

Nonpoint Source Pollution Responses Simulation for Conversion Cropland to Forest in Mountains by SWAT in China

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Abstract Several environmental protection policies have been implemented to prevent soil erosion and nonpoint source (NPS) pollutions in China. After severe Yangtze River floods, the “conversion cropland to forest policy” (CCFP) was carried out throughout China, especially in the middle and upper reaches of Yangtze River. The research area of the current study is located in Bazhong City, Sichuan Province in Yangtze River watershed, where soil erosion and NPS pollution are serious concerns. Major NPS pollutants include nitrogen (N) and phosphorus (P). The objective of this study is to evaluate the long-term impact of implementation of the CCFP on stream flow, sediment yields, and the main NPS pollutant loading at watershed level. The Soil and Water Assessment Tool (SWAT) is a watershed environmental model and is applied here to simulate and quantify the impacts. Four scenarios are constructed representing different patterns of conversion from cropland to forest under various conditions set by the CCFP. Scenario A represented the baseline, i.e., the cropland and forest area conditions before the implementation of CCFP. Scenario B represents the condition under which all hillside cropland with slope larger than 25° was converted into forest. In scenario C and D, hillside cropland

with slope larger than 15° and 7.5° was substituted by forest, respectively. Under the various scenarios, the NPS pollution reduction due to CCFP implementation from 1996–2005 is estimated by SWAT. The results are presented as percentage change of water flow, sediment, organic N, and organic P at watershed level. Furthermore, a regression analysis is conducted between forest area ratio and ten years’ average NPS load estimations, which confirmed the benefits of implementing CCFP in reducing nonpoint source pollution by increasing forest area in mountainous areas. The reduction of organic N and organic P is significant (decrease 42.1% and 62.7%, respectively) at watershed level. In addition, this study also proves that SWAT modeling approach can be used to estimate NPS pollutants’ impacts of land use conversions in large watershed.

Keywords Nonpoint source pollution · Conversion of cropland to forest · SWAT · Simulation · China

Introduction

Watershed environmental issues, especially water quality and soil erosion are becoming an increasing concern in China and other parts of the world (Wang and others 2006, Chen and others 2006). The soil losses and nonpoint source (NPS) pollutants formations in the middle and upper reaches of Yangtze River in central China are highly vulnerable. Destruction of vegetation has led to soil erosion and NPS pollutions in the upper reaches. In the past 30 years, the forest cover has been reduced to half, while the area exposed to severe erosion doubled in size (Yin and Changan 2001, Zhang 2003). Soil erosion on cultivated

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land not only results in on-site soil degradation and NPS pollutions, but also causes off-site problems related to downstream sedimentation and water pollution (Zhang and others 2003, Martin and others 2006). After Yangtze River floods in 1998, there was wide agreement that agricultural production on sloped land in upper and middle reaches of Yangtze River was one of the most important causes of rapid runoff and soil erosion in the basin and a major contributor to flooding (Eckhardt and Ulbrich 2003). Since 1999, for preventing soil erosion and water pollution, the Chinese government has carried out the so-called “Conversion Cropland to Forest Policy” (CCFP), which encourages the farmers to return hillside crop cultivation to grassland and forest with detailed compensation and subsidy schemes. From the beginning of the 21st century, 14.7 million ha of cropland have been converted to forest (Zhang and others 2003). Despite enormous scales of CCFP, to date, there have been few assessments of the policy impact on regional sediments and NPS pollution (Wanga and others 2006). In this article, we estimate not only the environmental effects of CCFP in preventing soil erosion and NPS pollutants, but also formulate the regression equations between forestry area ratio and environmental index. Then, the regional sediment, organic nitrogen (N), and organic phosphorus (P) can be effectively estimated with forestry ratio.

To assess the effects of CCFP, field experiments or long-term monitoring is very expensive and time consuming. During the repeated monitoring process, there are uncertainties associated with the results and is very difficult without additional resources. Watershed soil erosion and NPS pollution loading are generally a combined result of many influencing factors including climate, land cover, topography, land uses and soil conditions that characterize the watershed (Tripathi and others 2003). When implementing CCFP, it is quite difficult to assess the environmental quality improvements by extensive sampling and monitoring data. Under these conditions, application models become useful and efficient. The Soil Water Assessment Tool (SWAT) is a watershed simulation model system and can be applied to quantify environmental impacts of CCFP in watershed scale (Behera and Panda 2006). During simulation, the climate, land use, soil, topography, and geological variances are all taken into considerations (Arnold and Fohrer 2005). SWAT has been applied by several authors to study impacts of watershed environmental policies in different perspective. Zhang and Jogensen (2005), for example, have applied the model to assess regional point and NPS pollution reductions for best management practices in Denmark. Attwood and others (2000) have used SWAT to evaluate the impacts of natural resource policy in terms of environmental and economic implications at differing spatial scales.

For the advantages of SWAT model system, it can be used for regional environmental benefits assessment for CCFP implementations. The research motivation is to identify the reductions of NPS pollution with SWAT model, which is the foundation for conversion cropland to forest policy decision making. The objectives of this article, therefore, are to: (I) estimate NPS pollutant loading in this typical study area with support of SWAT model, (II) suggest approach to estimate CCFP long-term benefits for regional NPS pollution reduction at watershed level, and (III) analyze the linkage and correlation between NPS pollution load change and the various CCFP implementation levels.

Methods

Model Description

The watershed water quality model, SWAT, was developed by the United States Department of Agriculture (USDA) (Arnold and others 1998). The Soil and Water Assessment Tool was selected for this study because of its ability to simulate land management processes and hydrological responses in larger watershed. The Soil and Water Assessment Tool is a semi-distributed watershed model with a GIS interface that outlines the subbasins and stream networks from a digital elevation model (DEM) and can calculate daily water balances from meteorological, soil and land-use data. The surface runoff is predicted at a daily step by a modification of soil conservation service (SCS) curve number method and the peak runoff rate is estimated according to rational formula. The erosion and sediment yields are estimated in each subbasin with modified universal soil loss equation (Ramanarayanan and others 1996). SWAT applies a multilayer storage routing technique to partition drainable soil water content for each layer into components of lateral subsurface flow and percolation into the layer below.

