Thai J. For. 6 : 109–133 (1987)

WATERSHED CLASS PREDICTION EQUATIONS FOR THREE MAIN ROCK TYPE WATERSHED IN HUMID TROPICAL THAILAND

Samakkee Boonyawat [1]

บทคัดย่อ

การกำหนดชั้นคุณภาพลุ่มน้ำในประเทศไทย ได้ใช้สมการเส้นตรงแบบสหพันธ์ที่เสนอโดย Wooldridge (1984) ซึ่งใช้ปัจจัยตัวแปรอิสระ ๕ ตัว ได้แก่ ความลาดชัน, ระดับความสูง, ลักษณะแผ่นดิน, ลักษณะดิน, และลักษณะหิน ตามทฤษฎีพบว่าความสัมพันธ์ระหว่างชั้นคุณภาพลุ่มน้ำ กับ ตัวแปรอิสระบางตัวนั้น ไม่ได้สัมพันธ์กันในรูปเส้นตรง นอกจากนี้สมการที่ใช้ยังใช้ตัวแปรอิสระมากไป จึงน่าที่จะได้พัฒนาสมการขึ้นใหม่ โดยใช้ตัวแปรอิสระน้อยลง

จากการทดสอบรูปแบบของสมการหลาย ๆ แบบ พบว่า สมการที่ใช้ log (e) สำหรับตัวแปรอิสระให้ค่าความสัมพันธ์ดีที่สุด ดังนั้นจึงใช้รูปแบบสมการที่ใช้ log ทางด้านขวาของสมการในการพัฒนาสมการใหม่ เพื่อใช้ในการกำหนดชั้นคุณภาพลุ่มน้ำ สำหรับลุ่มน้ำที่มีหินแกรนิต, หินทรายและหินปูน โดยสุ่มตัวอย่างพื้นที่ในภาคเหนือแต่ละชนิดหิน ๓๐๐ กริด (ตร.กม) เพื่อนำมาพัฒนาสมการในการประเมินชนิดคุณภาพลุ่มน้ำในแต่ละชนิดหิน และทุกหินรวมกัน

ผลการศึกษาพบว่า สำหรับลุ่มน้ำที่เป็นหินแกรนิตและหินปูน ค่าความลาดชันเพียงปัจจัยเดียวก็เพียงพอในการประเมินชั้นคุณภาพลุ่มน้ำ ส่วนลุ่มน้ำที่เป็นหินทราย ต้องใช้ปัจจัยตัวแปรถึง ๓ ตัวคือ ความลาดชัน ลักษณะแผ่นดินและระดับความสูง จึงจะได้ผลที่ถูกต้อง เนื่องจากลุ่มน้ำที่เป็นหินทราย มักจะพบที่ราบบนยอดเขา ดังนั้นความลาดชันเพียงปัจจัยเดียว จึงไม่เพียงพอในการประเมินชั้นคุณภาพลุ่มน้ำ

สำหรับสมการเดียวรวมที่สามารถใช้ได้กับหินทั้ง ๓ ชนิดนี้ ก็สามารถใช้ในการประเมินชั้นคุณภาพลุ่มน้ำได้ผลดีและถูกต้องเช่นกัน ดังนั้นถ้ามีเวลาและงบประมาณไม่จำกัดแล้วควรใช้สมการรวมใช้ได้ทั้งสามชนิดหิน ดีกว่าใช้สมการแยกในแต่ละชนิดหิน ในทางตรงข้าม ถ้าเวลาและงบประมาณมีจำกัด ควรใช้สมการอย่างง่าย ๆ ในแต่ละชนิดหิน เพราะจะได้ผลลัพท์ที่รวดเร็วกว่า

ABSTRACT

A watershed class prediction equation in Thailand was proposed by Wooldridge (1984). The equation is a multiple linear regression which was developed

[1] Department of Conservation, Faculty of Forestry, Kasetsart Universiry, Bangkok 10903. Thailand.

using five variables. i.e., slope, elevation, landform, soil and geology without any transformation. Theory, however, suggests that the relationship between watershed class and the explanatory variables in not linear and the original equation requires too many variables. Therefore, linearized models were developed using one to five explanatory variables.

An analysis of the different equations tested showed that the equation using logarithmic transformation at the right side of the equation was the most appropriate form. Therefore, this form of the equation was used to develop the equations to predict watershed classes for the three rock type watersheds.

Watershed class prediction equations for all rock types taken together and each rock type considered individually, namely : granite, sandstone and limestone were developed from 300 randomly selected grids of each rock type of northern Thailand. Several variable combinations were used to develop the regression equation for watershed classes. The equations having the highest R^2 were selected for field validation. Field validation was necessary to verify the usefulness and accuracy of these selected equations together with the Wooldridge equation. Eight selected watersheds were used : three watershed areas each for granite and sandstone rock type and only two watershed areas of limestone rock type due to unavailability of additional data on this rock type watershed.

For the granite and limestone rock type watersheds, it was observed that slope alone is sufficiently adequate to predict watershed class. This is due to the strong direct correlation between slope and soil erosion rate and land use in these watersheds.

For the sandstone rock type watershed, slope alone is not adequate to accurately predict watershed class. This is due to the presence of flat areas on top of these mountain watersheds. This condition is not distinctly present in the granite and limestone rock type watersheds. The inclusion of landform and elevation into the equation makes the model sufficiently accurate in predicting watershed class for the sandstone rock type watershed.

