ASSESING THE WATER QUALITY TRADING RATIO IN THE NORTH BOSQUE WATERSHED AS AN ALTERNATIVE OF MAINTAINING WATER QUALITY

FADHLIANI
Jurusan Teknik Sipil, Universitas Malikussaleh

ABSTRACT

Water quality standard is defined by the level of environment absorptive capacity of pollutants. Total Maximum Daily Load (TMDL) is a program to maintain the water quality in the impaired river segments. Using the Soil Water Assessment Tool (SWAT). The study objective is to assess the possibilities of water quality trading, within the North Bosque Watershed, in term of trading ratios. The model simulation result was not very satisfying, where the calibration of the PO_4 has a very high error. For the soluble phosphorus trading, the model cannot be used as the only tool in defining the trading ratio.

Keywords: ***Water Quality, Total Maximum Daily Load (Tmdl), Trading Ratio***

INTRODUCTION

The North Bosque Watershed (NBW) consists of segment 1226, the North Bosque River, and segment 1255, the Upper North Bosque River. The segments are enlisted in the Texas Clean Water Act (CWA) Section 303(d) List as being impaired, which identifies the insufficient achievement of water quality standard. It implies that water quality standard is defined by the level of environment absorptive capacity of pollutants. One of the concerning pollutant parameters is nutrient as it is being contributed enormously by a Waste Water Treatment Plant (WWTP) discharges as Point Source (PS) and dairies/croplands areas run off as Non Point Source (NPS).

The nutrients, phosphorous and nitrogen, of PS can be managed on-site at each plant by controlling the pollutant's level allowed to be discharged also known as Permit Compliance System (PCS). Meanwhile managing the impact of NPS where the pollutant distributed within the watershed is somehow difficult. The amount of nutrient in the streams, which affects the water quality, however is both from PS and NPS. The state of Texas, under the Texas Commission on Environmental Quality (TCEQ) and the Texas State Soil and Water Conservation Board (TSSWCB), maintains the water quality in the impaired river segments by implementing the Total Maximum Daily Load (TMDL) Program.

The TMDL not only defines the limit level of pollutant received by the streams or water bodies but also allocates the allowable pollutant discharged by PS and NPS within the watershed. Implementing the pollutant allocation between PS and NPS based on the TMDL program in order to maintain the water quality is plagued by the pollutant level uncertainty from the NPS that the pollutant is spatially distributed. The well-known method in assessing the NPS/PS pollutant distribution is a watershed modeling. By modeling, the condition of watershed can be easily analyzed and predicted. However, since a model does not fully represent the detail characteristic of what being modeled, in this case watershed, the best way to solve uncertainties in modeling is calibration. The model being used in this study is Soil Water Assessment Tool (SWAT), which developed by the United States Department of Agriculture–Agricultural Research Service (USDA–ARS).

Another concerning issue aside from the limit level of pollutant and the type of pollutant in water system is to find the most cost effective approach in maintaining water quality since the increasing population has driven the amount of the pollutants being added into the water bodies. In the past several years the water community has been analyzing the issue from the market based point of view, which is Water Quality (WQ) trading that believed to be the most cost effective. The market is defined similarly to a regular market where the exchange for buying and selling commodities occurs. The credit of pollutant is treated as the commodity while the stakeholders or the PS/NPS producers within the watershed act as the buyer and the seller. The key factors of the market are: the type of pollutant, demand/ supply-the willingness of the stakeholders to enter the market, and the regulations.

Ignoring the regulation and the stakeholders' willingness factors, this study objective is to assess the possibilities of water quality trading, within the NBW, in term of trading ratios. The watershed model, SWAT built in BASINS 3.1, is used to measure the pollutant distribution within the watershed, which the type of pollutant to be assessed is soluble phosphorous and TMDL to be used as the cap value.

