Journal of Hydrology 524 (2015) 780–788

Contents lists available at ScienceDirect

Journal of Hydrology

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

Event-based soil loss models for construction sites

William R. Trenouth, Bahram Gharabaghi *

School of Engineering, University of Guelph, Guelph, Ontario N1G 2W1, Canada

ARTICLE INFO

Article history:
Received 12 December 2014
Received in revised form 3 March 2015
Accepted 4 March 2015
Available online 20 March 2015
This manuscript was handled by G. Syme, Editor-in-Chief, with the assistance of John W. Nicklow, Associate Editor

Keywords:
Modeling
Monitoring
Construction sites
Soil loss
Artificial neural networks

SUMMARY

The elevated rates of soil erosion stemming from land clearing and grading activities during urban development, can result in excessive amounts of eroded sediments entering waterways and causing harm to the biota living therein. However, construction site event-based soil loss simulations – required for reliable design of erosion and sediment controls – are one of the most uncertain types of hydrologic models. This study presents models with improved degree of accuracy to advance the design of erosion and sediment controls for construction sites. The new models are developed using multiple linear regression (MLR) on event-based permutations of the Universal Soil Loss Equation (USLE) and artificial neural networks (ANN). These models were developed using surface runoff monitoring datasets obtained from three sites – Greensborough, Cookstown, and Alcona – in Ontario and datasets mined from the literature for three additional sites – Treynor, Iowa, Coshocton, Ohio and Cordoba, Spain. The predictive MLR and ANN models can serve as both diagnostic and design tools for the effective sizing of erosion and sediment controls on active construction sites, and can be used for dynamic scenario forecasting when considering rapidly changing land use conditions during various phases of construction.

1. Introduction

The USEPA (2012) reports that typical rates of soil erosion on construction sites can climb to levels that are between 130 and 1000 times greater than pre-development conditions, while Harbor (1999) has measured anthropogenically-induced soil erosion rates on construction sites that are 40,000 times above pre-development levels with adverse effects on aquatic ecosystems and the species of which they are comprised.

The deposition of sediments results in the siltation and smothering of spawning beds and feeding grounds, which leads to increased piscivorous mortality and the loss of many benthic species, including macroinvertebrates and mollusk species (Liu et al., 2015; Gharabaghi et al., 2006; Hayes et al., 2005; Mol and Ouboter, 2004; Pimentel et al., 1995). Eroded sediments are also linked to nutrient transport and eutrophication, particularly sediment-bound phosphorous (Correll, 1998; Eckholm and Lehtoranta, 2012). Upon entering receiving waters, such nutrients give rise to nuisance algal blooms that quickly consume the added phosphorous, resulting in an autotrophic population crash that consumes large amounts of dissolved oxygen (DO) during the decay process. This cyclic ‘boom and bust’ sequence for algal communities leads to dissolved oxygen concentrations in the water column that are both unstable and frequently unable to support most sensitive or commercially important species (Schindler, 2006). In watersheds impacted by urban development characterized by rapid growth in the suburban areas this problem is especially acute and of serious concern (LSRCA, 2009).

Despite an abundance of data which clearly underscores the myriad negative effects of inflated soil erosion rates, the issue continues to persist. Agencies the world over have developed a plethora of regulatory mechanisms aimed at reducing sediment yields at the outlet of sediment ponds or other construction phase stormwater controls, as summarized previously (Trenouth et al., 2013). Criteria developed on the basis of direct sediment load, turbidity or other parameters requires developers and permitting agencies to be vigilant in their ongoing monitoring of the performance of such facilities. However, such monitoring is not only time consuming, but can also be quite expensive. The net result of this is an exigent need for improved erosion and sediment control designs for reducing the risk of failure of these systems, and also to curtail a portion of the costs surrounding continuous monitoring programs with random site inspection programs (Caughlan and Oakley, 2001). One important step in satisfying this need is the continued refinement of field-calibrated predictive models which afford erosion control planners the ability to estimate site-specific sediment loads in advance of construction or land use change (Cox et al., 2006; Morgan et al., 1984).

---

* Corresponding author at: Room 2417, Thornbrough Building, School of Engineering, University of Guelph, 50 Stone Road East, Guelph, Ontario N1G 2W1, Canada. Tel.: +1 (519) 824 4120x58451; fax: +1 (519) 836 0227.

E-mail address: bgharaba@uoguelph.ca (B. Gharabaghi).

URL: http://www.uoguelph.ca/~bgharaba/ (B. Gharabaghi).

http://dx.doi.org/10.1016/j.jhydrol.2015.03.010

The importance of having accurate, high-resolution water quantity and quality data to aid in the analysis of event-based soil loss, in addition to the need to develop predictive models that can be used to size onsite erosion and sediment controls based on predicted sediment loading are the two main drivers of this research (Bowes et al., 2009). Subsequently, this paper summarizes the findings of high-resolution field research and monitoring activities, as well as the outcome of a thorough investigation into event-based soil loss modeling. Both an empirical model based on permutations of the Revised Universal Soil Loss Equation (RUSLE) and an artificial neural network (ANN) model that can assist in the aforementioned regard are proposed.

