SECTION 6
APPLICATION OF THE CEEOT MODEL TO ALBERTA WATERSHEDS

6.1 Introduction

Activities for the third year of applying the Comprehensive Economic and Environmental Optimization Tool (CEEOT) were completed by Alberta Agriculture and Rural Development (ARD) in collaboration with the Texas Institute for Applied Environmental Research (TIAER). The CEEOT model is a computer program that enables interfacing the Soil and Water Assessment Tool (SWAT), Agricultural Policy/Environmental eXtender (APEX), and Farm-level Economic Model (FEM) programs. The environmental modelling portion of CEEOT is SWAPP, which is a modelling system that links SWAT and APEX. A more detailed explanation of CEEOT is in Olson and Kalischuk (2009).

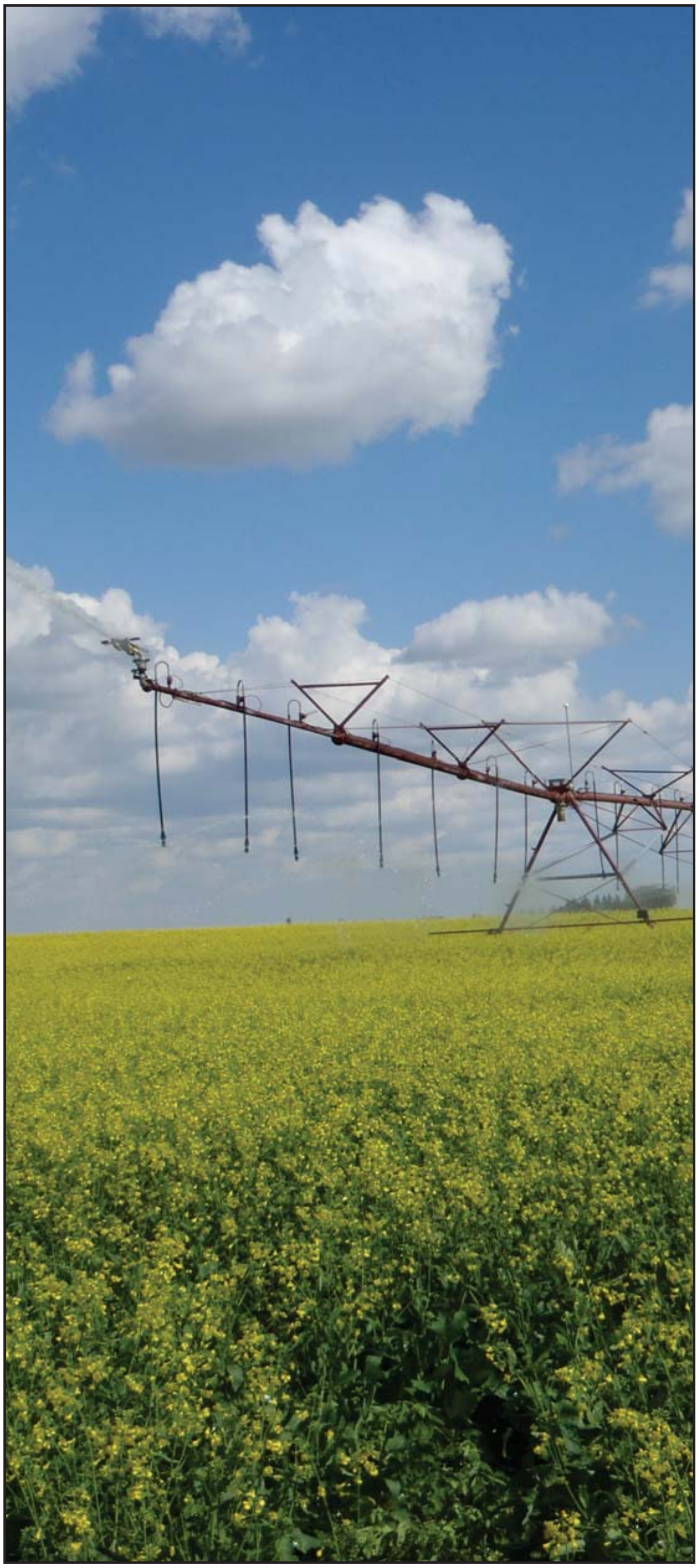
In 2010, efforts were directed towards (1) verifying the quality of the 2007 to 2009 input data; (2) improving SWAPP calibrations for stream flow, TSS loadings, and nutrient loadings; (3) preparing the pre-beneficial management practice (BMP) (base line) and the post-BMP simulation scenarios; and (4) evaluating the environmental and economic effects of implementing BMPs. These activities were applied to the Indianfarm Creek (IFC) Watershed, Whelp Creek (WHC) Sub-watershed, Battersea Drain Field (BDF) site, and Lower Little Bow River Field (LLB) site. In addition, datasets were developed to work towards calibrating flow in the Red Deer River (RDR) and its tributaries.

