 10 years, was found to have a net present value (NPV) of about 9.52 million Thai baht, erosion (soil loss) could be reduced about 78 % while the social net benefit index increased by 47 % from current conditions. The system proposed in this research enables quick review of results for different erosion management alternatives using preference criteria settings, which might not be possible with a dispersed analytical systems computation. It is suggested that this system can be applied to other watersheds for evaluating and enhancing the accuracy in effective decision-making in the optimal erosion management at the small watershed level.*

## 1. Introduction

Mountainous terrain covers 72% of northern Thailand. Mountainous areas form parts of the head-watershed, have rolling topography and were formerly covered with forests. Unsustainable land use practices have degraded some of this land, causing accelerated erosion problems for centuries (Hansen, 2001, LDD, 2002 and Forsyth, 2007). While erosion problems on farm fields reduce potential crop production by altering soil chemical and physical properties (Lal, 1998, Tenge et al., 1998 and Arriaga and Lowery, 2003), the most important consequences of erosion are pollution and sedimentation downstream. These consequences include siltation of canals, reservoirs sedimentation, flooding disaster, etc., rather than loss of productivity on-site alone (Vanoni, 1982, Morgan et al., 1998, FAO, 1999, Mihara et al., 2005 and Sadeghi et al., 2007), a problem which – combined with damage by on-site and off-site erosion – will require a large amount of money to solve. Proper soil erosion management, planning and implementation could prevent these problems. The main objective in erosion management is to increase agricultural production while minimizing erosion to an acceptable level (Tenge et al., 2004). In the past, erosion control management mainly aimed at reduction of erosion occurring in the highlands and generally neglected the economic/financial implications of the proposed erosion measures and farmers/other stakeholders' participation in the planning stage (Conte, 1999). However, for the erosion control management to be attractive, its costs should not exceed the benefits. Translating the erosion losses and benefits of erosion management


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measures into economic terms will motivate farmers, policy makers and other actors to invest in soil erosion control measures (Lal, 1998). Erosion management practice selection in particular areas, in line with a maximum level requirement, is a complex process, normally based on other factors beside the physical effectiveness, benefit and cost of implement and social acceptance (Troch et al., 1999) and often without a fully satisfactory solution, making it subject to critical analyses of each option. Planners are required to develop basic conservation plans which are designed to reduce erosion to T (tolerable) level. Where reducing erosion to T is more costly (Tenge et al., 2004), each option is subject to critical analysis of its economic efficiency, and this often involves a difficult decision-making process. In each case, the best alternative can be determined by its physical effectiveness, together with a cost-benefit analysis (FAO, 1996 and Troch et al., 1999). The effective costs and benefits of erosion control management usually involve farmers' and public investors' benefit returns. Generally the benefit return from soil erosion control can be evaluated both on-site and off-site. The on-site benefit implies saving soil for future use, while the off-site benefits include protection of reservoirs against sedimentation, nutrient pollution, reduced flooding, etc. (Barbier, 1995 and Crosson, 2003). The erosion measures with cost-benefit analysis of positive net present value (NPV) and economic internal rate of return (EIRR) greater than the respective discount rate were considered to be profitable and financially attractive (Renaud, 1996 and Tenge et al., 2004). DSS are developed using GIS under the belief that these systems are able to improve our understanding of the inter-relationships between natural and socio-economic variables and, hence, result in improved decision making (Fabbri, 1998, Westmacott, 2001 and Ross et al., 2005). A GIS-based DSS includes the integration of a geographic database management system with a decision element model, and features multi-criteria optimized analytical modeling capability, a visualization component, and a user-friendly interface for more effective decision-making in multi-objective spatial decision problems (Georgakakos et al., 2002 and Boroushaki and Malczewski, 2008). DSSs as management tools can assist strategy developers by defining the problem, generating alternative solutions, evaluating the alternatives, and indicating the best alternative for implementation (Geneletti, 2004 and Mbilinyi et al., 2007). Many GIS based DSSs have been developed for various spatial decision problems in the environmental domain, such as for soil and water conservation measures on a watershed (Sarangi et al., 2004), for precise best management practice selection (Gitau et al., 2004 and Muleta and Nicklow, 2005), and for precision agriculture (Wang, 2001). Based on the above, a GIS based DSS has great potential for use in decision making for sustainable land use planning. However, there are only a few GIS based DSS systems for optimal erosion management evaluation in terms of site-specific multiple objectives that include the greatest effectiveness, cost-benefit return. The objectives of this research are to explore the possibilities of developing GIS-based DSS technology as a participatory way for decision making about the most preferred erosion management practice options according to the greatest effectiveness and cost-benefit return of land category and watershed level to assist planners in optimal erosion management.

