The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

CSBE | SCGAB

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

Paper No. CSBE09-609

Modeling Variable Source Area from an Agricultural Watershed

Kamran Chapi, Research Associate
School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1, kchapi@uoguelph.ca
College of Natural Resources, University of Kurdistan, Sanandaj, Iran, Postal Code 66177-15175

Ramesh P. Rudra, Professor
School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1, rrudra@uoguelph.ca

S. Imran Ahmed, Post Doctorate Fellow
School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1, sahmed@uoguelph.ca

W.T. Dickinson, Professor Emeritus
School of Engineering, University of Guelph, Guelph, Ontario, N1G 2W1, wdickins@uoguelph.ca

Pradeep K. Goel, Senior Surface Water Scientist, Environmental Monitoring and Reporting Branch, MOE, Ontario, M9P 3V6, **Pradeep.Goel@ontario.ca**

Written for presentation at the
CSBE/SCGAB 2009 Annual Conference
Rodd's Brudenell River Resort, Prince Edward Island
12-15 July 2009

Abstract

The concept of Variable Source Areas (VSAs) depicts that runoff is generated by the mechanism of saturation-excess in different times and spaces within watersheds. Identification of VSAs allows exploring the hydrologically sensitive areas of a watershed which generate more runoff and have higher potential of delivering contaminants to streams. A hydrological model was developed to simulate variable source areas of a small agricultural watershed in southern Ontario. Two summer storms of August 9, 2008 and August 10, 2008 were selected to evaluate the capability of the model for VSA simulation. Calibration of model resulted in the Nash-Sutcliffe model efficiency coefficient of 63% with relative errors of 12%, 23%, and 0% for peak flow, total flow, and time to peak. Application of model for the second storm was tested with Nash-Sutcliffe coefficient of 28%. Simulation of VSA showed a high efficiency of the model to identify the locations of source areas in the watershed which generate more runoff and have higher potential of delivering contaminants to streams.

Keywords. Variable source areas, model, SCS-CN, southern Ontario

INTRODUCTION

Source water protection is becoming a major environmental issue due to the lack of safe, clean and reliable drinking water for the future (Davidson et al., 2005). Protecting sources of water from pollution and contaminants is vital to ensuring human and ecosystem health and to prevent repeating Walkerton, Ontario, and North Battleford, Saskatchewan, tragedies. Source water protection adopts strategies, plans and activities to avoid direct or indirect release of pollutants into surface water or groundwater resources as sources of drinking water (O'Connor, 2002; Krewski et al., 2004). Point and nonpoint sources (NPS) of pollution are two major sources of water quality impairments (Wolfe, 2000), of which NPS is responsible for more than 50% of the total water contamination (Novotny and Chesters, 1981) by delivering approximately 80% of the total nitrogen load and more than 50% of the total phosphorus load to water bodies (Loehr, 1972).

As a nonpoint source of pollution, agricultural runoff plays a significant role in water quality problem in Ontario as it delivers 70% of the total phosphorus load to Lake Erie (Miller, 1982); therefore, it is crucial that these sources of pollution are remediated to prevent human and environmental problems.

Best Management Practices (BMPs) can dramatically reduce the impacts of NPS on water quality in agricultural watersheds (Tomer et al., 2003); however these practices will not be effective if they do not target NPS in the right places on time. BMPs should, therefore, be assigned to the areas of the watershed with higher potential of runoff generation (PLUARG, 1978; Duda and Johnson, 1985; Maas et al., 1985; Megahan and King, 1985; Myers, 1986; Qiu, 2003; Strauss et al., 2007; Freitas et al., 2008; Leh et al., 2008).

The identification of the most sensitive areas of a watershed, termed also variable source areas (VSAs) by Hewlett and Hibbert (1967) is difficult due to its variability in space and time (Megahan and King, 1985) on the contrary of Horton's infiltration theory (Horton, 1933), indicating that a thin uniform layer of surface runoff is generated once the rainfall intensity exceeds the infiltration capacity. Monitoring and modeling as two important approaches can be applied to locate VSAs of a watershed (Qiu, 2003). Modeling is a cost-effective option to simulate VSAs; however there are few models to predict the times and spaces of variable source areas, e.g. SHAM (Kirkby et al., 1976), VSAS1 (Troendle, 1979), VSAS2 (Bernier, 1982), SMORMOD (Zollweg et al., 1996), SMR (Frankenberger et al., 1999), and VSLF (Schneiderman et al., 2007). These models can fairly well simulate VSAs; however, they need more data if the structure of the model is based on the physics of the process. The SCS-Curve number can be a reliable method to simulate VSA with some modifications (Lyon et al., 2004; and Agnew et al., 2006).

This paper addresses the use of the modified Moglen approach to SCS-Curve number (Moglen, 2000) to model the hydrologically sensitive areas of a small agricultural watershed in southern Ontario according to discretization of the watershed based on soil, land use, and topography.

