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A Variety of Meteorological and Geographical Characteristics Effects on Watershed Responses to a Storm Event

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***Abstract*—**The Chichiawan stream in the Wulin catchment in Taiwan is the natural habitat of Formosan landlocked salmon. Human and agriculture activities gradually worsen water quality and impact the fish habitat negatively. To protect and manage Formosan landlocked salmon habitat, it is important to understand a variety land-uses affect on the watershed responses to storms. This study discusses watershed responses to the dry-day before a storm event and a variety of land-uses in the Wulin catchment. Under the land-use planning in the Wulin catchment, the peak flows during typhoon events do not have noticeable difference. However, the nutrient exports can be highly reduced under the strategies of restraining agriculture activities. Due to the higher affinity of P for soil than that of N, the exports of TN from overall Wuling catchment were much greater than Ortho-P. Agriculture mainly centralized in subbasin A, which is the important source of nutrients in nonpoint source discharge. The subbasin A supplied about 26% of the TN and 32% of the Ortho-P discharge in 2004, despite the fact it only covers 19% area of the Wuling catchment. The subbasin analysis displayed that the agricultural subbasin A exports higher nutrients per unit area than other forest subbasins. Additionally, the agricultural subbasin A contributed a higher percentage to total Ortho-P exports compares to TN. The results of subbasin analysis might imply the transport of Ortho-P was similar to the particulate matter which was mainly influenced by the runoff and affected by the desorption from soil particles while the TN (dominated as nitrate-N) was mainly influenced by base-flow.

***Keywords*—**Chiachiawan stream, Formosan landlocked salmon, modeling, typhoon, watershed response.

I. INTRODUCTION

THE Formosan landlocked salmon (Oncorhynchus masou formosanus) hailing from the Ice Age is endemic to Taiwan. The fish is migratory specie and survives in clean water with a temperature below 18 ^{o}C and inhabits slow-flowing streams with gently sloping beds at elevations above 1500 m. During the recent several decades the habitat of the Formosan landlocked salmon has gradually decreased from 6 to 1 remained stream [1]-[3]. Recently, the Formosan landlocked salmon were added to the International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species. Therefore, the Chichiawan stream in the Wulin catchment, the last natural habitat of the fish attracts attention from government to keep suitable environment for the fish [4]. Because of the use of fertilizer in agriculture has impacted its habitat negatively, primarily impacted the water quality. It is necessary to understand the watershed responses to various land-use activities and the weather characteristics during a storm event.

Taiwan is hit by 3-4 typhoons per year on average. The winds and heavy rainfall come with typhoons cause agricultural and industrial damages, which affect human lives and may greatly affect watershed structure. E.g., in 1996, the typhoon Herb caused 70 death and about $5 billion damage to agriculture and property [5]. The hydrological response of a watershed to an extreme meteorological event largely depends on e.g. precipitation amount, intensity and duration. Studies showed that runoff, erosion and pollutant exports tend to increase with increasing rainfall intensity [6]-[10].

The WinVAST model, developed by the University of Virginia in 2003 was applied to predict watershed responses in this study. A better understanding of the potential hydrological watershed responses and their effect on the Formosan landlocked salmon habitat will allow watershed managers of the Wulin catchment to develop strategies to face potential calamity and protect natural environment of precious species. The aims of this study were (1) to discuss watershed responses including hydrologic responses and total nitrogen (TN) and ortho-phosphate (Ortho-P) exports in the Wulin catchment during a typhoon event, (2) to evaluate the effects of various dry days before a storm event on the nutrients exports, (3) to analyze the effects of a variety of land-use in each subbasins on watershed responses.

II. MATERIALS AND METHODS

A. Model description

The WinVAST model uses tree-view structure to describe streams in a watershed. It combines flow calculation, pollutant transport and pollutant exports computation in Windows interface. WinVAST model is more friendly for model users than its former version—VAST model. It provides several methodology for computing excess precipitation, rainfall

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abstraction, hydrograph and pollutant transport.

The pollutant accumulation on the land surface prior to a storm event is computed by the following formula:

$$P(p,l) = AREA(l) * LR(p,l) * DD + P0(p,l) \quad (1)$$

where P(p,l) is the accumulation of pollutant p on land use l just prior to storm event; P0(p,1) is the weight of pollutant p on land use l just after the previous storm; AREA(l) is the area of land use l; LR(p,1) is the loading rate for pollutant p on land use l; DD is the number of dry days since the previous storm.

