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Estimation of Sediment Yield and Transportation in a Watershed River Reach Due to Climate Change

Estimation of Sediment Yield and Transportation in a Watershed River Reach due to Climate Change

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ABSTRACT

Climate change has huge impact on countries and will bring huge impacts to nations all over the world. Those impacts including the followings: change in biosphere, long-duration drought, large floods trigger by extreme torrential rain, spatial change in homelands, and food scarcity. The extreme weather induced by climate change is the most direct factor influencing the floods, e.g. the extreme rainfall increases discharge and inundation area, sea level and estuary water level raising induce overbank floods, and land-use abuse and landslides trigger high concentration of sediment discharge and riverbed aggradations, spatially in the Shihmen reservoir watershed, in Taiwan. The Shihmen reservoir is a multi-functional reservoir and its functions include irrigation, water supply, hydroelectric power, flood prevention and sightseeing. The major allocation of registered water rights for irrigation and water supply. In 2004, Typhoon Aere attacked Taiwan and generated more than 973 mm rainfall within 4 days in the watershed of the Shihmen reservoir. Highly turbid inflows affected the water supply system seriously. Sediment concentration of the inflow water in the Typhoon Aere rose to 242,000 Nephelometric Turbidity Unit (NTU) and was far-exceeded water treatment capacity which can only handle 6,000 NTU. Therefore, the inflow discharge and inflow sediment yield of Shihmen reservoir is a vital important issue for reservoir sedimentation and watershed management. In this study, the SRH-2D model is adapted to simulate sediment transport and flow discharge propagation in upstream river reach. The upstream and lateral inflow discharge are estimated from rainfall runoff simulation on specified typhoon events. The upstream and lateral inflow sediment yield consisted of landslide production and soil erosion. The distributed model is one of landslide production models to estimate sediment yield and a total station is selected to monitor post-failure sediment yields in landslide sites of the Shihmen reservoir watershed for calibration. Universal soil loss equation, USLE, is suggested to evaluate the quantity of soil erosion and field erosion pins are set up for verification. Based on preliminary results of climate change condition, the sediment yield consisted of 80% landslide production and 20% soil erosion. It is about 19% increasing of sediment yield. In the following stage, the SRH-2D model will simulate sediment transport and flow discharge in upstream river reach to realize the magnitude of inflow discharge and inflow sediment yield of Shihmen reservoir. The results can provide information for reservoir sedimentation management.

KEY WORDS: climate change; SRH-2D model; landslide; soil erosion; reservoir sedimentation management

INTRODUCTION

The Sedimentation and River Hydraulics - Two-Dimensional (SRH-2D) model is adapted to simulate the sediment transport and flow discharge propagation in upstream river of Shihmen reservoir for studying depth and river reach of severe scouring.

Simulation Area and Mesh Generation

Using 2015 measurement section (Fig.1) to simulate and analyze the mesh generation from Showluan to Luofu Bridge of Tahan river (Fig.2). There are 14 large torrents from to Showluan to Luofu Bridge (Fig.3) for setting the tributary boundary condition.

Importing topographic data into Surface Water Modeling System (SMS), which is the mesh generation pre-procession tool of SRH-2D model, to generate the calculating mesh of simulation area. Processing topographic measurement data with linear interpolation of mesh elevation will yield the contour-line distribution of bed elevation as the initial bed for simulation. The minimum elevation of major deep groove area is about 300 m, maximum elevation of highland beach range is about 560 m height, river longitudinal length is about 28 km and average riverbed slope is about 0.013. Locations of 7 sections showed in Fig. 4 for model validation.

Setting Simulation Parameter

As the boundary condition of upstream and tributary inflow, simulation period is from Jan. 12th to Aug. 29th, 2009, including Typhoon Morakot (Aug.6th~10th, 2009). To saving the calculating time, collected timing data under 300m^3/s were excluded. Upstream inflow hydrograph was estimated to scale which depend on data of Yufeng gauge station with its catchment area and tributary inflow hydrography used the collected data of Lengchiao gauge station (Fig. 5). Due to movable bed simulation, the boundary condition of upstream and tributary inflow need to assume the suspended sediment load such as the measured rate showed in Fig. 6. In the other hand, the boundary condition of downstream out flow was the measurement hydrography of Hsiayun gauge station (Fig. 7).

