Sediments discharge analysis using tank model for disaster mitigation

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Abstract. Environmental degradation as a result of deforestation carried out in the Catchment resulted in a decrease in its ability to store water. This has the effect of increasing the amount of sediment discharge. The process of estimating sediment discharges is very difficult because the data input variables are many and varied, usually, the data are very limited, because the erosion process occurs until the sediment discharge mechanism is quite complex. The process of sediment discharges in Catchment s is influenced by rain and surface runoff and is represented in the storage type. In this study, an approach using the Tank Model was conducted. The purpose of this study is to develop a tank model for sediment discharge analysis in disaster mitigation. The steps are setting the field experiment for collecting rain and discharge sediment data as the model input and setting the model analysis by making the structure and formulation of the tank model. There are 3 proposed tank models namely Tank Model 1 (three tanks, series, and cascade), Tank Model 2 (two cascade tanks), and Tank Model 3 (three cascade tanks). Model parameters are determined using the Genetic Algorithm (AG) method optimization approach. The analysis shows that Tank Model 3, composed of 3 (three) cascade tanks, represents a Catchment better than the other 2 tank models. This can be seen from the value of the accuracy of the model, namely the value of volume error (VE), the value of relative error (RE), the value of the mean least square error (RMSE), and the value of the correlation coefficient (R). But still has a range of differences for the value of sediment discharges, the cause may be a factor in the pattern of rain spread in the hydrological process, synchronization of the measurement process and data length, and the possible assumptions of the model parameters.

1. Introduction

Environmental degradation as a result of deforestation carried out in the Catchment resulted in a decrease in its ability to store water. Irresponsible deforestation has resulted in 58 critical Catchments in Indonesia [1], then increased to 62 critical Catchments [2], and currently, there are 108 Catchments in critical condition [3]. Critical Catchment indications increase with high sediment flow rates, resulting in floods, landslides, this causes damage to water structures and reservoir sedimentation [4].

The process of estimating sediment discharges is very difficult because the data input variables are many and varied, usually, the data are very limited, because the erosion process occurs until the sediment discharge mechanism is quite complex. Sediment discharge analysis is usually done by making a sedimentary curve (Sediment Rating Curve) which requires a fairly long measurement data that covers a variety of small to large discharge ranges and if carried out measurements require time, money and energy [5]. Sediment erosion-discharge models, such as the WEPP model [6], KINEROS
model [7], ANSWERS model [8], AGNPS model [9,10] and SWAT model [11,12] include erosion and sediment discharge analysis in regional land areas river flow caused by rainfall and land surface flow [13]. Apply the Time-Area method for prediction of sediment yield with time variations [14,15] with a lumped sediment runoff model analyzing sediment flow covering areas on sloped land and in rivers in Catchments.

Application of the tank model for sediment yield, with analysis using 3 (three) cascade tank arrangements and the same tank model parameters [16], both for surface runoff analysis in the form of discharge [17-20], and analysis of sediment results, namely discharge multiplied by sediment concentration. The application of the tank model to the sediment yield assumes that sediment concentrations undergo infiltration, percolation, and actual conditions are unlikely to occur in such a process, this is a weakness in the model. Application of the tank model uses Kalman filter for sediment yield, with analysis using the arrangement of 3 (three) cascade tanks and the same tank model parameters, both for rain-flow analysis in the form of discharge, and analysis of sediment yield i.e. discharge multiplied by sediment concentration [21]. The tank model parameters are determined by the vector condition in the model system on the Kalman filter using the optimal sequential estimation technique and the Kalman filter algorithm is formed by three components: (1) the system model; (2) measurement models; and (3) Kalman filter. Sediment flow analysis uses the lumped sediment runoff model which includes areas in sloped land and rivers in river basins and analyzes sediment discharges based on the rain-flow model, which is a tank model by incorporating sediment elements with 2 (two) tank arrangements) [22], but not yet implemented.

