Reducing Uncertainty in Sediment Yield Through Improved Representation of Land Cover: Application to Two Sub-catchments of the Mae Chaem, Thailand

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EXTENDED ABSTRACT

A sediment source, transport, and deposition model known as SedNet has been applied to two sub-catchments of the Mae Chaem River in Thailand, the Mae Suk (95 km^2) and the Mae Kong Kha (91 km^2). The applied models were analysed to determine the dominant sources and sinks of suspended sediment in these catchments, and to examine the uncertainty in model inputs and results.

Two landuse grids were available for these catchments; one in 1995 was derived from satellite imagery and contained a relatively undifferentiated landuse classification (lumping all forest types into one category); the other in 2003 was derived from a mix of satellite imagery, ground truthing, and mapping, and better differentiated between landuse types (dividing forest types into evergreen, deciduous, and pine plantations).

Results indicate significant differences in sediment export in 2003 compared to 1995, with exports from the Mae Suk reduced by 10 kt/y, and exports for the Mae Kong Kha increased by 6 kt/y. It is difficult to say whether these changes were due to actual changes in landuse between 1995 and 2003, or due to the improved landuse classification in 2003. Given the range of uncertainties associated with these predictions (Figure 1), these relatively small increases / decreases are not significant. The source areas of suspended sediment also changed significantly between 1995 and 2003, and these changes in source area can clearly be linked to the improved mapping of landuse in 2003.

The improved landuse classification in 2003 also led to significant reductions in the uncertainty associated with the export of suspended sediment from both catchments. The uncertainty in suspended sediment export associated with the landuse classification for the Mae Suk reduced by 23%, while that for the Mae Kong Kha reduced by 17% (Figure 1). These reductions in uncertainty were primarily due to improvements in the classification of forest type, with the range of uncertainty in sediment yield from forests declining from 28.99 kt/y to 12.92 kt/y in the Mae Suk and 26.91 kt/y to 11.44 kt/y in the Mae Kong Kha.

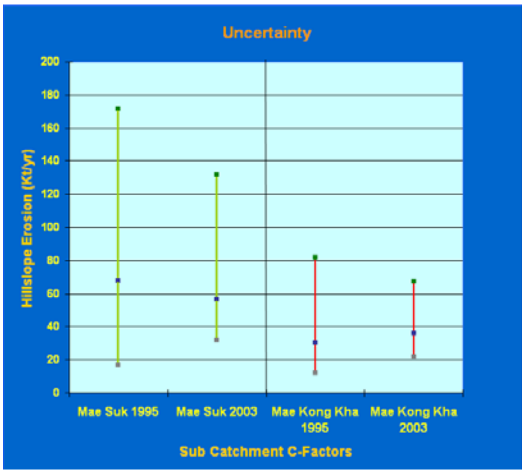


Figure 1. Reductions in uncertainty with improved landuse classification in the Mae Suk and Mae Kong Kha sub-catchments.

Despite these improvements in landuse classification, significant uncertainty in suspended sediment yield still exist for both sub-catchments. Much of this uncertainty is due to the uncertainty in suspended sediment yields from field crops and fallow fields. There are two reasons for this, firstly, these landuses produce the vast majority of the suspended sediment from the Mae Suk and Mae Kong Kha sub-catchments (75% and 54% respectively), and secondly, the landuse grids do not distinguish the *type* of crop being grown. This leads to a large range in the possible values of the C-factor used in the USLE grid, from 0.25 to 0.79. Further improvements in identifying the total volume, source areas, and uncertainty in suspended sediment yields will best be achieved through an improved landuse coverage which identifies the type of crop being grown.

1. INTRODUCTION

The Mae Chaem catchment is approximately 3900 km² in area, and is located in the North-Western region of Thailand forming part of the Ping drainage basin. The catchment is representative of large areas of Southeast Asia, where intense competition for land and water use requires management options which maintain socio-economic opportunities yet minimise environmental problems such as erosion, low dry season flows, and water pollution (Merritt 2002). The population in the catchment in 1994 was approximately 92,000 comprising 49,000 Thai locals and 43,000 hill tribe people originating from Laos and Myanmar (Burma). The Mae Chaem catchment is a relatively steep catchment ranging from 250 to 2570 metres elevation, with small narrow floodplains. Rainfall is highly variable from year to year with 95% of yearly rainfall occurring in the wet season (Merritt, 2002; Post and Hartcher, 2005).