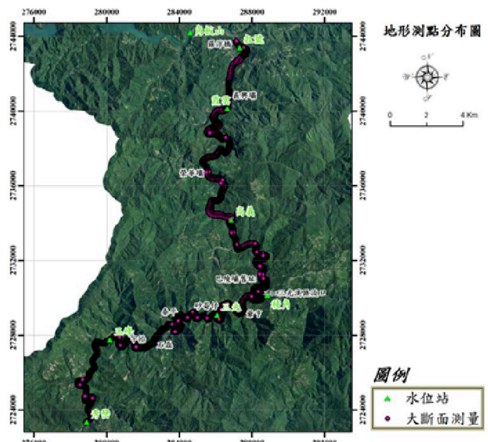


Fig. 1 Measurement section of 2015.

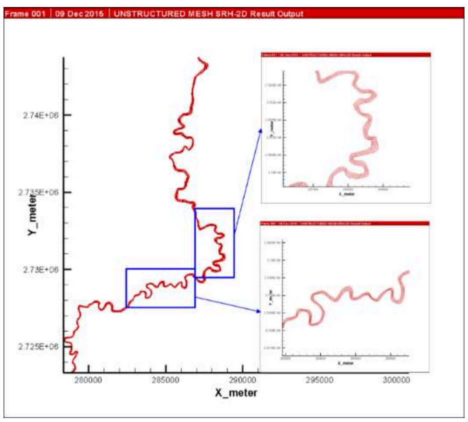


Fig. 2 Mesh generation of Tahan river (from showluan to Luofu Bridge).

Fig. 3 Simulation boundary condition of Tahan river

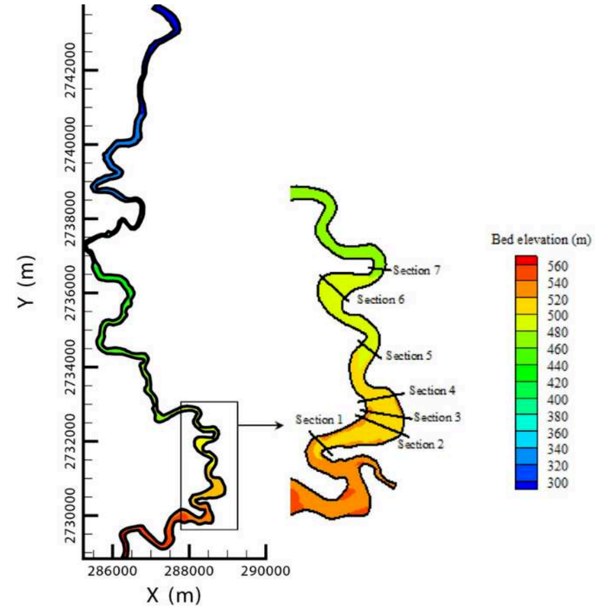


Fig. 4 Initial bed elevation distribution of simulation area and locations of sections for model validation

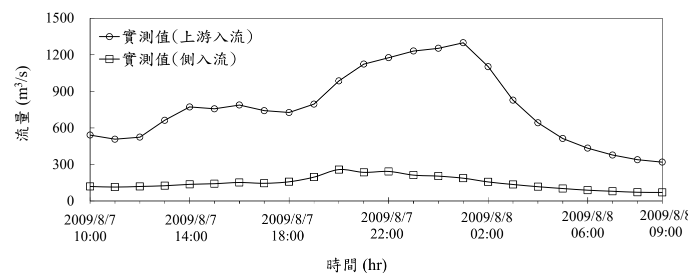


Fig. 5 Boundary condition hydrograph of upstream and tributary inflow.

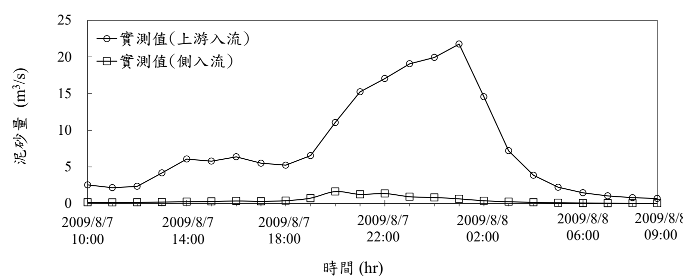


Fig. 6 Supended load hydrograph of Typhoon Morakot.