There is a significant difference from the results of previous studies with the research offered, that this study represents the process of erosion - sediment discharges in the Catchment in the form of reservoirs that is modifying the tank model developed for prediction of sediment discharge, namely Model Tank 1 with 2 (two) cascade tanks, Tank Model 2 with 3 (three) cascade tanks and Tank Model 3 with 1 (one) tank. Here this study aims to develop a tank model with predictive analysis of sediment discharges in Catchments for disaster mitigation by modifying tank structures based on erosion and sediment discharge processes in Catchments. Limitation of the study Sediment discharge referred to in this study is the result of erosion caused by rainfall and surface runoff in the Catchment (sloping land, grooves, and ditches). The implication of the model development is to provide supporting information, especially to the stakeholders of the Catchment management in carrying out sediment discharge monitoring to determine environmental degradation in the Catchment and the planning of water structures.

2. Methods
This research is located in the Kreo sub-catchment which has an area of 1692,812 hectares (Figure 1). The research location is the entry in the territory of Kendal district and Semarang city, with a description of the research areas, that the Kreo sub-catchment has a tropical climate that is influenced by monsoons. The rainy season occurs from November to May and the dry season from June to October.
The method in this study is a computational simulation to obtain sediment discharges with optimum tank model parameters, through calibration with measured sediment discharge data on the Catchment, to produce the best value of sediment discharge from the model output. Computational simulations are carried out on tank models using the Genetic Algorithm method. Computational simulations for tank models are carried out to analyze the prediction of sediment discharges in the Catchment in the Kreo sub-Catchment with model input data in the form of measured rain and measured sediment discharges. The steps are setting the field experiment for data retrieval as the model input data, and setting the model analysis by making the structure and formulation of the tank model. Research steps as shown in Figure 2.

Data collection includes rain data Automatic rainfall recorder (ARR) at Sta. Gonoharjo and measured sediment discharge data at an estimated post or river flow observation station (SPAS) in Purwosari Village, Gunungpati District, Semarang City. The examples of rainfall data and sediment discharge data that are used as model input data are shown in Table 1.

| Time (minutes) | 0   | 10  | 20  | 30  | 40  | 50  | 80  | 110 | 150 | 180 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Rainfall (mm) | 0.5 | 0.5 | 0.5 | 1   | 5   | 11.5| 8   | 9   | 2.5 | 1   |
| Sediment Discharge(ton/day) | 45.30 | 67.55 | 422.13 | 1063.24 | 1176.26 | 1243.66 | 748.824 | 679.67 | 173.12 | 90.20 |
There are 3 tank models with the proposed parameters, namely Tank Model 1 (three cascade series tanks), Tank Model 2 (two cascade tanks), and Tank Model 3 (three cascade tanks) Figure 3.

Figure 3. Tank model structure with parameters for prediction sediment discharge in Kreo subcatchment.

where: P(t) is rainfall (mm); Sed\textsubscript{1a}(t), Sed\textsubscript{2a}(t), Sed\textsubscript{3a}(t), Sed\textsubscript{4a}(t), Sed\textsubscript{5a}(t) is the Sediment Discharge (ton/day); Sed\textsubscript{0a}, Sed\textsubscript{0b}, Sed\textsubscript{0c} is Sediment Discharge deposition (ton/day); Q\textsubscript{w} is the subsurface flow (mm); Ha(t), Hb(t), Hc(t), is storage height the Sediment Discharge (mm); \textit{a}1, \textit{a}2, \textit{b}1, \textit{b}2, \textit{c}1, \textit{c}2 are parameters model sediment discharge; \textit{a}0, \textit{b}0, \textit{c}0 is the parameters model sediment deposition; \textit{ha}1, \textit{hb}1, \textit{hc}1 is high of upper hole the sediment discharge on a model (mm); \textit{ha}2, \textit{hb}2, \textit{hc}2 is high of bottom hole the sediment discharge on a model (mm).