MATERIALS AND METHODS

Study Area

A 4.45 ha agricultural watershed located on the Guelph Turfgrass Institute (GTI) of the University of Guelph, between latitudes of 43° 32′ 42″ N and 43° 32′ 50" N, and longitudes of 80° 12′ 17″ W and 80° 12′ 30" W, in southern Ontario was selected to study the simulation of variable source areas (Fig. 1). The mean elevation and slope of the watershed are 303 m and 4.5%, respectively. The mean annual precipitation is 810 mm. The long-term average annual temperatures for spring, summer, fall, and winter seasons are 9.2˚C, 18.5˚C, 5.2˚C, and -5.2˚C, respectively. The soil is uniform over the entire watershed and belongs to the Guelph series. The texture of the soil is sandy loam and falls in Group A in term of soil hydrological groups. The watershed was under the cultivation of corn in 2008 - the year of the experiment.

Data Acquisition

In order to model VSAs, the GTI watershed was discretized into 8 homogenous fields based on soil, land use and topography (Fig. 2). The characteristics of these 8 fields are shown in Table 1. A Wireless Sensor Network (WSN) was developed to measure the flow and soil moisture. This system includes a pressure sensor, a soil moisture sensor (both sensors were attached to the same board), a base station, and a laptop. The pressure sensor along with the soil moisture sensor were placed at the outlet of each field. The pressure sensors measured the depth of overland flow over a V-notch weir by means of the changes in output voltages. The soil moisture sensors registered the volumetric soil water content using another series of output voltages designed for them. The green dots in Figure 2 show the locations of the 8 sensors. The V-notch weir was hammered into the ground at the outlet of each field and the pressure sensor pipe was attached to the angle of the V-notch. A soil moisture sensor was placed into the ground beside the V-notch such that both sensors were fed by the same power source. Figure 3 shows the installation of equipments for this research. The sensors recorded the data in time intervals of 10 minutes and stored them in a small flash memory located on the sensor board. The data were then transferred to the base station remotely and stored in a WordPad file on the laptop. The pressure and soil moisture sensors were tested and calibrated in the laboratory and field repeatedly to ensure that they function effectively in the field experiments and provide as accurate data as possible. The rainfall data were collected from the Guelph Turfgrass Institute tipping bucket raingage in time interval of 5 minutes. Eighteen natural storms (10 in summer, 5 in fall, and 3 in spring) were recorded from July 2008 to April 2009 to be modeled.

Development of model

The Soil Conservation Service Curve Number method was developed in 1954 for the estimation of direct runoff from storm rainfall (Rallison and Miller, 1982). It is the most widely used procedure in hydrologic engineering to analyze the impacts of land use and treatment on direct runoff (Ponce and Hawkins, 1996). The model estimates surface runoff by assessment of one parameter called curve number based on land use, soil hydrologic group, and treatment of the watershed (Soil Conservation Service, 1972). This method computes direct runoff as follows:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad for \qquad P > I_a \tag{1a}$$

$$Q = 0 \qquad for \qquad P \le I_a \tag{1b}$$

where Q is direct runoff (mm); P is rainfall (mm); I_a is initial abstraction (mm); and S is the potential maximum retention of the soil (mm). I_a and S are obtained:

$$I_a = 0.2S \tag{2}$$

$$S = \frac{25400}{CN} - 254 \tag{3}$$

CN is curve number, a dimensionless parameter which is given according to soil, land use and treatment of the watershed.

Potential maximum retention of the soil is an important factor by which the initiation of surface runoff is controlled. It also has a close relationship with the degree of saturation which is important in the concept of variable source area. Therefore, in this research several approaches were examined to compute this factor. Equation 4 was explored to be the best for calculation of potential maximum retention of the soil as below:

$$S = (n - \theta_0)D_S \tag{4}$$

where n is the soil porosity which is 41%, 46%, and 48% for summer, fall, and spring in the study area. Θ_o is the initial soil moisture in percent, and D_s is the depth of impending layer (Mishra and Singh, 2003) or the depth of surface layer (ASCE, 1996). The depth of impending layer is differently defined by various studies. NeSmith et al. (1986) have suggested 10 cm for this layer; Thornthwaite and Mather (1955) and Steenhuis and Van Der Molen (1986) have defined it as 10-20 cm; Holtan (1961) has referred to it as 20 cm; Western et al. (1999) have given importance to the first 30 cm of the soil as a key layer for saturation studies; and Mishra and Singh (2003) have suggested 1-1.5 m. In this research, 20 cm was evaluated as the best estimate of this layer since the soil moisture sensors measure soil water content up to 20 cm depth. Also 20 cm is a good approximation for plow layer. S was computed for each field of the GTI watershed based on Equation 4. Since each field was in a different soil moisture condition, S values were different, resulting in different initial abstractions.