For a single comprehensive watershed class prediction equation, a regression model with dummy variables for the three rock type was developed. The model has slope, elevation, landform, soil and rock type as explanatory variables with zero–one variables representing the rock types. If resources are not limited this equation could be used to determine watershed class for the three rock type watersheds instead of using three separate equations. On the other hand, if time is a constraint, the simpler model using one to three variables could be used to predict the watershed class for each rock type watershed.

INTRODUCTION

The Kingdom of Thailand had a total land area of 514,000 km^2. The country is divided into six regions: the north continental highland, the west continental highland, the northeast plateau, the central plain, the central highland and the south peninsula.

The head watershed areas in the north, which are covered by dense hill evergreen forests, are the main sources of water supply for agriculture in the northern lowland and in the central plain of the country through Bangkok.

The forest area of Thailand has been greatly reduced in the past two decades. In 1961, 57 percent of the country was covered by forest. Forest area was reduced to 37 percent in 1974, 32 percent in 1982 and 30 percent in 1985. The second largest reduction occurred in the north portion of Thailand. Forest areas were converted into agricultural land to provide food for a rapidly increasing population.

Statement of the Problem

The rapid economic expansion and population growth which are causing changes in land–use pattern are of national concern. Already, the conflicting objectives in land use among government agencies and other entities are creating a problem for the national government.

Another problem is shifting cultivation in mountainous areas. In northern Thailand, 30,000 to 40,000 ha of forest lands are cleared each year for cultivation by several hilltribes.

Considering this situation in watersheds, there is a need for watershed classification which would properly evaluate land areas for various uses. Watershed classification will help implement the government's desire to identify these areas that should be maintained as protection forest. Likewise, it may help in prescribing uses for associated areas which may be suitable for timber species, fruit trees or crops. It may also help solve the problem of conflicting land use among government agencies, thereby making the mountainous watershed areas more productive and better managed.

The watershed classification system being used in Thailand was proposed by Wooldridge (1984). He developed a multiple linear regression equation for the prediction of the watershed class using five explanatory variables, namely, slope, elevation, landform, soil and geology. However, it was found out that the relationship between the watershed classes (WSC) and each variable was not linear. The existing equation also makes use of five variables.

Considering these conditions, there is thus a need to develop a more adequate watershed classification system. The limitations of Wooldridge's equation necessitate the formulation of a revised equation for predicting watershed classes. A study to determine the efficiency of using less variables in prediction equation without sacrificing prediction accuracy was thus designed.

Objectives

The objectives of the study are:

1. To develop prediction equations for the classification of granite, sandstone and limestone rock type watersheds in humid tropical Thailand;

2. To identify important variables (i.e., slope, elevation, landform soil, vegetation) associated with watershed classification for the different rock type watershed for proper zoning ; and

3. To validate the equations and determine the final equations for the watershed classes.

MATERIALS AND METHODS

Study Area

The study was conducted in northern Thailand, which is located approximately between latitude 15°N to 20°N and longitude 97°30' to 101°31'E. It has an area of 169,644 km^2 which is about 30 percent of the total land area, and comprises 17 provinces. It is the headwaters of the nation's most important river, the Chao Phraya. Its mountainous watersheds not only feed the four major tributaries of the Chao Phraya River and irrigate the Central Plains but also produce 70 percent of the nation's timber. About 70 percent of the area is mountainous and has been designated mostly as forest land.

Materials

The following materials were used in the study :

1. Topographic, geologic, soils and forest maps with scale of 1:50,000 of northern Thailand.

2. Aerial photograph and LAND SAT Imagery.

3. IBM PC/AT 512 KB Microcomputer with Epson FX 286 Printer and Televideo Model 295 with Disk Drive of SIERA Data Science and Map 4, MGRID Program with Mannesman printer operated under the Department of Conservation, Faculty of Forestry, Kasetsart University.

Data Gathering

Three hundred landscape units (1 km^2 grid) of granite, sandstone and limestone rock-type watersheds from a geologic map (scale 1:50,000) with 150 grids, were randomly selected from areas with elevations higher than 700

MSL (overlay geologic map grid with topographic map of the same scale).

Slope, elevation, landform from topographic map, soil and forest from soil and forest maps for every selected grid, were documented. Each variable was scaled using the same method of Wooldridge (1984). The rationale for the use of these variables in the watershed classification was to develop a watershed classification with the following components :

Slope. Many physical processes related to rates of soil erosion or mass wasting were direct functions of steepness of slope. More steeply sloping areas and stream channels had greater energy for transportation of eroded materials and bedload. Overland flow had similar energy relations with slope steepness. Slope was measured in percentage based on contour maps.

Elevation. Elevation has a negative effect on watershed class as increased elevations represented both steeper landforms and increased erosional poten tial. Elevation was read from contour maps as the average for one square kilometer divided by ten (700 meter = 70).

Landform. Current landform was the product of recent erosional history. Properly scaled, landforms were arrayed from the most erosive to the most stable. Scaling of landform had assigned minimum values to peaks, ridges, canyons and dissected landforms. Maximum values were assigned to the most stable landforms such as broad plains or broad alluvial valleys. Landform was assigned a numerical value (1–21) based on landform description read from contour maps. Soils were arrayed numerically based on properties related to inherent stability. Geologic formations were arrayed numerically in a manner based on the evaluation to a stable soil or dispersion ratio.