The SWAT model is built to simulate the physical processes of pollutant in watershed as realistically as possible. Most model inputs are physically based. However, it is important to note that SWAT is not a parametric model with a formal optimization to fit any data. In-stream nutrient dynamics have been incorporated into SWAT using kinetic routines from in-stream water quality model. The N processes, soil pools, plant supply, and demand of N can also be simulated by SWAT. The N Circle, with plant biomass, N transported with runoff, lateral flow, and percolation, can have different N formations estimated daily. The Soil and Water Assessment Tool can also model P circle and formations in similar approach to N. While predicting the amount of soluble P removed in runoff, the labile P concentration in top soil, runoff volume, and P soil-partitioning factor are all considered. Sediment

Table 1 Data type scale and data description/properties

| Data type | Scale | Data description/properties |
|-----------------------------|------------|---|
| Topography | 1:200 000 | Elevation, overland and channel slopes, lengths |
| Land use | 1:1000 000 | Land use classifications, area and management information |
| Soils geographic databases | 1:400 000 | Soil physical and chemical properties. |
| Weather | 7 stations | Daily precipitation and temperature |
| Land management information | – | Fertilizer application, planting and harvesting information |

Table 2 The geographical features of seven weather stations

| ID | NAME | Lat (°) | Long (°) | Elevation(m) |
|----|----------|---------|----------|--------------|
| 1 | GUANYUAN | 32.48 | 105.90 | 1939.00 |
| 2 | WANYUAN | 32.01 | 108.03 | 674.00 |
| 3 | LINZHONG | 31.51 | 105.95 | 1826.00 |
| 4 | BAZHONG | 31.90 | 106.70 | 1777.00 |
| 5 | DAXIAN | 31.20 | 107.50 | 1449.00 |
| 6 | NANCHONG | 30.70 | 106.10 | 1097.00 |
| 7 | SUINING | 30.50 | 105.55 | 355.00 |

transport of P is simulated with a loading function, as is organic N transport (Santhi and others 2006).

The Soil and Water Assessment Tool was applied all over the world with diverse missions. The basic function is to estimate regional NPS pollution load. In recent years, more applications have been focused on regional managements, pollutant source identifications based on simulation results. Under assumed condition, it can assess regional NPS pollution load changes induced by, for example, climate change. Agriculture has been identified as the major contributor of NPS pollution of water resource (Cheng and others 2007). Simulation of agricultural NPS pollutions in relation to crop patterns is one of the strong traits of SWAT.

Study Area

The study area of Bazhong City, Sichuan province is located in central China and in upper stream of the Yangtze River Basin (Fig. 1). There are 65,959 Km² cultivated land and 70% of them are cultivated slope land. The soil erosion area in Sichuan is 199,800 Km², which is 40.87% of the total soil erosion area in Yangtze River watershed. There are about 600 million tons of sediments transported from Sichuan into Yangtze River every year. In this area, the natural vegetation has been destroyed by tillage, grazing, and deforestation, which led to soil erosion and ecosystem degradation; therefore, this region is the core area to implement CCFP. Also, 34% of high to medium productivity hillside cropland has been converted to forest or grassland in the last several years.

The climate of Bazhong City is moderate, with the highest temperature at 40.2° C occurring in July and the lowest average monthly temperature is -4.7° C in January. The average annual temperature is 16.0–16.9° C and average yearly precipitation is 1120.7–1203.1 mm. The whole research area is 960,154.45 ha and the mean elevation is 773 m. The terrain is higher in the north and the maximum and minimum altitude is 2464 m and 332 m respectively. The various land uses in this watershed are: agricultural land (dry land and garden land) (48.0%), mixed forest (9.94%), range-grasses (8.12%), rice (paddy) (6.54%), honey mesquite (5.21%), sesbania (3.87%), and range-brush (0.05%). The main land use is agricultural land. The Paddy is defined as a separate land use type because of its small area and lower slope distributions. Most of the soils are purple soil and lateritic red soil.

Model Inputs

The ArcView Geographic Information System interface of AVSWAT model was used to develop input files. The 1:200 000 geographic database with topography, land use, and soils were constructed (Table 1). The watershed climate condition was simulated from 1996 through 2005 using daily historical weather information collected from seven weather stations in Sichuan Province around the study area (Table 2). The SWAT delineates watershed into subwatersheds based on topography. The land use and soil map in this region was overlaid on subbasins. The land use was classified in seven types and codes of each land use were listed in Table 3.

In the research watershed, there are five types of soils. The dominant soil types in Bahe River watershed are purple soil and lateric red soil. The purple soil occupies more than half of the area and lateric red soil dominates another 41.71% in the north part of the watershed (Fig. 2). The main soil properties are listed in Table 4. The typical management practices information, such as cropping schemes, fertilizer application, and tillage operation were gathered from farmer surveys and local administrative agents.

Table 3 The land use type area and percentage in study area

| LANDUSE | Area (ha) | % |
|--------------------------|-----------|-------|
| Range-Brush (RNGB) | 522.0 | 0.05 |
| Range-Grasses (RNGE) | 77958.3 | 8.12 |
| Honey Mesquite (MESQ) | 50041.5 | 5.21 |
| Mixed Forest (FRST) | 95470.7 | 9.94 |
| Agricultural Land (AGRC) | 636190.9 | 66.26 |
| Sesbania (SESB) | 37183.2 | 3.87 |
| Rice (RICE) | 62787.8 | 6.54 |

Model Calibration

With reference to actual historical monitoring data on stream flow and water quality, AVSWAT model was calibrated (Arnold and others 1995). The calibration simulation period for flow and water quality was started from January, 2004 to December, 2004. The related SWAT model parameters were adjusted (Table 5) to correct the overestimation of average monthly stream flow. After calibration, the curve number (CN2), plant water uptake compensation factor (EPCO), the soil evaporation compensation factor (ESCO), threshold depth of water in the shallow aquifer for “revap” or percolation to the deep aquifer to occur (REVAPMN), amount of shallow aquifer water that moved into the soil profile (GW_REVAP), and groundwater delay coefficient (GW_DELAY) were determined as listed in. As a result, the simulated water flow was acceptable.