Population pressure on the landscape from expanding agriculture is a critical factor, with hillslope erosion due to forest clearance a dominant issue for the region. The major crops grown in the region are rice, maize, vegetables, and tree crops. Due to a combination of landscape classification and forest zoning policies, there is little remaining land available for development (Merritt, 2002). A number of studies have also focused on catchment resources and hydrologic response to landuse change in the Mae Chaem catchment, including Perez *et. al* (2002), Merritt (2002), Merritt *et. al* (2004), Croke *et. al* (2004), and .Hartcher *et al.* (2005).

Two of the Mae Chaem sub-catchments, namely, the Mae Suk (95 km²) and Mae Kong Kha (91 km²), are representative of typical landuse and have been classified at a finer resolution than for the whole of Mae Chaem. Figure 2 shows the location of the two sub-catchments within the Mae Chaem catchment, Thailand. These finer resolution landuse maps were derived in different ways with the 1995 landuse coming from satellite imagery and the 2003 landuse from a mix of satellite imagery, ground truthing, participatory mapping, and better differentiation between landuse types. The 2003 landuse classification also contained a more detailed representation of forest type than the 1995 coverage.

This paper presents SedNet modelling results for landuse scenarios describing the Mae Suk and Mae Kong Kha sub-catchments in 1995 and 2003.

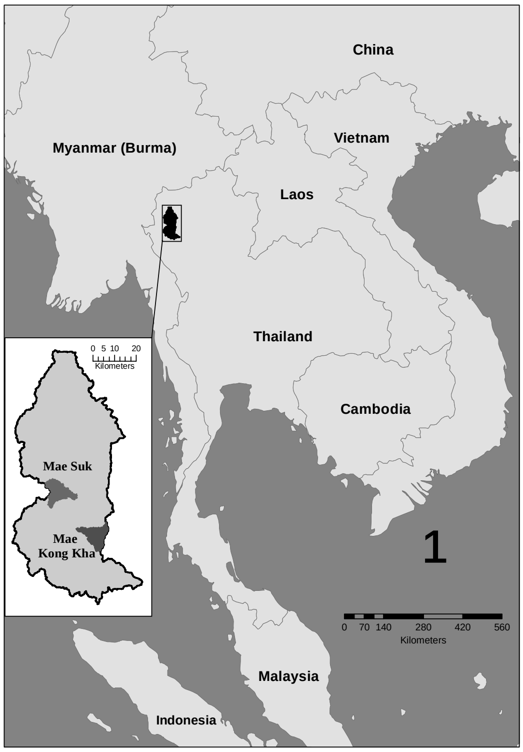


Figure 2. Location of Mae Suk and Mae Kong Kha within Mae Chaem.

2. MODELLING

The acronym SedNet stands for the Sediment River Network Model. SedNet is a software package originally developed by CSIRO for use in the Australian National Land and Water Resources Audit for use in assessing water quality in the major catchments throughout Australia. (Prosser *et al.*, 2001). It is now being applied at regional scales such as river catchments, using more detailed inputs (eg. DeRose *et. al.*,2002; Prosser *et. al.*, 2002; and Hartcher *et. al.*,2005).

SedNet models estimate river sediment loads by constructing material budgets that account for the main sources and stores of sediment. SedNet models use a simple mean annual conceptualisation of transport and deposition processes in streams. Information on SedNet model development are detailed in a series of CSIRO Land and Water technical reports and other related publications such as Gallant (2001), Lu *et. al* (2001), Prosser *et. al* (2001), and Young *et. al* (2001). On-line documentation and SedNet software is available via the CRCCH toolkit website (http://www.toolkit.net.au).

3. DATA PREPARATION

The base data for Mae Chaem, such as the digital elevation model (30m DEM), landuse, stream flow, and rainfall grids, as well as the 2003 landuse for the Mae Suk and Mae Kong Kha sub-catchments were supplied by the World Agroforestry Centre at Chang Mai University, and the 1995 landuse was supplied by the Land Development Department in Thailand.

3.1. Stream links and Watershed

The basic unit of a SedNet Model is a stream link. These stream links are generated automatically from the DEM. Topology was created for each stream link to identify its upstream and downstream relationship to other stream links and its overall position within the system (stream order). For each stream link, a unique watershed is identified by a polygon area. The watersheds, as well as providing measurement of upstream catchment area for hydrological parameterisation, define the areas within which spatially distributed erosion data need to be summarised for each stream link (from Kinsey-Henderson *et. al*. 2005a). Figure 3 illustrates the suspended sediment budget of a river link within SedNet.