According to Emmet (1978), when it rains, the initial abstraction should first be satisfied. Surface runoff is generated after the process of satisfying initial abstraction. The initial abstraction was, therefore, subtracted from the rainfall amount at the beginning of rainfall event and assumed zero for the remaining duration of rainfall event. S values were then recalculated for each time step by subtracting cumulative infiltration for time step from value of S for the previous time step using following equation:

$$S_{t_{n+1}} = S_{t_n} - F_{t_n} \tag{5}$$

$S_{t_{n+1}}$ is the potential maximum retention for the next time step of rainfall; S_{t_n} is for the previous time step; and F_{t_n} is cumulative infiltration in the previous time step. The cumulative infiltration was estimated by the approach suggested by Philip equation (Equation 6) as it was successfully used in many previous studies (Gupta, 2002; and Sajid, 2009).

$$I = S_p t^{1/2} + A_s t \tag{6}$$

I is cumulative infiltration; S is soil sorptivity; t is time; and A is transmission factor. For overland flow routing, the modified moglen approach by Mishra and Singh (2003) was formulated as:

$$Q_{i_{(t_{n+1})}} = \frac{\left[P_{i_{(t_{n+1})}} + \left(Q_{i-1_{(t_n)}} \frac{A_{i-1}}{A_i}\right)\right]^2}{\left[P_{i_{(t_{n+1})}} + \left(Q_{i-1_{(t_n)}} \frac{A_{i-1}}{A_i}\right) + S_{i_{(t_{n+1})}}\right]} \tag{7}$$

where Q is outflow from each field (mm); A is area of the field (m^2); t is time (min); i is the number of fields; and n is the number of rainfall time step in hyetograph. In the routing module of the model, the amount of surface runoff which is received by the downstream field from the upstream field is calculated by the equation below:

$$Q_2 = Q_1 \times \frac{A_1}{A_2} \tag{8}$$

in which Q_2 is the outflow of downstream field; Q_1 is the outflow of upstream field; A_2 is the area of downstream field; and A_1 is the area of upstream field. This model was applied to predict the most sensitive field of the GTI watershed, the field which produces more surface runoff.

RESULTS AND DISCUSSIONS

Calibration, validation and sensitivity analysis of model

To evaluate the capability of the developed model in simulation of variable source areas in the study area, two summer storms of August 9, 2008 (Storm 1) and August 10, 2008 (Storm 2) were selected to model. Table 2 shows the characteristics of these two storms. The first storm was chosen for calibration of model, while the second one was used for validation. The results indicated that the designed model successfully simulated the hydrograph of the watershed as shown in Figure 4. The Nash-Sutcliffe model efficiency coefficient (Nash and Sutcliffe, 1970) was 63 percent and the relative errors for peak flow, total flow, and time to peak were 12, 23, and 0 percent. The procedure is a one-parameter model based on curve number. To calibrate the model, ± 5% and ± 10% changes were made in curve number as well as applying the traditional curve number selection to assess their impacts on the error of peak flow, total flow, time to peak, and on Nash-Sutcliffe coefficient. Even though, the changes of 5% and 10% reduced the relative errors of peak flow and total flow, they increased the time to peak error by 7% and decreased the model efficiency coefficient by minimum 25%. The traditional CN was the poorest scenario since the model efficiency coefficient was -17% and minimum relative error was 79% for time to peak. Figure 5 illustrates the sensitivity analysis of the model. These findings demonstrate that calibration did not improve the results of simulation of storm August 9, 2008; therefore, the model was applied as such for the storm of August 10, 2008. As Figure 6 shows, the model can fairly well simulate the storm of August 10, 2008 with model efficiency of 28%, and relative errors of 33%, 10%, and 0% for peak flow, total flow, and time to peak, respectively. Table 3 summarizes comparison of some observed and modeled factors for these two storms.

Investigation of variable source areas

To evaluate the efficiency of the model for identification of variable source area in the watershed, the areal percentage of VSA, and two factors including time to start runoff and total flow of each field as the sensitivity of fields were analyzed for the two storms. The model assessed the percentage of VSA for storm 1 and storm 2 to be 85% and 100%, respectively, while observed data showed 66%, and 100%. The model also shows that Fields 2 and 4 start runoff before the other fields for both storms. These findings were confirmed by observed data. The observed data showed that Fields 4 and 2 produced more runoff than the other fields in both storms as the most sensitive areas. Same results were obtained from the model for Fields 4 and 2. The results of this study are in a good agreement with Betson's findings (Betson, 1964) as he found that the variable source areas are relatively constant areas of a watershed, producing different amounts of flow for different rainfalls. The results indicate that the model can investigate the time and location of variable source areas in the watershed and evaluate the most sensitive area of the watershed, generating more runoff than other areas.

CONCLUSION

The dynamics of variable source areas in a small agricultural watershed in southern Ontario was modeled by a simple approach to SCS-CN for two summer storms. The model successfully simulated both storms with fairly well Nash-Sutcliffe model efficiency coefficient. The designed model overestimates peak flow and total amount of flow with acceptable relative errors. The structure of the model allows the model to be applied without calibration even though calibration is always suggested. The applicability of the model for simulation of VSAs was successful for both storms with a relative error of 25% for storm 1 in the estimation of areal computation of VSA. The model can be used as a management tool to identify the areas of a watershed, producing more runoff and contaminants to place appropriate BMPs. The designed model is a simple procedure, having high potential to be improved for larger watersheds and other seasons in southern Ontario; however its applicability must be tested for large watersheds and for different seasons.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the useful contributions to this paper by Dr. Stefano Gregori, assistant professor of the School of Engineering, University of Guelph, Dr. Amanjot Singh, former research associate of the School of Engineering, University of Guelph, and Steven P. Poret, former M.Eng. student of the School of Engineering, University of Guelph.