The stream monitoring data in Bazhong watershed includes only total N and total P without distinguishing organic nutrients from mineral components. Therefore, SWAT model was calibrated with the reference to the actual monitoring data of total N and total P. The adjusted SWAT model parameters after calibration are listed in Table 6, including the average slope steepness (SLOPE), average slope length (SLSUBBSN), initial soil organic N concentration (SOL_ORGN), initial soil organic P concentration (SOL_ORGP), organic N enrichment ratio (ERORGN), N percolation coefficient (NPERCO), universal soil loss equation soil erodibility factor (USLE_K1), depth of the top layer of the Aledo soil (SOL_Z1), initial

residue cover (RSDIN), N in rainfall (RCN), and biological mixing efficiency (BIOMIX).

After calibration, the estimated average monthly N density at the outlet of Bazhong watershed was slightly lower than the actual average monthly N yield in the rainy season and slightly higher in the winter (Table 7). The simulated average monthly P density after calibration has similar variance trend as that of total N.

Conversion Cropland to Forest Scenarios Analysis

In order to estimate the reductions in soil erosion and NPS pollution due to implementation of land use conversion from cropland to grassland/forest policies, four scenarios are constructed representing different conditions of implementation of CCFP in the simulated basin: baseline with (I) no conversion, (II) conversion of cropland with slope greater than 25°, (III) conversion of cropland with slope greater than 15°, and (IV) conversion of cropland with slope greater than 7.5°. Under existing conditions, the evaluation of impacts of CCFP was carried out in four scenarios. The first, Scenario A, was original land use condition, 66.26% of land use was agricultural land and 9.94% was forest. In Scenario B, agricultural land on slope bigger than 25° was transferred into forest and other land use did not change; therefore, agricultural land dropped to 383,429.2 ha and forest area climbed to 349,834.3 ha. In Scenario C, agricultural land on slope bigger than 15° was all converted to forest, which resulted in forest area that rose to 562,971.5 ha and agricultural land that decreased to 170,292.1 ha. In the last scenario, D, agricultural land on slope bigger than 7.5° was turned into forest. As the result, forest area occupied 73.43% of regional land use (706,260.7 ha) and agricultural land was cut down to 27,002.9 ha.

To substantiate the four scenarios and simulate and assess their impacts by SWAT, an analytical framework was developed (Fig. 3). Firstly, the land use distribution characteristics was analyzed according to use type and land slope (Table 8). The average agricultural land slope is 16.49°. The study area is a highly mountainous region with

Table 4 Soil properties under different soil series of Bahe River watershed

| Soil Type | Area /ha | Area ratio/% | Depth /mm | Coarse sand/% | Fine sand/% | Silt /% | Clay /% | Organic carbon/% | TN /% | TP /% | TK /% |
|------------------------------|----------|--------------|-----------|---------------|-------------|---------|---------|------------------|-------|-------|-------|
| <i>Lateritic red Soil</i> | 401104.5 | 41.71 | 70 | 6.58 | 34.06 | 28.96 | 30.40 | 2.42 | 0.110 | 0.033 | 1.30 |
| <i>Yellow Soil</i> | 12519.4 | 1.30 | 100 | 39.11 | 11.29 | 34.80 | 14.80 | 2.78 | 0.146 | 0.024 | 1.88 |
| <i>Yellow brown Soil</i> | 9946.5 | 1.03 | 60 | 0.36 | 20.37 | 59.12 | 20.15 | 3.52 | 0.206 | 0.066 | 2.30 |
| <i>Carbonate purple Soil</i> | 52897.6 | 5.50 | 100 | 6.20 | 11.30 | 42.50 | 40.00 | 2.04 | 0.142 | 0.058 | 1.92 |
| <i>Purple Soil</i> | 485297.5 | 50.46 | 95 | 0.61 | 20.67 | 37.95 | 40.77 | 1.34 | 0.095 | 0.027 | 1.65 |

Table 5 The SWAT model parameters adjusted during calibration for stream flow

| Parameter | Default value | Calibration value |
|-----------|---------------|-------------------|
| CN2 | 0 | -7 |
| EPCO | 1.0 | 0.5 |
| ESCO | 0.95 | 0.55 |
| REVAPMN | 1.0 | 0.65 |
| GW_REVAP | 0.02 | 0.1 |
| GW_DELAY | 31 | 45 |

Table 6 The SWAT model parameters adjusted during calibration for stream sediment and nutrient loads

| Parameter | Default value | Calibration value |
|-----------|---------------|-------------------|
| SLOPE | 0.129 | 0.100 |
| SLSUBBSN | 24.390 | 7.000 |
| SOL_ORGN | 0 | 4000 |
| SOL_ORGP | 0 | 2000 |
| ERORGN | 0.0 | 4.0 |
| NPERCO | 0.20 | 0.30 |
| USLE_K1) | Various | -20% |
| SOL_Z1 | 101.6 | 65.0 |
| RSDIN | 0 | 4000 |
| RCN | 1.0 | 0.4 |
| BIOMIX | 0.92 | 0.40 |

limited suitable arable land resources. Consequently, much of the hillside land is also cultivated, including those with slope greater than 25°. There are 252,761.7 ha agricultural land with slope greater than 25°, which is about 26% of the entire study area. The details of the four scenarios are listed in Table 9.

The land use distributions of the four scenarios were also mapped in Fig. 4. Based on these four kinds of land use conditions, the regional water flow, soil erosions, organic N, and organic P loading in 10 years were estimated respectively using the calibrated SWAT model.

Results and Discussion

Stream Flow Variation

The volume of surface runoff under different scenarios is simulated for the whole watershed from 1996–2005. Obviously, the overall pattern of stream flow variation is determined by the variation of precipitation (PRECIP). The highest peak runoff value (331.4 m³/s) simulated by the model was in Scenario C and the lowest in Scenario B. The stream flow are very similar between Scenario A and D

Table 7 The monthly (M) simulated and monitored results after calibration at watershed outlet

| TN density/(mg/L) | | | TP density/(mg/L) | | |
|-------------------|-----------|-----------|-------------------|-----------|-----------|
| M | Simulated | Monitored | M | Simulated | Monitored |
| 1 | 1.007 | 0.956 | 1 | 0.017 | 0.013 |
| 2 | 0.914 | 0.877 | 2 | 0.020 | 0.016 |
| 3 | 0.953 | 1.077 | 3 | 0.019 | 0.013 |
| 4 | 1.203 | 1.124 | 4 | 0.044 | 0.040 |
| 5 | 1.008 | 1.098 | 5 | 0.023 | 0.020 |
| 6 | 0.930 | 0.943 | 6 | 0.033 | 0.031 |
| 7 | 0.563 | 0.613 | 7 | 0.017 | 0.020 |
| 8 | 0.543 | 0.641 | 8 | 0.011 | 0.013 |
| 9 | 0.737 | 0.763 | 9 | 0.019 | 0.023 |
| 10 | 0.723 | 0.704 | 10 | 0.035 | 0.033 |
| 11 | 0.709 | 0.697 | 11 | 0.029 | 0.023 |
| 12 | 0.902 | 0.914 | 12 | 0.031 | 0.026 |

