Point-by-point response to Interactive comment on "Sediment trap efficiency of paddy fields at the watershed scale in a mountainous catchment in Northwest Vietnam" by J. I. F. Slaets et al.

Original comments in italic
Responses in non-italic

Anonymous Referee #3

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The present article "Sediment trap efficiency of paddy fields at the watershed scale in a mountainous catchment in Northwest Vietnam" investigates a major issue in soil conservation (soil erosion and sedimentation) with key implications for soil fertility and food security in high land tropical ecosystems (loss of fine soil particles in the uplands, siltation in the low lands). This paper is well illustrated and well written.

Despite that I found it did not acknowledge the existing literature on the subject (impact of land use change on soil erosion in the uplands of South-East Asia with numerous papers such as by Ingram et al. 1996; Gafur et al. 2003; Chaplot et al. 2007; : : :: : :: : :: : :: : :: : :.) and on sedimentation in basins (Gafur et al. 2003, Lapon, 2010, Chaplot and Poesen, 2012; Schmitter et al. 2012, Nunkaew, 2012,: : :: : :: : :: : :: : :..: : :)

We thank reviewer #3 for his interest in our research question. We have added an additional selection of literature relating land use change, soil erosion and scaling effects in sedimentation to the introduction.

and faces a major flaw (continuous inputs of sediments occur in irrigation canals from dam to paddy field outlet which are not considered.

The irrigation channel is fed by the surface reservoir via an outlet in the dam, and the amount of sediments that leave the surface reservoir were quantified by measurement location 1, and this sediment concentration was the same that entered the paddies as in a concrete lined fast-flowing channel, during no-rain there are no additional inputs or losses. Additional sediment inputs from upland area adjacent to the channel was quantified as the load difference between measurement location 1 and measurement location 2. The channel effectively isolates the paddies from surrounding areas, as the entire rice area is separated from upland fields by the channel. There are no additional inputs to the paddy area that do not pass the irrigation channel system first. The dam does trap sediments, but we are measuring past the dam outflow and therefore these processes do not affect the paddy area nor our experimental setup: as the spillover flows into the river, there is no direct dam overflow to the paddies.

The authors made other methodological choices which are very difficult to defend such as the use of MIRS for evaluating sediment texture for 100 samples and Laser, an broadly accepted and accurate methods for 50 samples, while all the 150 samples could have been analyzed by laser and the whole paragraphs dedicated to MIRS modeling could have been deleted.

Texture analysis with conventional methods typically requires a minimum of one gram of sample. Collecting this amount can be unpractical when the sediment is obtained from water samples which have a very low sediment concentration. The base-flow sediment concentrations in this study fluctuated around 250 mg L-1, which would mean that samples of approximately 4 L would have to be collected, transported, refrigerated for storage and analysed in order to have enough material for

conventional analysis, which was deemed not feasible given the large dataset collected. Diffuse reflectance Fourier transform mid-infrared spectroscopy (MIRS) is a practical alternative to determine particle size distribution on sediment samples, as only 25 mg is needed for analysis and the measurement is not destructive (Cobo et al., 2010; Demyan et al., Schmitter et al., 2010, Towett et al., 2015). The MIRS method was calibrated and validated with the laser diffraction, which is as reviewer #3 points out a broadly accepted and accurate method, but in order to have enough material for samples at low concentrations, up to ten base-flow samples needed to be bulked. It was not feasible to obtain this many samples at each time point of the sampling campaign where concentrations were low, and additionally bulking results in a loss of temporal information which is undesirable.
We have clarified the need for MIRS with regard to available material and required sampling volume in the material and methods section: "Texture analysis with conventional methods typically requires a minimum of one gram of sample. Collecting this amount can be unpractical when the sediment is obtained from water samples which have a very low sediment concentration. The base-flow sediment concentrations in this study fluctuated around 250 mg L-1, which would mean that samples of approximately 4 L would have to be collected, transported, refrigerated for storage and analyzed. Diffuse reflectance Fourier transform mid-infrared spectroscopy (MIRS) is a practical alternative to conventional methods for determining particle size distribution on sediment samples, as only 25 mg is needed for analysis and the measurement is not destructive (Schmitter et al., 2010)."