6.2 Nutrient Beneficial Management Practices Evaluation Project Activities

6.2.1 SWAPP Model Calibration

6.2.1.1 Background

The SWAPP stream flow calibrations for IFC and WHC were initiated in 2009 (Olson and Kalischuk 2010) and continued in 2010. Calibrations were also STARTED for BDF and



LLB in 2010. In general, measured and modelled flow compared well at main channel stations for IFC; however, SWAPP flow predictions needed improvement for WHC and some field stations in IFC. The focus in 2010 was on the (1) evaluation and analysis of measured datasets at all the sampling stations in IFC and WHC, (2) improvement of flow calibrations at the field stations and main channel stations in IFC and WHC, (3) investigation of SWAPP to predict flow at the two irrigated field sites (BDF and LLB), and (4) calibration of IFC, WHC, BDF, and LLB loadings of total suspended solids (TSS) and nutrients, such as nitrate nitrogen (NO_3-N), phosphate phosphorus or orthophosphate (PO_4-P), organic nitrogen (ON), organic phosphorus (OP), total nitrogen (TN), and total phosphorus (TP).

It is important to note that in contrast to the water monitoring data, SWAPP splits phosphorus (P) into PO_4-P and OP fractions, and nitrogen (N) into NO_3-N and ON fractions. The PO_4-P and NO_3-N fractions are water soluble and OP and ON fractions are sediment bond. In SWAPP calibration, the PO_4-P and OP fractions are assumed to be equivalent to TDP and PP fractions, respectively, reported in Sections 2, 3, 4, and 5 of this report.

The 2010 calibrations were conducted on a daily basis from 2000 to 2009 for IFC, BDF, and LLB, and from 2002 to 2009 for WHC. Data from 2010 were not included. The first 7 yr (2000 to 2006) and 6 yr (2002 to 2007) of simulations were considered as an equilibration period for the model. With few exceptions, the last 3 yr (2007 to 2009) of simulations were used for assessing model performance for IFC, and the last 2 yr (2008 to 2009) were used for BDF, LLB, and WHC. A few BMP sites were actually implemented at different times (e.g., the Wintering site was implemented in 2009), and these were reflected in the model calibration exercises. The 2007 irrigation volumes were not measured at the irrigation sites, and therefore, 2007 was not used in the calibration process at the BDF and LLB sites.

To calibrate the model appropriately, the same pre- and post-BMP management situations needed to be reflected in the model. The calibration process results in a set of parameters and assumptions that are collectively referred to as the environmental base line or calibration base line. Once calibration is completed, the model is ready for use in scenario simulations. To facilitate scenario comparisons, another base line is defined, which is referred to as the scenario base line or policy base line. The scenario base line in this study is strictly the pre-BMP situation in both watersheds. A BMP scenario, which is essentially the post-BMP situation for each field in both watersheds, has also been defined and simulated in CEEOT.

Annual precipitation was well below the 30-yr average at IFC, BDF and LLB, and well above average at WHC in 2007 (Table 6.1; Environment Canada 2011). In 2008, the annual precipitation was well above average at IFC, BDF, and LLB, and WHC was well below the average annual total. Precipitation was above normal at IFC, BDF, and LLB in 2009; whereas, WHC was still well below the 30-yr average.

For model calibrations in 2010, the 2009 land management, crop growth, and soil data were reviewed and some errors were identified. Most of the errors were found in the land management files and were addressed by correcting farm operation schedules, manure and fertilizer application rates, livestock stocking rates, and the type of crop rotations. At some field sites, SWAPP underestimated crop biomass because the depth of some soil types restricted root growth. After checking that the bedrock was not near the soil surface (i.e., within 2 m) for these soil types (Tony Brierley 2010, personal communication, Agriculture and Agri-Food Canada, Edmonton, Alberta), the depth of the lowermost soil layer in the soil profiles was increased to greater than 1 m and the soil hydrologic group values were adjusted accordingly.