METHODOLOGY

The watershed is delineated based on the DEM with resolution 30 meter, NHD and USGS/TIAER Station the outlet. Two conditions of delineating the watershed are conducted. First condition is Watershed1 where the outlet selected at TIAER Sta. 11956 or at USGS Sta. 08095000 (Figure 2). Second condition is Watershed2 where the outlet selected at TIAER Sta.11950 (Figure 3).

The model is calibrated using the Watershed1 condition and the simulation is conducted from January 1990 to December 2003. The stream flow is calibrated from year 1991 to 2003, as year 1990 is assumed as the warming up stage of model simulation. The measured data of the stream flow is acquired from USGS Sta. 08095000. The PO_4 is calibrated from May 1997 to June 2002. The monitoring data of PO_4 is acquired from TIAER Sta. 11956. The calibration result is assumed to be reasonably justified the next simulation study of the Watershed2.

The TMDL value to be used for the cap is defined as a 50% reduced of the condition of mid-1990s, which is also estimated from the simulation result not from the monitoring data. The reason for that is because the simulation result highly bias to the monitoring data. Therefore, the analysis is conducted within the same condition. In this study the TMDL values is based on the simulation result by averaging the PO_4 values from 1995 to 1998.

For analyzing the trading scenario three year conditions are to be analyzed which are 1999, 2001 and 2003 since the simulation were conducted only up to 2003. Moreover, since the TMDL condition is based on simulation year 1995 to 1998, it would be useless to assess the condition of the previous year to that. The three year results are assumed to represent the other two years, 2000 and 2002, that being canceled out from the analysis. The simulation is conducted in monthly period.

However the pollutant trading analysis is conducted based on the annual value since the monthly simulation results are quite erratic. This condition also reported by TNRCC, 2001, where the SWAT was also used for the model simulation.

"If plotted directly, the raw model output produces a time series of SRP (Soluble Reactive Phosphorus - PO_4) that reflect temporal variability, which appears erratic and very difficult to interpret. So, review of model output focused on predicted annual average-SRP concentration." (TNRCC, 2001)

In addition, the PO_4 calibration in this study is very unsatisfying, but since the analysis is comparing the TMDL value and the year 1999, 2001 and 2003 values from the same simulation result, the study somehow is still reasonable.

Having the discharges data from six WWTP as a point inlet by converting the annual condition to constant daily is somehow indefinite. Therefore the PS is canceled out from the trading network. NPS is the only party to be addressed in this study. What meant by NPS here is actually the sub basins. The result simulation at every sub basin outlet along the segment 1255 and 1226 (Figure 4) is defined as the discharged pollutant from the related sub basins into the stream.