## 2. GIS based DSS Development Approach and Procedure

The concept of developing a GIS based DSS for evaluating the optimal erosion control management is to create a new systematic tool to evaluate the optimal multi-criteria erosion control management for the land unit class (LUC) in a watershed. Erosion control management is defined in this study as a combination of soil and water conservation practice (SWC) and crop management system (CMS). There are 3 decision elements to be evaluated in the set of optimal SWC and CMS: erosion level, economic return and social benefit return as well as ordering the best options of user decision scores by the analytical hierarchy process (AHP) approach. The system was developed in a vector-based GIS environment using ArcView 3.2a software, and is operated via a user interface written in Visual Basic. A tight coupling method (Burrough, 1986 and Wesseling et al., 1996) was employed for data exchange between the GIS, the decision element models, and optimization model. The details of the system can be summarized as:

### *2.1 User Interface Development*

The DSS system consists of four main menus, which are operated via a graphical user interface (GUI). The main menus are: Decision Element Models-Data Input; SWC-Knowledge-Based System, Data-Analysis, and DSS-Report. The main menu for the Decision Element Models-Data input is designed for users to input/edit the parameters requirement of decision element models and preference criteria settings in the optimization approach. The SWC-Knowledge-Based System menu is designed to collect the database and the regulations requirement of various SWC and CMS in terms of physical setting. The DSS-Data Analysis menu is designed for automatic simulation of the decision element models and the best SWC& CMS selection by optimization model. Finally, the DSS-Report menu displays a tabular quantitative decision element models simulation that reports the optimal erosion management option for each LUC and watershed level.

### *2.2 Decision Element Models*

Three decision elements to be evaluated to select the optimal erosion management alternative include the erosion model (soil loss, sediment yield and potential nutrient loss model), the economic model (Cost-benefit analysis: CBA) and the social benefit return (net benefit increment Index: NBI). The details of each decision element models are as follows:

#### *2.2.1 Soil loss model*

The Universal Soil Loss Equation: USLE (Wischmeier and Smith, 1978) has been used to predict soil loss and rank alternative practices with regard to their likely impact on onsite erosion (Laflen et al., 1991; Rosa et al., 2005) for comparison between current conditions and the set of SWC & CMS options in each LUC. The equation enables planners to predict average rate of soil loss for each alternate SWC & CMS on any particular site. A soil-loss tolerance level then can be established by comparing the accepted value with the predicted soil loss. The details of the USLE model are seen in the equation.

$$A = RKLSCP$$

Equation 1

where A is the computed soil loss per unit area (tons/ha/yr), R is the rainfall factor (erosivity in units of metric tons/ha/yr), K is the soil erodibility factor (tons/ha/yr), LS is the slope gradient and slope length factor (dimensionless), C is the crop management factor (dimensionless), and P is the soil and water conservation practice factor (dimensionless).

#### *2.2.2 Sediment yield model*

Sediment yield from upland areas is the net result of detachment, transport, and deposition processes occurring from the watershed divide down to the point of interest where sediment yield information is needed (Sadeghi et al., 2007). The MUSLE has been used to rank alternative practices with regard to their likely impact on offsite erosion. The MUSLE has been widely used and validated to estimate sediment yield in many countries (Johnson et al., 1986, Epifanio et al., 1991, Clemente, 1991, Clemente et al., 1993, Kinnell and Riss, 1998, Erskine et al. 2002, Fontes et al., 2004, Kandrika and Venkataratnam, 2005 and Sadeghi et al., 2007). The MUSLE developed as a watershed-based model to estimate the sediment yield produced by each individual storm event. (Williams, 1975). In MUSLE, the rainfall (R) factor is replaced with a term that combines storm runoff volume ($Q_v$ in $m^3$) and peak runoff rate ($q_p$ in $m^3 s^{-1}$), and interprets the other USLE factors on a watershed-wide and individual storm event basis. The model is calculated as:

$$X_t = 11.8(Q_v q_p)^{0.56} KLSCP$$

Equation 2

where $X_t$ is the sediment yield from a rainfall event in metric tons, $Q_v$ is the runoff volume ($m^3$), $q_p$ is the peak runoff rate ($m^3 s^{-1}$), and K, LS, C, P are the same as in USLE. $Q_v$ is the runoff volume ($m^3$) given by $100AQ_t$, $q_p$ is the peak runoff rate ($m^3 s^{-1}$). The runoff volume ($100AQ_t$) is estimated using the SCS method (USDA-SCS, 1972):