The process of obtaining sediment discharge is stimulated by the release of soil by rain and surface runoff. The basic assumption of this model is that sediment is transported and generated when surface runoff occurs. Thus, the carrying capacity of the surface runoff is estimated to simulate the sediment discharge process. Soil release, sedimentation, and sediment discharge are handled with the equation of sediment flow continuity as in Equation 1 [23-25].

\[
\frac{\partial(h_o C)}{\partial t} + \frac{\partial(q_o C)}{\partial x} = e(x,t)
\]  

(1)

where:  
\begin{align*}
C & = \text{sediment concentration in the flow (kg/m}^3) \\
h_o & = \text{depth of surface flow (m)} \\
q_o & = \text{discharge per unit width (m}^2/\text{second)} \\
e(x,t) & = \text{erosion by rainfall and surface runoff (kg/m}^2/\text{hour)}
\end{align*}

To calculate the sediment discharge from the three tank models using equations 2 through equation 25 which is the development of equation 1

2.1. Tank model 1

\begin{align*}
Q\textsubscript{w}(t) & = [(Ha(t)+P(t)) \times a_1] \\
\text{Sed}_{2a}(t) & = [((Hb(t)+P(t)+Q\textsubscript{w}(t)) \times C_b) - hb_1] \times b_1 \\
\text{Sed}_{3a}(t) & = [((Hb(t)+P(t)+Q\textsubscript{w}(t)) \times C_b) - hb_2] \times b_2 \\
\text{Sed}_{4a}(t) & = [((\text{Sed}_{2a}(t)+\text{Sed}_{3a}(t))+(Hc(t)+P(t)) \times C_{N}) \times hc_1] \times c_1 \\
\text{Sed}_{5a}(t) & = [((\text{Sed}_{2a}(t)+\text{Sed}_{3a}(t))+(Hc(t)+P(t)) \times C_{N}) \times hc_2] \times c_2 \\
\text{Sed}_{0a}(t) & = [(Hb(t)+P(t)+Q\textsubscript{w}(t)) \times C_b] \times b_0 \\
\text{Sed}_{0b}(t) & = [(Hc(t)+P(t)) \times C_{N}] \times c_0 \\
\text{Total sediment discharge on the right side of the tank} & = \text{Sed}_{\text{total}} = \text{Sed}_{a}(t) + \text{Sed}_{b}(t)
\end{align*}
2.2. Tank model 2

\[
\text{Sed}_1(t) = [((Ha(t)+P(t)) \times Ch) - ha] \times a_1
\]
\[
\text{Sed}_2(t) = [((Ha(t)+P(t)) \times Ch) - ha] \times a_2
\]
\[
\text{Sed}_3(t) = [((Sed_i(t)+Sed_2(t)+((hb(t)+P(t)) \times Ch)) \times hb] \times b_1
\]
\[
\text{Sed}_4(t) = [((Sed_i(t)+Sed_2(t)+((hb(t)+P(t)) \times Ch)) - hb] \times b_2
\]
\[
\text{Sed}_5(\text{tot}) = [(Ha(t)+P(t)) \times Ch] \times a_0
\]
\[
\text{Sed}_6(\text{tot}) = [(Ha(t)+P(t)) \times Ch] \times b_0
\]
Total sediment discharge on the right side of the tank = \(\text{Sed}_{\text{total}} = \text{Sed}_1(t)+\text{Sed}_2(t)\)

2.3. Tank model 3

\[
\text{Sed}_1(t) = [((Ha(t)+P(t)) \times Ch) - ha] \times a_1
\]
\[
\text{Sed}_2(t) = [((Sed_i(t)+(hb(t)+P(t)) \times Ch)) - hb] \times b_1
\]
\[
\text{Sed}_3(t) = [((Sed_i(t))+(hb(t) \times Ch)) - hb] \times b_2
\]
\[
\text{Sed}_4(t) = [((Sed_2(t)+Sed_3(t)+((Hc(t)+P(t))(\times Ch))) - hc] \times c_1
\]
\[
\text{Sed}_5(t) = [((Sed_2(t)+Sed_3(t)+((Hc(t)+P(t))(\times Ch))) - hc] \times c_2
\]
\[
\text{Sed}_6(t) = [(Ha(t)+P(t)) \times Ch] \times a_0
\]
\[
\text{Sed}_6(t) = [(Ha(t)+P(t)) \times Ch] \times b_0
\]
Total sediment discharge on the right side of the tank = \(\text{Sed}_{\text{total}} = \text{Sed}_1(t)+\text{Sed}_2(t)\)

All of parameters non negative : \(0 < a_0 + a_1 + a_2 \leq 1\); \(0 < b_0 + b_1 + b_2 \leq 1\); \(0 < c_0 + c_1 + c_2 \leq 1\); \(a_1 \geq a_2\); \(b_1 \geq b_2\); \(c_1 \geq c_2\); \(ha \geq ha_0\); \(hb \geq hb_0\); \(hc \geq hc_0\).