REFERENCES

Agnew, L.J., S. Lyon, P. Gerard-Marchant, V.B. Collins, A.J. Lembo, T.S. Steenhuis and M.T. Walter. 2006. Identification hydrologically sensitive areas: Bridging the gap between science and application. *Journal of Environmental Management* 78(1): 63-76.

American Society of Civil Engineers. 1996. Hydrology Handbook. Second Edition, ASCE Manuals and Reports on Engineering Practice No. 28.

Bernier, P.Y. 1982. VSAS2: a revised source area simulator for small forested basins. Unpublished Ph.D thesis, University of Georgia, Athens, Georgia, USA, 143 pp.

Betson, R.P. 1964. What is watershed runoff? *Journal of Geophysical Research* 69: 1541-1552.

Davidson, A., G. Howard, M. Stevens,P. Callan, L. Fewtrell, D. Deere and J. Bartram. 2005. Water Safety Plans: Managing Drinking-Water Quality From Catchment To Consumer. Geneva, Italy: WHO.

Duda, A. M. and R.J. Johnson. 1985. Cost-Effective Targeting of Agricultural Nonpoint-Source Pollution Controls. *Journal of Soil and Water Conservation* 40(1): 108-111.

Emmet, W.W. 1978. Overland Flow. In Hillslope Hydrology, ed. M.J. Kirkby, 145-176. New York, NY: John Wiley and Sons.

Frankenberger, J.R., E.S. Brooks, M.T. Walter, M.F. Walter and T.S. Steenhuis. 1999. A GIS-based variable source area hydrology model. *Hydrological Processes* 13: 805-822.

Freitas, L.G., H. Singer, S.R. Muller, R.P. Schwarzenbach, and C. Stamm. 2008. Source area effects on herbicide losses to surface water – A case study in the Swiss Plateau. *Agriculture, Ecosystems and Environment* 128: 177-184.

Gupta, N. 2002. Investigation of rainfall-runoff mechanism of field scale. Unpublished Ph.D Thesis, University of Guelph, pp. 273.

Hewlett, J.D. and A.R. Hibbert. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. In *Proceedings of The International Symposium on Forest Hydrology*, eds. Sopper, W.E. and H.W. Lull, 275-290. Pennsylvania State University, PA, New York: Pergamon.

Holtan, H.N. 1961. A concept of infiltration estimates in watershed engineering. ARS41-51, U.S. Dept. of Agri. Service, Washington, D.C.

Horton, R.E. 1933. The role of infiltration in the hydrologic cycle. *Transactions of the American Geophysical Union* 14: 446-460.

Kirkby, M.J., J. Callan, D.R. Weyman and J. Wood. 1976. Measurement and modeling of dynamic contributing areas in very small catchments. Working Paper No. 167, School of Geography, University of Leeds, 40 pp.

Krewski, D., J. Balbus, D. Butler-Jones, C.N. Haas, J. Isaac-Renton, K.J. Roberts and M. Sinclair. 2004. Managing the Microbiological Risks of Drinking Water. *Journal of Toxicology and Environmental Health* 67: 1591-1617.

Leh, M. D., I. Chaubey, J. Murdoch, J.V. Brahana and B.E. Haggard. 2008. Delineating runoff processes and critical runoff source areas in a pasture hillslope of the Ozark Highlands. *Hydrological Processes* 22: 4190-4204.

Loehr, R. C. 1972. Agricultural Runoff - Characterization and Control. *Journal of Sanitary Engineering Division* 98: 909-923.

Lyon, S.W., M.T Walter, P. Gerard-Marchant and T. Steenhuis. 2004. Using a topographic index to distribute variable source area runoff predicted with the SCS curve number equation. *Hydrological Processes* 18: 2757-2771.

Maas, R. P., M.D. Smolen and S.A. Dressing. 1985. Selecting Critical Areas for Nonpoint-Source Pollution Control. *Journal of Soil and Water Conservation* 40(1): 68-71.

Megahan, W.F. and P.N. King. 1985. Identification of Critical Areas on Forest Lands for Control of Nonpoint Sources of Pollution. *Environmental Management* 9(1): 7-18.

Miller, M. H., J.B. Robinson, D.R. Coote, A.C. Spires and D.W. Wraper. 1982. Agriculture and Water Quality in the Canadian Great Lakes Basin: III. Phosphorus. *Journal of Environmental Quality* 11(3): 487-493.

Mishra, S.K. and V.P. Singh. 2003. Soil Conservation Service Curve Number (SCS-CN) Methodology. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Moglen, G.E. 2000. Effect of orientation of spatially distributed curve numbers in runoff calculations. *Journal of the American Water Resources Association* 36(2): 1391-1400.

Myers, P. C. 1985. Nonpoint Source Pollution Control: The USDA Position. *Journal of Soil and Water Conservation* 41(3): 156-158.