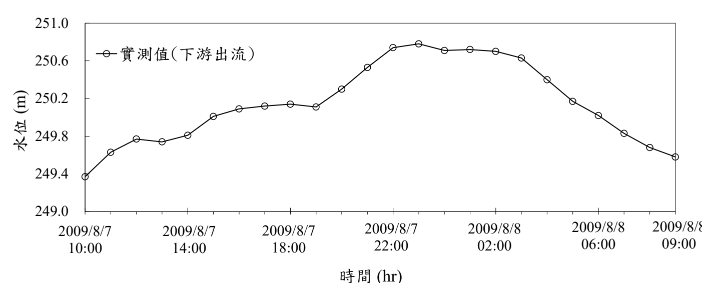
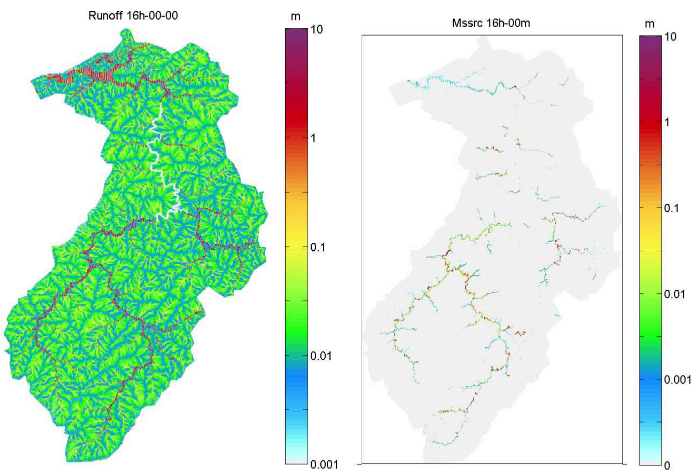


Fig. 7 Boundary condition hydrograph of downstream outflow.

Manning's roughness coefficient and data of bed material particle size consulted the Manning *n* value calculating results of “Tahan river upstream riverbed change investigation and treatment planning” project. Parker (1990) sediment transport equation was chosen according to National Taiwan university (2010): critical shearing stress is 0.0386 (N/m^2). Hidden coefficient is the parameter of Parker equation which can reveal the hidden sediment characteristics and estimate sediment yield amount between liquidity difference of particle size. The hidden coefficient of this study is 0.905 National Taiwan university (2010).

This study used 50-years recurrence period to show case simulation. The runoff depth and sediment yield distribution during flood peak showed as Fig.8. Fig.9 revealed runoff and sediment yield amount results of the boundary condition of upstream and tributary. Different colors represent the boundary condition and simulation hydrograph of upstream and every tributary.



(a) Runoff depth distribution (b) Sediment yield distribution
Fig. 8 50-years recurrence period flood simulation results of Shihmen reservoir catchment area.

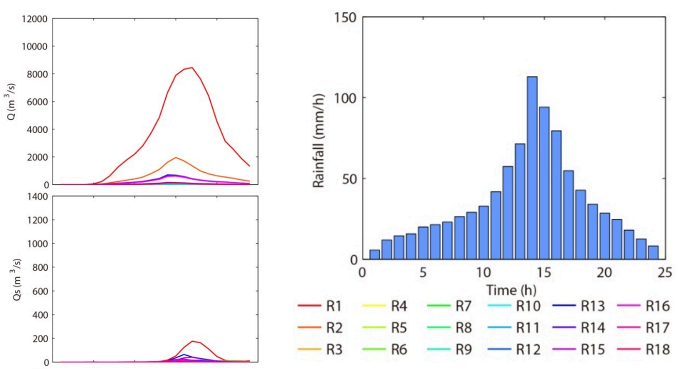


Fig. 9 50-years recurrence period runoff and sediment yield amount simulation results of the boundary condition of upstream and tributary.

At 50-years recurrence period rainfall condition, the maximum inflow sediment yield amount was from Yufeng stream that peak inflow is 176 m^3/s and the percentage of total sediment yield amount is 36%. Sanguang stream is the second one which peak inflow is 17 m^3/s and the percentage of total sediment yield amount is 8%. The rest of sediment yield amount is given by other tributary.