Table 8 Land use distributions characteristics with maximum, mean slope and their standard deviation (STD)

| Land use | Slope Features | | |
|----------|----------------|-------|-------|
| | Max | Mean | STD |
| RNGB | 79.33 | 10.78 | 9.68 |
| RNGE | 84.81 | 13.61 | 9.53 |
| MESQ | 85.96 | 18.38 | 11.94 |
| FRST | 85.12 | 18.07 | 11.65 |
| AGRC | 85.70 | 16.49 | 10.12 |
| SESB | 85.31 | 16.11 | 10.78 |
| RICE | 70.22 | 16.48 | 10.46 |

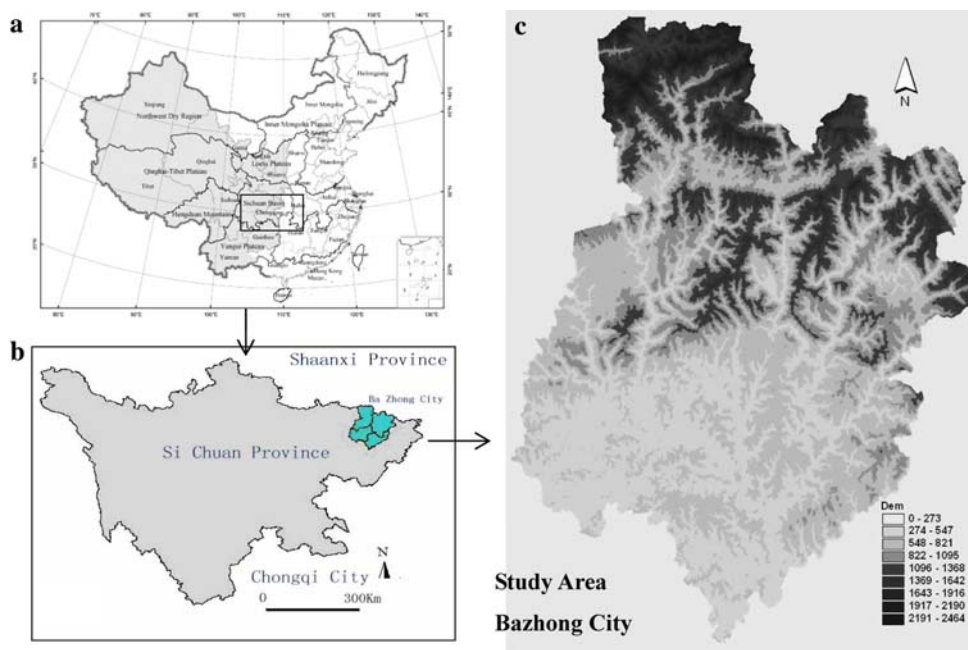
despite the different land use structure. With sloppy agricultural lands converted into forest from Scenario A–B, the stream flow did not decrease dramatically. However, when the agricultural land located on a slope larger than 15° was converted into forest (Scenario C), the stream flow climbed intensively, ranging from 112.0 m³/s to 331.4 m³/s, but not the highest in the first three years. With more lands transferred into forestry, the stream flow dropped to an original situation. The distributions of stream flow value in Scenario A and D were plotted graphically with respect to the same line from 78.5 to 302.9 m³/s.

Transported Sediment Variation

Sediment yield is the amount of overland soil loss due to water erosion in the whole study of watershed, which reflects the integrated response of sediment generation processes and stream processes at watershed scale (Fig. 6).

Table 9 Details of the four scenarios

| Scenarios | Agriculture land(ha) | % | Forest (ha) | % | Conversion ($\geq 25^\circ$) | Conversion ($\geq 15^\circ$) | Conversion ($\geq 7.5^\circ$) |
|-----------|----------------------|-------|-------------|-------|--------------------------------|--------------------------------|---------------------------------|
| A | 636190.9 | 66.26 | 95470.7 | 9.94 | – | – | – |
| B | 383429.2 | 39.87 | 3498384.0 | 39.87 | 100% | – | – |
| C | 170292.1 | 17.71 | 562971.5 | 58.54 | 100% | 100% | – |
| D | 27002.9 | 2.81 | 706260.7 | 73.43 | 100% | 100% | 100% |

Fig. 1 Location, topography of study area in China

shows the change in annual average sediment generation and precipitation of four scenarios from 1996–2005. The sediment yields exhibit similar trends with the PRECIP. Under the original land use condition, Scenario A, the sediment yields of whole watershed ranged from 1535×10^3 to 4456×10^3 t. By implementing the CCFP in scenario B and C, the sediment yields decreased, but not intensively. However, the estimated results of these two conditions seemed to be the same as in Fig. 5. When the agricultural land on slope bigger than 7.5° was changed into forest in scenario D, the sediment yields dropped sharply and ranged from 569×10^3 to 3037×10^3 t. With the exception of four scenario analysis, the watershed sediment yield decreased as the forest area increased.

Organic N Variation

Comparisons of the assessed organic N concentrations in the runoff water under the four scenarios and the corresponding simulated precipitation values in ten years are shown in Fig. 7. The precipitation has a similar trend with estimated results, which proved the NPS pollutants

transportations were mainly controlled by the climate conditions. By the analysis of watershed organic N yields, the yield decreased with the forest area climbing, which demonstrated that the implementing of CCFP to prevent NPS pollutions was feasible. In scenario A, the organic N yield was 67.9×10^4 to 394.1×10^4 kg/ha, which dropped to 63.3×10^4 to 251.7×10^4 kg/ha in scenario D, except the simulation error (1284×10^4 kg/ha) in 1996. The estimated value of scenario C in 1996 was also treated as unreasonable. But the other estimations were reasonable for the reference to the local monitored values. By the simulation, the pollutant prevention benefits of different policy implementations level can be concluded clearly for the simulation differences of the four scenarios. Based on those assessments, the CCFP benefits can be estimated in advance and the environmental quality index can be forecasted, which is the guidelines for management.

