22nd International Congress on Modelling and Simulation, Hobart, Tasmania, Australia, 3 to 8 December 2017
mssanz.org.au/modsim2017

Determination of BMPs to Reduce Soil and Water Pollution in Tile-Drained Watersheds in Southern Ontario, Canada under Changing Climate

Golmar Golmohammadi[1], Shiv Prasher[2], Ramesh Rudra[1], Prasad Daggupati[1], Pradeep Goel[3], and Rituraj Shukla[1]

[1]School of Engineering, The University of Guelph, Guelph, Ontario, Canada, [2]Department of Bioresource Engineering, McGill University, Montreal, Quebec, Canada, [3]Ontario Ministry of the Environment and Climate Change, Toronto, Ontario, Canada
Email: shiv.prasher@mcgill.ca

Abstract: Best Management Practices (BMPs) can be implemented on agricultural landscapes to manage water flows and reduce nonpoint source pollution. However, given the specificity of each landscape, there are presently no credible methods of determining, *a priori*, which BMP would work best under a given situation and, more importantly, where in the watershed should it be located. Furthermore, climate change in Ontario, Canada is going to cause non-uniform spatial and temporal distribution of precipitation, thereby causing and aggravating flooding, drought, and pollution problems. Hydrological simulation models are useful tools to understand how a change in global climate could affect the availability and variability of regional water resources. This research addresses this important issue in two different watersheds in Ontario. The main goal of this study is to develop an agricultural landscape assessment tool by simultaneously considering physical, chemical, and biological landscape parameters and carry out a holistic analysis of the agricultural and environmental state of the landscape.

Our research team has developed SWATDRAIN, a watershed scale model for subsurface-drained agricultural landscapes, by fully integrating SWAT and DRAINMOD models. While the SWAT model has been used extensively around the world to simulate surface hydrology of watersheds, it leaves much to be desired when it comes to subsurface hydrology, specially for tile-drained landscapes. Therefore, DRAINMOD was fully incorporated into the SWAT model's subsurface hydrology module as an alternative method for simulating tile drainage, water table depth, and soil water status. The newly developed SWATDRAIN model is based on the DRAINMOD subsurface hydrology simulation and the SWAT surface hydrology simulation. SWATDRAIN computes the soil water balance for each HRU (Hydrologic Response Unit) in every sub-basin on a daily basis.

In this paper, the impact of controlled drainage on watershed hydrology and sediment loadings will be presented. The effects of climate change on annual and seasonal water budgets, sediment loads will also be reported.

Keywords: *Best Management Practices (BMPs), SWATDRAIN, climate change*

1. INTRODUCTION

Best Management Practices (BMPs) are proven to be sustainable management options in agricultural watersheds in restoring and ensuring sustainability of water quality and quantity (Panagopoulos et al., 2014). There are various BMPs such as structural practices (engineered physical structures) and operational practices (involving modifications to the farm management system). The Soil and Water Assessment Tool (SWAT) can predict long-term impacts of land use and management on water, sediment and agricultural chemical yields at varying scales. SWAT has also been applied in several projects around the world dealing with the impacts of climate change. On water supplies and reservoir operations, including the regional impact of climate changes on the recharge of groundwater in the Ogallala aquifer (Rosenberg et al., 2000; Stonefelt et al., 2000; Hotchkiss et al., 2000; Wollmuth and Eheart, 2000. Recently, Grady et al., 2013; Daggupati et al., 2015; and Golmohammadi et al. 2016a; 2017c) evaluated the impacts of climate change on flow and water table dynamics and nitrate loads in a small agricultural watershed in eastern Ontario. They also integrated the hydrology component of the DRAINMOD model (Skaggs, 1980) into SWAT, calling it SWATDRAIN which was successfully applied in various agricultural watersheds in Ontario (Golmohammadi et al., 2016c; Golmohammadi et al., 2017b). The integrated model also indicated a significant improvement in the simulation of flow and water table dynamics compared to the SWAT model.

In this study, the SWATDRAIN model was used to evaluate the impacts of different BMPs on watershed hydrology and sediment losses. The model was also used to estimate the impacts of climate change on surface and subsurface hydrology and sediment losses in a tile-drained agricultural watershed in Ontario, Canada.