Model Validation

Figure 10 showed the equivalent velocity distribution results of simulation calculating with maximum velocity 20m/s which occurred at Junghua dam overflow. Fig.11 revealed the final erosion and deposition simulation results that maximum value of erosion is 6 meters and deposition is 2 meters. Fig. 12 showed the bed elevation changes of every section: the initial bed elevation is green line, collected data of Jan. 12, 2009 is blue line and the simulation results of Aug.29, 2009 is red line. Section 1 revealed the differences between measured and simulation erosion depth of main deep groove depth is 1.5 meters but there is no erosion sign at left shore in simulation. Section 2 and 3 revealed the difference depth is 1.1 and 0.8 meters with the same erosion and deposition trend. The simulation result corresponded the measurement data at section 4 with obvious erosion sign at right shore. Quay erosion showed at left shore with lateral erosion 10 meters but SRH-2D model cannot showed the sign and the simulation results corresponded the measurement data at right shore. The simulation results and the measurement data were same but the erosion sign cannot simulate at right shore may be due to curve effect error. The river narrowing caused a large error of the results at section 7.

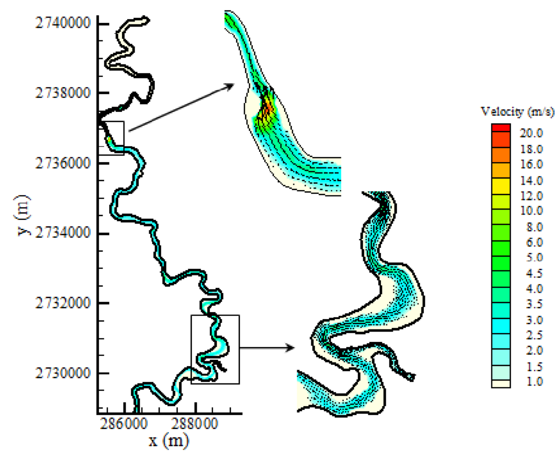


Fig. 10 The equivalent velocity distribution results of simulation calculating at 24 hours.

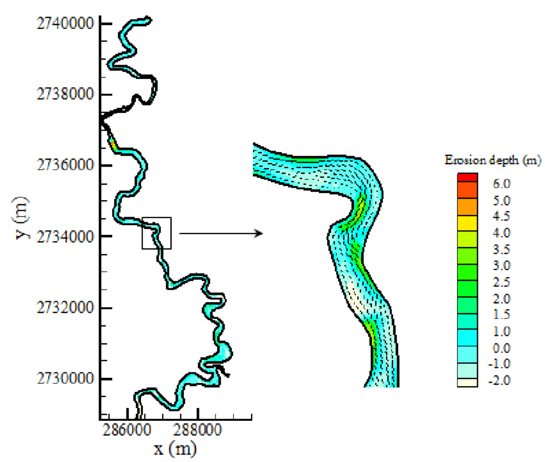


Fig. 11 The final erosion and deposition simulation results at 24 hours.

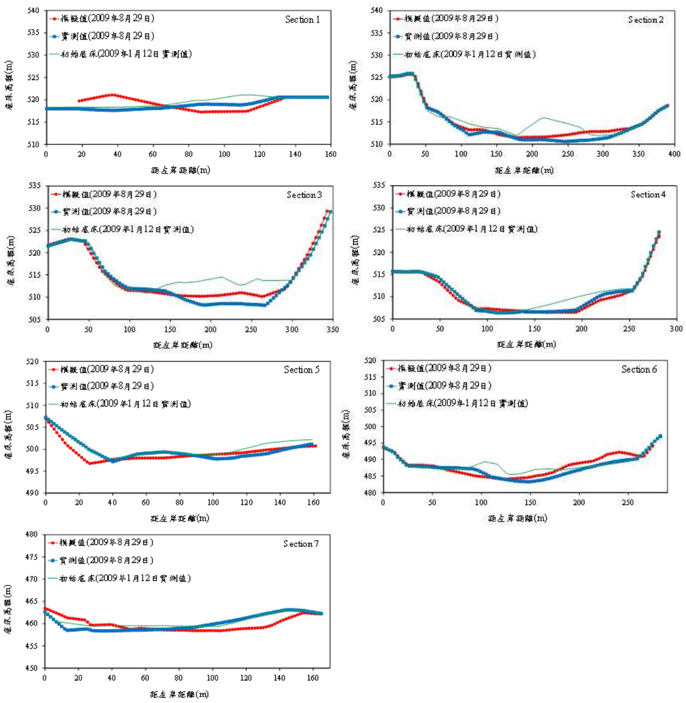


Fig.12 Comparison of simulation results and measured data.