All of this gives the impression that the authors put more emphasis on the tool they had at their disposal, going in different directions (why a sediment prediction part in this paper?)

The sediment concentration predictions in p20443, Line 6 are statistical predictions in the sense of predicted values of the response variable (sediment concentration) based on the predictor variables (turbidity and discharge). In other words, we are continuously estimating sediment loads using turbidity and discharge as a proxy, while simultaneously analysing the uncertainty introduced by using that method. The predictions provide us with an estimate of the sediment concentration every two minutes of the two year study period, which allows the estimation of the annual sediment load. These predictions as such are therefore not predictions in the future, but rather interpolations within the monitored period. This terminology was clarified in the manuscript: "Continuous statistical predictions of sediment concentration for the two year study period (temporal resolution of two minutes) were then obtained from a linear mixed model (Slaets et al., 2014), which is a regression-type model with SSC as response variable and turbidity, discharge and cumulative rainfall as predictor variables."

while they lacked setting up a proper experimental scheme.
We are not certain what the reviewer means with 'lacked setting up a proper experimental scheme'. As mentioned by reviewer one and addressed in an earlier comment of this reviewer, each of the potential sediment entering and exiting points was measured using field validated and published measurement strategies for both water quantity and quality. Based on these measurements, the SSC function was developed in order to calculate loads with a higher accuracy while aiming at minimizing laboratory costs. Additionally the paper discusses the potential sources of uncertainty and their effect on the overall load estimates.

Below are some additional comments:

Page 4 line 5 : "Implications of these land use changes have been studied in detail on the upland fields, and the increased erosion due to these changes are well documented." A proper literature review on these aspects should be performed

We have added additional references to the section on erosion and sedimentation affected by land use change, as suggested: "In shifting cultivation systems, forest plots are cleared and burned followed by cultivation of subsistence crops. Cultivation lasts for one to three seasons, after which the plots are left fallowed for a minimum of six times the cropping duration (Ziegler *et al.*, 2009). Traditional shifting cultivation systems are very extensive in space and time, generating very limited runoff and erosion at the watershed scale (Ziegler *et al.*, 2009). Gafur *et al.* (2003) reported soil losses amounting to 30 Mg ha^{-1} a^{-1} for an upland area with shifting cultivations, while the regional average sediment yield was 1.2 Mg ha^{-1} a^{-1}, as 43% of soil loss from upland areas was captured by filtering elements in the lower area of the watershed. Chaplot and Poesen (2012) similarly found large sediment accumulations downslope in a slash and burn system in Southeast Asia, pointing towards the lower impact of the land use at the watershed scale. In recent years, under the influence of market mechanisms and population pressure, the traditional shifting cultivation systems on the slopes have been replaced by permanent upland cultivation (Ziegler *et al.*, 2009). Implications of these land use changes have been studied in detail on the upland fields, and the increased erosion due to these changes are well documented. Chaplot *et al.* (2007) found water erosion rates of 6 to 24 Mg ha^{-1} a^{-1} in an intensifying slash and burn system in Northern Laos. Lacombe *et al*. (2015) determined that conversion of fallow into teak plantation versus forest communities has opposite effects on catchment hydrology. Infiltration increased and runoff decreased for the forest communities, while the opposite was true for the teak conversion, illustrating the effects of disappearing fallow depend strongly upon the replacing vegetation."

P 7 from line 10: how many samples, when, what calibration/validation procedure for the turbiditimeter?

The number of samples for each location is given in Table 1, which was clarified in the corresponding section: "Total sample sizes for each location are shown in Table 1." The relationship between sediment concentration and predictor variables turbidity, discharge and cumulative rainfall (the field calibration) was established using a linear mixed model, which is a regression-type model that can take into account the serial correlation between the within-storm samples. The validation was performed with five-fold cross validation. The manuscript was updated to re-emphasize this: "Field calibration of the sensors resulted in continuous statistical predictions of sediment concentration for the two year study period (temporal resolution of two minutes) which were obtained from a linear mixed model (Slaets et al., 2014). The linear mixed model is a regression-type model with SSC as response variable and turbidity, discharge and cumulative rainfall as predictor variables. … The models were validated with five-fold cross validation using a SAS macro described in Slaets et al. (2014)."