To get a tank model for prediction of sediment discharges that represent actual Catchment conditions using the research criteria volume error (VE), relative error (RE), correlation coefficient (R) and root mean squares error (RMSE) shown by equations 26 through 29, with a limit value of research criteria for \(VE < 5\%\), \(RE -10\%\) to \(10\%\), \(R > 0.7\) and RMSE close to 0. Its formula is as follows:

\[
\text{VE} = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}}}{\text{Sed}_{\text{obs}}} \right) \times 100
\]
\[
\text{RE} = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}}}{\text{Sed}_{\text{obs}}} \right) \times 100
\]
\[
R = \frac{\sum (\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}}) (\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}})}{\sqrt{\sum (\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}})^2 \sum (\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}})^2}}
\]
\[
\text{RMSE} = \frac{\sum (\text{Sed}_{\text{obs}} - \text{Sed}_{\text{sim}})^2}{N}
\]

where: \(VE\) is volume error [%]; \(RE\) is relative error [%]; \(R\) is correlation coefficient; \(RMSE\) is the root mean squares error; \(\text{Sed}_{\text{obs}}\) is sediment discharge simulation period-i [t/d]; \(\text{Sed}_{\text{sim}}\) is sediment discharge measurable period-i [t/d]; \(N\) is the number of data; \(\text{Sed}_{\text{avg}}\) is average of sediment discharge simulation period-i [t/d]; \(\text{Sed}_{\text{avg}}\) is the average of sediment discharge measurable period-i [t/d].
3. Results and discussion

The results of the simulation of 3 tank models (Figure 3) for prediction of sediment discharge in the Kreo sub-Catchment based on rain input data and sediment discharge data (Table 1), on January 6, 2014, and January 26, 2014, is shown in Figure 4:

![Figure 4](image_url)

- **November 6, 2014**
- **November 10, 2014**
- **November 26, 2014**

Figure 4. Calibration Results of Observation and Simulation Sediment Discharge using 3 Tank Models in Kreo Sub-Catchment on (a) 10 January 2014, (b) 6 January 2014 and (c) 26 January 2014.

Calibration results using 3 tank models are shown in Table 2.

| Parameter 3 tank models. Parameters | Tank Model 1 | Tank Model 2 | Tank Model 3 | Tank Model 1 | Tank Model 2 | Tank Model 3 | Tank Model 1 | Tank Model 2 | Tank Model 3 |
|-----------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| a0                                | 0.094       | 0.012       | -           | 0.192       | 0.459       | -           | 0.061       | 0.001       |
| a1                                | 0.761       | 0.319       | 0.028       | 0.289       | 0.188       | 0.466       | 0.263       | 0.527       |
| a2                                | 0.016       | -           | -           | 0.015       | -           | 0.015       | -           | 0.015       |
| b0                                | 0.264       | 0.235       | 0.047       | 0.098       | 0.065       | 0.068       | 0.164       | 0.022       |
| b1                                | 0.423       | 0.372       | 0.400       | 0.122       | 0.130       | 0.427       | 0.113       | 0.342       |
| b2                                | 0.217       | 0.152       | 0.145       | 0.080       | 0.130       | 0.296       | 0.075       | 0.003       |
| c0                                | 0.122       | -           | 0.228       | 0.039       | -           | 0.000       | 0.165       | -           |
| c1                                | 0.152       | -           | 0.516       | 0.578       | -           | 0.532       | 0.507       | -           |
| c2                                | 0.081       | -           | 0.058       | 0.375       | -           | 0.026       | -           | 0.188       |
| h1                                | 57.490      | 0.920       | 0.145       | 58.952      | 0.718       | 47.285      | 0.274       | -           |
| h2                                | 0.091       | -           | -           | 0.164       | -           | 0.303       | -           | -           |
| h1                                | 58.130      | 56.055      | 49.146      | 59.833      | 51.271      | 58.496      | 59.879      | 41.489      |
| h2                                | 0.650       | 0.104       | 0.441       | 0.091       | 0.091       | 0.002       | 0.200       | 0.269       |
| h1                                | 56.111      | 33.002      | 37.476      | 40.406      | 40.406      | 32.399      | 47.278      | -           |
| h2                                | 0.969       | 0.233       | 0.016       | 0.338       | 0.338       | 0.006       | -           | 0.442       |