WSC Values. The watershed class values were determined in continuous number based on the graphs showing the relationships between watershed class number and important variables which were identified by Wooldridge

(1984). The effect on the WSC value depends on the contribution of each variable (in percent) as indicated in Wooldridge (1984) as follows: slope, 35; landform, 30; soil, 15; elevation, 10; and geology, 10.

Vegetation. The presence and absence of forest cover were included as a variable for two reasons: (1) an overall objective of watershed classification is to maintain a minimum area in Thailand as permanent forests; and (2) certain areas which were classified as watershed class 1A are being used for agriculture for several decades already. It may not be possible to force people living on these lands to leave.

Other variables included in the equation were rainfall, temperature, water yield, water quality, soil depth, endangered species and aesthetic values. Close examination revealed that most of these variables had insufficient data base, hence the problem of scaling for numerical solutions. Thus, these variables were no longer included in the equation.

Data Analysis

All data were entered/processed into a microcomputer file. The multiple regression analysis using logarithmic transformation on both sides and one side together with reciprocal on the right side of the equation were developed to the appropriate equation for watershed class of the three geologic rock type watersheds, The watershed classes (WSC 1 – WSC 5) were determined according to the range recommended by Wooldridge (1984). These watershed classes are:

WSC 1 = when the value is less than 1.50

WSC 2 = when the value is between 1.5 – $2.2\bar{1}$

WSC 3 = when the value is between 2.21 – $3.2\bar{0}$

WSC 4 = when the value is between 3.20 – $3.9\bar{9}$

WSC 5 = when the value is greater than 3.99

where :

WSC = watershed class.

Important variables which were included in the equations were identified in the regression analysis. Less important variables were eliminated from final equations.

Field Validation

The watershed classes resulting from the equation were field validated using the selected watersheds in the north. This field validation was necessary to evaluate the usefulness and accuracy of the developed equations.

Eight selected watersheds were used for filed validation : three watershed areas each for granite and sandstone rock types and only two areas of limestone rock type watershed due to the unavailability of this type.

Mapping Procedure

The classes of the selected watersheds were determined from the prediction equations. These watershed classes were manually located on the topographic map with grids. These classes, in addition to sociocultural and forest cover data, were used to delineate the boundary of each watershed class.

RESULTS AND DISCUSSION

Testing the Equation

According to Wooldridge (1984), the relationship between the watershed class (WSC) values and slope, elevation, and landform are non-linear. Theory, however, suggests that the relationship were described in negative and positive logarithmic forms. Therefore, logarithmic transformation of the multiple regression analysis, i.e., logarithmic on both sides and on the right side, together with reciprocal on the right side where geology was a dummy variable, were tested. These modified equations are of the following forms :

Equation 1 : $\log WSC = a + b_1\log(\text{slope}) + b_2\log(\text{elevation}) + b_3\log(\text{landform}) + b_4\log(\text{soil}) + b_5(\text{granite}) + b_6(\text{sandstone}) + b_7(\text{limestone})$

Equation 2 : $WSC = a + b_1\log(\text{slope}) + b_2\log(\text{elevation}) + b_3\log(\text{landform}) + b_4\log(\text{soil}) + b_5(\text{granite}) + b_6(\text{sandstone}) + b_7(\text{limestone})$

Equation 3 : $WSC = a + b_1/\text{slope} + b_2/\text{elevation} + b_3/\text{landform} + b_4/\text{soil} + b_5(\text{granite}) + b_6(\text{sandstone}) + b_7(\text{limestone})$

The data for testing these mathematical equations were 150 randomly selected grids from granite, sandstone and limestone watersheds, together with the determined WSC values.

The developed equations with the coefficient of determination (R^2) and the t-values were analyzed. The analysis showed that equation 2 gave the highest R^2 (0.96) which was significant. The equation with the second highest R^2 (0.91) is equation 1. Equation 3 gave an R^2 value of 0.63. Therefore, equation 2 in logarithmic form at the right side was used to develop the equation to predict watershed class.

Equations for Watershed Classes

All Rock Type Watersheds

The equations for watershed class of all rock types were developed from the 450 selected grids using the multiple regression analysis in log form at the right side. Several variable combinations were used for each equation with their corresponding R^2 and t–values. The equation having the highest R^2 and significant variable in each combination of variables were selected for field validation. These equations are :

$$TWSC_1 = \underset{(t=86.7)}{5.227} - \underset{(t=-57.8)}{1.129}\ LSLP \qquad (R^2 = 0.88)$$

$$TWSC_2 = \underset{(t=64.7)}{6.186} - \underset{(t=-57.0)}{1.046}\ LSLP - \underset{(t=-12.0)}{0.287}\ LELEV \qquad (R^2 = 0.91)$$

$$TWSC_3 = \underset{(t=28.0)}{4.844} - \underset{(t=-32.9)}{0.865}\ LSLP - \underset{(t=-12.0)}{0.266}\ LELEV + \underset{(t=9.0)}{0.367}\ LLF \qquad (R^2 = 0.92)$$

