ARTICLE IN PRESS

International Soil and Water Conservation Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Assessment of sediment inflow to a reservoir using the SWAT model under undammed conditions: A case study for the Somerville reservoir, Texas, USA

Dagbegnon Clement Sohoulande Djebou [a,b,*]

[a] Department of Biological and Agricultural Engineering, Texas A&M University, Scoates Hall, CE-TTI Bldg 303H, 3135 TAMU, Spence Street, College Station, TX 77843, USA

[b] Texas A&M Transportation Institute - Texas A&M University, CE-TTI Bldg 303H, 3135 TAMU, Spence Street, College Station, TX 77843, USA

ARTICLE INFO

Article history:
Received 10 December 2017
Received in revised form
10 March 2018
Accepted 12 March 2018

Keywords:
Reservoir watershed
Sedimentation
Runoff
SWAT
Soil conservation

ABSTRACT

Worldwide, sedimentation represents a major problem for reservoir and dam management due to the related environmental and economic consequences. However, reservoir sedimentation can be significantly mitigated by controlling the rates of sediment loss across a watershed. This article uses a case study to highlight an assessment technique for sustaining effective soil conservation strategies by providing an insight into the spatial variability of sediment loss rates at the watershed scale. The assessment method employs the Soil and Water Assessment Tool (SWAT) and the Modified Universal Sediment Loss Equation (MUSLE) to quantify sediment losses in a case study for the Somerville reservoir, located in Texas. The SWAT model was employed to simulate upstream inflows in the studied reservoir watershed. The goodness-of-fit analyses suggested a realistic representation of the watershed behavior and satisfactory values of Nash-Sutcliffe Efficiency were obtained during the calibration and validation stages ($0.76 \leq$ NSE ≤ 0.69). Then the calibrated SWAT was used to generate MUSLE estimates of soil losses under undammed conditions. A weight-average formulation was developed to evaluate the rates of sediment loss at the sub-basin level. Meaningful contrasts were outlined between the sub-basins located at the downstream, the midstream, and the upstream. The study was able to pinpoint sub-basins with critical needs of soil conservation (sediment loss $>$ 4 t/ha/year). Overall, the outcomes of the case study demonstrated the value of the methodology and that the outcomes may be used to address the complex problem of sedimentation in watersheds with reservoirs.

1. Introduction

In general, the hydrologic behavior of a watershed is the resultant of multiple biophysical factors interplaying diversely in the time and space (Sohoulande Djebou, 2017). However, the understanding of the watershed functionality is critical for achieving a realistic water resources planning. For most catchments, the inflowing water originates from atmospheric precipitations. Thus, when the precipitation is highly seasonal, this seasonality often affects freshwater resources' availability during the year. To cope with this seasonality and poise water resources' availability at the watershed scale, human societies have often considered water control systems such as dams and reservoirs. Historically, the first constructed dams and reservoirs date back to thousands of years ago (Shaw & Sutcliffe, 2003). For instance, specific reservoirs are reported in several ancient manuscripts, and one of them is probably the famous reservoir of Siloam mentioned in the Bible (Ussishkin, 1976). Exceptionally, reports asserted that several dams constructed during Ancient Egypt and the Roman empire time are still operating these days (Mays, Koutsoyiannis, & Angelakis, 2007; Shaw & Sutcliffe, 2003). Over generations, dams and reservoirs have served for multi-purposes including energy production (e.g. turning hydro-power turbines, cooling nuclear reactors), domestic water supply, flood control, agriculture, industry, recreation, and fishing. However, the construction and operation of a reservoir often cause substantial ecological disturbances within the streamflow network. As a result, reservoirs frequently drive critical environmental concerns (Zhang, Degroote, Wolter, & Sugumaran,

* Corresponding author at: Department of Biological and Agricultural Engineering, Texas A&M University, Scoates Hall, CE-TTI Bldg 303H, 3135 TAMU, Spence Street, College Station, TX 77843, USA.

E-mail addresses: sohoulande@tamu.edu, sohoulande@gmail.com, sohoulande@yahoo.fr

Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

https://doi.org/10.1016/j.iswcr.2018.03.003

2009). Particularly, the problem of sedimentation is a common concern for reservoirs as it affects the storage capacity and depletes the water quality (Fan & Morris, 1992; Palmieri, Shah, & Dinar, 2001). Whereas the cumulated sediments can be periodically removed, the subsequent dredging activities generally necessitate a large investment of money and human resources. In addition, the management of dredged materials is often a puzzle as it raises serious environmental concerns. In that situation, it seems reasonable to encourage environmentally friendly solutions which would reduce or decelerate sedimentation in reservoir watersheds.