$$Q_t = (R_t - 0.2S_t)^2/(R_t + 0.8S_t)$$

Equation 3

where $Q_t$ is the storm runoff depth (cm.), $R_t$ is the storm rainfall (cm), and $S_t$ is the retention potential (cm.) which can be expressed in terms of Curve Number (CN) as $S_t$ equal (2540/CN) – 25.4.The peak runoff is estimated using the SCS method (USDA-SCS, 1972):

$$q_p = 0.028\,A\,(R_t/T_t)^{*}(Q_t/R_t - 0.2S_t)$$

Equation 4

where $q_p$ is the peak runoff ($m^3 s^{-1}$), A is the area (ha.), $R_t$ is the daily total rainfall (cm), $T_t$ is the rainfall duration (hr), $Q_t$ is the storm runoff depth (cm), and $S_t$ is the retention potential (cm).

#### *2.2.3 Potential nutrient loss*

Erosion carries away soil particles and organic matter with their associated nutrients, and fertilizer (FAO, 1999 and Mihara et al., 2005); generally the nutrient losses come with soil loss which reflects the loss of soil productivity (Lal, 1987). Assessing the nutrient loss is essential for effective planning of soil erosion control strategies.

The potential nutrient loss in this research is computed based on the assumption of Troch et al. (1999) that nutrient loss depends on the characteristics of eroded soil, and that 0-3% of total soil is organic matter (OM) consisting of about 5% N (nitrogen), 0.5% P (phosphorus) and trace amounts of K (potassium), combined with mineral forms of nitrogen, phosphorus and potassium of each soil type. The weight of total nitrogen, phosphorus and potassium loss per ton of eroded soil is then calculated, assuming that a ton of each soil loss will represent the nutrient loss proportion from each soil type.

### *2.2.4 Economic analysis*

Analysis of economic feasibility of erosion management alternative using CBA was applied (Renaud, 1996, Tenge et al., 2004 and Perkins et al., 2006). Cost-benefit analysis consists of three main steps: 1) analysis of the SWC & CMS cost; 2) analysis of the benefit return; and 3) analysis of the feasibility of SWC & CMS options for each LCU. Analysis of the cost includes the cost of practices investment (per ha); the analysis of benefit return includes benefits from the new proposed SWC & CMS options which are determined by a comparison between the current and new management systems. The important indicators of CBA are NPV, B/C and EIRR, which can be expressed as follows:

$$NPV_i = \sum_{t=1}^{n} (B_{ti} - C_{ti})/(1+r)^t$$

Equation 5

$$B/C_i = \sum_{t=1}^{n} (B_{ti})/(1+r)^t / \sum_{t=1}^{n} (C_{ti})/(1+r)^t$$

Equation 6

$$EIRR_i = \sum_{t=1}^{n} (B_{ti} - C_{ti})/(1+r)^t = 0$$

Equation 7

where $NPV_i$, $B/C_i$ and $EIRR_i$ are the net present value, benefit/cost ratio and economic internal rate of return of SWC & CMS of option i; $B_{ti}$ is the benefit from decreased potential nutrient loss and the benefit from CMS of option i at year t; $C_{ti}$ is the cost of SWC & CMS of option i at year t; r is the opportunity cost; and t is the year of effective SWC & CMS of option i.

### *2.2.5 Social benefit model*

Analyses of the social benefit component are a complex process. Farmers are the key figures involved in the decision process of soil and water conservation and cropping system selection.

Thus, the cost sharing system (people participation) is very essential for the success of soil and water conservation in Thailand. Normally farmers pay for the practices that produce short term profit. Investment in practices with large direct cost, that require long term to become profitable, may be shared between landowners, a government agency, and the operating and maintaining agency. So, the suitable household incomes from a new cropping system are the only possible consideration of the cost sharing of the farmers. The social benefit model in this research is a simple social benefit index adapted from the concept of Schaefer-Kehnert (1981), using net benefit increment (NBI) to determine the difference between the net benefit increment of the current and proposed new CMS condition in units of area. The NBI adopted in this study was computed using the following equation:

$$NBI_i = NBNCMS_i - NBCCMS_i * 100 / NBNCMS_i$$

Equation 8

where $NBCCMS_i$ is the net benefit increment of each LUC per ha from current CMS option i, and $NBNCMS_i$ is the net cost benefit per unit area from the proposed new CMS option i.