The pollutant wash-off from the land surface during a storm event can be computed by the following general formula:

$$M(p,l) = A(p) * P(p,l) * \left(1.0 - \exp\left[-k(p) * R\right]\right) + FSUS(p) * M(sus) + FSET(p) * M(set) \quad (2)$$

where M(p,1) is the wash-off rate of pollutant p from land use l; A(p) is the fraction of pollutant p available for wash-off from the land surface; K(p) is wash-off decay coefficient for pollutant p; R is surface runoff; FSUS(p) is the fraction of suspended solids that is pollutant p; M(sus) is the wash-off rate of suspended solids; FSET(p) is the fraction of settleable solids that is pollutant p; M(set) is the wash-off rate of settleable solids [11], [12].

B. Site description

The Wulin catchment, as shown in Fig. 1, has a drainage area of 73.3 km^2. The Chichiawan stream is the mainstream in the Wulin catchment. The elevation in the Wulin catchment is between 2000-2500 m. The average slope is about 30%. The main land-use activity in the area is forest. The average curve

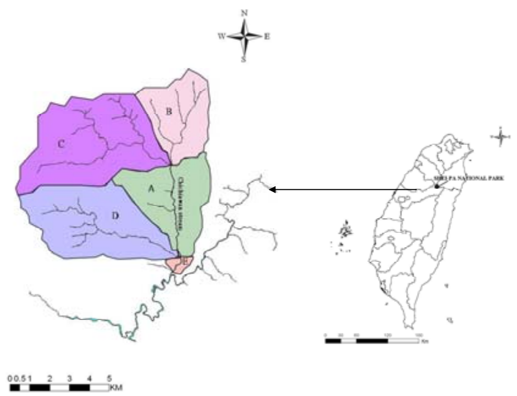

Fig. 1 Wulin watershed in Taiwan

number (CN), which represents land-use condition and soil type [13]-[15], is about 56 for the area [16]. The nutrient loadings of TN and Ortho-P in forest are about 8 g as N/day/ha and 0.5 g as P/day/ha respectively [17]. The Wulin catchment was divided into 5 subbasins by Geographic Information System (GIS) technique. The area of subbasin A, B, C, D and E are 14.3, 11.3, 25.4, 21.4 and 0.8 km^2 respectively. The mainstream length in subbasin A, B, C, D and E are 5.4, 4.2, 6.7, 7.4 and 1.1 km respectively.

III. RESULTS AND DISCUSSIONS

A. Relationship between storm characteristic and watershed responses

The storm event, typhoon Minduli, was chosen as the model case. The precipitation records of typhoon Minduli was acquired from the Taoshan rainfall station of the Der-Gi reservoir administration. Minduli attacked Taiwan in July 2004. The total precipitations are 397 mm.

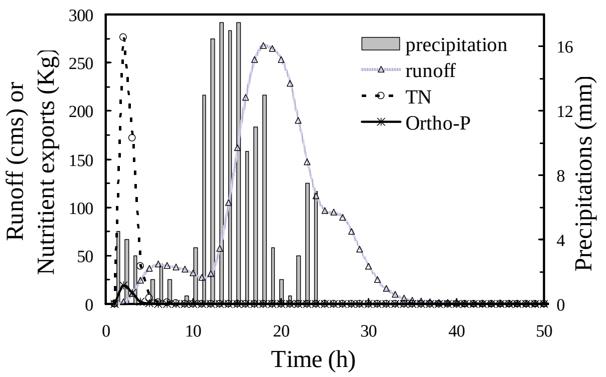

Fig. 2 Rain precipitations and watershed responses during typhoon Minduli

Fig. 2 shows the hyetographs of typhoon Minduli and watershed responses, which include hydrographs and nutrient exports during Minduli. The peak runoff was around 268 cms. The peak loadings of TN and Ortho-P washed out during Minduli were 276 and 18.8 kg/hr respectively. The runoff flow pattern with time is similar to the precipitation but exists a lag of approximate 5 hrs. However, the modeling result shows that the initial erosion from the land surface is the main washout during a typhoon event. The peak TN and Ortho-P loadings occur at the 2nd hr and there was almost zero nutrients washed out after five hours even the peak precipitation occurred at the 13th hr. These phenomena could be attributed to the different characteristics of nutrients and flow. The runoff flow results from the discharge of water after the pores of soil are fully charged by rain precipitation. The continuous rainfall accounts for the charge source of runoff water. However, the nutrients, TN and ortho-P were already existed in the soil before a storm. There was no immediate charge source after the initial washout.