Reservoir sedimentation is, in most cases, caused by water erosion occurring at the watershed scale. However, the extent of sediment losses varies from one location to another depending on the watershed's biophysical characteristics (Williams, 1975). Thus, it is desirable to envision soil conservation strategies which exploit effectively the spatial disparity of sediment loss rates. Indeed, at a given location of the watershed, water erosion depends on several factors including the local rainfall patterns, the surface runoff, the type of soil, the land-cover, the soil conservation practices, the slope, and the watershed shape. Universally, sediment losses are often estimated and interpreted using the Universal Sediment Loss Equation or its modified formulations (Neitsch, Arnold, Kiniry, & Williams, 2011; Williams, 1975). Especially in watershed modelling, the Modified Universal Sediment Loss Equation (MUSLE) incorporated into the Soil and Water Assessment Tool (SWAT) has been successfully used to address water erosion in different watersheds across the globe (Arnold et al., 2012; Bonumá et al., 2014; Xu, Pang, Liu & Li, 2009). However, the reliance on SWAT for sedimentation assessment depends primarily on the capacity of the model to realistically simulate the hydrological behavior of the targeted watershed. While this seems to be a common fact in hydrological modelling, a realistic quantification of water erosion at the watershed level may turn to be more complex when the spatial disparity is to be highlighted. Hence, case studies and methodologies development are needed to support soil and water conservationists.

The scope of this study is to use a case study to present a coherent approach adequate for quantifying the patterns of water erosion in a complex configuration of a reservoir watershed (i.e. watershed representing the drainage area of a reservoir). Hence, the assessment approach developed focused on the Somerville reservoir, located in the State of Texas. Firstly, the study evaluates the suitability of SWAT at simulating the hydrological behavior of the targeted catchment. Thus, SWAT (Arnold et al., 2012; Neitsch et al., 2011) is employed to model the inflow and outflow within the drainage area of the Somerville reservoir. The assessment technic exploits the contrast between the upstream and the downstream flows. Especially, SWAT is calibrated and validated based on observed reservoir's inflows, thereafter the parameter setting is considered to simulate outflow under an undammed condition. Both runoff and sediment loss rates were addressed in the study. Besides this introduction, the paper is structured in four sections including: a) data and method's section which provides a description of the study approach and the data used for the case study, b) results' section which outlines the outcomes of the study, c) discussion section which examines the results from a practical prospective, and d) conclusion section which summarizes the practical implications of the study.

2. Data and method

The methodology developed in this study comprises three stages. The first stage consists in a multi-site parameter setting for SWAT based on the inflow. The second stage consists in an outflow simulation under an undammed condition. The third stage addresses the spatial pattern of sediment loss rates at the watershed level. These three stages are inter-related, but they also exploit specificities such as the biophysical characteristics of the studied reservoir watershed. This section is structured in three distinct sub-sections which provide successively a description of the studied reservoir watershed, the data used in the study, and the detailed study method.

2.1. Studied reservoir watershed

The studied catchment corresponds to the drainage area of the Somerville reservoir, located in the State of Texas (Fig. 1). The Somerville reservoir, is a multipurpose reservoir operated since 1967 by the United States' Army Corps of Engineers (USACE). The reservoir primarily serves for flood control, water conservation, recreation, and fishing. The dam retaining the impoundment is elevated at a height of 85.4 m above sea level, but the emergency spillway is at 78.7 m above sea level while the conservation pool is at 72.6 m. At the conservation pool level, the Somerville lake has a total storage capacity of 197 million m^3 and a surface of 47 km^2. However, historical records show that during the year, the reservoir is often below its storage capacity. In that circumstance, the outflow at the downstream of the reservoir is essentially man-controlled and the related records can hardly be considered to mimic the natural hydrological behavior of the watershed. Alternatively, the dendritic stream network at the upstream of the Lake is essentially free flowing. This consideration is particularly valued in the present study. Thus, the SWAT model was calibrated then validated for inflow simulation using historical records at upstream streamgages. The model setting was later considered for outflow and sediment loss estimates under an undammed condition. The details of the data and the modelling approach are presented in the next sub-sections.

2.2. Data

Five categories of data are involved in the modelling framework reported in this paper. The first category consists in weather data. A total of five weather stations were targeted across the studied catchment. Thus, daily time series of precipitation, maximum and minimum temperature were considered for both calibration and validation periods which are respectively 2008–2011 and 2012–2016. The weather data were retrieved from the National Oceanic and Atmospheric Administration (NOAA) database. The second category of data consists in time series of stream discharge collected from the United States Geological Survey (USGS) database. Precisely, the series of monthly discharge of the period 2008–2016 were obtained for a total of three streamgage stations. In accordance with the scope of the study, two streamgages were selected at the upstream side of the reservoir and the third streamgage at the downstream (see Fig. 1). Each of the two streamgages spotted at the upstream correspond to the outlets of the two major tributaries flowing into the reservoir. The locations of the weather stations and the targeted streamgages are illustrated in Fig. 1, but Table 1 outlines their geographic coordinates and some of their descriptive statistics. The third category of data involved in the study consists in digital elevation model (DEM). Specifically, the study used a 30 m spatial resolution DEM developed by the United States Environmental Protection Agency (US-EPA) (www.epa.gov). The fourth category of data consists in the most recent National Land-Cover Database (NLCD) developed by the Multi-Resolution Land Characteristics MRLC Consortium (www.mrlc.gov). The NLCD has also a 30 m spatial resolution and its classification is based on 16 classes of Land-Cover types (Homer et al., 2015). Finally, the fifth category of data used in the study is