Why "and then 16 siphoning off the supernatant followed by ovendrying of the sediment at 35_C." ? does not seem standard procedure! Should have been 100_C

This study was part of a larger project where reallocation of organic carbon and nitrogen via sediment transport to irrigation systems was also studied. As oven drying over 40°C would render the samples purposeless for those analyses, the choice was made to dry all samples at 35°C until sample weight remained constant. This clarification was added to the methodology: "Sediment concentration in the samples was determined gravimetrically (ASTM, 2013) as recommended for samples with very high Suspended Sediment Concentration (SSC), by letting the sediment settle overnight in cold storage (<4°C) and then siphoning off the supernatant followed by oven-drying of the sediment at 35°C until the sample weight remained constant."

Why "Continuous predictions of sediment concentration were then obtained from a linear mixed 18 model (Slaets et al., 2014) with SSC as response variable and turbidity"? Prediction for what purpose?

The sediment concentration predictions here refer to statistical predictions, as in predicted values for the response variable (sediment concentration) based on the continuously measured (every two minutes) predictor variables turbidity and discharge. They are therefore not future concentration predictions, but rather interpolations to obtain estimated sediment concentrations for each time point of the two year study period based on a regression type model (the linear mixed model). This terminology was clarified in the manuscript: "Field calibration of the sensors resulted in continuous statistical predictions of sediment concentration for the two year study period (temporal resolution of two minutes) which were obtained from a linear mixed model (Slaets et al., 2014). The linear mixed model is a regression-type model with SSC as response variable and turbidity, discharge and cumulative rainfall as predictor variables."

Same for "To account for temporal correlation in the observations, an error with a first-order autoregressive covariance structure was fitted to the data. The response variable was log-transformed to stabilize the variance, as were the predictor variables discharge and turbidity. Model fit was evaluated with five-fold cross validation using a SAS macro described in Slaets et al. (2014)."

As the storm-based sampling strategy resulted in samples taken very closely together in time, a normal sediment rating curve, which is a linear regression model that assumes independent observations, is not a suitable approach. Samples taken closely together in time are autocorrelated, and we took this into account by fitting a first-order autoregressive structure to the residual error, which allows an observation to be correlated to the previous sample.

Similarly, linear models assume constant variance, while in sediment data the variability typically increases with increasing sediment concentration. The purpose of the log-transformation was to take this into account.

Five-fold cross validation was used as a tool to validate the performance of the statistical model of the sediment concentrations.

This has been clarified as follows: "As the storm-based approach resulted in samples taken at very short consecutive time intervals (i.e. 2 min), the assumption required for a traditional sediment rating curve of independence of errors was not fulfilled in this dataset. Similarly, we found the variance to increase with increasing sediment concentration, violating the assumption of homoscedasticity. To account for temporal correlation in the observations, an error with a first-order autoregressive covariance structure was fitted to the data. The response variable was log-transformed to stabilize the variance, as were the predictor variables discharge and turbidity. The models were validated with five-fold cross validation using a SAS macro described in Slaets et al. (2014)."

"2.4 Separating sediment sources" was not introduced There are different sources of water and sediments in the catchment as exposed by authors "ponds in the paddy area. The river receives outflow from both banks of paddy fields, and we only monitored the overland flow entering the right bank. Therefore, in order to quantify the net sediment balance for the paddy fields, the assumption is made that the upland fields on the left bank of the river generated the same amount of erosion as those on the right bank,"

There are only two sources of sediment inputs to the paddy area: sediments in irrigation water from the surface reservoir, and overland flow which enters the paddies via the channel. Our choice of monitoring locations enabled us to separate these two sources by the same flow component separation published by Schmitter et al (2012): the measurement location in the channel just below the reservoir quantified sediment outflow whereas the measurement location at the point where the channel exits the channel allows to calculate the load entering the both paddy banks.

Inputs from overland flow to the right bank of paddies could be calculated as the difference between location 1 (just downstream of the reservoir) and location 2 (channel watershed exit) during rainfall. As the land use, slopes and area of the upland area on both banks is very similar in our study area, hence our assumption of similar inputs from overland flow to both banks of the paddy area.