Nash, J.E. and J.V. Sutcliffe. 1970. River flow forecasting through conceptual models. I. A discussion of principles. *Journal of Hydrology* 10(3): 282-290.

NeSmith, D. S., W.L. Hargrove, E.W. Tollner and D.E. Radcliffe. 1986. A comparison of three soil surface moisture and bulk density sampling techniques. *Transactions of the ASAE* 29(5): 1297-1299.

Novotny, W. and G. Chesters. 1981. *Handbook of Nonpoint Pollution: Sources and Management*. New York : Van Nostrand Reinhold Company.

O'Connor, D.R. 2002. A Strategy for Safe Drinking Water, Report of the Walkerton Inquiry 2. Toronto : Ministry of the Attorney General.

PLUARG. 1978. Environmental Management Strategy for the Great lakes Basin. Final report of the pollution from land use activities reference group to the International Joint Commission, Windsor, Ontario.

Ponce, V.M., and R.H. Hawkins. 1996. Runoff Curve Number: Has it Reached Maturity?, *Journal of Hydrologic Engineering* 1(1): 11-19.

Qiu, Z. 2003. A VSA-Based Strategy for Placing Conservation Buffers in Agricultural Watersheds. *Environmental Management* 32(3): 299-311.

Rallison, R.E., and N. Miller. 1982. Past, present, and future of runoff procedure. In *Rainfall-Runoff Relationship*, ed. V.P. Singh, 353-364. Chelse, Michigan: BookCrafts, Inc.

Sajid, A.H. 2009. Investigation of rainfall-runoff process in relation to soil physical and hydraulic properties. Unpublished Ph.D Thesis, University of Guelph, pp. 421.

Schneiderman, E.M., T.S. Steenhuis, D.J. Thongs, Z.M. Easton, M.S. Zion, A.L. Neal, G.F Mendoza and M.T. Walter. 2007. Incorporating variable source area hydrology into a curve-number-based watershed model. *Hydrological Processes* 21: 3420-3430.

Soil Conservation Service. 1972. National Engineering Handbook Section 4 Hydrology. USDA (Also know as National Engineering Manual Part 630).

Steenhuis, T. and W.H. Van Der Molen. 1986. The Thornthwaite-Mather procedure as a simple engineering method to predict recharge. *Journal of Hydrology* 84, 221-229.

Strauss, P., A. Leone, M.N. Ripa, N. Turpin, J.M. Lescot and R. Laplana. 2007. Using critical source areas for targeting cost-effective best management practices to mitigate phosphorus and sediment transfer at the watershed scale. *Soil Use and Management* 23(Suppl. 1): 144-153.

Thornthwaite, C.W. J.R. Mather. 1955. The water balance. Publication in climatology, Volume VIII, Number 1.

Tomer, M.D., D.E. James and T.M. Isenhart. 2003. Optimizing the placement of riparian practices in a watershed using terrain analysis. *Journal of Soil and Water Conservation* 58(4): 198-206.

Troendle, C.A. 1979. A variable source area model for stormflow prediction on first order forested watersheds. Unpiblished Ph.D thesis, University of Georgia, Athens, Georgia, USA, 115 pp.

Western, A.W., R.B. Grayson, G. Blöschl, G.R. Willgoose and T.A. McMahon. 1999. Observed spatial organization of soil moisture and its relation to terrain indices. *Water Resources Research* 35(3): 797-810.

Wolfe, M.L. 2000. Hydrology. In Agricultural Nonpoint Source Pollution: Watershed Management and Hydrology, eds. W.F. Ritter and A. Shirmohammadi, Agricultural, Boca Raton, Florida: CRC Press.

Zollweg, J. A., W.J. Gburek and T.S. Steenhuis. 1996. SMORMOD — A GIS-integrated rainfall–runoff model. *Transactions of the American Society of Agricultural Engineers* 39: 1299–1307.

List of Tables

Table 1. Characteristics of 8 fields in the GTI watershed

Field	Length of Overland Flow (m)	Area (ha)	Mean Slope (%)
1	270	1.22	5.5
2	310	0.31	3.8
3	165	0.31	9.3
4	245	0.35	7.5
5	275	1.10	5.0
6	220	0.36	2.6
7	190	0.40	3.0
8	125	0.40	2.3

Table 2. Characteristics of storm 1 and storm 2 for the GTI watershed

Rainfall Event	Time	Total Rainfall (mm)	Duration Time (min)	Rainfall Intensity (mm/min)	Return Period (yr)
August 9, 2008 (Storm 1)	5:30 – 8:20 PM	20.6	170	0.12	3.2
August 10, 2008 (Storm 2)	2:10 – 4:20 PM	25.6	130	0.20	3.8

Table 3. Model efficiency factors for the two summer storms

Storm	Mode	Nash-Sutcliffe Coefficient (%)	Peak Flow (L/S)	Total Flow (L)	Time to Peak (min)
August 9, 2008	Observed	---	2.8	5123.5	140
	Modeled	63	3.3 (23)	6650.0 (12)	140 (0)
August 10, 2009	Observed	---	7.1	24745	110
	Modeled	28	10.6 (33)	22555 (10)	110 (0)

Values in the brackets are relative errors for simulation.