1.1. Artificial neural network modeling

ANNs have been used as a predictive tool for applications in which the complexities of natural processes confound many traditional approaches to understanding water quantity and quality issues (Harvey et al., 2013; Sabouri et al., 2013; Asnaashari et al., 2013). What makes ANNs such a useful tool is the way in which they are structured – a network of connected nodes is developed which exist in discrete layers, and the corresponding layers are connected by neurons which feed data pertaining to the input variables further up the network chain (Fig. 1). These multi-layer perceptrons can have varying degrees of connectivity, and the accompanying user interface (UI) gives the modeler the ability to assign a weighting (w) to each input variable, which in turn is summed before being fed into a transfer function. The transfer function is ultimately responsible for producing the scalar neural output (Hanrahan, 2010). Transfer functions in neural network models use non-linear, sigmoidal activation approaches, either logistic or tangential in nature. These transfer functions squash the scalar output from each node between the appropriate limits (0.1 for logistic and −1.1 for tanh functions, respectively), and multiply it by an optimized weighting function.

ANNs have been applied with some success in situations where they have been trained to predict flows in ungauged watersheds (Mondal et al., 2012; Seckin et al., 2013). ANNs have been applied in sediment prediction approaches at both the watershed and basin scale, and they have also been used to predict riverine sediment concentrations based on turbidity inputs (e.g. Bayram et al., 2012; Chen and Zhang, 2009; Yitian and Gu, 2003). However, their use in event-based soil loss simulations at the field and catchment scale to date appears to be limited. Abrahart and White (2001) compared the performance of neural network and regression models on sediment transfer in Malawi and found that ANN performance exceeded that of the regression model, but their work did not utilize standard USLE parameters and was developed specifically for Malawi. Neural networks have also been used to predict other water quality parameters, including nutrient loading, direct runoff volumes and overall water quality (Chebud et al., 2012; Kim et al., 2012). Ha and Stenstrom (2003) used an ANN approach to predict land use based on runoff quality, and their model was validated using runoff quality data from three separate highways in the Los Angeles region. Given this, the use of measured volumetric runoff and land use data for ANN erosion estimation can be viewed as an extension of existing applications.

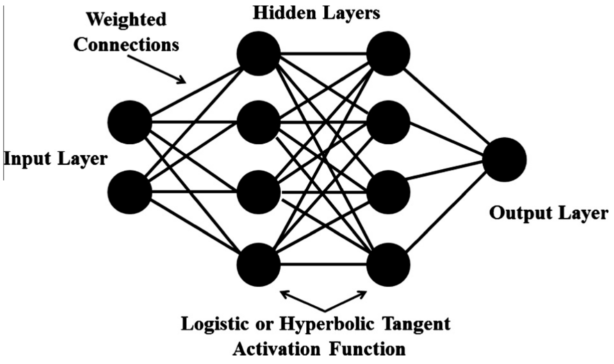

Fig. 1. Schematic representation of ANN layers and nodes.

Back-propagation (BP; also referred to as recurrent) networks – a subset of the neural network family – feed information back and forth to higher and lower level neurons in an iterative approach; BP ANNs are self-learning, self-organizing and require no a priori weighting of the relative importance of input variables (Zhang et al., 2010). As such, ANNs constructed of multiple (three or more) layers of nodes have the ability to approximate any continuous, non-linear function using a global optimization approach, and it is for this reason that their use as a predictive genetic algorithm has increased in recent years (e.g. Khuan et al., 2002; Kim et al., 2012; Mondal et al., 2012). The growing potential of ANNs in hydrologic research warrants their application within the context of this research, and as such their utility will be explored.

2. Site descriptions

Three separate field sites undergoing various degrees of land disturbance were monitored over four years between 2004–2005 and 2009–2010. Sites ranged from largely alfalfa, woodland and grass cover to a heavily disturbed, active construction site.

2.1. Cookstown Public School

The Cookstown Public School site is located at UTM coordinates 17T 603560 m E, 4894504 m in Ontario, Canada (Fig. 2). This site was selected for monitoring in coordination with the regional school board as the school site was initially slated to undergo expansion during the summer of 2010. Monitoring efforts onsite took place between April and November, 2010. This small, 78.8 ha catchment drains via an unnamed tributary into Cookstown Creek, which ultimately empties its waters into the Nottawasaga River. Soils on site are characterized as being predominantly silty clay-loam (Schomberg Series), with basin relief being approximately equal to 33 m over 2 km (Hoffman and Acton, 1974). Land use over the course of monitoring activities was predominantly forage crop cover (alfalfa and clover mix) with some winter wheat and forested areas. The Cookstown schoolyard and surrounding grounds are 5.4 ha in size and are predominantly grass covered, with some imperviousness associated with the school buildings and surrounding parking lot. Runoff from the upland agricultural areas passes through a box culvert under Highway 27 (herein referred to as CTC-1), then around the school property via a constructed drainage ditch before leaving the catchment through a small corrugated steel culvert (CTC-2) which passes under a now-defunct spur of the Canadian National (CN) railway.

2.2. Alcona site

From July, 2009 to November, 2010 a 75.5 ha site south of the town of Alcona, Ontario (herein referred to as the Alcona Site; Fig. 2) was monitored for a suite of water quantity and quality parameters. The access road leading to the drainage outlet, Culvert A, is located at UTM position 17T 615176 m E, 4904844 m N in Ontario, Canada. The small, unnamed ditch at this location drains directly into Lake Simcoe. Soils on site were