The value of the research criteria for the calibration results of the three tank models to show an accurate tank model is shown in Table 3.
Table 3. Value criteria accuracy of the three tank models.

| Rainfall Date | Tank Model 1 | Tank Model 2 | Tank Model 3 | Tank Model 1 | Tank Model 2 | Tank Model 3 | Tank Model 1 | Tank Model 2 | Tank Model 3 | Tank Model 1 | Tank Model 2 | Tank Model 3 |
|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 06/01/2014   | 413.63       | 277.67       | 254.13       | 119.73       | 57.08        | 50.75        | 0.52         | 0.52         | 0.52         | 275.4        | 183.11       | 176.74       |
| 10/01/2014   | 154.41       | 300.64       | 135.43       | 62.63        | 203.70       | 58.36        | 0.65         | 0.65         | 0.65         | 742.6        | 1851.7       | 744.14       |
| 26/01/2014   | 433.74       | 375.67       | 104.35       | 165.54       | 129.69       | 16.23        | 0.89         | 0.89         | 0.89         | 81.71        | 63.64        | 20.95        |

The results showed that the tank model 3 is better than the other 2 tank models. This is evidenced by the results of the calibration using the parameter values in Table 2, with the sediment discharge values and the accuracy criteria values are shown in Figure 4 (a), (b), (c) and Table 3. The calibration results on the three tank models show that tank model 2 is less representative of the actual Catchment conditions.

The results of the analysis of the tank model for prediction of sediment discharge, the rising limb and peak value of the simulation sediment discharge is greater than the measured sediment discharge value, this rainfall tends to be high, of course, the amount of surface flow increases so that the output value of sediment discharge in the tank model becomes greater (Figure 4 (b), (c)) and recession limb simulation sediment discharge value decreases, this is because rainfall tends to decrease and surface flow also decreases so that the output value of sediment discharge in the tank model becomes small. Except for Figure 4 (a) there may be a disturbance upstream of the tentative measurement, the measured sediment discharge value is greater than the simulated sediment discharge value. Another cause is the pattern of rainfall distribution in the hydrological process, synchronization of the measurement process, and the length of the data and the possible assumptions of the model parameters.

4. Conclusion

By representing the process of erosion - sediment discharges in the River Basin, the three tank models can be used for prediction of sediment discharges: Tank Model 1 with 3 (three) series cascade tanks, Tank Model 2 with 2 (two) cascade tanks, Tank Model 3 with 3 (three) cascade tanks. The arrangement or configuration of the tank model that provides predictive results of sediment discharges close to the measured sediment discharge is Tank Model 3, composed of 3 (three) cascade tanks. the mean least square error (RMSE) and the correlation coefficient (R). But it still has a different range for sediment discharge values. This is possible because the factors are the pattern of rainfall distribution in the hydrological process, synchronizing the measurement process and the length of the data as well as the possible assumptions of the model parameters.

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References

[1] Soenarno S 2001 Integrasi dan Keterpaduan Pengelolaan Sumberdaya Air yang Berkelanjutan dalam Era otonomi Daerah Prosiding Diskusi Panel Nasional Kerjasama Universitas Diponegoro dengan Departemen Energi dan Sumberdaya Mineral (Semarang)
[2] Tarigan S D 2009 Pengembangan Sistem Informasi Spasial Berbasis Web (Web GIS) untuk Sinergi Rehabilitasi DAS Kritis Nasional Prosiding Seminar Nasional “Kebijakan dan Aplikasi Teknologi Informasi dan Komunikasi untuk Peningkatan Daya Saing Agribisnis Indonesia” Himpunan Informatika Pertanian – Institut Pertanian Bogor – Departemen Pertanian Republik Indonesia (Bogor)

[3] Sustayo M O 2016 Pendekatan Spasial Ekologis dan Skala Multidimensi Dalam Pengelolaan DAS Berkelanjutan (Yogyakarta: Fakultas Kehutanan, Universitas Gadjah Mada)