List of Figures

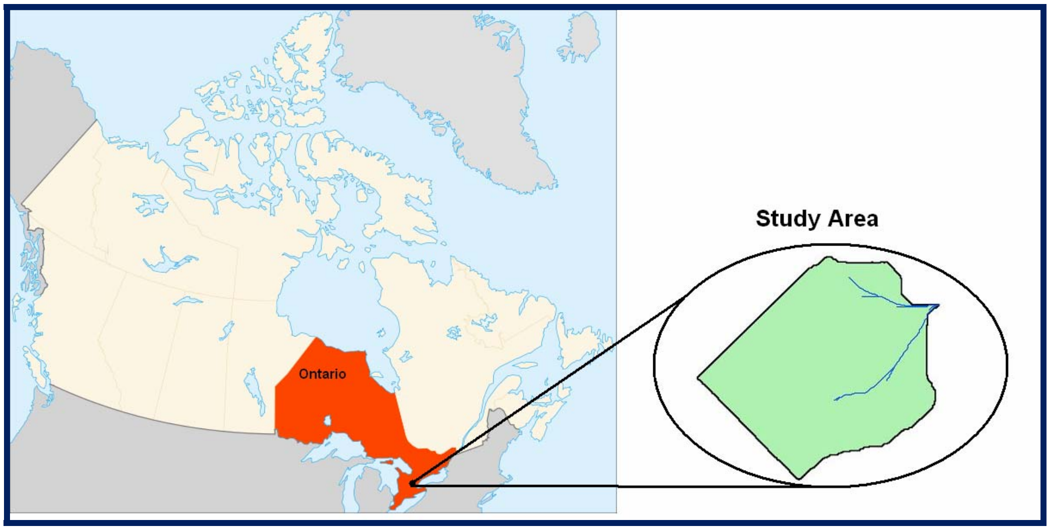


Fig. 1. Geographical position of the study area

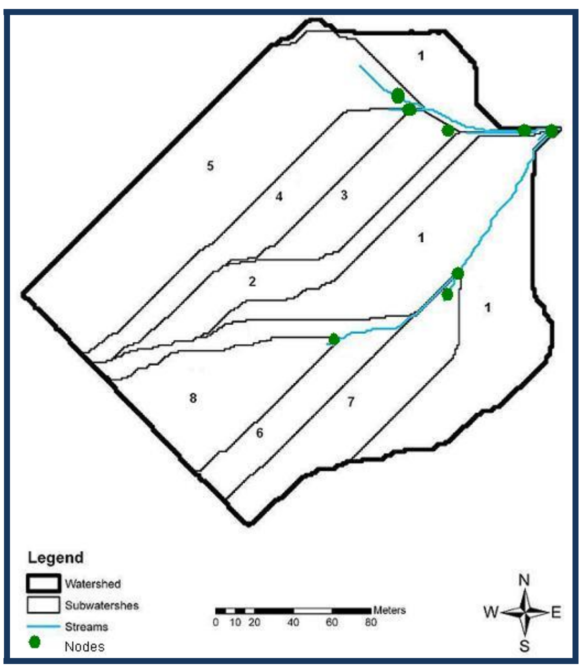


Fig. 2. Map of the 8 fields in the GTI watershed and the sensor places

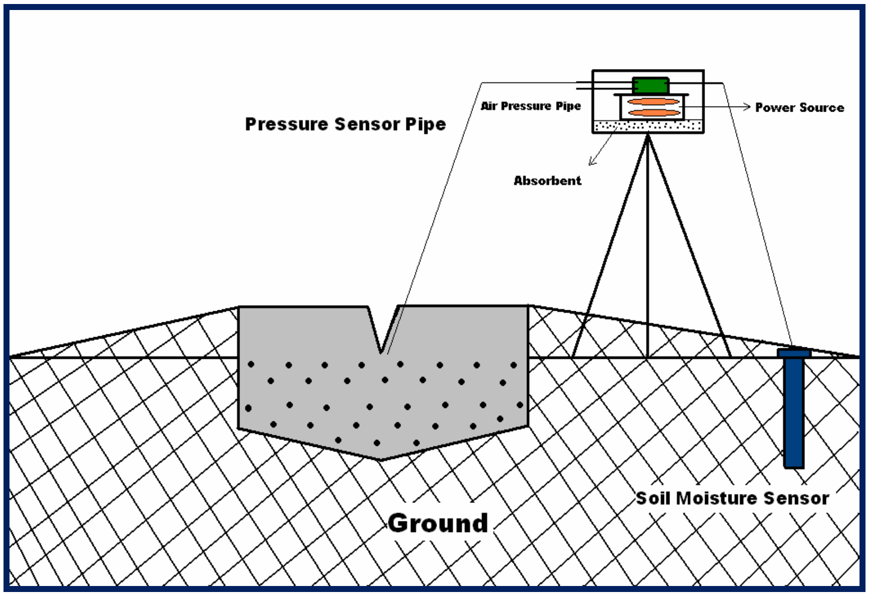


Fig. 3. Installation of the equipments at the outlet of each field in the GTI watershed