### *2.3 Soil Water Conservation Knowledge Based System (SWC-KBS)*

The SWC and CMS databases were evaluated by reviewing relevant research conducted by FAO (1993) and LDD (2003). Mechanical SWC measures are adapted to sloping lands; they include terracing to allow the agricultural use of steep slopes with modified slopes to control soil erosion. These are used in conjunction with vegetative measures such as strip cropping and crop rotation, with proper crop types. The rules or the requirement of SWC in term of physical setting can be defined in quantitative terms such as slope classes, soil depth and suitable soil texture. The details can be summarized as:

- *Terracing in gentle slopes:* is suitable for a slope of 5-12%. This technique reduces slope length and minimizes soil erosion, intercepts runoff from cultivated land at frequent intervals and diverts it to protected waterways or runoff disposal areas, and uses spacing between each terrace and the ridge of the terraces for growing crops. This can be classified into level terracing and graded terracing (Table 1).
- *Terracing in high slopes:* is suitable for a slope of 12-47%. These techniques are to reduce run-off or its velocity and to minimize soil erosion, to conserve soil moisture and fertility and to promote intensive land use and permanent agriculture on slopes and reduce shifting cultivation. This can be classified into continuous terrace, discontinuous terrace. The continuous type terracing is the series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or

risers. It is suitable for a slope of 12-47% with deep soil depth (level bench terraces, upland bench terraces). Discontinuous type terracing is suitable for cultivated land having various soil depths and a slope between 12-46% (hillside ditches, orchard bench terrace, and individual basin).

Precautionary considerations for the potential CMS include socioeconomic conditions, soil suitability for agriculture, marketing and free trade area (FTA) agreements (OAE, 2007), and the requirement of soil and water conservation practices (FAO, 1993). The CMS database of the system can be established, as shown in Figure 1. These SWC and CMS data are then input into the SWC knowledge-based system (Figure 2).

*2.4 Analysis for selecting the optimal SWC & CMS*

In the system, a watershed is divided into multiple LCUs – consisting of homogeneous existing land use/cropping systems and soil, slope and rainfall characteristics – based upon the similarity of land management system in terms of physical setting (slope class, soil depth, soil texture, etc.).

An LCU is the main unit for system analysis, working with a database of various SWC &CMS data in a knowledge-based system to compute the best selection. LCUs were inputted into the SWC knowledge based system which then returns various potential alternatives of SWC & CMS according to requirements in terms of physical settings (slope class, soil depth, soil texture, etc.). However, candidate alternatives suggested by the system fed into erosion, economic and social decision element models. The data simulated from each model are then be classified into several classes. Each class is numerically coded and subsequently used in the best SWC & CMS selection system. The best SWC & CMS selection system which is based on the analytical hierarchy process (AHP) optimization approach (Saaty, 2000) was employed to select the best alternative. In this process, the users are able to prioritize their decision elements; the weight of the decision element is determined by the relative importance of one over another using pair wise comparison. Finally, the best SWC & CMS are the final output (Figure 3).

Table 1 Potential soil and water conservation of the Huai Talupkup watershed

| SWC | Mechanical Measures | | | Physical setting | | | Potential | P value |
|---|---|---|---|---|---|---|---|---|
| Code | Main type | Sub-type 1 | Sub-type 2 | Slope % | Soil texture | Soil depth | Cropping system | |
| swc01 | 1./ Terraces on high slope land | 1.1 Continuous type | Level terrace | 12-47 | Fine-texture | >150 cm | Paddy rice | 0.010-0.050 |
| swc02 | | | Upland bench-terrace | 12-47 | Fine-texture | >150 cm | Crop rotation/ Intercropping/ Relay cropping | 0.061-0.090 |
| swc03 | | 1.2 Discontinuous-type | Hillside ditches | 12-47 | Fine to medium-texture | >90 cm | same as SWC-02 | 0.269 |
| swc04 | | | Orchard terrace | 12-57 | Fine to medium-texture | >100 cm | Fruit tree | 0.267-0.310 |
| swc05 | | | Individual basin + Hillside ditches | 12-57 | Any | variable depth | Fruit tree+ Crop rotation/ Intercropping/ Relay cropping | 0.320-0.350 |
| swc06 | | 1.3 Transitional - type | Convertible terrace | 12-36% | Fine to medium-texture | >100 cm | same as SWC-02/ SWC-05 | 0.243 |
| swc07 | 2./ Terrace on gentle slope land | 2.1 Continuous - type | Broad base graded-terrace | 5-12% | Fine to medium-texture | >100 cm | same as SWC-02/ SWC05 | 0.300-.400 |
| swc08 | 3./ Contouring | | Contour plowing | Any | Any | >100 cm | same as SWC-02/ SWC-05 | 0.500-0.800 |