B. Effects of the number of dry day before a typhoon event

Because of the nutrients were washed out by initial erosion, the remained nutrients in soil affect the stream water quality significantly. Fig. 3 displayed the effects of the number of dry day before a storm event on the discharge and nutrient exports. Fig. 3a indicated that the quantity and time evolution of discharge were not influenced by the number of dry day. However, the nutrient exports considerably depend on the number of dry day before the Minduli event. The more number of dry day before a storm event results in the more nutrients remained in soil and the more first flush of nutrients during a storm event. Figure 3b and 3c show that the exports of TN were much greater than that of Ortho-P. These results can be accounted for the chemical properties of these nutrients. TN was composed of the nitrate-N, nitrite-N, ammonia-N and organic N. Most of the form of N are inert (or weak affinity) for the major constituents, such as silica, iron (hydro)oxides, aluminum (hydro)oxides, and manganese (hydro)oxides [18]. Therefore, TN was easily washed out from the soil during a storm event.

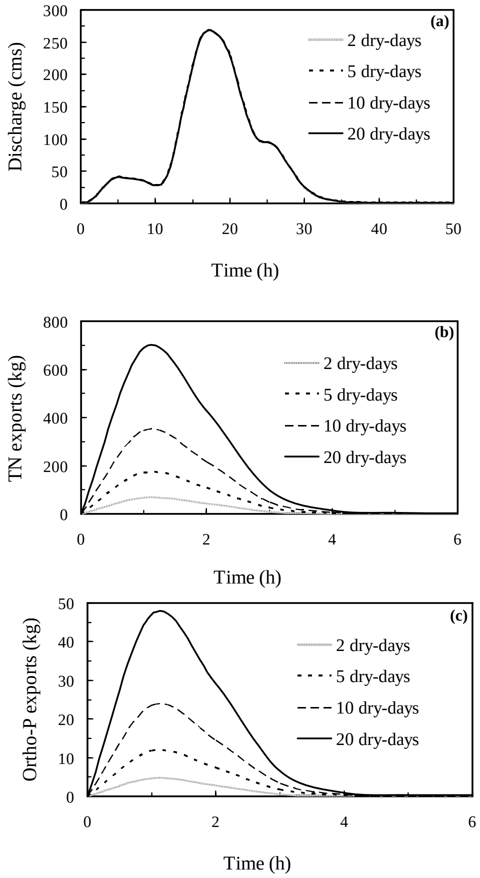

Fig. 3 Effects of the number of dry day before a storm event on the discharge and nutrient exports.

By contrast, phosphate possesses stronger affinity with most of the soil constituents, such as iron (hydro)oxides, aluminum (hydro)oxides, and manganese (hydro)oxides [19]. The strong affinity imply the less desorption of Ortho-P from soil during a storm. In most agricultural watershed, phosphorus transport is also reported occurred mainly in surface runoff and soil erosion, the transport of pathways of nitrogen are considered to be different from the phosphorus [20].

C. Land-use effects on the nutrient exports from each subbasin

To protect the natural habitat of the Formosan landlocked salmon, the government began a land-use planning in 2005 and planned to reduce the area of agriculture activities gradually to totally filled with forest in the catchment until 2010. The agriculture was mainly centralized in subbasin A and the other subbasins, including B, C, D and E are covered by forest during the planning period 2004-2010. Table 1 lists the land use changes of subbasin A from 2004 to 2010.