2. Materials and Methods

2.1 Watersheds Descriptions

The Canagagigue Creek Watershed, selected for this study, has a total drainage area of 143 km^2 and is a tributary of the Grand River (**Error! Reference source not found.**). It lies between latitudes 43°36' N and 43°42' N and longitudes 80°33' W and 80°38' W, and is about 25 km northwest of the city of Guelph, Ontario, Canada.

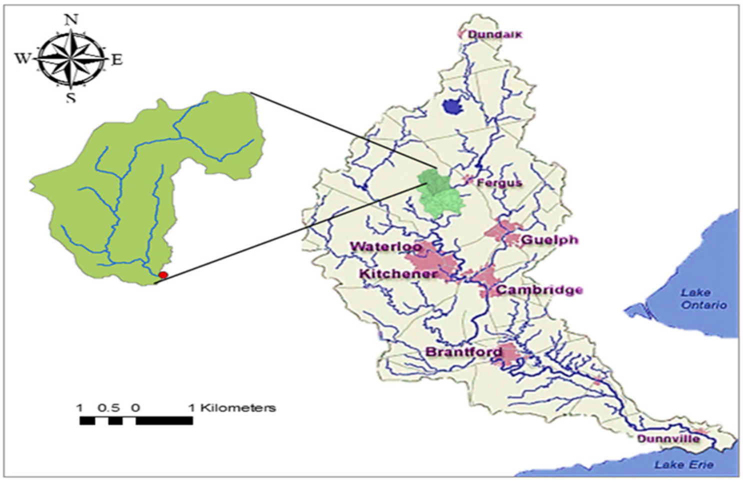

Figure 1. Location of the study area, Canagagigue West watershed, in Grand River Basin

2.2 Development of BMP Scenarios

The purpose of this modelling study was to evaluate the impacts of selected BMP scenarios on hydrology and sedimentation, both under existing conditions in the watershed as well as possible future implemented BMPs. In the evaluation process, a baseline scenario was defined and modeled in order to establish a reference condition to which the other scenarios could be compared too. The baseline and the other BMP scenarios are defined as below:

Baseline Scenario (Scenario I): This scenario was a simulation of the current (existing) Canagagigue watershed conditions, i.e. existing land management practices and tile drainage systems. All other scenarios were compared against this baseline scenario

***BMP Scenarios (Scenario* II to VIII)**

- Scenario II: Existing Tile Drainage + Conservation Tillage
- Scenario III Existing Tile Drainage + Red Clover Cover Crop
- Scenario IV: Existing Tile drainage + Conservation Tillage + Red Clover Crop
- Scenario V: Controlled Drainage + Existing Condition
- Scenario VI: Controlled Drainage + Conservation Tillage
- Scenario VII: Controlled Drainage + Red Clover Cover Crop

- Scenario VIII: Controlled Drainage + Conservation Tillage + Red Clover Crop

2.3 Climate Change Modeling

Global Circulation Models (GCMs) was selected to simulate future climatic conditions. The Canadian GCM (CGCM) provides for several types of GCMs to explain various future greenhouse gases emission scenarios. In this study, Canadian Global Circulation Model 2 (CGCM2) with A2 scenario was selected as it would have stronger adverse impacts on water quality (Rong et al., 2009). Due to temperature change in future years, warmer winters and hotter summers are expected to yield more evaporative water losses (**Error! Reference source not found.**).

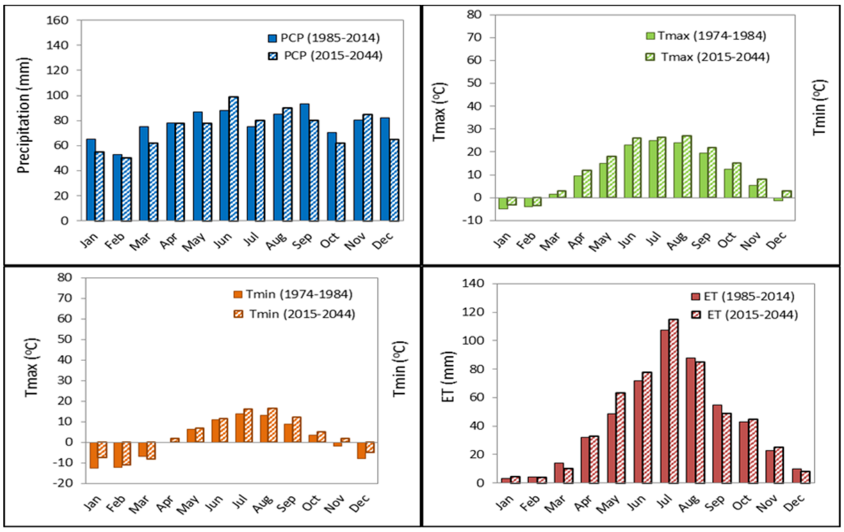

Figure 2. Historical and future predicted monthly average precipitation, temperature and evapotranspiration