$$TWSC_4 = \underset{(t=28.0)}{4.782} - \underset{(t=-33.7)}{0.875}\ LSLP - \underset{(t=-11.5)}{0.254}\ LELEV + \underset{(t=8.8)}{0.355}\ LLF + \underset{(t=4.1)}{0.179}\ LSOIL \qquad (R^2 = 0.93)$$

$$TWSC_5 = \underset{(t=32.2)}{4.261}\ GRAN + \underset{(t=34.0)}{4.466}\ SAND + \underset{(t=35.7)}{4.634}\ LIME - \underset{(t=-42.5)}{0.839}\ LSLP - \underset{(t=-14.2)}{0.239}\ LELEV + \underset{(t=13.9)}{0.434}\ LLF + \underset{(t=6.0)}{0.197}\ LSOIL \qquad (R^2 = 0.96)$$

where :

$TWSC_{1-5}$ = WSC for all rock type watersheds. Subscripts 1-5 refer to number of variables used in the equation.

LSLP = $\log_e$ (slope)

LLF = $\log_e$ (landform)

LELEV = $\log_e$ (elevation)

LSOIL = $\log_e$ (soil)

The Granite Rock Type Watershed

The watershed class equations for the granite rock type watersheds were developed from 300 selected grids of the granite rock type watershed. The multiple regression analysis with log at the right side was used in developing the equations. The selected equations for field volidation are :

$$GWSC_1 = 5.163 - 1.172\ LSLP \qquad (R^2 = 0.88)$$
$$(t=64.4)\ (t=-45.7)$$

$$GWSC_2 = 4.790 - 1.120\ LSLP + 0.617\ LSOIL \qquad (R^2 = 0.93)$$
$$(t=73.6)\ (t=-57.3) \qquad (t=15.2)$$

$$GWSC_3 = 2.504 - 0.787\ LSLP + 0.683\ LLF + 0.512\ LSOIL$$
$$(t=15.4)\ (t=-29.0) \qquad (t=14.7) \qquad (t=16.1)$$
$$(R^2 = 0.96)$$

$$GWSC_4 = 3.374 - 0.812\ LSLP + 0.592\ LLF + 0.409\ LSOIL$$
$$(t=15.3)\ (t=-31.0) \qquad (t=12.5) \qquad (t=11.5)$$
$$- 0.136\ LELEV \qquad (R^2 = 0.96)$$
$$(t=-5.6)$$

$$GWSC_5 = 4.489 - 0.850\ LSLP + 0.411\ LLF + 0.196\ LSOIL$$
$$(t=35.0)\ (t=-44.4) \qquad (t=13.4) \qquad (t=6.3)$$
$$- 0.204\ LELEV - 0.301\ GRAN \qquad (R^2 = 0.96)$$
$$(t=-12.9) \qquad (t=-18.0)$$

where :

$GWSC_{1-5}$ = WSC for the granite rock type watershed. The subscript 1–5 refer to the number of variables used in the equation.

The Sandatone Rock Type Watershed

For the sandstone rock type watershed, the equations were developed using the 300 selected grids of the sandstone rock type watershed. The selected equations for field validation are :

$$SWSC_1 = 5.159 - 1.075\ LSLP \qquad (R^2 = 0.91)$$
$$(t=90.6)\ (t=-56.2)$$

$$SWSC_2 = 4.175 - 0.948\ LSLP + 0.304\ LLF \qquad (R^2 = 0.92)$$
$$(t=25.5)\ (t=-35.4) \qquad (t=6.4)$$

$$SWSC_3 = 4.617 - 0.906\ LSLP + 0.333\ LLF - 0.154\ LELEV$$
$$(t=27.7)\ (t=-35.0)\quad (t=7.4)\quad (t=-6.6)$$
$$(R^2 = 0.93)$$

$$SWSC_4 = 4.614 - 0.906\ LSLP + 0.334\ LLF + 0.007\ LSOIL^*$$
$$(t=27.5)\ (t=-35.0)\quad (t=7.4)\quad (t=0.1)$$
$$- 0.154\ LELEV \quad (R^2 = 0.93)$$
$$(t=-6.6)$$

$$SWSC_5 = 4.653 - 0.875\ LSLP + 0.365\ LLF + 0.178\ LSOIL$$
$$(t=27.7)\ (t=-34.7)\quad (t=9.0)\quad (t=4.4)$$
$$- 0.229\ LELEV + 0.040\ SAND^* \quad (R^2 = 0.94)$$
$$(t=-11.0)\quad (t=1.8)$$

where :

$SWSC_{1-5}$ = WSC for sandstone rock type watershed. The subscript 1–5 refer to the number of variables used in the equation.

*$SWSC_4$ equation; soil is not significant.

*$SWSC_5$ equation; geology (SAND) is not significant.