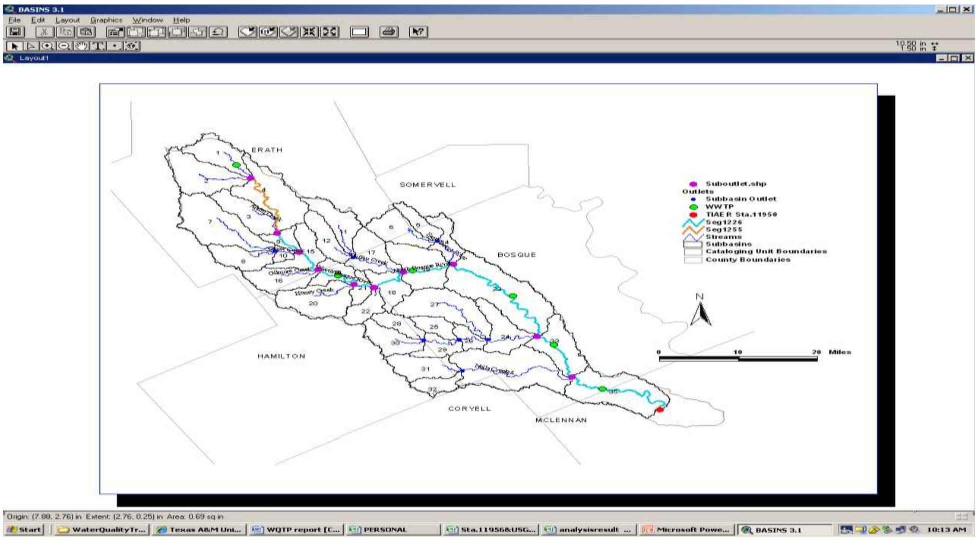

Figure 4. Subbasin outlet along the impaired river segments 1226 and 1255

MODEL

The SWAT in BASINS version 3.1 will be used in this study in developing the watershed model. SWAT is developed by the United States Department of Agriculture–Agricultural Research Service (USDA–ARS) as a tool to model watershed. The BASINS, which stand for Better Assessment Science Integrating Point and Non-point Sources, is a multi-purpose environmental analysis system that integrates a geographical information system (GIS), national watershed data, and state-of-the-art environmental assessment and modeling tools into one convenient package (EPA, 2007).

BASINS allows the user to prepare input data for SWAT by acquiring GIS data and databases using the data extraction tool in BASINS. The BASINS provides statewide data. Hence, for studying a small watershed, it is recommended to obtain data from reliable sources for a smaller scale.

Input Dataset

All the input datasets were downloaded directly from the BASINS Interface but land use and weather data. The National Elevation Dataset (NED) which was the Digital Elevation Model (DEM) with 30 m resolution was used. Derived from BASINS, the NED came in elevation's scale of centimeter. National Hydrography Dataset (NHD) was downloaded and prepared properly by BASINS directly from USGS website.

Geographic Information Retrieval and Analysis System (GIRAS land use) acquired from EPA website, http://www.epa.gov/waterscience/ftp/basins/gis_data/huc/12060204/12060204_giras.exe. Soil data was from BASINS databases, State Soil Geographic (STATSGO) dominant soil phase. Collected in 1- by 2-degree topographic quadrangle units and merged and distributed as statewide coverage. The STATSGO data set was developed by the National Cooperative Soil Survey (NCSS). The Hydrologic Response Unit (HRU), the land use-soil dominant combination, was defined as 10% dominant soil and 5% dominant land use.

The management condition of the watershed was generalized by defining autofertilization of dairy fresh manure and autoirrigation for land use type AGRL (Agriculture) applied to all sub basins for the initial simulation. The initial value of nutrient in soil was taken from Steward et al. 2006, which shown in Table 1.

Table 1. Initial soil nutrient concentrations from Steward, 2006 from Santhi, 2001

Land use	Nutrient	mg/Kg
Waste application fields	Organic N	5,000
	Organic P	700
	Mineral P	250
Pasture/range land	Organic N	850
	Organic P	150
	Mineral P	5
Agricultural	Organic N	1100
	Organic P	200
	Mineral P	20
Urban	Organic N	2,000
	Organic P	400
	Mineral P	5

In this study, the waste application field was neglected since the application of dairy fresh manure was assumed applied for the entire watershed of AGRL land use.

The weather data, precipitation and temperature, were obtained from 11 rain gauge stations within and around the watershed. Data should be available from the National Climatic Data Center (NCDC).

Monthly stream flow data at Sta. 08095000 was acquired from USGS website while water quality data, PO_4 at TIAER Sta. 11956 was downloaded from http://wqweb.brazos.org/. The measured data from monitoring stations were used for the model calibration.

Of point sources in the watershed only four of WWTP, Stephenville, Hico, Iredell and Meridian, were included in the calibrated Watershed1 simulation. In addition to the four WWTP, Clifton and Valley Mills also included in the study simulation of Watershed2. The annual data of flow and nutrient loading of the WWTP based on data from November 1995 to March 1998 of TIAER PR 9911 report by McFarland and Hauck, 1999 (Table 2). Converted to constant daily value as point discharges input for SWAT the data is shown in Table 3.