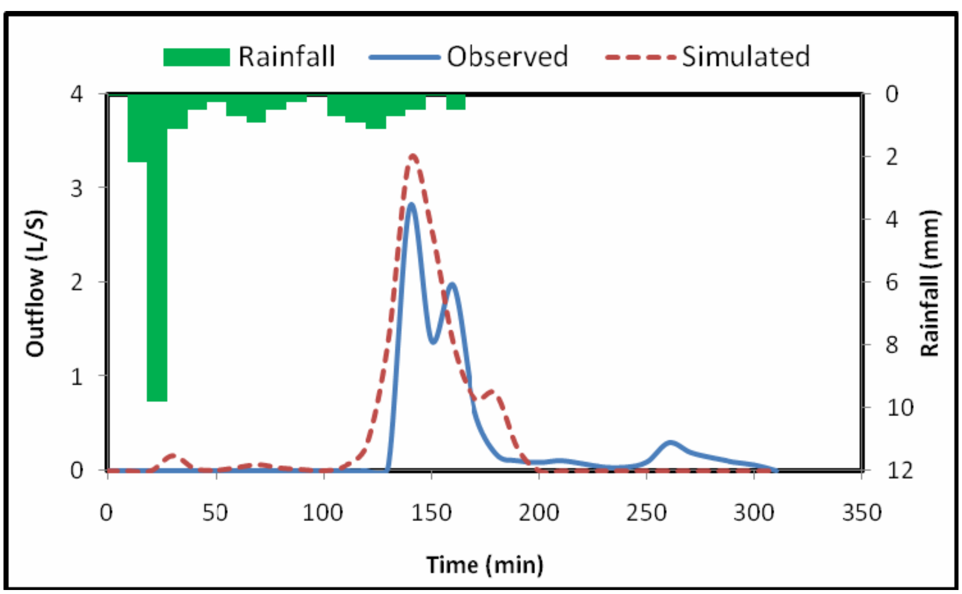


Fig. 4. Observed and simulated outflow for the storm of August 9, 2008

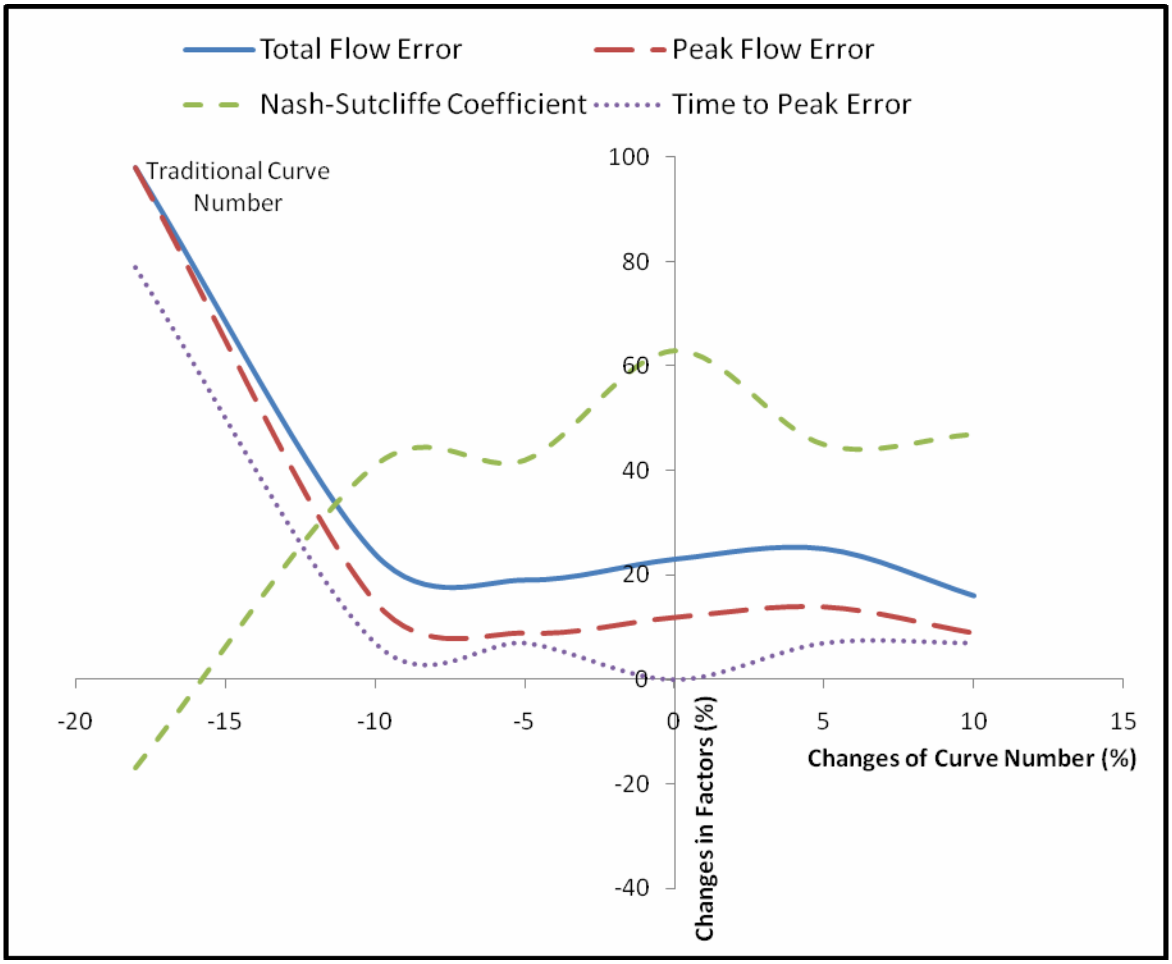


Fig. 5. Sensitivity analysis of the model using ±5%, ±10%, and traditional curve number

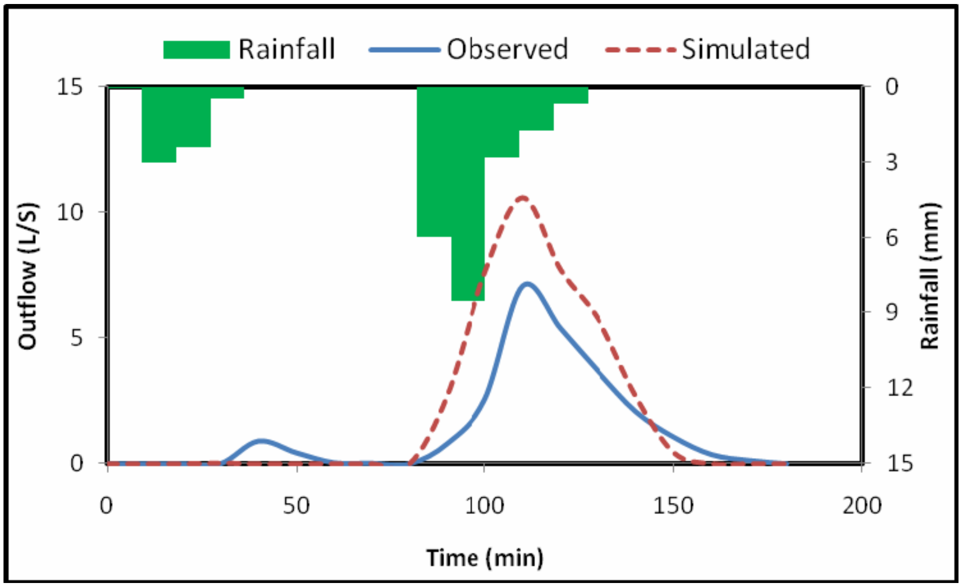