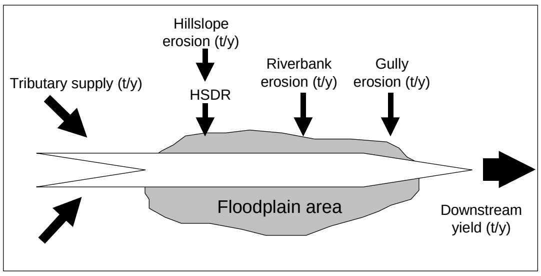


Figure 3. Conceptual diagram of the SedNet river sediment budget for one river link (Prosser *et al* 2002).

3.2. Hydrological Setting

To run SedNet, hydrological parameters for prediction of sediment transport and deposition within the river system need to be estimated and attached to each stream link. In the Audit and the regional studies, channel width, mean annual flow and bank full discharge are generally only known in a few places, so regionalized values were created based on potential evapotransporation /rainfall ratios and catchment area.

As with all other SedNet studies, connectivity, channel gradients, and stream order information were derived during stream link creation within the toolkit. There are no significant reservoirs or lakes in the Mae Chaem catchment, while some floodplains occur in the lower Mae Suk sub-catchment, but none in the Mae Kong Kha. These are the areas which SedNet models as depositional, where fine sediment may potentially be deposited. Coarse sediment deposition occurs in-stream in the model based on transport capacity estimates.

3.3. Gully and Stream Bank Erosion

As the purpose of this study was to investigate the effect of improved landuse classification on predicted hillslope delivery of sediment, gully and stream-bank erosion, and the contribution from roads and landslides, were not considered. However, anecdotal evidence suggests that rates of gully and stream-bank erosion in this catchment are low, while there is evidence of landslides, although their significance is not certain.

3.4. Hillslope erosion

Hillslope erosion was estimated using the Revised Universal Soil Loss Equation (RUSLE) where:

$$\text{Soil Loss (t/ha/yr)} = R \times K \times L \times S \times C \times P \quad (1)$$

R = rainfall erosivity factor

K = soil erodibility factor

$L\ S$ = hill length/slope factor

C = vegetation cover factor

P = Land Use Practice Factor (not used)

All factors were represented as spatially variable grids (30m cells), allowing for derivation of a spatially distributed hillslope erosion grid. An additional term, the hillslope delivery ratio (HSDR) is also used to account for redeposition of hillslope sediment before it reaches a stream. Therefore:

$$\text{Total sediment delivered to stream} = \text{Soil Loss} \times \text{HSDR} \quad (2)$$

Rainfall Erosivity Factor (R)

Rainfall erosivity is a measure of the intensity of rainfall events and so is determined by climatic data. For Mae Chaem we used an annual average value based on the existing monthly rainfall grids. The grid cells used in the available rainfall data were 1 km. The average annual rainfall grid had the following equation applied to create a rainfall erosivity grid:

$$R = 38.5 + 0.35\,(P) \quad (3)$$

P represents mean annual precipitation (Merritt, 2002).

Erodibility Factor (K)

Erodibility is a measure of the susceptibility of the soil to erosion. It is based on the nature (structure, texture etc) of the topsoil. A K-factor grid was supplied by Chiang Mai University based on existing soils data.

Hill slope/length Factor (LS)

The hillslope factor accounts for the fact that soil erosion increases with increasing slope. A grid of slope in degrees was created from the existing DEM. Length of slope was not incorporated due to lack of available data, and so slope length was left as a constant value (=1).

Cover Factor (C)

The 1995 landuse, supplied by the Land Development Department in Thailand, was classified using Landsat TM imagery. The new landuse grids for the two sub-catchments, supplied by ICRAF at Chiang Mai, were created by overlaying the map outputs from participatory mapping with the forest maps (from surveying) for the year 2003, then performing field surveys to verify the classification. Cover factors for each landuse were taken from an existing table of 'Crop Management Factors' for Thailand (Merritt, 2002). The C-factor represents a comparison of soil loss with that expected from freshly tilled soil and has a range between 0 and 1 where higher values mean more erosion. Some updated cover factors were given to fallow and forest types, however the old cover values were still applied to the 1995 classification, as they were based on the best knowledge at that time.

Land Use Practice Factor (P)

This accounts for the effects of contours, strip cropping or terracing. As data on these are not available for the Mae Chaem catchment, this factor was not used (i.e. set to 1), although it may be accounted for, to some degree, in the choice of C-factors.