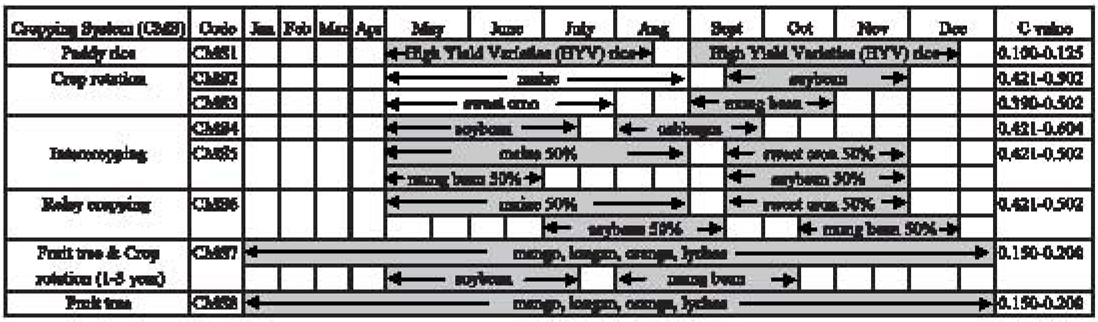

Figure 1: Potential cropping system and vegetative SWC measures of the Huai Talupkup watershed

Figure 2: Soil and water conservation knowledge-based system

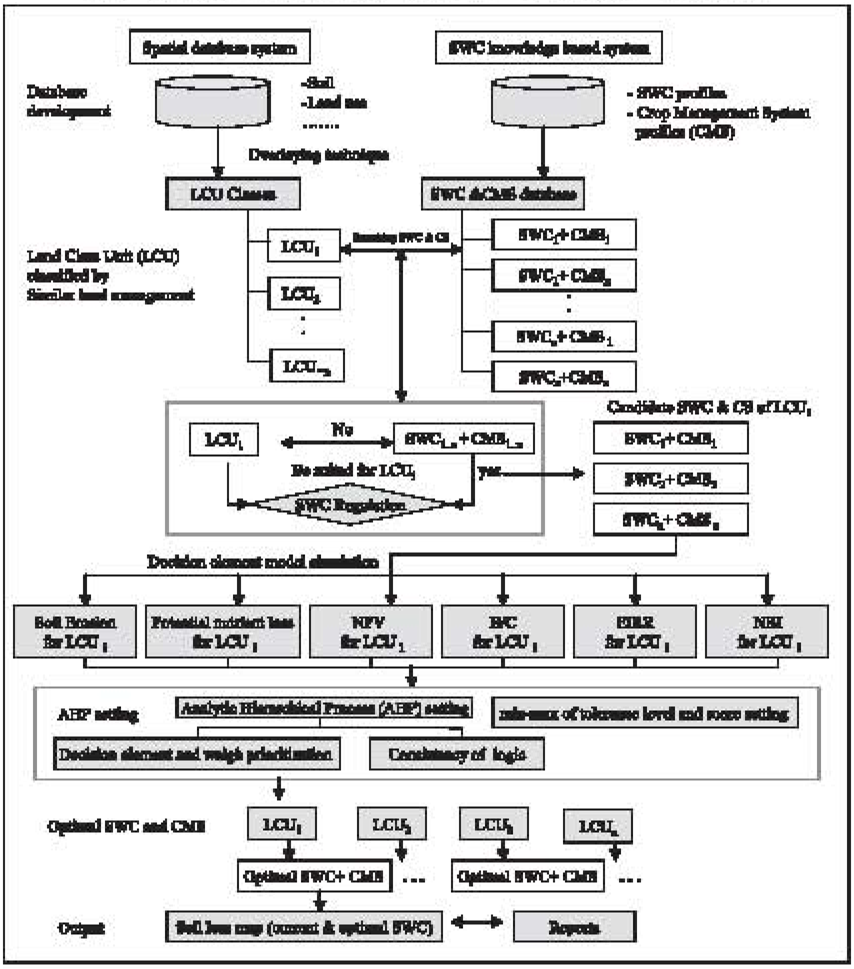

Figure 3: Data analysis flow diagram of GIS-based DSS for optimal SWC & CMS selection