[4] Suripin S 2002 Pelestarian Sumber Daya Tanah dan Air (Yogyakarta: Penerbit Andi)

[5] Suripin S 2002 Kelemahan Lengkung Sedimen dalam Memprediksi Sedimen layang 237-248

[6] Nearing M A, Foster G R, Lane L J and Finkner S C 1989 A process-based soil erosion model for USDA-Water Erosion Prediction Project technology Transaction of the American Society of Agricultural Engineers 32 1587-1593

[7] Woolhiser D A, Smith R E and Goodrich D C 1990 KINEROS, A Kinematic Runoff and Erosion Model: Documentation and User Manual (ARS-77 Fort Collins, Colo.: USDA Agricultural Research Service)

[8] Beasley D B and Huggins L F 1991 ANSWERS. User’s Manual, Agricultural Engineering Department, Purdue University (West Laffayete, Indiana)

[9] Young R A, Onstad C A, Bosch D D and Anderson W P 1987 AGNPS, Agricultural nonpoint-source pollution model: A Catchment analytical tool. Conservation Research Report No. 35 (Washington, D.C.: USDA)

[10] Young R A, Onstad C A, Bosch D D and Anderson W P 1989 AGNPS: A nonpoint-source pollution model for evaluating agricultural Catchment s J. Soil and Water Conservation 44 2 168-173

[11] Arnold J G, Srinivasaran R, Muttiah R S and Williams J R 1998, Large-area hydrologic modeling and assessment: Part I. Model development J. American Water Resources Assoc. 34 1 73-89

[12] Borah D K and Bera M 2003 Catchment -Scale Hydrologic and Nonpoint-Source Pollution Models: Review of Mathematical Bases American Society of Agricultural Engineering 46 6 1553-1566

[13] Kothyari U C, Tiwari A K and Singh R 1996 Temporal Variation of Sediment Yield Journal of Hydrologic Engineering 169-176

[14] Takahiro S, Yasuto T and Kaoru T 2007 The Spatio-Temporal Predictions of Rainfall-Sediment-Runoff Based on Lumping of a Physically-based Distributed Model Annuals of Disas. Prev. Res. Inst. 50 B 79-94

[15] Yasuto T, Takahiro S and Kaoru T 2008 Lumping a Physically-based Distributed Sediment Runoff Model with Embedding River Channel Sediment Transport Mechanism Annuals of Disas. Prev. Res. Inst. 51 B 103-117

[16] Lee Y H and Singh V P 2005 Tank Model for Sediment Yield Water Resources Management 19 349-362

[17] Sugawara M, Watanabe W, Ozaki E and Katsuyama Y 1984 Tank Model with Snow Component (Japan: National Research Center for Disaster Prevention)

[18] Sugawara M and Ozaki E 1991 Runoff analysis of the Chang Jiang (the Yangtze River) Hydrological Sciences Journal 36 2 135-152

[19] Sugawara M 1979 Automatic calibration of the tank model Hydrology. Sci. Bull. 24 375–388

[20] Phien H N and Pradhan P S S 1983 The tank model in rainfall-runoff modelling Water S.A. 9 3 93-102

[21] Lee Y H 2007 Tank Model Using Kalman Filter for Sediment Yield Journal of the Environmental Sciences 1319-1324

[22] Takahiro S, Yasuto T and Kaoru T 2007 The Spatio-Temporal Predictions of Rainfall-Sediment-Runoff Based on Lumping of a Physically-based Distributed Model Annuals of Disas. Prev. Res. Inst. 50 B 79-94

[23] Lopes V L and Lane L J 1998 Modelling sedimentation processes in small Catchment s
Sediment Budgets (Proceedings of the Porto Alegre Symposium) IAHS Publ. 174

[24] Jayawardena A W and Bhuiyan R R 1999 Evaluation of an interrill soil erosion model using laboratory catchment data Hydrol. Process. 13 89-100

[25] Takahiro S, Yasuto T and Kaoru T 2008 Lumping of a Physically-based Distributed Model For Sediment Runoff Prediction in a Catchment Scale Annuals Journal of Hydraulic Engineering, JSCE 5 43-48