Simulation Results of 50-years Recurrence Period Flood Frequency

Fig. 13 revealed the erosion and deposition simulation results of 50-years recurrence period flood frequency. We could find out that flow with high sediment concentration will bring large amount sand into upstream river channel which caused large deposition especially at curve zone and the biggest change was from Yufeng gauge station to Shaluntzu. The simulation results corresponded with deposition phenomenon caused by extremely rainfall in the past history.

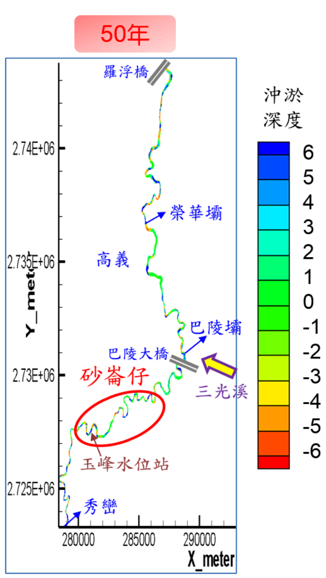


Fig. 13 Erosion and deposition simulation results of 50-years recurrence period flood frequency.

CONCLUSIONS

1. According to the erosion and deposition changes of every section above, SRH-2D model might has more error at some section, such as left shore of section 1, right shore of section 6 and left shore of section 7, but still can get erosion and deposition trend approaching to measurement data. Besides, simulation results excluding flow data below 300m^3/s will show the correct and reasonable results.
2. Simulation results which corresponded with deposition phenomenon caused by extremely rainfall in the past history showed flow with high sediment concentration will not only caused erosions but also bring large amount sand into river channel which results in a lot of deposition at 24 hours.

REFERENCES

Beven, K.J., Kirkby, M.J. (1979). A physically based, variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24, 43-69.

Cardinali, M., Galli, M., Guzzetti, F., Ardizzone, F., Reichenbach, P., Bartoccini, P. (2006). Rainfall induced landslides in December 2004 in south-western Umbria, central Italy: types, extent, damage and risk assessment. Natural Hazards and Earth System Sciences. 6, 237-260.

Chang, K.T., Chiang, S.H., Hsu, M.L. (2007). Modeling typhoon- and earthquake-induced landslides in a mountainous watershed using logistic regression. Geomorphology 89: 335-347

Cheng, Y.P., Yang, S.Y., Chen, K.H. (1997). River training and unitization of flood plain between leaves in Taiwan. pp. 14.

Chow. V,T. (1959). Open-channel hydraulics: New York, McGraw-Hill, 680 p.

Gallant, J.C., Wilson, J.P. (2000). Primary topographic attributes, in Terrain Analysis: Principles and Applications, edited by J. P. Wilson and J. C. Gallant pp. 51-86, John Wiley, Hoboken, N.J.

Guns M., Vanacker V. (2012). Logistic regression applied to natural hazards: rare event logistic regression with replications. Natural Hazards and Earth System Sciences. 12, 1937-1947.

Imaizumi, F., Sidle, R.C. (2007). Linkage of sediment supply and transport processes in Miyagawa Dam catchment, Japan. Journal Geophysical Research 112 (F03012).

Julien, P.Y., Lan, Y.Q. (1991). Rheology of hyperconcentrations. J. Hydraul. Eng., 117, 346-353.

Lai, Y.G. (2010). Two-Dimensional Depth-Averaged Flow Modeling with an Unstructured Hybrid Mesh, J. Hydraulic Engineering, ASCE, 136, 12-23.

Lane, L.J., Foster, G.R., Nicks, A.D. (1987). Use of Fundamental Erosion Mechanics in Erosion Prediction. International Winter Meeting of the American Society of Agricultural Engineers.

Lane, L.J., Nearing, M.A., eds. (1989). USDA Water Erosion Prediction Project: Hillslope profile model documentation. NSERL Report No. 2. West Lafayette, Ind.: USDA- ARS National Soil Erosion Research Laboratory.

Lee, H.Y., Lin, Y.T., Chiu, Y.J. (2006). Quantitative estimation of reservoir sedimentation from three typhoon events. Journal of Hydrologic Engineering, 11(4), 362-370.

Leopold, L.B., Wolman, M.G., Miller JP. 1964. Fluival Process in Geomorphology, W. H. Freeman, New York.