## 3. A Case Study of the Huai Talupkup Watershed

### *3.1 Study Area*

The pilot area selected for this study is the Huai Talupkup watershed, located in Nan province, northern Thailand, covering an area of 1,550 ha. The topography of the watershed ranges from flat terrain to mountains, with an elevation of 350 m to 580 m above mean sea level, and a slope range of 5 to 35 %. Over 80% of the watershed area lies within the high slope terrain. The climate is monsoonal, with three distinct seasons: the rainy season (mid May-October), the cold-dry season (November-January), and the hot-dry season (February-early May). The land use of the area consists mainly of degraded forest and upland agriculture, with upland rice in both shifting cultivation and permanent cultivation patterns (LDD, 2007). The total population of the study area is 652 (91 households) within Khunsatan villages. Most of the dwellers are farmers. Average farm size is about 1-2 ha. Average household incomes range from 175 to 350 US$ per year (CDD, 2007), which is classified as lower than the average income of the northern region. The main LCUs of the Huai Talupkup watershed, categorized by soil type, current land use in 2007 (LDD, 2007 and field survey, 2007), and slope steepness class (FAO, 1993): A (0-5 %), B (5-12%), C (12-35 %) and D (>35%), include 12 LCUs. Of the 12 LCUs, 10 are agricultural land use areas which consist mainly of upland cultivation (upland rice), and various soil textures, clay loam, silt loam and silty clay with various soil depths: 25-50 cm (shallow), 50-100 cm (moderately deep) and >150 cm (very deep). These areas are used to evaluate the optimal SWC and CMS, as shown in Table 2.

### *3.2 Decision Element Models Parameterization*

The USLE parameters requirement is the R factor based on annual rainfall from the Huai Khun Satan research station located nearby the study area. The K value was based on soil samples at depths of 0-30 cm for each soil type according to a soil map of Nan province (LDD, 1995). Soil organic matter was analyzed using the method recommended by Black (1965), while soil texture analysis was made using the pipette method (Gee and Bauder, 1986). Soil permeability under disturbed conditions (soil core) was measured using saturated hydraulic conductivity (K-sat) measurement in a laboratory (Klute and Dirksen, 1986). Infiltration was measured in the field (undisturbed) using double ring infiltration (Klute and Dirksen, 1986). The K value was computed from the nomograph of USLE (Wischmeier and Smith, 1971). The topographic factor (LS factor) was established in the GIS platform using a digital elevation model (DEM) derived from contour intervals of 20 m. The LS factor was analyzed using the method recommended by McCool et al. (1987) under existing conditions and potential SWC measures. C and P values, under current and potential SWC and CS conditions, were referenced from LDD (2000) and Wischmeier and Smith (1978). The potential nutrient loss model is based on laboratory tests of the total N, P and K of each soil type in the watershed, collected from soil samples at depths of 0-30 cm for each soil type. The MUSLE parameters requirement is the rainfall amount and intensity to simulate the runoff depth and runoff peak. Fifty-two rainfall events recorded on a daily basis by automatic rain gauge from July to November 2007 were used. The total of 52 rainfall day events was 1,410 mm. The CN values for computing runoff depth and peak (Equation 3, 4) were estimated from land use conservation practice, hydrologic conditions, and hydrologic soil group. The SCS (1972) classifies all soils into four hydrologic soil groups according to their infiltration rate which is obtained from bare soil after prolonged wetting. Soil hydrologic group also depends on antecedent wetness of the watershed, three classes of antecedent moisture condition (AMC) are defined: dry, average, and wet; or AMC I, II, and III. The economic model includes cost and benefit parameters.

Table 2: Land class unit (LCU) of the Huai Talupkup-Khunsatan watershed

| LCU Code | Land use (year 2008) | Soil resources | | | | | Slope (%) classes |
|---|---|---|---|---|---|---|---|
| | | Soil series name | USDA classification | Texture | Depth (cm) | K-value | |
| 01 | Upland Rice | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0.13 | 2-5% |
| 02 | | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0.13 | 5-12% |
| 03 | | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0.13 | 12-35% |
| 04 | | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0.13 | >35 % |
| 05 | | SC with Silt loam | Unclassified | Silt loam | 50-100 | 0.13 | 2-5% |
| 06 | | SC with Silt loam | Unclassified | Silt loam | 50-100 | 0.13 | 5-12% |
| 07 | | SC with Silt loam | Unclassified | Silt loam | 50-100 | 0.13 | 12-35% |
| 08 | | Pak Chong | Oxic Paleustults | Silty clay | >150 | 0.12 | 2-5% |
| 09 | | Pak Chong | Oxic Paleustults | Silty clay | >150 | 0.12 | 5-12% |
| 10 | | Pak Chong | Oxic Paleustults | Silty clay | >150 | 0.12 | 12-35% |
| 11 | Disturbed forest | Pak Chong+ | Oxic Paleustults+ | Silty clay | >150 | 0.12 | |
| | | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0.13 | |
| 12 | Undistrubed Forest | Muak Lek | Ultic Haplustalfs | Clay loam | 25-50 | 0,13 | |

The investment cost of eight potential SWC was referenced from FAO (1993), which was based on man-days of manual labor work. These include initial costs and maintenance costs. Initial costs are mainly based on the cut and fill ($m^3$) calculation, whereas annual maintenance costs are derived as fixed percentages of the initial costs (LDD, 2003). The eight potential cropping systems costs (crop budget per ha) were referenced from OAE (2007). The benefits of soil erosion control in this research included only on-site benefits, based on potential nutrient loss per each eroded soil versus the benefit from new cropping systems. The price of fertilizer in 2007 (OAE, 2007) was used to evaluate the price equivalent to the nutrient loss value. The parameter requirement in the social model, based on net benefits per ha under current cropping systems and evaluation of potential cropping systems, is the crop budget per ha.