3. Results and Discussion

3.1 Flow and Sediment Simulations

The SWATDRAIN model was calibrated and validated for streamflow and sediment loads for the Canagagigue Watershed (Golmohammadi et al., 2017b and c). Time series plots of monthly streamflow during calibration and validation period are given in **Error! Reference source not found.**. The results show that the observed and simulated stream flows were in a good agreement. Observed and simulated monthly sediment loads, during calibration and validation periods, are presented in **Error! Reference source not found.**. The monthly calculated values of NSE (Nash-Sutcliffe Coefficient), PBIAS (Percent bias) , and RSR (Root Mean Square Error) for stream flow are 0.74, 3.67, and 0.37 and similarly for sediment loads the values are 0.80, 25.88, and 0.44 during the validation period.

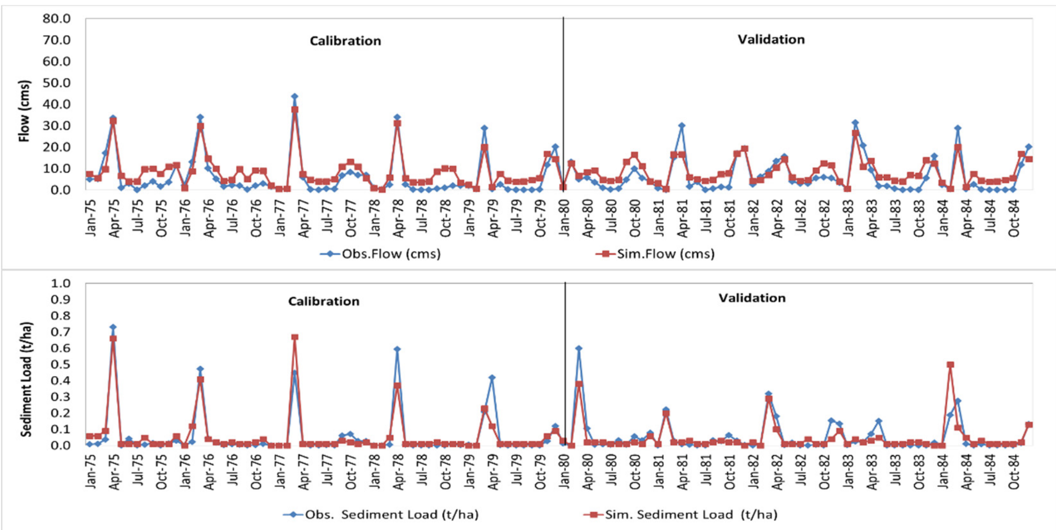

Figure 3. Observed and simulated monthly streamflow and sediment loads during calibration and validation periods (Adopted from Golmohammadi et al., 2017c)

3.2 BMPs Modeling

Baseline Scenario: The calibrated SWATDRAIN model was used to simulate water balance for a 10-year period, from 1975 to 1984, under existing climate and land management conditions, and the average annual water balance results are presented in Figure 4. The results showed that a major portion of precipitation (46.8%) contributed to streamflow at the outlet of the watershed. The simulated average values of surface runoff and tile drainage were respectively 25.6% and 11.9% of precipitation. Lateral flow was 5.3% of the annual precipitation. During the simulation period, 46.6% of the annual precipitation was lost as evapotranspiration.

BMP Scenarios: SWATDRAIN was run for 7 BMPs. The average annual water balance for the 10-year simulation period under different BMP scenarios is presented in Figure 4. Seasonal simulation results of sediment load under different BMP scenarios are presented in Figure5.