Organic P Variation

The simulated decreases in sediment and organic N load indicated for efficiency of CCFP implementations and

Fig. 2 The soil type distribution in the Bahe River watershed

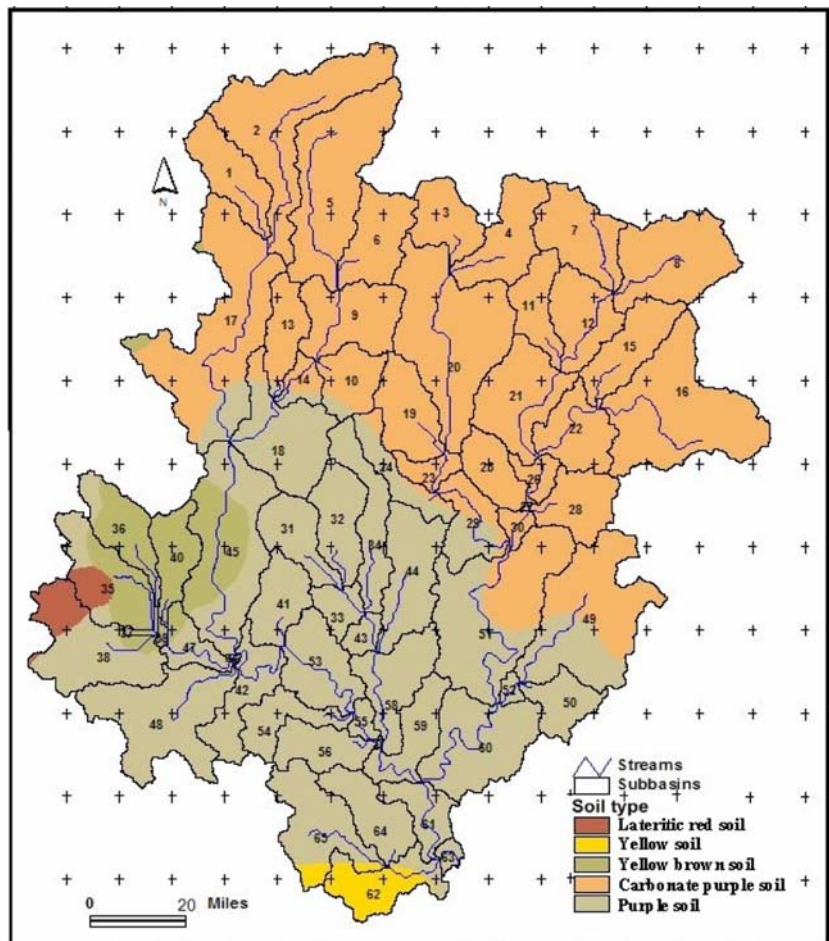
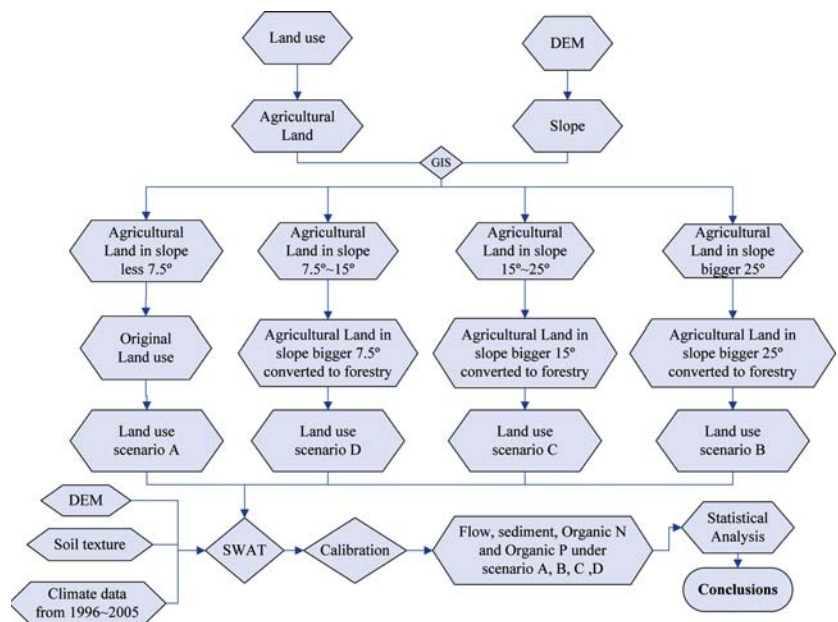