The Limestone Rock Type Watershed

The equations for the limestone rock type watershed were developed from the 300 selected grids of the limestone rock type watershed. The selected equations for field validation are :

$$LWSC_1 = 5.326 - 1.118\ LSLP \quad (R^2 = 0.93)$$
$$(t=92.8)\ (t=-62.1)$$

$$LWSC_2 = 6.275 - 1.000\ LSLP - 0.307\ LELEV \quad (R^2 = 0.95)$$
$$(t=71.1)\ (t=-57.8)\quad (t=-12.6)$$

$$LWSC_3 = 5.384 - 0.860\ LSLP + 0.262\ LLF - 0.311\ LELEV$$
$$(t=39.5)\ (t=36.7)\quad (t=8.1)\quad (t=14.1)$$
$$(R^2 = 0.96)$$

$$LWSC_4 = 5.332 - 0.859\ LSLP + 0.240\ LLF + 0.210\ LSOIL - 0.307\ LELEV \quad (R^2 = 0.96)$$

(t=40.9) (t=-38.4) (t=7.7) (t=5.5) (t=−14.6)

$$LWSC_5 = 4.224 - 0.824\ LSLP + 0.495\ LLF + 0.166\ LSOIL - 0.241\ LELEV + 0.276\ LIME \quad (R^2 = 0.96)$$

(t=30.2) (t=−39.9) (t=14.7) (t=5.0) (t=−14.2) (t=15.1)

where :

$LWSC_{1-5}$ = WSC for the limestone rock type watershed. The subscript 1–5 refer to the number of variables used in the equation.

The above equations show that in any rock type, slope was the most significant and most important variable in the equation. This could be due to its direct correlation with soil erosion rate and land use. Similar results were reported by Sheng (1978) and Hawes and Hamilton (1980).

Landform was the next important variable in the watershed class equation. This is because landform is directly related to the shape of the mountain. A mountainous landform is always developed and changes until it becomes flat because of soil erosion. Moreover, landform usually has a direct effect on soil erosion and land use (Eiumnoh, 1983). As such, it could be directly related to watershed classification.

Elevation is a less important variable than slope and landform in the equation. This is because of the presence of some flat areas in the highland areas with high elevation, especially in the sandstone rock type watershed. In flat areas, soil erosion is less likely to occur. Soil, while included in the equation, contributes much less than the other three variables in explaining the variation in the equation. It can be seen that in some equations, soil is not significant. These relationships between important variables such slope elevation, landform, soil and watershed class determination had been reported by Rukkanam (1985).

The above explanatory variables may be expected to significantly contribute to the total variation in the equation to determine watershed class. This is so because of the inherent relationship between soil erosion and soil productivity and these important variables. This relationship had been reported by Wooldridge (1985) and Hudson (1971).

Validation of the Equation

Several variables are known to affect the equations for watershed class. As previously identified, these variables include slope, elevation, landform and soil. In addition, any or a combination of these variables may be sufficient to produce an acceptable equation to predict watershed class. An acceptable equation would require a high value of R^2 ; significant equation must have a minimum number of variables with the values of the variables included in the equation readily available, easily read and scaled. Given the above circumstances, field validation was needed to validate the usefulness and accuracy of these selected equations.

The Granite Rock Type Watershed

Out of the 65 total grids used for the granite rock type watershed. 59 grids (91%) matched the actual watershed class for the 3 equations ($GWSC_1$, $GWSC_5$ and $TWSC_5$). However, the number of matching grids for each watershed varied slightly. For other equations ($GWSC_2$, $GWSC_3$, $GWSC_4$), including the Wooldridge equation (WWSC), less number of grids matched the actual watershed class in all the selected granite watershed. The results of the validation indicated that the simpler $GWSC_1$ equation derived from slope variable was adequate enough to predict the watershed class for the granite rock type watershed. The possible reasons for this result have been discussed previously.

The Sandstone Rock Type Watershed

There was a slight difference in the number of matching grids between the equation derived from the slope variable ($SWSC_1$) and the equation derived from all variables ($SWSC_5$) and Wooldridge equation (WWSC), especially in the sandstone watershed 3.

For the sandstone watershed 3, this result could have been affected by its flat topography on the top portion of the mountain. Because of its flat terrain, the area was occupied and disturbed by the people who converted the forest into agricultural land. As a result, many of the watershed class predictions from these equations were erroneous. Even in the Wooldridge equation, which has the highest number of matching grids (37 out of 45), 8 grids were wrong.

If compared with the potential watershed class, all the developed equations are better than that of Wooldridge in predicting the watershed class. The Wooldridge equation gave the least number of matching grids (31 out of 45 grids used or 60% correct) while $SWSC_5$ and $TWSC_5$ had the highest (93%) number of matching grids (42 out of 45 grids used). For $SWSC_1$, only 37 grids out of 45 grids (82%) were correct. It can be seen that for the sandstone rock type watershed, which has a flat area on top of the mountain (lower slope but high elevation), the equation derived using slope only may not be the best equation to predict the watershed class. Instead, the equation ($SWSC_3$) with three explanatory variables (slope, elevation and landform) was more acceptable. This equation had 40 (89%) matching grids, 2 grids lower than $SWSC_5$ and $TWSC_5$ equations. In addition, the three explanatory variables can be more easily read and scaled than the soil and geology variables.

The Limestone Rock Type Watershed

All equations had almost the same result in the prediction of watershed class. Out of 36 grids used, there were 34 matching grids (94%) while the $LWSC_2$ and the Wooldridge equation had 33 (92%) correct grids. Therefore, for this rock type watershed, the $LWSC_1$ equation can be used to predict watershed class. This result re–emphasizes the significance of slope in predicting watershed class.