Hillslope Delivery Ratio (HSDR)

The HSDR is traditionally set as a constant value in the SedNet model. However, it is recognised that factors such as slope, vegetation cover, and distance from stream can all affect the HSDR (e.g. Kinsey-Henderson et al. 2005a). The exact nature of this relationship however is still under investigation (e.g. Kinsey-Henderson, et al, 2005b). In this study we chose to reduce HSDR exponentially with distance from stream according to:

$$HSDR = 0.2844 \times e^{-9.1x10^{-4} d} \quad (4)$$

d = distance from stream.

This relationship is shown in Figure 4. It provides an average HSDR of 10% for the whole of the Mae Chaem catchment, and approximately 11.5% for the Mae Suk and Mae Kong Kha sub-catchments.

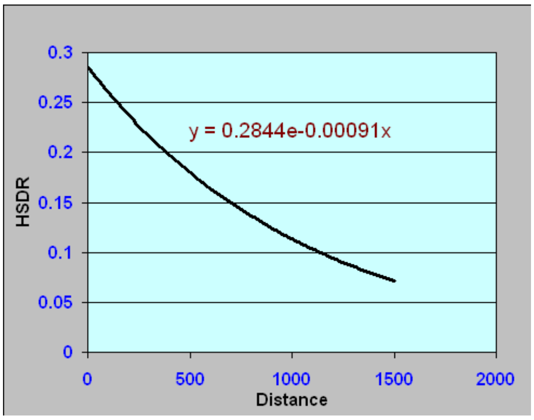


Figure 4. The assumed relationship between HSDR and distance from stream.

4. RESULTS

The first component of this study was to examine how improving the landuse cover classification might affect the nature of predicted sediment sources within our study areas. The sub-catchment results (Table 1 and Table 2) indicate that we find greater accuracy in identifying sediment sources where more discrete landuse classes are given. The breakdown of forest from the 1995 classification, into 4 or 5 discrete classes in the 2003 classification shows that 'hill evergreen forest' comprises around 30% of each sub-catchment and approximately 50% of total forest, yet has a relatively small predicted sediment yield with a cover factor of only 0.003. In our previous classification we were unable to differentiate between forest types and therefore had to apply a single cover factor of 0.020 for all forest types. The improved classification has cover factors for forest classes ranging from 0.003 to 0.088.

However, the lack of discrete classes for the field crop and fallow has left many questions unresolved, relating to the effects of crop choice and fallow practices on sediment yield. In 1995 fallow and field crops were predicted to contribute approximately 59 kt/y (87%) of sediment for Mae Suk (Table 1). In 2003 the fallow, field crop, and fruit tree landuse only contributed 43 kt/y (77%) of total predicted sediment yield for Mae Suk. This reduction may be attributed to a lower cover value for fallow, even though it appears that some fallow has become permanent field crops.

In the Mae Kong Kha 1995 classification, fallow and field crops contributed approximately 21 kt/y (70%) of sediment. In the 2003 classification field crop, and fruit tree landuse contributed 19 kt/y (54%) of total sediment yield, and there was no fallow due to the introduction of permanent fields which are not left as fallow. In reality the field crops are probably quite variable, and may have a variety of different management practices resulting in different C-factors. In the case of the Mae Kong Kha it may be that the 2003 landuse classification, which involved more ground truthing surveys, has yielded a more accurate depiction of crops than the 1995 classification, which was based on satellite classification with limited ground truthing.

The total predicted sediment yield for the Mae Suk has decreased from 67.79 kt/y in 1995 to 56.58 kt/y in 2003. This is probably due to a lower fallow C-factor of 0.100, as advised by Chiang Mai University, compared with the 1995 value of 0.200. Conversely, the total predicted sediment yield for the Mae Kong Kha has increased from 30.26 kt/y in 1995 to 35.94 kt/y in 2003. This appears to be the result of improved forest classification where mixed and dry deciduous forests, which comprise approximately 30% of the Mae Kong Kha, have C-factors of 0.040 for 2003, as opposed to 0.020 for all forest in 1995. Also, the total forest area has decreased by about 6% with field crop area, with higher C-factor, increasing by 10% and all fallow becoming field crop.

Table 1. Summary of vegetation cover categories and C factors for Mae Suk.