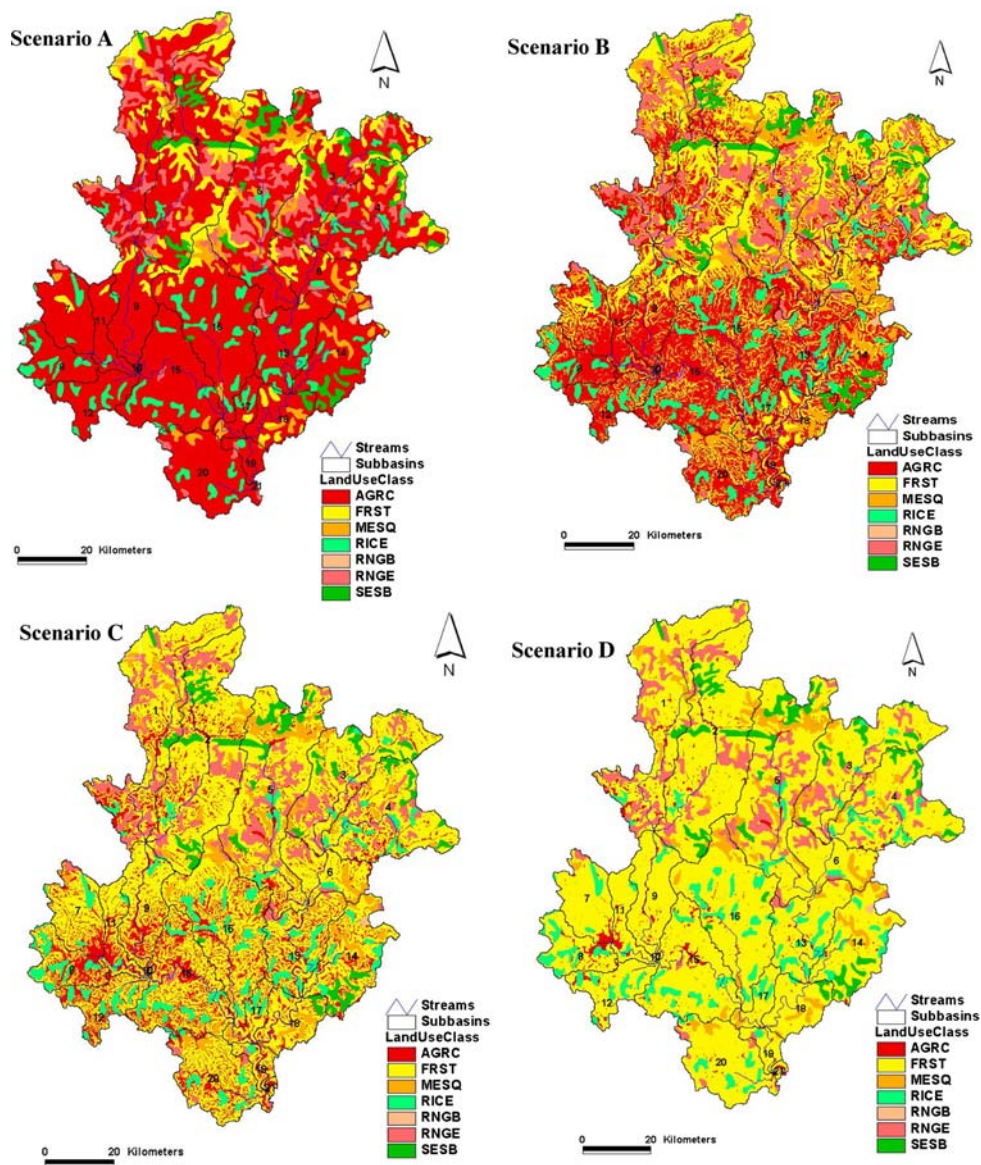
Fig. 3 The research framework for the NPS pollution response for conversion of cropland to forest



organic P load was also reflected in the similar estimated differences. The simulated organic P yields under the four scenarios over the 10-year period were mapped in

Fig. 8. The organic P yields were the organic P transported with sediment out the watershed during the time step. Similar to organic N yield simulations, the

Fig. 4 Land use distribution about Bahe River watershed of four scenarios



estimated values of organic P of scenario A and B in 1996 were unreasonable and were treated as errors. In Scenario D, when the agricultural land slope was bigger than 7.5° and was transferred into forest, the organic P yields dropped. The yield was between 92.3×10^3 kg/ha and 758.9×10^3 kg/ha. However, at the same time under the original land cover situation, the yields were ranged from 168×10^3 kg/ha and 2438×10^3 kg/ha. Within the other two situations, the variations were not dramatic, but can prove the benefits of CCFP implementations. Compared to sediment variations and organic N estimations, the organic P yields difference of four scenarios over ten years was not dramatic. One important reason is that parts of the organic N come from residue of the ground in forestry.

Statistical Analysis

The modeling approach was applied to estimate the 10-year impacts of implementing the CCFP in Bazhong City in the Yangtze River basin. The ten years' average results (sediment, stream flow, organic N, and organic P, respectively) of four scenarios were estimated respectively. With the ten years' average estimations, the order 2 polynomial trendline was mapped to examine the correlation between the NPS pollutants yields and forest area ratio (Fig. 9). The result shows that the regression between stream flow, sediment, and forest area ratio are not significant. However, regression correlation between simulated organic N, P values, and forest area ratio is highly significant with high r^2 of 0.9966 and 0.9980, respectively. With the forest area

Fig. 5 Comparison between simulated stream flow of four scenarios and precipitation from 1996–2005

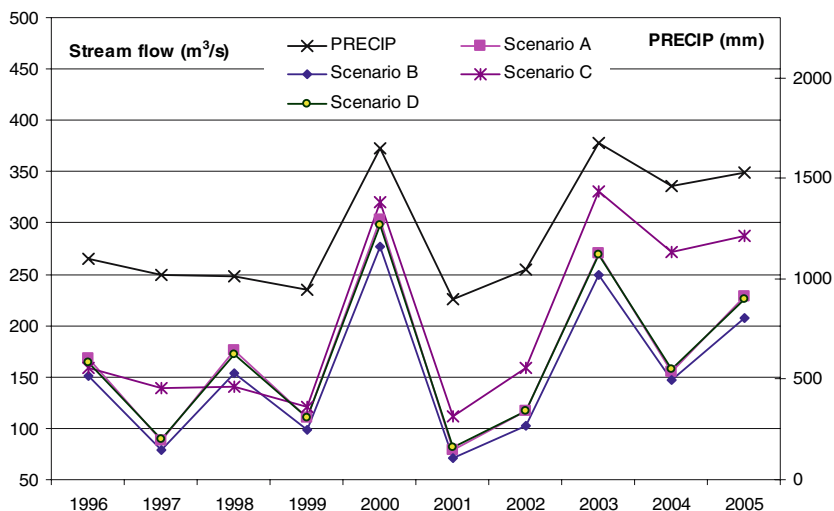


Fig. 6 Comparison between simulated sediments yields of four scenarios and precipitations from 1996–2005

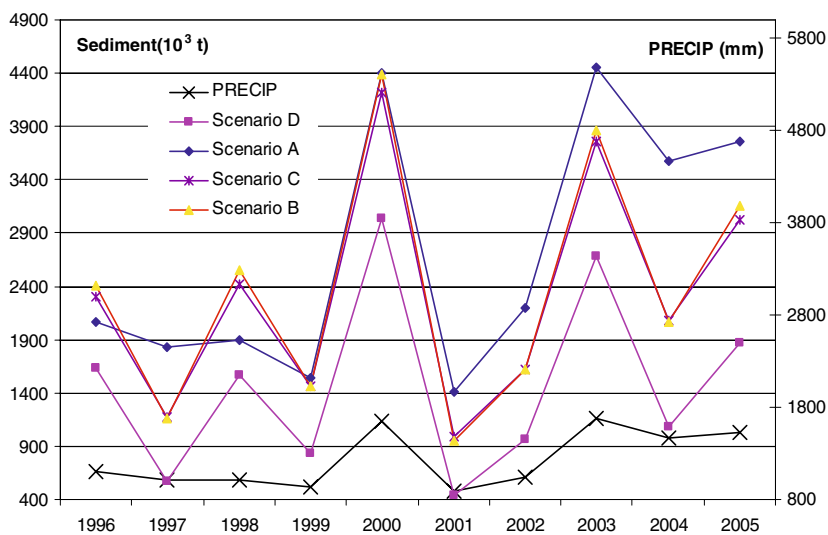


Fig. 7 Comparison between simulated organic N value of four scenarios and precipitation from 1996–2005