Lin, C.Y., Lin, W.T., Chou, W.C. (2002). Soil erosion prediction and

sediment yield estimation: the Taiwan experience. Soil & Tillage Research, 68: 143-152.
McCool, D.K., Brown, L.C., Forster, G.R., Mutchler, C.K., Meyer, L.D. (1987). Revised slope steepness factor for the universal soil loss equation. Trans. ASAE. 30(5): 1387-1396.
Menard, S. (2002). Applied Logistic Regression Analysis, 2d ed. Sage, Thousand Oaks, CA.
Okada, K. (2002). Soil Water Index. Weather service bulletin, 69.5, 67-97.
Parker, R.N., Densmore, A.L., Rosser, N.J., de Michele, M., Li, Y., Huang, R., Whadcoat, S., Petley, D.N. (2011). Mass wasting triggered by the 2008 Wenchuan earthquake is greater than orogenic growth. Nature Geoscience 4: 449-452.
Renard, K.G., Foster, G.R., Weesies, G.A., Porter, J.P. (1991). RUSLE: Revised Universal Soil Loss Equation. J. Soil and Water Conservation 46(1):30-33.
S.C.S. (1985). Hydrology. National Engineering Handbook, Supplement A, Section 4, Chapter 10. Soil Conservation Service, USDA, Washington, DC.
Williams, J.R., Berndt, H.D.. (1977). Sediment yield prediction based on watershed hydrology. Trans. of the ASAE 20(6): 1100-1104.
Wilson JP, Gallant JC, 2000. Terrain Analysis: Principles and Applications. John Wiley, Hoboken, N.J.
Wischmeier, W.H., Smith, D.D., Uhland, R.E. 1958. Evaluation of factors in the soil loss equation, Agricultural Engineering, 39: 458-462.
Wischmeier, W.H., Smith, D.D. (1978). Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agriculture Handbook No. 537. USDA/Science and Education Administration, US. Govt. Printing Office, Washington, DC. 58 pp.
Wu, Y.H., Liu, K.F., Chen, Y.C. (2013). Comparison between FLO-2D and Debris-2D on the application of assessment of granular debris flow hazards. Journal of Mountain Sciences. 10(2): 293-304.
Yoder, D.C., McCool, D.K., Weesies, G.A., Foster K.G, Renard, G.R. (1997). Predicting soil erosion by water-a guide to conservation planning with the revised universal soil loss equation (RUSLE), Agriculture Research Service, Agriculture Handbook Number 703.
林建宏，2010，石門水庫集水區泥砂收支與遞移率之研究，國立臺灣大學土木工程學系碩士論文。
國立中興大學，2005，石門水庫集水區泥砂產量推估之研究(3/3)，經濟部水利署。
國立臺灣大學，2008，石門水庫集水區泥砂推估與處置綜合評析計畫成果報告，水利署北區水資源局。
國立臺灣大學，2010，台美合作案之技術引進及應用研究，水利規劃試驗所。
國立臺灣大學，2012，石門水庫集水區保育治理研究綜整計畫委託專業服務(2/2)成果報告，水利署北區水資源局。
國立臺灣大學，2012，淡水河流域因應氣候變遷防洪及土砂研究計畫(1/2)，水利署水利規劃試驗所。
國立臺灣大學，2012，淡水河流域因應氣候變遷防洪及土砂研究計畫(1/2)，經濟部水利署水利規劃試驗所。
國立臺灣大學，2013，國有林莫拉克風災土砂二次災害潛勢影響評估，行政院農委會林務局。
國立臺灣大學，2013，國有林莫拉克風災土砂二次災害潛勢影響評估研究報告，行政院農委會林務局。
國立臺灣大學，2013，淡水河流域因應氣候變遷防洪及土砂研究計畫(2/2)成果報告，水利署水利規劃試驗所。
國立臺灣大學，2013，濁水溪流域因應氣候變遷防洪及土砂研究計畫成果報告，水利規劃試驗所。
國立臺灣大學，2014，石門水庫自來水水質水量保護區巡守持續推動及管理協勤計畫(1/2)期末報告，水利署北區水資源局。
許振崑、林伯勳、鄭錦桐、高丞瑋、冀樹勇、黃文洲、尹孝元，2009，結合3S技術於石門水庫集水區不同植生坡面沖蝕量調查，水保技術，4(3)：191-203。
經濟部水利署水利規劃試驗所，2009，美國國家計算水科學及工程中心河道變遷模式之引進及應用研究(3/3)成果報告。
葉宗泰，2003，石門水庫集水區降雨逕流模擬，國立中央大學土木工程研究所碩士論文。