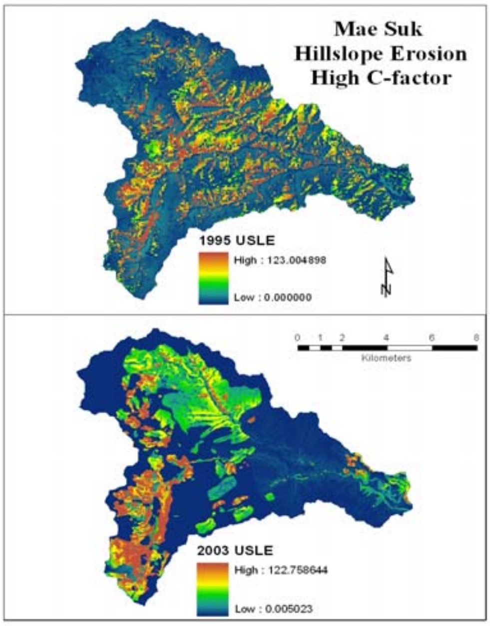
1995 Land Use	C-factor	Area(%)	Sediment Contribution (kt/yr)
Forest	0.020	70.14	7.98
Fallow	0.200	21.80	45.45
Field crop	0.340	6.78	13.59
Paddy	0.280	1.24	0.77
Urban	0.000	0.03	0.00
	TOTAL	100	67.79
2003 Land Use	**C-factor**	**Area(%)**	**Sediment Contribution (kt/yr)**
Hill evergreen forest	0.003	35.49	3.95
Mix deciduous forest	0.040	8.05	2.24
Dry deciduous forest	0.020	13.99	1.68
Pine forest	0.088	0.62	0.41
Hill evergreen/Dry deciduous forest	0.020	2.84	0.35
Total Forest		***(61.00)***	***(8.62)***
Fallow	0.100	17.28	10.21
Field crop	0.340	16.09	32.25
Fruit tree	0.150	0.82	1.18
Paddy	0.280	3.84	4.31
Urban	0.000	0.98	0.00
	TOTAL	100	56.58

Table 2. Summary of vegetation cover categories and C factors for Mae Kong Kha.

1995 Land Use	C-factor	Area(%)	Sediment contribution (kt/y)
Forest	0.020	82.63	7.72
Field crop	0.340	7.86	9.50
Fallow	0.200	7.13	11.63
Paddy	0.280	2.29	1.41
Urban	0.000	0.08	0.00
	TOTAL	100	30.26
2003 Land Use	**C-factor**	**Area(%)**	**Sediment contribution (kt/y)**
Mix deciduous forest	0.040	21.17	4.56
Pine forest	0.088	8.21	3.62
Hill evergreen forest	0.003	32.97	2.19
Dry deciduous forest/Pine forest	0.040	11.38	1.81
Dry deciduous forest	0.020	2.97	0.33
Total Forest		***(76.70)***	***(12.51)***
Field crop	0.340	17.70	19.28
Paddy	0.280	4.65	3.69
Urban	0.000	0.73	0.20
Fruit tree	0.150	0.10	0.07
Mine	0.800	0.09	0.19
	TOTAL	100	35.94

As can be seen in Figure 5 the 2003 landuse has a significant effect on the hillslope erosion grid. It appears that the 1995 classification, which was based on satellite imagery alone, has a generally more even spread of erosion rates, although it also showed overprinting effects from hill shadow in the image classification process. The 2003 classification results in the hillslope erosion classes being more uniform in specific areas and clearly demarcating landuse differences not identified in 1995.

Figure 5. Hillslope erosion grid for Mae Suk using 'best-guess' C-factors.



5. UNCERTAINTY

As the landuse classifications for both 1995 and 2003 are still lacking in some detail, there is still a range of uncertainty in what cover factors are appropriate, especially for classes such as field crops. As this study focused on examining the importance of estimation of cover on sediment delivery, the 1995 Mae Chaem landuse classification was compared with the 2003 landuse for predicted maximum ranges of C-factors. Assumptions were made in assigning high and low C-Factor values for the different scenarios, as some of the cover classes could be interpreted very broadly, (for example fallow). The 2003 sub-catchment landuse has however been able to reduce the uncertainty by re-classifying forest into a number of discrete forest classes.

The range (low to high C-factors) of total predicted sediment yield for 1995 in Mae Suk was 154.45 kt/y (16.98 to 171.43 kt/y). This range was reduced by 35% to 99.76 kt/y (31.86 to 131.62 kt/y) using the 2003 landuse classification (Table 3). There was an increase in total predicted sediment yield of about 15 kt/y for the low C-factors and a reduction of approximately 40 kt/y for the high C-factors. The high cover factor for fallow was reduced for 2003 with improved knowledge of fallow practices in the sub-catchment; however field crops still have a high range of uncertainty contributing between 27.1 and 85.71 kt/y from low to high cover scenarios. Forest cover has decreased by around 10% which may have been converted into field crop, fallow, paddy and urban.