All Rock Type Watersheds

The accuracy of each prediction equation for all rock type watersheds are summarized in Table 1. It was observed that only $TWSC_5$ equation is better than Wooldridge equation (WWSC) in predicting watershed class for all these rock type watersheds. The percentage of matching grids for all rock types was higher than 91, while the other equations were lower and varied within rock type watersheds. Therefore, $TWSC_5$ equation is recommended.

For the granite rock type watershed, analysis indicated that $TWSC_1$ and $TWSC_5$ equations had 59 (91%) matching grids out of the 65 total grids used. This result would mean that slope alone was adequate in predicting watershed class for the granite rock type watershed.

For the sandstone rock type, it was found that $TWSC_4$ and $TWSC_5$ equations had 42 (93%) matching grids. On the other hand, $TWSC_3$ equation had 41 (91%) correct grids while $TWSC_2$, $TWSC_1$ and Wooldridge equation had 38 (84%), 36 (80%), and 31 (69%) correct grids, respectively. Based on these results, it would seem that for the sandstone rock type watershed, $TWSC_5$ equation is the most suited. However, $TWSC_3$ equation is also acceptable. $TWSC_3$ showed that slope, elevation and landform were the three most important variables in predicting watershed class. For this rock type watershed, slope alone was not adequate to accurately predict watershed class on account of the presence of flat areas on the top of these mountain watersheds. This condition is not distinctly present in the granite and limestone rock type watersheds. It is thus necessary to include landform and elevation

Table 1. Summary of the accuracy of each equation in predicting the watershed class for all three rock types

SELECTED WATERSHED		TOTAL GRIDS EMPLOYED	PERCENTAGE AND NO. OF GRIDS MATCHING WITH POTENTIAL WATERSHED CLASS											
			$TWSC_1$	%	$TWSC_2$	%	$TWSC_3$	%	$TWSC_4$	%	$TWSC_5$	%	WWSC	%
GRANITE	1	26	23	88	22	85	23	88	22	85	23	88	20	77
	2	27	24	89	16	59	14	52	17	63	26	96	22	81
	3	12	12	100	11	92	12	100	12	100	10	83	12	100
	Total	65	59	91	49	75	49	75	51	78	59	91	54	83
SANDSTONE	1	13	10	77	11	65	11	85	12	92	12	92	9	69
	2	8	6	75	6	75	6	75	6	75	6	75	5	62
	3	24	20	83	21	88	24	100	24	100	24	100	17	71
	Total	45	36	80	38	84	41	91	42	93	42	93	31	69
LIMESTONE	1	18	14	78	13	72	13	72	14	78	17	94	17	94
	2	18	18	100	14	78	14	78	15	83	17	94	16	89
	Total	36	32	89	27	75	27	75	29	80	34	94	33	92

in the watershed class prediction equation for the sandstone rock type watershed to improve its accuracy.

For the limestone rock type watershed, $TWSC_5$ equation also had the highest percentage of matching grids (94%), followed by WWSC and $TWSC_1$ equations with 92% and 89% respectively. The rest were rather low. These results indicated that $TWSC_5$ equation was the most acceptable equation. However, WWSC and $TWSC_1$ equations which are simpler than the $TWSC_5$ equation could also be used to predict watershed class for limestone rock type watershed.

Final Equations for Watershed Class Prediction

The results of the field validation were used as basis for the selection of final equations for all and each of the rock type watershed. These equations are :

For All Rock Type Watersheds

$$\begin{aligned} TWSC_5 = {} & \underset{(t=32.2)}{4.261\ GRAN} + \underset{(t=34.0)}{4.466\ SAND} + \underset{(t=35.7)}{4.634\ LIME} \\ & - \underset{(t=-42.5)}{0.839\ LSLP} - \underset{(t=-14.2)}{0.289\ LELEV} + \underset{(t=13.9)}{0.434\ LLF} \\ & + \underset{(t=6.0)}{0.197\ LSOIL} \qquad (R^2 = 0.96) \end{aligned}$$

For Granite Rock Type Watershed

$$GWSC_1 = \underset{(t=64.4)}{5.163} - \underset{(t=-45.7)}{1.172\ LSLP} \qquad (R^2 = 0.88)$$

For Sandstone Rock Type Watershed

$$\begin{aligned} SWSC_3 = {} & \underset{(t=27.7)}{4.617} - \underset{(t=-35.0)}{0.906\ LSLP} + \underset{(t=7.4)}{0.333\ LLF} \\ & - \underset{(t=-6.6)}{0.154\ LELEV} \qquad (R^2 = 0.93) \end{aligned}$$

For Limestone Rock Type Watershed

$$LWSC_1 = 5.326 - 1.118\ LSLP \qquad (R^2 = 0.93)$$
$$(t=92.8)\ (t=-62.1)$$

From the above, $TWSC_5$ equation with geology as a dummy variable was found highly acceptable in determining watershed class for these three rock type watersheds. However, $GWSC_1$, $SWSC_3$, and $LWSC_1$ equations were used to determine separately the watershed class for these eight selected granite, sandstone and limestone rock type watersheds. These predicted watershed classes were used as the basis for mapping the watershed classes. In addition, forest cover and socio-cultural data were also considered in delineating or zoning the watershed classes.

SUMMARY AND CONCLUSIONS

Watershed class prediction equations for three main rock type watersheds in humid tropical Thailand were developed. The important variables slope, elevation, landform and soil were identified and scaled and the watershed class values were determined.