Table 6.1. Annual precipitation [z] at the Indianfarm Creek (IFC) Watershed, Whelp Creek (WHC) Sub-watershed, Battersea Drain Field (BDF) site, and Lower Little Bow River Field (LLB) site from 2007 to 2010.

Year	IFC	WHC	BDF and LLB
30-yr average	515	446	365
2007	327	517	255
2008	644	280	409
2009	544	295	387

[z] Precipitation values are from the nearest Environment Canada (2011) weather station.

In the IFC Watershed, nine sub-basins (Figure 6.1) were selected for the 2010 SWAPP calibration. Six of the sub-basins were the outlets of BMP sites (Stations 2, 4, 9, 15, 18, and 21). Two were located along the main creek (Stations 5 and 11) and one was the watershed outlet (Station 1). The observed maximum average monthly flow was 1.35 $m^3 s^{-1}$ at the watershed outlet. The maximum average monthly flow recorded at a primary tributary (Station 2) was 0.036 $m^3 s^{-1}$, and with the exception of Station 18 (maximum flow: 0.008 $m^3 s^{-1}$), the BMP field sites rarely exceed 0.002 $m^3 s^{-1}$. After the 2009 calibration, the SWAPP results at Stations 9 and 4 were unsatisfactory.

In the WHC Sub-watershed, the 2010 SWAPP calibrations were conducted for nine of 22 sub-basins (Figure 6.2). Six of them were the outlets of BMP sites (Stations 307, 309, 314, 318, 319, and 324) and one (Station 311) was within the North Field BMP site. One main tributary was located in Sub-basin 18 (Station 303) and the WHC outlet was located in Sub-basin 20 (Station 301). The observed maximum average monthly flow was 0.002 $m^3 s^{-1}$ at the field-scale stations and 0.043 $m^3 s^{-1}$ at the sub-watershed outlet. Last year, attempts were made to calibrate flows at Stations 304 and 305; however, calibration has ceased for these stations because the measured flow was likely inaccurate due to downstream water tending to backup at these sites.

6.2.1.2 Methods

Parameters that were considered to be sensitive for the water balance and TSS and nutrient loadings were selected for calibration (Table 6.2). Before each simulation, one or more of the parameters was adjusted manually, and then after running the model, the predicted average monthly flow and total monthly loads were compared with the measured values. To evaluate model predictions, the correlation coefficient (R^2) and the Nash and Sutcliffe coefficient (E) were calculated for flow and nutrient loads as described in Olson and Kalischuk (2010). An E value of one indicates perfect agreement between the observed and model predicted values. An E value of zero indicates that the predicted values are no better than the observed average. Furthermore, an E value less than zero indicate that the model predictions are worse than using the observed average. In this study, an E value of 0.6 or higher was considered indicative of a satisfactory calibration; however, it is expected that lower E values may be obtained based on the very low magnitude of flow, and TSS and nutrient loadings at the field scale.

In the SWAPP model, the user has the option of selecting land use categories that can be simulated either in SWAT or APEX. With the exception of farmstead areas, the majority of the land use categories was assigned to be simulated with APEX. The SWAT model was primarily used to route the APEX predicted flow, TSS, and nutrients through existing stream channels and reservoirs to the watershed outlet. The majority of the parameters selected for calibrations was included in the APEX files PARM0604.dat and the APEXCONT.dat. Most values selected for the SWAT