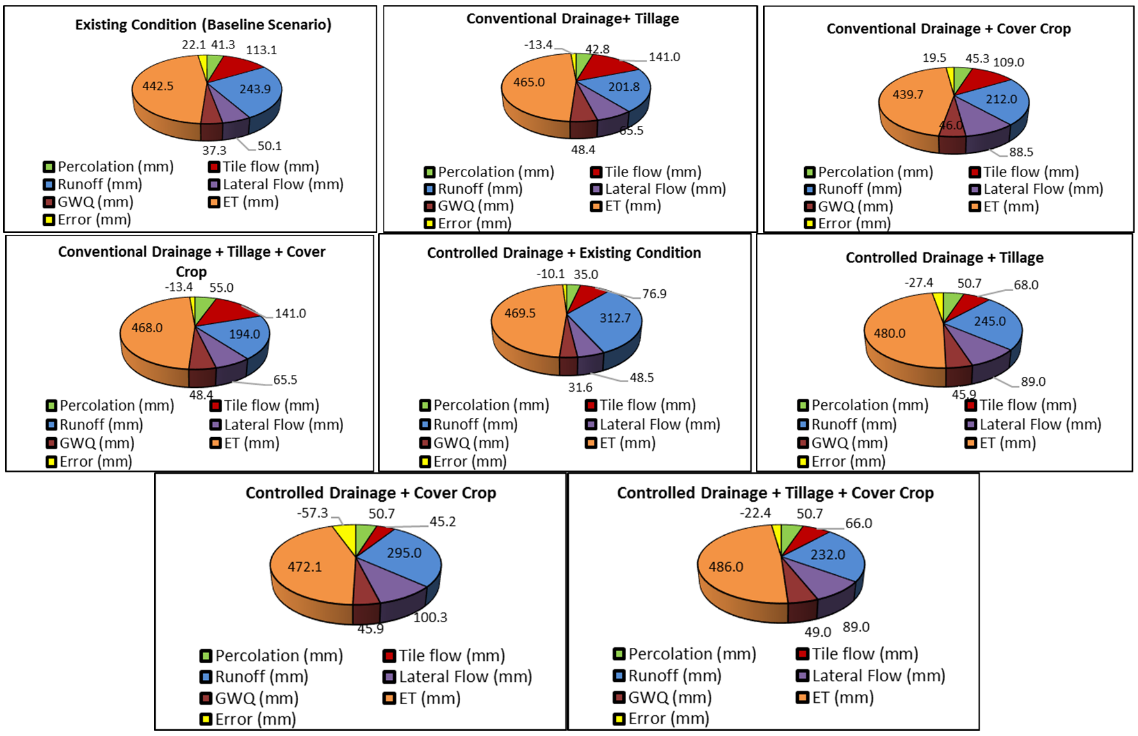

Figure 4. Annual water balance for the Canagagigue Watershed under different BMP Scenarios (negative values represent errors in water balance simulated by the SWATDRAIN model)

Amongst the three different land management practices of controlled drainage, conservation tillage and cover crops, the scenario of conservation tillage was ranked the highest to reduce sediment loads, which is mainly due to its ability at controlling rill and inter-rill erosion. The SWATDRAIN model estimated the red clover cover crop after winter wheat ranked second in terms of sediment load reductions.

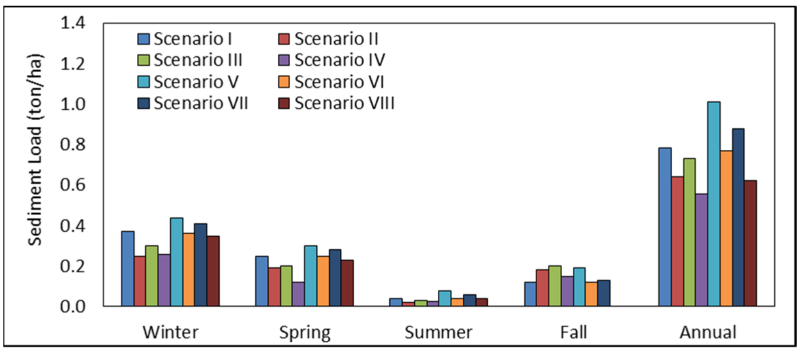

Figure 5. Sediment loads for the Canagagigue Watershed under different BMP Scenarios