Three hundred randomly selected landscape units (grids) of granite, sandstone and limestone rock type watersheds in northern Thailand were used in the study. A microcomputer was used to develop the mathematical equations for predicting watershed classes. The transformed form of the multiple regression analysis and simple multiple regression were tested. The analysis showed that the equation with log at the right side gave the highest coefficient of determination (R^2) which was significant. Therefore, this form of equation was used to develop the equations for predicting watershed class.

Several variable combinations were analyzed for each equation. The analysis showed that in any rock type, slope was the most important and most significant variable in the equation, followed by landform, elevation and soil. The equations having the highest R^2 value in each combination of variables for each rock type and all rock types were selected for field validation, together with the Wooldridge equation.

Three selected watershed areas each of the granite and sandstone rock type and two of the limestone rock type watersheds were used for field validation to verify the usefulness and the accuracy of the selected equations.

The results of field validation showed that for the granite rock type watershed, the equation derived from slope alone ($GWSC_1$) and from using all explanatory variables ($GWSC_5$) predicted the same watershed class and better than the Wooldridge equation. This could be due to slope having a direct correlation with soil erosion rate and land use.

For the sandstone rock type watershed, the equation ($SWSC_3$) derived from three variables (slope, landform and elevation) was the most acceptable. This equation had almost the same number of matching grids (40 out of 45) as those of the equations ($SWSC_5$) using all the five variables (42 out of 45) and also better than the Wooldridge equation. This result could be attributed to the presence of flat areas on top of these sandstone mountains. The equation derived from slope alone is not acceptable. Thus, to improve its accuracy, landform and elevation were included in the prediction equation.

For the limestone rock type watershed, all the equations gave almost the same results in watershed class prediction. Therefore, for this rock type watershed, the equation derived from slope alone ($LWSC_1$) was used.

For all rock type watersheds, slope alone ($TWSC_1$) was highly sufficient to predict watershed class for granite and limestone rock types. $TWSC_1$ was just as accurate as $TWSC_5$ in predicting watershed class. But for the sandstone rock type, slope alone was inadequate in accurtely predicting watershed class. The equation derived using three variables ($TWSC_3$) was acceptable. This result is in accordance with the findings in each rock type watershed. However, $TWSC_5$ equation is recommended to predict watershed class for all rock type watershed. The equation had better prediction accuracy than the Wooldridge equation in all rock types.

The results obtained from the field validations led to the selected of the final equation for all and each rock type of watershed. These equations are:

For All Rock Type Watersheds

$$TWSC_5 = \underset{(t=32.2)}{4.261\ GRAN} + \underset{(t=34.0)}{4.466\ SAND} + \underset{(t=35.7)}{4.634\ LIME} - \underset{(t=-42.5)}{0.839\ LSLP}$$
$$- \underset{(t=-14.2)}{0.239\ LELEV} + \underset{(t=13.9)}{0.434\ LLF} + \underset{(t=6.0)}{0.197\ LSOIL}$$
$$(R^2 = 0.96)$$

For Granite Rock Type Watershed

$$GWSC_1 = \underset{(t=64.4)}{5.163} - \underset{(t=-45.7)}{1.172\ LSLP} \qquad (R^2 = 0.88)$$

For Sandstone Rock Type Watershed

$$SWSC_3 = \underset{(t=27.7)}{4.617} - \underset{(t=-35.0)}{0.906\ LSLP} + \underset{(t=7.4)}{0.333\ LLF} - \underset{(t=-6.6)}{0.154\ LELEV}$$
$$(R^2 = 0.93)$$

For Limestone Rock Type Watershed

$$LWSC_1 = \underset{(t=92.8)}{5.326} - \underset{(t=-62.1)}{1.118\ LSLP} \qquad (R^2 = 0.93)$$

$GWSC_1$, $SWSC_3$ and $LWSC_1$ were used to predict watershed class for the individual eight selected watersheds of granite, sandstone and limestone rock type watershed, respectively. These predicted watershed class values, together with forest cover and socio-cultural factors, were used as the bases for mapping.

However, the $TWSC_5$ equation with geology as a dummy variable could also be used to determine watershed class instead of using three separate equations. In fact, there was no watershed which had only one geologic rock type for the entire area. The $TWSC_5$ equation is more accurate for it generated more matching grids than the Wooldridge equation. Therefore, the $TWSC_5$ equation would be more accurate in predicting watershed class for the watershed area which has composite rock types. On the other hand, if time is a constraint, the simpler model derived from slope would be recommended to be used in predicting the watershed class for granite and limestone rock type watersheds. For the sandstone rock type watershed, the equation derived from slope, elevation and landform could be used to predict watershed class.