Paddy outflow was calculated as the difference between the two river locations (one upstream, one downstream of the paddy area). There is a very small percentage of the paddy area which is actually fish ponds (<1%) and therefore indeed, some part of the sediment outflow into the river may also originate from these ponds. The outputs are thus combined lowland activities of paddy and pond systems rather than solely rice fields. Local knowledge shows that often, ponds are kept closed with no in-and outflow, and this in combination with their much smaller area leads us to attribute the paddy hydrology as the driving force of sediment redistribution in that area. Furthermore, paddy and pond sediments originate from the same source (surrounding upland area) and therefore consist both of the same quality and texture of material. While ponds are deeper, they are kept full so they have low buffering capacity, and therefore freeboard volume as well as overflow are very similar for ponds and paddies.

The manuscript has been updated to reflect these clarifications: "There are only two sources of sediment inputs to the paddy area: sediments in irrigation water from the surface reservoir, and overland flow which enters the paddies via the channel. The paddies are isolated from surrounding uplands by the channel, and no overland flow enters the paddies without passing through the irrigation channel (Figure 1). The monitoring locations in the concrete irrigation channel were chosen in order to separate these contributions of irrigation water from the surface reservoir, and Hortonian overland flow, to the paddy fields. The station situated furthest upstream in the channel (Location 1 in Figure 1) was placed directly below the reservoir outlet, and thus monitored the discharge and water quality of the surface reservoir, which equals the sediment concentration of paddy inflow when it is not raining. … Thus, sediment inputs from reservoir outflow to both banks of the paddy area could be quantified."

2.6 Sediment texture with mid-infrared spectroscopy ?
"As the MIRS method requires a subset of the samples to be analyzed with conventional wet analytical methods for calibration and validation, laser diffraction with a Coulter LS 200 (Beckman Coulter, Germany) was performed on 50 samples." Laser diffraction also needs to be calibrated. Can understand why using MIRS when laser available. Lots of work for so little samples: "Sand, silt and clay were predicted from the spectral data using Partial Least Squares Regression (PLSR; Wold, 1966). All spectral manipulation and model selection was performed using QUANT2 package within software OPUS 7.0 (Bruker Optik, Germany). Models were evaluated with leave-one-out cross validation. OPUS offers several spectral processing techniques to enhance spectral information and reduce noise. The selection of the most suitable method can be automatized using the OPTIMIZATION function, which selects the method resulting in the highest r2 of observed versus predicted values after cross- validation. For sand, the pre-processing method was the calculation of the second derivative of the spectra, which can help to emphasize pronounced but small features over a broad background. After validation, an r2 of 0.81 was obtained. For silt, multiplicative scattering correction was applied, which performs a linear transformation of each spectrum for it to best match the mean spectrum of the whole set, and the model resulted in an r2 of 0.83. For clay, no satisfactory model could be obtained, and so the clay percentage was calculated as the remaining amount of sediment after subtracting the sand and silt fractions."
The choice for MIRS was driven by the amount of material available per sediment sample. Most conventional methods including laser diffraction require a minimum of one gram of soil or sediment. For our concentration range in the water samples, which fluctuated around 250 mg L-1, samples of approximately 4 L would have to be collected, transported, refrigerated for storage and analysed in order to have enough material for conventional analysis, which was deemed not feasible given the large dataset collected. Diffuse reflectance Fourier transform mid-infrared spectroscopy (MIRS) is a practical alternative to determine particle size distribution on sediment samples, as only 25 mg is needed for analysis and the measurement is not destructive (Schmitter et al., 2010). The MIRS method was calibrated and validated with the laser diffraction, which is as reviewer #3 points out a broadly accepted and accurate method, but in order to have enough material for laser diffraction analysis at low concentrations, up to ten base-flow samples needed to be bulked, and it was not feasible to obtain this many samples at each time point of the sampling campaign where concentrations were low.
We have clarified the need for MIRS with regard to available material and required sampling volume in the material and methods section: "Texture analysis with conventional methods typically requires a minimum of one gram of sample. Collecting this amount can be unpractical when the sediment is obtained from water samples which have a very low sediment concentration. The base-flow sediment concentrations in this study fluctuated around 250 mg L-1, which would mean that samples of approximately 4 L would have to be collected, transported, refrigerated for storage and analyzed. Diffuse reflectance Fourier transform mid-infrared spectroscopy (MIRS) is a practical alternative to conventional methods for determining particle size distribution on sediment samples, as only 25 mg is needed for analysis and the measurement is not destructive (Schmitter et al., 2010)."