*3.3 AHP Setting*

The preference criteria for optimal SWC selection in this research involve multiple requirements. Optimal SWC & CMS selection for each LCU has evolved from a mechanism for the selection of the best alternative from a set of competing options, making it possible to analyze the trade-off between different objectives. The trade-off between the maximization of all benefits is the focus of AHP setting. The AHP approach (Saaty, 2000) was employed for prioritizing and weighting the decision elements. Each element is composed from sub-elements. Both farmers and government agents in the area have interacted and participated in defining the objectives and criteria to appraise erosion measures; the outcome has emphasized the importance of reducing erosion and potential nutrient loss while ensuring the best economic return on investment, as well as sustaining the livelihoods of local people and promoting their participation.

*3.3.1 Selecting the optimal SWC& CMS*

To select the optimal SWC & CMS for each LCU, the AHP processes the data using the following equation.

$$MaxSWC\&CMS_i = \Sigma(Wenv_i * SCenv_i) + \Sigma(Wecon_j * SCecon_j) + \Sigma(Wsoc_k * SCsoc_k)$$

**Equation 9**

Where, $Wenv_i$ is the weight of soil loss and potential nutrient loss decision element; $Wecon_j$ is the weight of economic decision element (NPV, B/C and EIRR); $Wsoc_k$ is the weight of the social decision element (NBI); $SCenv_i$ is the score of the soil loss and potential nutrient loss decision element (scored according to severity level); $SCecon_j$ is the score of the economic decision element (scored according to suitability level); and $SCsoc_k$ is the score of the social decision element (scored according to suitability level). The score setting of each decision element was based on the T level and the suitability level. The results show that the soil erosion decision element is the most important (0.58 or 58%), the economic decision element is 0.31 or 31% while the least important decision element is the social decision element at 0.11 or 11%. The score setting of each decision element was based on the tolerant level and suitability level.

*3.4 Current Condition of Erosion*

An overview of the Huai Talupkup watershed of 1,550 ha found gross soil loss of 54576 tons per year (averages of 64.03 and 35.21 tons/ha/yr for agricultural land and for the overall watershed, respectively), which is less than the average for highland cultivation in northern Thailand (76 tons per ha per yr) (Kongkaew et al., 2002). However, this rate is higher than the tolerance level of 12 tons/ha/yr (FAO, 1996). The total sediment yield was 12,803 tons/yr. The total potential nutrient loss was 874.04 tons/yr. High rates of soil loss and sediment yield occurred in highland agricultural areas not subject to soil and water conservation measures. The soil loss rate from highland cultivation (upland rice) in LUC 1 to LUC 10 varied from 16-131 tons/ha/yr, depending on soil type and the slope gradient classes. However, these rates of soil loss are classified as a severe level (LDD, 2004). The soil loss in each LCU under current conditions is shown in Table 3.

*3.5 Selected Optimal Erosion Management Conditions*

The optimal erosion management from the system indicated that gross erosion could be reduced to 11,842 tons/yr (an average of 7.64 tons/ha/yr), which is within the tolerance level (Table 3). Nutrient loss would be 237.35 tons/yr, which represents a decrease of about 78 % from current conditions. The differences of erosion level between optimal SWC & CMS and the current condition of each LCU depend on their physical characteristics and SWC practice requirements. However for some LCUs, no optimal SWC & CMS having a decision element output within tolerant levels could be found. However, in the future, improved SWC & CMS databases will allow more candidate options for LCUs to be input into the SWC knowledge-based system.

Table 3: Soil loss, investment cost and benefit return of soil erosion control in the Huai Talupkup watershed