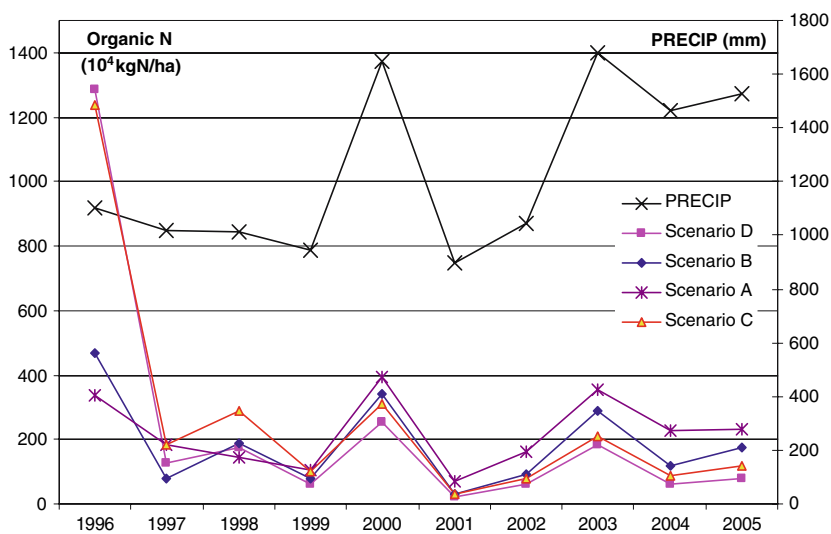


Fig. 8 Comparison between simulated organic P of four scenarios and precipitation from 1996–2005

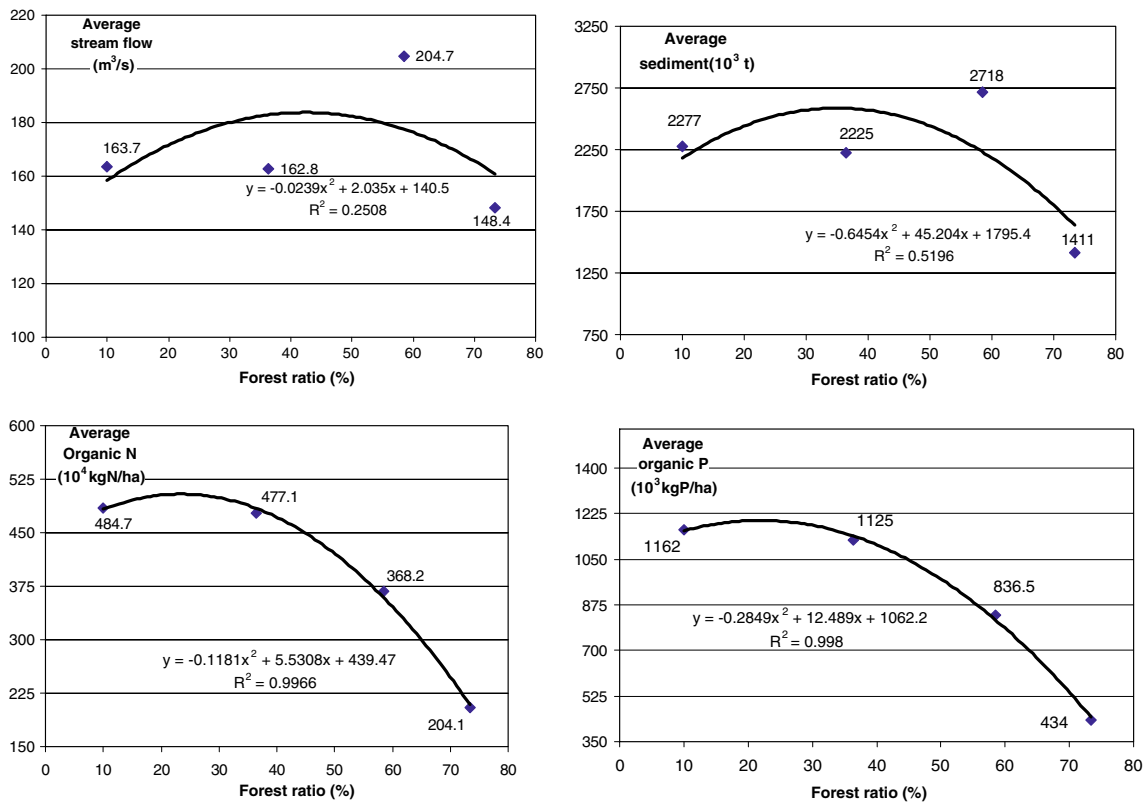
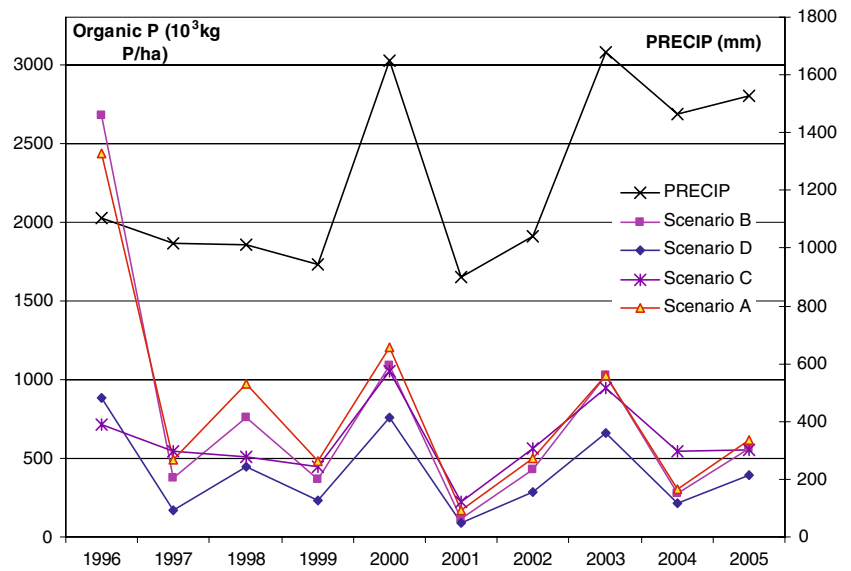