Table 1: 6 of water flux observations only? "Table 1: Number of observations (n), coefficient of determination (R2) and method used for stage-discharge relationship (Q); and number of observations and Pearson's correlation coefficient (r2) after five-fold cross-validation for suspended sediment concentration predictions (SSC)."
How were 6 data points used to estimate yearly loads?

These are the number of observations obtained to establish the stage-discharge rating curve which allowed calculating loads from the concentration data. As the channel is concrete lined with a fixed cross section and slope, and the salt dilution method was used, very few observations are required to obtain a reliable discharge rating curve, as can be seen from the resulting R^2 which ranged from 0.96 to 0.99 for the channel locations. It is not the case for this study that loads were calculated based on load measurements at certain time points which were then integrated over the monitoring period, in which case six load measurements would be an inadequate sample size. Rather, we used the continuous discharge and sediment concentration data to obtain instantaneous loads at each measurement time point of the water level and turbidity sensors (which was every two minutes). As the discharge rating curve is highly accurate, sampling strategies in such a program focus on the sediment concentration dataset, which has a much higher uncertainty as can be seen from Table 1.

Table 3: "Sediment inputs from irrigation water and overland flow from the 37 ha upland area 1 in the sub-watershed, and sediment export and trapping by the 13 ha paddy area (Figures 1 2 and S1). Loads are estimated as the median of the bootstrap estimates (Med), and 95% 3 confidence intervals are shown (LL=lower limit, UL=upper limit) in Mg per year. 4 Sediment load (Mg a-1)" What is Mg a-1 ?
The unit of this table is Megagrams (or tons) per year (a^{-1}), the abbreviation has been specified in the figure caption: "Loads are estimated as the median of the bootstrap estimates (Med) and therefore do not always sum up exactly within columns, and 95% confidence intervals are shown (LL=lower limit, UL=upper limit) in Mg per year (Mg a^{-1})."

Where is dam? How can sediments not be settled in dam? Sediments obviously come from slope nearby paddy fields, how to discriminate between the two origins?
"Figure 1: Sediment sources and water flows into and out of paddy rice fields in Chieng Khoi watershed. The dotted yellow arrows show the 3 irrigation channel leaving the reservoir and splitting in two, feeding the two banks of paddy rice. The rice fields subsequently drain into the river"
The dam creates the surface reservoir that feeds the irrigation channel, and is thus located upstream of channel, river and paddy area. We have added the location of the dam to Figure 1. The dam does trap sediment, but these inputs originate from the 490 ha contributing area of the reservoir which does not contain paddies. Part of the sediments is trapped in the reservoir, and part is released to the paddies, the latter being what we monitor at Location 1. The component of overland flow that directly enters the paddies via the irrigation system is the contributing upland area between Locations 1 and 2. This contribution is what we quantify with the flow component separation and differences between the sediment loads at Locations 1 and 2.

How many data points to generate: Figure 2: Total discharge from the reservoir irrigated to the 13 ha paddy area draining between Locations A and B in the river, and total discharge exported from the sub-watershed via the irrigation channel at Location 3, per rice crop (spring, summer) per year, and amount 4 of rainfall per rice crop per year.
Total reservoir discharge inputs to the paddy area are calculated as the difference during base-flow conditions between Locations 1 and 2 (upstream and downstream of the paddies in the channel). The discharge is based on water height measurements with automatic pressure sensors which register the data every two minutes, and the establishment of a discharge rating curve with the salt dilution method for each location with the number of stage-velocity measurements indicated in Table 1. As the concrete lined channel has a fixed cross section and slope, a small number of stage-velocity

measurements suffices to obtain highly accurate stage-discharge rating curves, as is evidenced by the resulting R^2 values in Table 1.

References

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