3.3 Climate Change

Streamflow: The climate change impacts on hydrology of subsurface drainage was evaluated by running the SWATDRAIN model for climate data from 1985-2014 (historical) and 2014-2044 (future). The average monthly and seasonal stream flows are presented in Figure 6. These data show that, in future, the streamflow would decrease significantly in March and increase in January and May. These results also show that the highest monthly total streamflow for the historical period was in March, whilst for the future period, the highest monthly flow would potentially occur in April. This might be explained by the fact that the projected precipitation for winter was less than the historical records. In addition, increased temperature may cause faster snowmelt throughout the winter not only in March, but also during the months of January and February, resulting in reduced flows in March. In addition, the precipitation plays more important role on streamflow generation in winter and spring months. The highest flow peaks may shift to April due to high precipitation and low evapotranspiration. In future, due to climate change, evapotranspiration may also be expected to increase and thus the total water yield may decrease significantly. This shows a severe loss of usable water resource in future years. The increase in streamflow during winter and early spring periods are mainly due to an increase in minimum daily temperatures as well as changes in precipitation regimes from snowfall to rainfall these periods. Table 1 shows the changes in snowmelt between the historical and future periods. Overall, the average future snowmelt is expected to decrease due to decrease in total precipitation and snowfall, which accounts for 11.08% of the total precipitation during historical period and 7.68% during the future years.

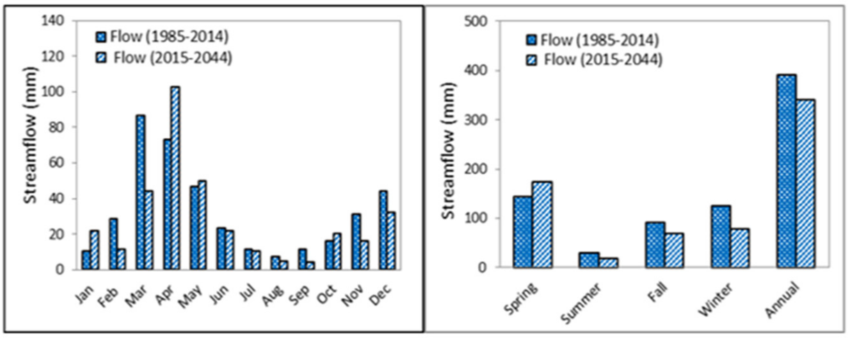

Figure 6. Historical and future simulated monthly and seasonal streamflow (Adopted from Golmohammadi et al., 2017c)

Table 1. Water Balance Components for Historical (1985-2014) and Future (2015-2044)

Component	Historical		Future	
	Value (mm)	%	Value (mm)	(%)
Precipitation	975.8	100	937.0	100
ET	475.3	48.70	525.5	56.08
Stream Flow	392.4	40.21	339.5	36.23
Base Flow	143.4	14.69	152.8	16.30
Snowmelt	108.1	11.08	72	7.68

Sediment loads: The impact of changes in hydrology on sediment loads in the Canagagigue Watershed were also assessed using the SWATDRAIN model. The average monthly and seasonal sediment loads during the historical and the future periods are given in Figure 8. From the figure, it can be seen that, in future, the month of April may be the only month with high sediment loads. Decrease of sediment in March could mainly be caused by the

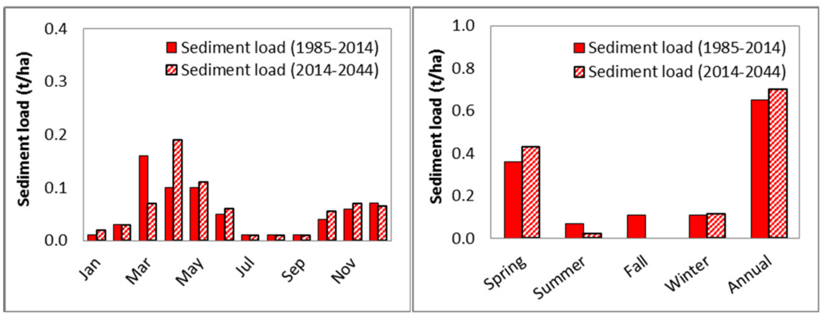

Figure 7. Historical and future simulated monthly and seasonal sediment loads (Adopted from Golmohammadi et al., 2017c)

significant decrease in streamflow during this month. In terms of seasons, spring is the only season with high sediment yields.