Fig. 9 Order 2 polynomial trendline between estimated results and forest area ratio

increase, the organic N and organic P yields dropped intensively, which proves that the CCFP implementation would be an effective way to prevent and reduce regional NPS pollutions. In scenario D, for example, the organic N yield is 204.1×10^4 kg/ha, a reduction of almost 60% compared to the “baseline” land use conditions. Similarly, the organic P yield decreased from the 1162.0×10^3 kg/ha

to 434.0×10^3 kg/ha with a 62.7% reduction. The change of average ten years’ stream flow under the four scenarios was not significant. Yet the impacts of land use conversion from cropland to grassland/forest on the sediments formations and transportations are still significant. With the implementation of CCFP in scenario D, reductions in sediment is about 38.0%. Given the area of CCFP would be

implemented, these reductions and benefits of the policy are reasonable at the watershed level.

Conclusions

Land use conversion of hillside cropland to grassland/forest is one of the major national policies that have been adopted by the Chinese government to curb ecological destruction, prevent soil erosion, and reduce NPS pollution. This study attempts to assess quantitatively the impacts of this policy on soil erosion and NPS pollution loading.

The need for implementing CCFP and assessing soil and forest conservation practices was climbing extensively for soil erosion and NPS pollutants management. The modeling approach was applied to estimate ten-year impacts of implementing CCFP in Bazhong City in the Yangtze River watershed. With GIS technologies, the agricultural land at four slope grades were converted to forest, respectively, which indicated typical CCFP implementation levels. The ten years' average simulation about sediment, stream flow, organic N, and organic P in the four scenarios were calculated. By SWAT modeling, the estimations demonstrated CCFP benefit about soil erosion and NPS pollution at regional scale. The results revealed that the organic N and organic P decreased 42.1% and 62.7%, respectively, when agricultural land with slope greater than 7.5° was transferred to forest. With regression principle between pollutant load and forest area ratio, the environmental benefits of CCFP at any level can be calculated. Quantifications of benefits of soil erosion and water quality were necessary for future planning.

The SWAT modeling approach was proved as an effective tool for decision makers to assess benefits of CCFP at watershed level. SWAT system was useful to identify effects of CCFP applied in a new watershed or to quantify long-term environmental consequence of CCFP in a watershed where they have been already carried out. However, we only discussed the land use conversions in this article. The other land management practices, which also cause better regional environmental quality, were not modeled.

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References

- Arnold JG, Allen PM, Muttiah RS, Bernhardt G (1995) Automated base flow separation and recession analysis techniques. *Ground Water* 33(6):1010–1018
- Arnold JG, Fohrer N (2005) SWAT2000: current capabilities and research opportunities in applied watershed modeling. *Hydrologic Processes* 19:563–572
- Arnold JG, Srinivasan R, Muttiah RS (1998) Large area hydrologic modeling and assessment. Part I: Model development. *Journal of the American Water Resources Association* 34(1):73–89
- Attwood JD, McCarl B, Chi-Chung Chen, et al. (2000) Assessing regional impacts of change: linking economic and environmental models. *Agricultural Systems*. 63(3):147–159
- Behera S, Panda R (2006) Evaluation of management alternatives for an agricultural watershed in a sub-humid subtropical region using a physical process based model. *Agriculture, Ecosystems and Environment* 113:62–72
- Chen ChingHo, Liu WeiLin, Leu HorngGuang (2006) Sustainable Water Quality Management Framework and a Potential impacts of climate change on groundwater recharge and stream flow in a central European low mountain range. *Journal of Hydrology* 284:244–252
- Cheng Hongguang, Ouyang Wei, Hao Fanghua, et al. (2007) The Non-point Source Pollution in Livestock-breeding Areas of the Heihe Riverbasin in Yellow River. *Journal of Stochastic Environmental Research & Risk Assessment* 21(3):213–221
- Eckhardt K, Ulbrich U (2003) Strategy Planning System for a River Basin. *Environmental Management* 38:952–973
- Martin Plusa, Isabelle La Jeunesse, Faycal Bouraoui, et al. (2006) Modelling water discharges and N inputs into a Mediterranean lagoon impact on the primary production. *Ecological Modelling* 193:69–89
- Ramanarayanan TS, Srinivasan R, Arnold JG (1996) Modeling Wister Lake Watershed using a GIS-linked basin scale hydrologic water quality model. In: *Third International Conference on Integrating Geographic Information Systems and Environmental Modeling*, January, Santa Fe, NM
- Santhi C, Srinivasan R, Arnold JG (2006) A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. *Environmental Modelling & Software* 21:1141–1157
- Tripathi MP, Panda RK, Raghuvanshi NS (2003) Identification and Prioritization of Critical Sub-watersheds for Soil Conservation Management using the SWAT Model. *Biosystems Engineering* 85(3):365–379
- Wang Qingeng, Gu Gang, Yoshiro Higano (2006) Toward Integrated Environmental Management for Challenges in Water Environmental Protection of Lake Taihu Basin in China. *Environmental Management* 37(5):579–588
- Wanga, Ouyanga H, Maclarenc V (2006) Evaluation of the economic and environmental impact of converting cropland to forest: A case study in Dunhua county, China. *Journal of Environmental Management*. Article in Press. Available online 22 December
- Yin Hongfu, Li Changan (2001) Human impact on floods and flood disasters on the Yangtzeriver. *Geomorphology* 41(2–3):105–109
- Zhang H (2003) Guidance and Practice of Converting Cropland to Forest, Chinese Press of Agricultural Science and Technology 2003:3–120
- Zhang J, Jørgensen SE (2005) Modelling of point and non-point nutrient loadings from a watershed. *Environmental Modelling and Software* 20:561–574
- Zhang Xinbao, Zhang Yiyun, Wen Anbang, et al. (2003) Assessment of soil losses on cultivated land by using the ^{137}Cs technique in the Upper Yangtze River Basin of China. *Soil and Tillage Research*. 69(1-2):99–106