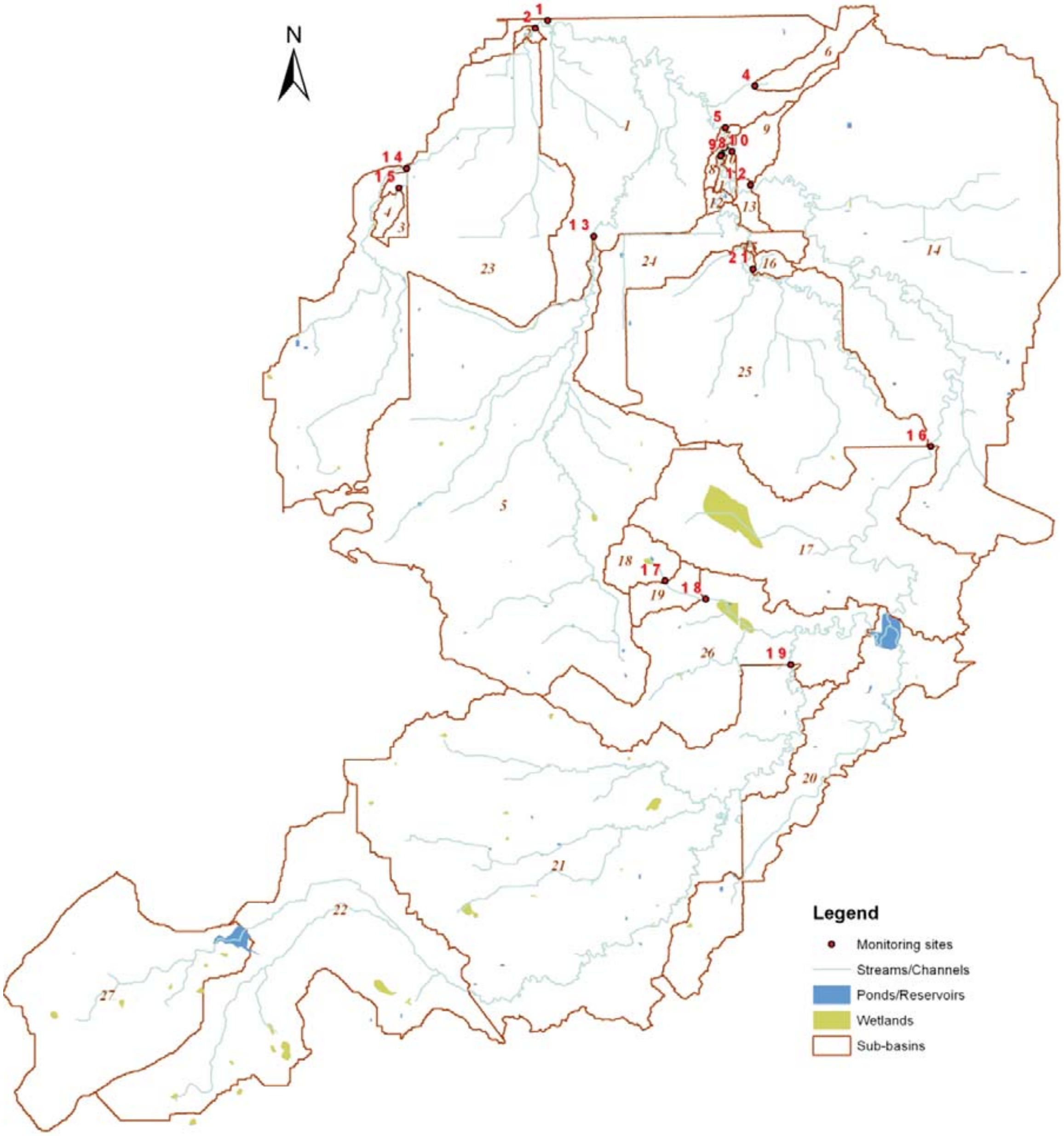


Figure 6.1. Water monitoring stations and sub-basins within the Indianfarm Creek Watershed.