4. CONCLUSIONS

SWATDRAIN model was run from 1975 to 1984 under the existing climate and land management conditions. The simulated water balance results showed that, on the long-term, stream flow, surface runoff, tile flow and lateral flows are about 47%. 26%, 12%, and 5% of the average annual precipitation, respectively. The average annual evapotranspiration is about 47% of the total annual precipitation and the input to ground water is about 4%. Between the three different land management practices (controlled drainage, conservation tillage, and cover crop) conservation tillage was found as the best management practice to reduce sediment yields. The red clover cover crop, after winter wheat, ranked the second best for sediment loads reduction. In future years, the month of April would produce the highest streamflow and sediments losses while the overall precipitation would decrease in future.

REFERENCES

Daggupati, P., N. Pai, S. Ale, K.R. Doulgas-Mankin, R. Zeckoski, J. Jeong, P. Parajuli, D. Saraswat, and M. Youssef (2015). A recommended calibration and validation strategies for hydrological and water quality models. Transactions of ASABE. 58 (6), 1705-1719. doi: http://dx.doi.org/10.13031/trans.58.10712.

Golmohammadi, G., R.P. Rudra, P.K. Goel, S.O. Prasher and A. Madani. (2016a). Assessing the Impacts of Tillage Practices on Water Table Depth, Drain Outflow and Nitrogen Loss under Future Climate Patterns in Eastern Ontario, Canada. Journal of Computers and Electronics in Agriculture. 124(2016)73-83.

Golmohammadi, G., R.P. Rudra, S. O. Prasher, A. Madani, P.K. Goel, and K. Mohammadi (2016b). Effect of Controlled Drainage on Watershed Hydrology. Arabian Journal of Geosciences. 9(582), 3-7.

Golmohammadi, G., S.O. Prasher, A. Madani, R.P. Rudra and M. Youssef. (2016c). SWATDRAIN, a New Model to Simulate the Hydrology of Agricultural Lands, Model Development and Evaluation. Journal of Biosystems Engineering. 141(1): 31-47.

Golmohammadi, G., R.P. Rudra, T. Dickinson, P.K. Goel, M. Veliz. (2017a). Predicting the Temporal Variation of Flow Contributing Areas Using SWAT. Journal of Hydrology. 547 (2017) 375-386.

Golmohammadi, G., S.O. Prasher, R.P. Rudra, A. Madani, M. Youssef, K. Mohammadi and P. Goel. (2017b). Impact of Tile Drainage on Water Budget and Spatial Distribution of Sediment Generating Areas in an Agricultural Watershed. Journal of Agricultural Water Management. 184 (2017) 124-134.

Golmohammadi, R.P. Rudra, P.K. Goel, S.O. Prasher Madani, A., Goel., P.K., Mohammadi, K.., and P., Daggupati. (2017c). Water Budget in a Tile Drained Watershed Under Future Climate Change using SWATDRAIN Model. Climate Journal. 5(39):1-12.

Grady, C.A., Reimer, A, Frankenberger, J, and L.S. Prokopy. (2013). Locating Existing Best Management Practices within a Watershed: The Value of Multiple Methods. Journal of American Water Resources Association.

Hotchkiss, R. H., Jorgensen, S. F., Stone, M. C., & Fontaine, T. A. (2000). Regulated river modeling for climate change impact assessment: The Missouri River. JAWRA Journal of the American Water Resources Association, 36(2), 375-386.

Panagopoulos, Y., Makropoulos, C., and Mimikou, M. (2014). "Decision support for agricultural water management." Global NEST J. 4(3), 255–263.

Rong Hu. and R P Rudra (2009). Water Quality Evaluation under Climate Change Impacts for Canagagigue Creek Watershed in Southern Ontario, Master of Applied Science thesis, University of Guelph, Ontario, Canada.

Rosenberg, D. M., McCully, P., & Pringle, C. M. (2000). Global-scale environmental effects of hydrological alterations: introduction. BioScience, 50(9), 746-751.

Skaggs, R.W., L.G. Wells, and S.R. Ghate. (1978). Predicted and measured drainable porosities for field soils. Transactions of the ASAE. 21(3): 522-528.

Stonefelt, M. D., Fontaine, T. A., & Hotchkiss, R. H. (2000). Impacts of climate change on water yield in the upper Wind River basin. JAWRA Journal of the American Water Resources Association, 36(2), 321-336.

Wollmuth, J. and J. Eheart (2000). Surface Water Withdrawal Allocation and Trading Systems for Traditionally Riparlan Areas. American Water Resources Association, 36(2), 293-303.