Table 2. Calculated WWTP nutrient loadings for November 1 1995 through March 30, 1998 prorated to an annual basis

Site WWTP	Flow (ft3/yr)	PO4-P (lbs/yr)	TP (lbs/yr)	TN (lbs/yr)
Stephenville	86,356,413	11,523	14,381	37,542
Hico	3,929,640	658	751	2,872
Iredell	1,224,213	209	1,318	365
Meridian	9,252,524	1,468	1,763	10,214
Clifton	14,936,658	1,621	2,191	7,735
Valley Mills	4,569,215	710	793	4,820

Table 3. Constant daily WWTP nutrient loadings

Site WWTP	Flow (m3)	PO4-P (kg)	TP (kg)	TN (kg)
Stephenville	6,699.565	14.320	17.872	46.654
Hico	304.863	0.818	0.933	3.569
Iredell	94.975	0.260	1.638	0.454
Meridian	717.815	1.824	2.191	12.693
Clifton	1,158.792	2.014	2.723	9.612
Valley Mills	354.482	0.882	0.985	5.990

Calibration Watershed1

The model was calibrated in order to get a reliable result from the simulation. For this purpose the watershed was delineated by defining USGS Sta. 08095000 or TIAER Sta. 11956 as the outlet. The author assumed that the calibrated model condition would justify for simulating the NBW whose outlet at TIAER Sta. 11950. The reason of having the outlet at that particular station for calibration was the availability of measured and monitoring data.

The model was simulated for monthly condition from year 1990 to 2003. The stream flow was calibrated from year 1991 to 2003, year 1990 was assumed to be the warming up phase of the simulation, using the Nash-Sutcliffe Method. The Nash-Sutcliffe formula is,

$$R^2 = 1 - [\ \Sigma(Qm - Qp)^2\ ] \ / \ [\Sigma(Qm - Qavg)^2\ ]$$

Where R^2 = coefficient of efficiency, $0.5 < R^2 \leq 1$ considered as a good model; Qm = measure value (m^3/s); Qp = predicted value (m^3/s); Qavg = average measured value (m^3/s), (Munster, 2007). The R^2 identifies the best fit of the simulation value to the measured value.

In this case, the R^2 for stream flow calibration was 0.75. Some parameters were adjusted during the calibration in order to have the model as fit as possible to the real condition of the watershed. The adjusted parameters were generalized by applying them to all sub basins. To reduce the surface flow, three parameters were adjusted; the Curve Number (CN) was reduced by 8 points, soil available water (SOL_AWC in.sol) was increased by 0.05 points, soil evaporation compensation factor (ESCO in *.bsn) was decreased by 50%.

To increase the evaporation and to reduce the base flow, three parameters were adjusted as well. Threshold depth of water in shallow aquifer (GWQMN in .gw) was increased by 90%, groundwater re-evaporation coefficient (GW_REVAP in.gw) was also increased by 90%, while the threshold depth of water in shallow aquifer for re-evaporation to occur (REVAPMN in.gw) was decreased by 90%. Aside from the adjusted parameters, the channel routing used was Muskingum and the evapotranspiration method used was Penman-Montieth.

Using the same method, the R^2 coefficient for the PO_4 was -14.761. Most likely it happened because not much of the real watershed conditions were captured in the simulation model, for instance the WWTP discharges, which were converted to constant daily condition based on the average annual data of year 1995 to 1998. Some extreme adjustments were taken for this calibration. The initial nutrients in soil were reduced by 100%. The WWTP discharges nutrients load were reduced by 10% for all the six plants.

The monthly result of the simulated PO_4 was quite erratic, Figure 5, which was also reported in the TNRCC report.