The range of total predicted sediment yield for the 1995 landuse in Mae Kong Kha was 69.56 kt/y (12.11 to 81.67 kt/y). This range was reduced by 35% to 45.53 kt/y (21.93 to 67.46 kt/y) using the 2003 landuse classification (Table 4). This was due to an increase in total predicted sediment yield of about 10 kt/y for the low C-factors and a reduction of approximately 14 kt/y for the high C-factors. Forest cover has decreased by about 7% which has possibly gone to field crop, paddy, and urban. Fallow has disappeared completely, having been replaced by crops with permanent fields. Figure 1 illustrates the range (from low to high cover factors) in uncertainty for hillslope erosion in both sub-catchments for 1995 and 2003 landuse data.

In both sub-catchments the 2003 forest landuse classification has improved with discrete categories of forest types. This has allowed for more appropriate cover factors to be applied and has therefore reduced uncertainty in the results. However, the field crop classification has not been refined so we are still left with a high range of uncertainty as to the actual crops being grown and therefore, a wide range of possible cover factors, and possible sediment yields.

Table 3. Summary of vegetation cover categories and C factors for Mae Suk.

1995 Landuse	Low C-factor	Sediment Contribution (kt/y)	High C-factor	Sediment Contribution (kt/y)
Forest	0.010	4.07	0.080	33.06
Fallow	0.020	2.75	0.800	110.39
Field crops	0.250	10.31	0.790	32.59
Paddy	0.100	0.28	0.280	0.79
Urban	0.000	0	0.300	0.03
	TOTAL	**16.98**	**TOTAL**	**171.43**
2003 Landuse	**Low C-factor**	**Sediment Contribution (kt/y)**	**High C-factor**	**Sediment Contribution (kt/y)**
Hill evergreen forest	0.001	2.69	0.003	10.18
Dry deciduous forest	0.001	0.2	0.020	2.32
Mix deciduous forest	0.001	0.38	0.040	2.89
Hill evergreen forest/Dry deciduous forest	0.001	0.02	0.020	0.45
Pine forest	0.088	0.41	0.088	0.78
Total Forest		***(3.7)***		***(16.62)***
Fallow	0.020	2.83	0.340	38.32
Field crop	0.250	27.1	0.790	85.71
Paddy	0.100	1.99	0.280	6.3
Urban	0.000	0.15	0.300	1.89
Fruit tree	0.150	1.16	0.600	2.31
	TOTAL	**31.86**	**TOTAL**	**131.62**

Table 4. Summary of vegetation cover categories and C factors for Mae Kong Kha.

1995 Landuse	Low C-factor	Sediment Contribution (kt/y)	High C-factor	Sediment Contribution (kt/y)
Forest	0.010	3.86	0.080	30.77
Field crops	0.250	7.06	0.790	21.91
Fallow	0.020	0.69	0.800	27.11
Paddy	0.100	0.51	0.280	1.40
Urban	0.000	0.00	0.300	0.47
	TOTAL	**12.11**	**TOTAL**	**81.67**
2003 Landuse	**Low C-factor**	**Sediment Contribution (kt/y)**	**High C-factor**	**Sediment Contribution (kt/y)**
Mix deciduous forest	0.001	0.99	0.040	6.13
Pine forest	0.088	3.59	0.088	3.60
Hill evergreen forest	0.001	1.17	0.003	3.58
Dry deciduous forest/Pine forest	0.001	0.39	0.088	3.91
Dry deciduous forest	0.001	0.07	0.020	0.43
Total Forest		***(6.21)***		***(17.65)***
Field crop	0.250	13.87	0.790	43.96
Paddy	0.100	1.49	0.280	4.43
Urban	0.000	0.11	0.300	1.02
Fruit tree	0.150	0.05	0.600	0.20
Mine	0.800	0.19	0.800	0.21
	TOTAL	**21.93**	**TOTAL**	**67.46**

6. CONCLUSIONS

The 2003 landuse classification improved the spatial representation of sediment yield, and reduced the uncertainty in results by around 35%. However, while forest has been reclassified into different types with specific cover factors, the major sediment yields come from field crops, which are still not represented as unique crops.

Concentrating efforts on improving the classification of crop types will reduce the range of possible C-factors. This will produce a significant reduction in uncertainty, and will then allow us to focus on the key source areas of hillslope erosion and sediment yield.

7. ACKNOWLEDGMENTS

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