| LCU Code | Area ha. | Existing Condition: Crop with no SWC | Net Benefit Baht/ha | Soil loss ton/ha/y | Nutrient Loss ton/ha/y | Sediment Yield ton/ha/y | Optimal Condition: CMS code | Net Benefit Baht/ha | NBI (%) | SWC code | Average cost Baht/ha | NPV million Thai Baht | B/C | EIRR (%) | Soil loss ton/ha/y | Nutrient Loss ton/ha/y | Sediment Yield ton/ha/y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01 | 3.63 | Upland Rice | 1470 | 6.46 | 0.26 | 1.90 | 01 | 2163 | 47.17 | 07+08 | 8,880 | 3,684 | 1.89 | 8.03 | 2.43 | 0.08 | 0.44 |
| 02 | 32.05 | Upland Rice | 1470 | 32.25 | 1.00 | 7.39 | 02 | 2163 | 47.17 | 07+08 | 15,560 | 122,017 | 1.65 | 13.17 | 9.12 | 0.28 | 1.69 |
| 03 | 295.85 | Upland Rice | 1470 | 91.40 | 2.53 | 16.99 | 02 | 2163 | 47.17 | 03 | 10,359 | 4,513,689 | 6.24 | 49.94 | 16.96 | 0.52 | 2.04 |
| 04 | 0.08 | Upland Rice | 1470 | 132.20 | 4.72 | 21.03 | 01 | 2163 | 47.17 | 03 | 18,314 | 799 | 6.25 | 49.97 | 31.80 | 0.99 | 3.25 |
| 05 | 26.11 | Upland Rice | 1470 | 7.59 | 0.25 | 2.15 | 01 | 2163 | 47.17 | 07+08 | 8,455 | 18,727 | 1.85 | 8.39 | 2.28 | 0.07 | 0.50 |
| 06 | 118.83 | Upland Rice | 1470 | 30.05 | 0.96 | 8.47 | 02 | 2163 | 47.17 | 07+08 | 15,322 | 422,428 | 1.68 | 12.79 | 8.73 | 0.27 | 1.84 |
| 07 | 310.38 | Upland Rice | 1470 | 78.47 | 2.10 | 17.63 | 02 | 2163 | 47.17 | 03 | 9,030 | 4,041,260 | 6.13 | 49.03 | 14.37 | 0.43 | 2.95 |
| 08 | 3.73 | Upland Rice | 1470 | 7.56 | 0.25 | 1.64 | 01 | 2163 | 47.17 | 07+08 | 8,604 | 2,612 | 1.83 | 8.27 | 2.17 | 0.07 | 0.38 |
| 09 | 10.53 | Upland Rice | 1470 | 27.79 | 0.81 | 7.30 | 02 | 2163 | 47.17 | 07+08 | 15,122 | 28,775 | 1.52 | 12.20 | 7.84 | 0.26 | 1.67 |
| 10 | 36.37 | Upland Rice | 1470 | 69.94 | 2.27 | 20.11 | 01 | 2532 | 72.26 | 01 | 50,171 | 361,200 | 1.47 | 11.74 | 0.39 | 0.01 | 0.09 |
| 11 | 690.00 | Disturbed forest | - | 0.15 | na | 0.03 | none | - | - | none | | | | | 0.15 | na | 0.03 |
| 12 | 20.73 | Forest | - | na | na | na | none | - | - | none | | | | | na | na | na |

na = not available; 1 US$= 30 Baht

The results of economic analysis of the watershed found that the proposed optimal SWC and CMS required a budget investment of a first-year construction cost of 10.48 million Thai baht (mainly labor cost). Using a discount rate of 8 % and a project lifetime of 10 years, it was found that NPV, B/C, EIRR and NBI were about 9.52 million Thai baht, 4.88, 39.05 % and 47% respectively. These findings show that this erosion control project is quite attractive in terms of economic feasibility and return on investment. An overview of the Huai Talupkup watershed shows that many conservation practices are economically desirable for society as a whole, even though their cost exceeds the on-farm benefits. The study has demonstrated the capabilities of using GIS and DSS for identifying the optimal soil erosion management involving multiple requirements. A developed system aims to strengthen the decision-making capacity especially in erosion control in line with the greatest physical effectiveness, together with a cost-benefit assessment. This capacity is affected by various factors within the decision-making environment. The findings of this study are in agreement with several previous studies, for instance, Tenge et al., (2004) and Geneletti (2004) who state that MCA analysis can provide room for both farmers and government agents to interact and participate in defining the objectives and criteria to appraise erosion measures. The DSS also have been successful in handling some watershed management issues, which agrees with Sarangi et al., (2004) and Mbilinyi et al., (2007). Attempting to mimic human decision-making in a computer system is therefore likely to be achievable and DSS should be seen as supporting systems decision-makers.

## 4. Conclusions

GIS based DSS for optimal erosion management version 1.0 is a combination of a spatial decision element model and an optimization approach that are incorporated into one simulation package of on-site soil erosion and the benefit of soil erosion control prediction. However, some processes are subject to improvement. The weakness of the system is that it does not include off-site effects and the cost-benefit evaluation of soil erosion (sediment yield); such as benefits from reduced flooding disaster and siltation of reservoirs, which are found throughout the small watersheds in northern Thailand. These should be included to better support effective decision making in soil erosion control project investment.

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