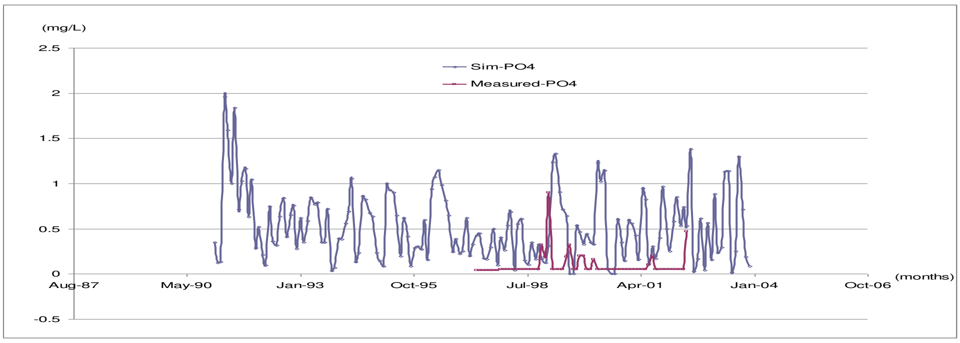

Figure 5. Calibrated simulated PO_4 vs. TIAER measured PO_4Despite the unsatisfying PO_4 calibration, the author decided to keep continuing the analysis on the PO_4 trading option in term of annual concentration of PO_4.

Simulation Watershed2

Watershed2 was simulated based on the calibrated condition of the Watershed1. Since the WWTP as the PS had been canceled out from the trading scenario, the only condition to assess was the NPS. For that purpose, eleven subbasin outlets along the impaired stream segments were selected.

The simulated PO_4 for each outlet was produced by the upstream subbasins of the outlet.

The model was also simulated for monthly condition from year 1990 to 2003. The simulation results of year 1995 to year 1998 were defined as the TMDL scenario. The result for each outlet was a total PO_4 produce by the upstream subbasins, for instance the PO_4 at Outlet 1 is a total value of PO_4 of subbasin1 and subbasin2. The results at each outlet was then reduced by 50% and averaged out to annual value in Kg/year. Simulated PO_4 results of year 1999, 2001 and 2003 were to compare with the TMDL condition.

SUMMERY AND RESULT

The simulated PO_4 of Year 1999 is below the TMDL limit. The annual precipitation of year 1999, 2001 and 2003 from some stations does convince that less precipitation occurred in year 1999. It is most likely affect the simulated PO_4 of year 1999 since less precipitation means less run off, which also means less phosphorus being transported or distributed.

The trading network is developed for year 2001 and 2003, shown in Figure 6. The outlets are now defined as the discharger (D). D1, D2, and D3 are colored green as the PO_4 level discharged into the stream is not alarming; the level is less than the TMDL requirement. D4 to D11 are colored red as the condition is very alarming where the PO_4 discharged into stream is over the TMDL limit. The loading profile of discharger is presented in Table 4.