RECOMMENDATIONS

On the basis of this study, the following recommendations are given:

1. In determining watershed class, the following prediction equations for the different rock type watersheds could be used:

   a. For All Rock Type Watersheds

$$TWSC_5 = \underset{(t=32.2)}{4.261\ GRAN} + \underset{(t=34.0)}{4.466\ SAND} + \underset{(t=35.7)}{4.634\ LIME} - \underset{(t=-42.5)}{0.839\ LSLP} - \underset{(t=-14.2)}{0.239\ LELEV} + \underset{(t=13.9)}{0.434\ LLF} + \underset{(t=6.0)}{0.197\ LSOIL} \qquad (R^2 = 0.96)$$

   b. For Granite Rock Type Watershed

$$GWSC_1 = \underset{(t=64.4)}{5.163} - \underset{(t=-45.7)}{1.172\ LSLP} \qquad (R^2 = 0.88)$$

c. For Sandstone Rock Type Watershed

$$SWSC_3 = 4.617 - 0.906\ LSLP + 0.333\ LLF - 0.154\ LELEV$$
$$(t=27.7)\ (t=-35.0)\quad (t=7.4)\quad (t=-6.6)$$

d. For Limestone Rock Type Watershed

$$LWSC_1 = 5.326 - 1.118\ LSLP \qquad (R^2 = 0.93)$$
$$(t=92.8)\ (t=-62.1)$$

2. If resources (i. e., budget, time, manpower) are unlimited, the equation for all rock type watersheds ($TWSC_5$) could be used to predict watershed class. However, if resources are limited, the simpler prediction equations involving only one to three variables should be used.

3. The above equations could be used to determine watershed class for the studied rock type watersheds instead of the Wooldridge equation which involves five explanatory variables.

4. Probit analysis should be used in future studies to predict watershed class in discrete number involving class variables on the left side of the equation.

5. Further studies should be undertaken to determine watershed class for other rock type watersheds (i.e., shale) in the humid tropics.

LITERATURE CITED

Chittavera, S. 1985. A Computer Analysis Application for Land Capability Classification. M.S. Thsesis, Kasetsart University, Bangkok, 111 pp.

Chunkao, K. 1981. Introduction to Watershed Resources Management in Humid Tropic. Paper presented during the Regional Training Course on Watershed Resources Management and Environmental Monitoring in Humid and Tropical Ecosystem. Chiangmai, Thailand. May 25–June 8, 1981. Vol. 5, pp. 1–24.

Davidson, D.A. 1980. Soils and Land

Use Planning. New York : Longman Inc. Comp. 129 pp.

Eiumnoh, A. 1983. Geomorphology. Department of Soil Science, Faculty of Agriculture, Kasetsart University, Bangkok. 560 pp.

FAO. 1976. A Framework for Land Evaluation. Soil Bulletin No 32. FAO, Rome.

Geological Survey Division. 1976. Geological Map of Thailand 1 : 250,000 : The Royal Thai Survey Department.

Hawes R.A and L.S. Hamilton. 1980. A Method of Watershed Land Classification and Assessment for the Tropics : A case Study of Rio Guanare, Venezuela. Department of Natural Res., Cornell University, Ithaca, New York. 32 pp.

Hawes, R.A. 1981. Method of Biophysical Land Classification and Assessment for Regional Planning of Tropical Mountain Watersheds. In : Assessing Tropical Forest Lands : Their Suitability for Sustainable Uses. Proceedings of Conference on Forest Land Assessment and Management for Sustainable Uses, June 19–28, 1979, East – West Center, Honolulu, Hawaii. 3 : 69–83.

Holdridge, L.R. 1981. World Life Zone System. In : Assessing Tropical Forest Lands : Their Suitability for Sustainable Uses. Proceedings of Conference on Forest Land Assessment and Management for Sustainable Uses. June 19–28, 1979. East–West Center, Honolulu, Hawaii. 3 : 84 –87.

Hudson, N. 1971. Soil Conservation. Ithaca, New York : Cornell University Press. 320 pp.

Land Development Department. 1982. Soil Map of Northern Thailand, Scale 1 : 500,000. Ministry of Agriculture and Cooperatives, Bangkok.

Rukkanam, J. 1985. An Application of Physical Parameters for Watershed Zoning in Upper North of Thailand. M.S. Thesis, Kasetsart University, Bangkok. 85 pp.

Saengkoowong, P. 1981. Mathematical Model to Estimate Watershed Classification. M.S. Thesis. Kasetsart University, Bangkok. 86 pp.

Sheng, T.C. 1978. Using Circle Interception Method for Slope Analysis. Technical Note No. 1. Mae Sa Integrated Watershed and Land Use Project.

Sirikunchot, S. 1976. Land Use Planning : Case Study of Northern Thailand. M.S. Thesis, Mahidol University, Bangkok.

Suksom-ard, P. 1984. Classification of Watershed Classes by Physiographic Characteristic of Watershed. M.S. Seminar. Faculty of Forestry, Kasetsart University, Bangkok. (Mimeographed)

Tangtham, N. 1983. Guidelines for Watershed Classification. Paper No. 4., Watershed Classification Project, Kasetsart Univ., Bangkok (Mimeographed).

Tevakul, W 1983. Research Guidelines and Practices for Watershed Classifcation. A papar prepared for the First Workshop on Watershed Classification, Rincome Hotel, Chiangmai, Dec. 16–18, 1983. (Mimeographed).

14–16, 1984. 28 pp. (Mineographed).

Wooldridge, D.D. 1985. A Method for Watershed Classification in Thailand. Watershed Classification Project, Kasetsart University, Bangkok. 17 pp. (Mimeographed).

Wooldridge, D.D. 1984. Watershed Classification in Thailand. Paper presented during the Second Workshop on Watershed Clasification in Thailand, Chiangmai Orchid Hotel, Chiangmai Dec.