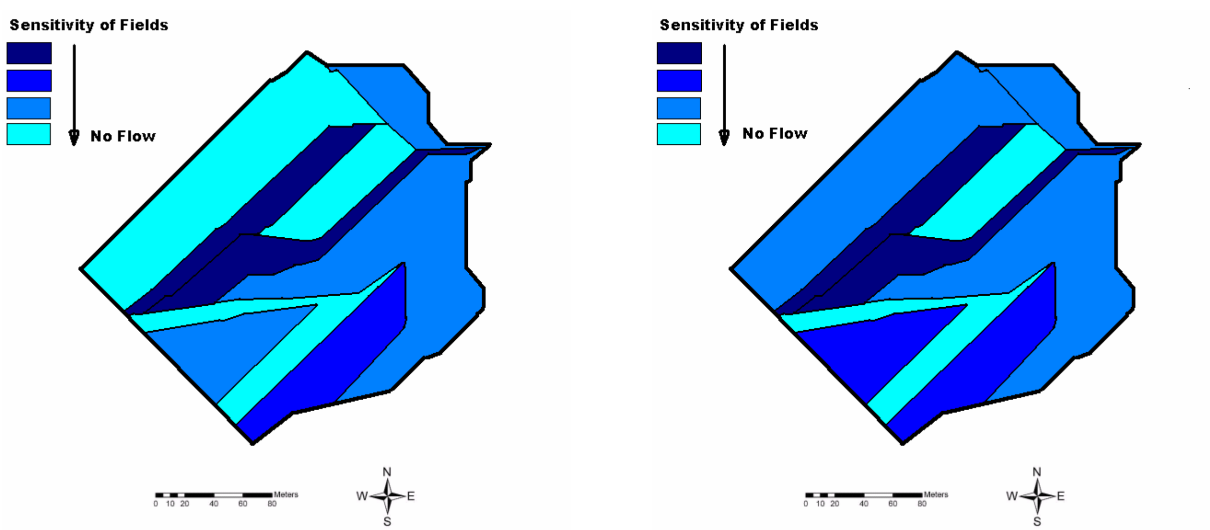


Fig. 6. Observed and simulated outflow for the storm of August 10, 2008



(a) (b)

Fig. 7. Variable source areas in the GTI watershed for the storm of August 9, 2008 (a) and their simulation by the designed model (b)