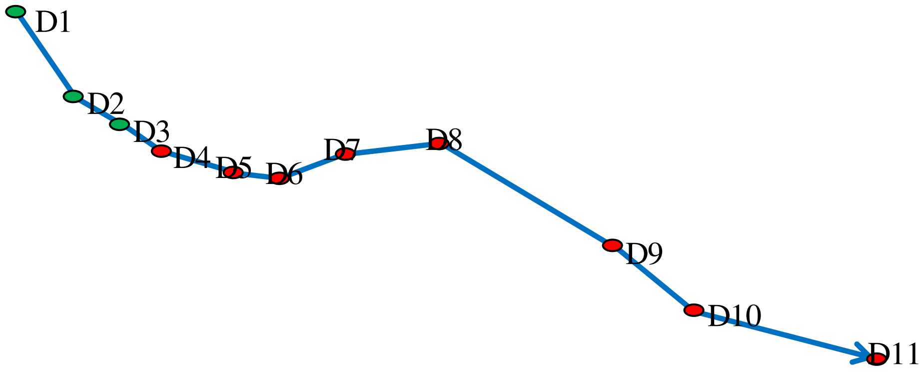

Figure 6. Subbasins trading network

Table 4. PO_4 loading profiles

Discharger (Outlet)	PO_4- TMDL (Kg/yr)	Distance from the upstream outlet (mi)	PO_4- produced		PO_4- to be reduced	
			2001 (Kg/yr)	2003 (Kg/yr)	2001 (Kg/yr)	2003 (Kg/yr)
D1	1,645.55	7.96	1,661.07	940.40	15.52	-705.14
D2	2,138.29	16.43	2,038.40	1,895.09	-99.90	-243.21
D3	2,745.02	5.70	2,742.15	1,157.78	-2.87	-1,587.23
D4	1,105.50	5.32	1,309.62	1,391.82	204.12	286.32
D5	1,179.92	7.76	1,687.89	2,467.49	507.97	1,287.56
D6	664.87	7.95	1,017.66	1,441.58	352.79	776.71
D7	2,091.31	6.70	2,827.97	4,360.41	736.67	2,269.10
D8	1,948.01	3.38	2,550.40	3,487.30	602.39	1,539.29
D9	5,647.73	27.55	10,141.52	13,786.06	4,493.79	8,138.33
D10	2,724.49	11.01	5,851.84	5,731.27	3,127.35	3,006.78
D11	1,647.88	22.28	4,334.21	3,184.61	2,686.34	1,536.74

In this case study, neglecting the complexities condition of PO_4 between seller and buyer and assuming the distance factor only, the ratio result is shown in Table 5.

The ratio was analyzed in downstream trading condition in order to avoid the occurrence of hot spot, where a very high level of PO_4 occurred at one point of the stream. For this condition, the seller can only be the one in the upstream. Assuming by 5 miles distance the buyer and seller can make up trading ratio 1:1, which indicates that for every 1 unit PO_4 reduced by the upstream discharger 1 unit PO_4 reduced will be achieved by the point downstream within 5 miles distance.

Table 5. Downstream trading ratio, assuming 1 unit PO_4 reduced by 5 miles

Outlet	1	2	3	4	5	6	7	8	9	10	11
1	1.00	0.30	0.23	0.18	0.14	0.12	0.10	0.09	0.06	0.05	0.04
2	0.30	1.00	0.88	0.45	0.27	0.19	0.15	0.14	0.08	0.07	0.05
3	0.23	0.88	1.00	0.94	0.38	0.24	0.18	0.16	0.09	0.07	0.05
4	0.18	0.45	0.94	1.00	0.64	0.32	0.22	0.19	0.09	0.08	0.06
5	0.14	0.27	0.38	0.64	1.00	0.63	0.34	0.28	0.11	0.09	0.06
6	0.12	0.19	0.24	0.32	0.63	1.00	0.75	0.50	0.13	0.10	0.07
7	0.10	0.15	0.18	0.22	0.34	0.75	1.00	1.00	0.16	0.12	0.08
8	0.09	0.14	0.16	0.19	0.28	0.50	1.00	1.00	0.18	0.13	0.08
9	0.06	0.08	0.09	0.09	0.11	0.13	0.16	0.18	1.00	0.45	0.15
10	0.05	0.07	0.07	0.08	0.09	0.10	0.12	0.13	0.45	1.00	0.22
11	0.04	0.05	0.05	0.06	0.06	0.07	0.08	0.08	0.15	0.22	1.00

D7 and D8 are just 3.38 miles apart, therefore the reductions of 1 unit PO_4 at D7 means reduction 1 unit PO_4 at D8. The trading ratio between D7 and D8 is 1:1. D8 and D9 however are 27.55 miles apart, therefore the reductions of 1 unit PO_4 at D8 means reduction only 0.18 units PO_4 at D9. The trading ratio between D8 and D9 is 1:0.18 or 50:9. In this second condition most likely the trading option will be even more expensive than upgrading the management system by D9. The trading ratios of all dischargers are shown in Table 5. Overall, the trading ratios less than 3:1 are likely to benefit the traders.

CONCLUSION

In this study the author concludes that the model simulation result was not very satisfying, where the calibration of the PO_4 has a very high error. For the soluble phosphorus trading, the model can not be used as the only tool in defining the trading ratio. The monitoring and water quality data have to be included as well. The model however is very useful in simulating changes in the system. The model calibration is also a very important part in any modeling studies. Uncalibrated model should not be used for simulating and interpreting any modeling studies.

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