The modeling results indicated that the peak flows during typhoon Minduli did not show significant difference under various land-use plans in the Wulin catchment (figure not shown). However, the nutrient exports including the exports of TN and Ortho-P can be decreased under the reduction of agriculture from 2004 to 2010 substantially (Fig. 4). In 2004, before the agricultural reduction plan, although subbasin A covers only 19% of the Wulin catchment, it was the most important source of most nutrients in nonpoint source discharge; it supplies about 26% of the TN and 32% of the Ortho-P discharges. With yearly reduced agriculture, the nutrient (both of TN and Ortho-P) discharges of subbasin A will also decrease to about 18% in 2010, which is proportional to the covered area, 19%. Compared to TN, Ortho-P was significantly contributed a higher percentage from subbasin A in agricultural years. Stutter et al. [21] pointed out that distributions of N and P in agricultural headwater were different; annual P fluxes of particulate and dissolved forms were equal, whilst N was dominated by NO_3-N. Kato et al. [22] reported that the load of first-flush (the increasing rate of nutrient loads is higher than runoff) of the particulate materials were stronger than other nutrients. Lee and Bang [23] reported that the strength of the first-flush was in the order of chemical oxygen demand (COD) > SS > Ortho-phosphorus (PO_4–P) > NO_3–N for the industrial and residential watersheds. Stutter et al. [21] analyzed the first-flush in two agricultural catchments in NE Scotland and reported that the strength of the first-flush was in the order of Particulate-P > PO_4–P > NO_3–N. The order of PO_4–P (Ortho-PP), and TN (dominated as NO_3–N) was consistent with the present study. Therefore, the transport of ortho-P was similar to the particulate matter which was mainly influenced by the runoff and affected by desorption from soil particles; while the TN (dominated as nitrate-N) was mainly influenced by base-flow.

TABLE I LAND-USE CHANGES OF SUBBASIN A FROM 2004 TO 2010

Land-use	Area(km^2)			
	2004	2005	2006	2010
Forest	13.39	13.56	13.60	14.27
Fruit farm	0.31	0.31	0.31	0
Vegetable farm	0.41	0.24	0.20	0
Tea farm	0.16	0.16	0.16	0

IV. CONCLUSIONS

The integrated management of Wulin catchment is the established policy of the government because the Formosan landlocked salmon residing in this watershed was added to the IUCN Red List of Threatened Species. The results of this study imply that land-uses and the number of dry day before a storm event influence the nutrient discharges significantly, which substainly govern the water quality of the stream.

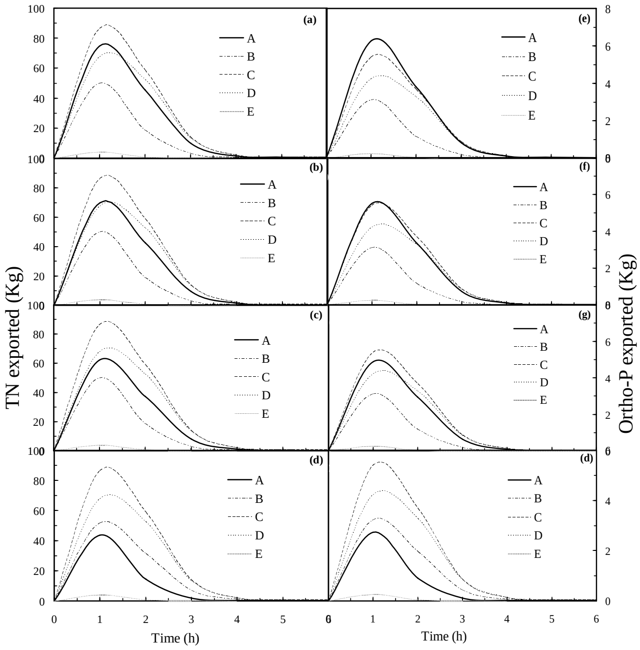

Fig. 4 Effects of land-use planning on the nutrient exports from subbasins (a) TN at 2004, (b) TN at 2005, (c) TN at 2006, (d) TN at 2010; (e) Ortho-P at 2004, (f) Ortho-P at 2005, (g) Ortho-P at 2006, Ortho-P at 2010.

The results are concluded as follows: (1) the evolution of runoff flow with time is similar to the precipitation but exists a lag of approximate 5 hrs; whilst the peak TN and Ortho-P loadings occur at the 2nd hr; (2) the number of dry day before a storm influences the amounts of nutrient exports significantly but not for the runoff flow; (3) the exports of TN from overall Wuling catchment were much greater than the Ortho-P; the phenomenon could be attributed to the higher affinity of P for soil than N; (4) Agriculture is the important source of nutrients in nonpoint source discharge, supplying about 26% of the TN and 32% of the Ortho-P discharge, despite the fact subbasin A only covers 19% area of Wuling catchment; (4) the higher first-flush of Ortho-P than TN implied the transport of ortho-P was similar to the particulate matter which was mainly influence by the runoff and affected by desorption from soil particles; while the TN (dominated as nitrate-N) was mainly influenced by base-flow.

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