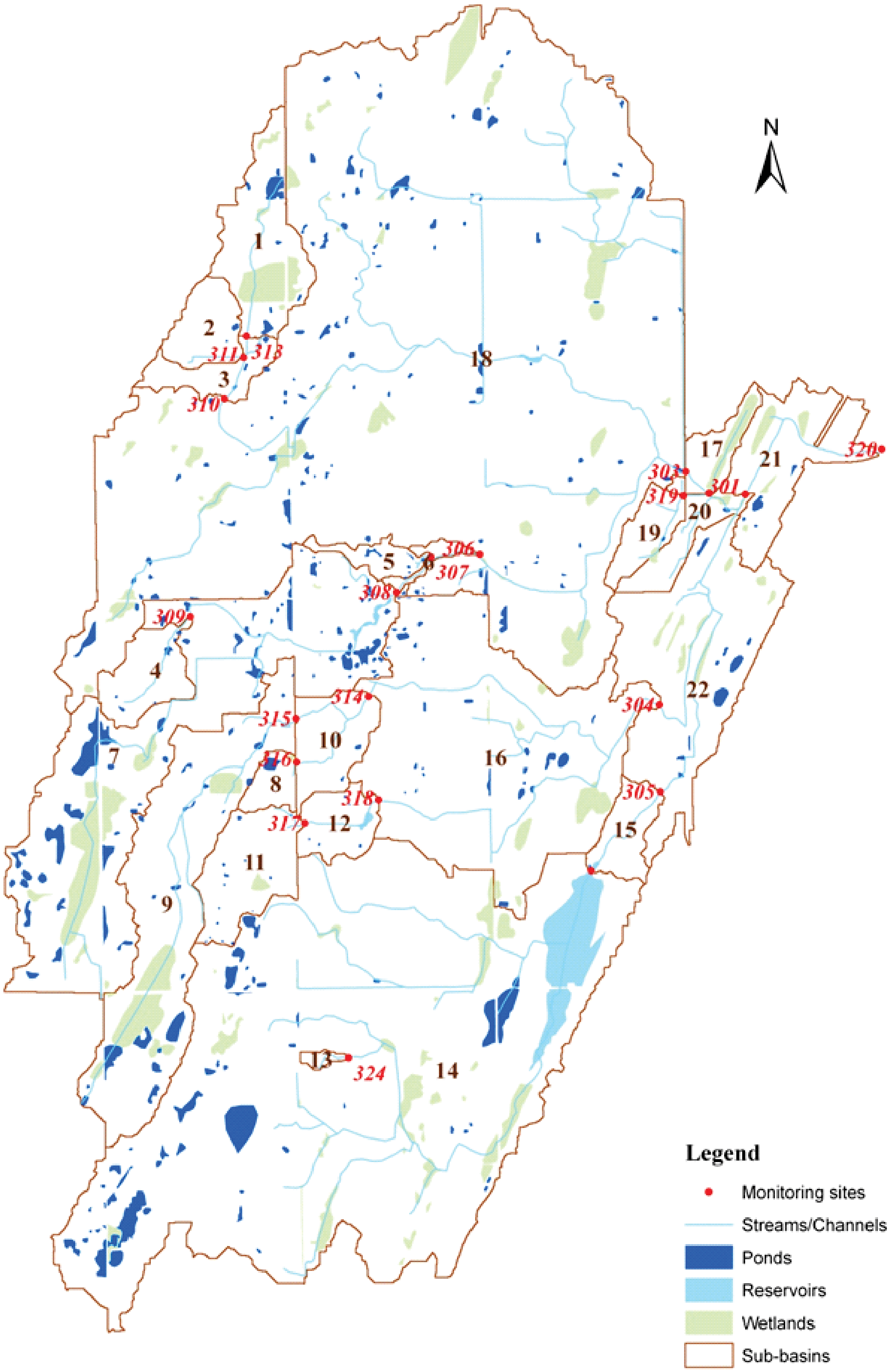


Figure 6.2. Water monitoring stations and sub-basins within the Whelp Creek Sub-watershed.

Table 6.2. Parameter values for APEX calibrations for the Indianfarm Creek (IFC) Watershed, Whelp Creek (WHC) Sub-watershed, and Lower Little Bow River Field (LLB) site.

Parameter	Range	IFC	WHC	LLB
Runoff curve number weighting factor	0.0 - 1.0	0.4	0.4	1.0
Curve number retention factor	1.0 - 1.5	1.5	1.0	1.5
Soil evaporation - plant cover factor	0.0 - 0.5	0.5	0.5	0.1
Runoff curve number initial abstraction	0.05 - 0.4	0.35	0.25	0.2
Runoff curve number for frozen soil	0.05 - 0.5	0.1	0.1	0.09
Rainfall intensity coefficient	0.0 - 2.0	0.5	1.0	1.5
Hargreaves PET[z] equation exponent	0.5 - 0.6	0.6	0.6	0.6
Groundwater storage threshold	0.001 - 1.0	1.0	1.0	0.5
Curve number index coefficient	0.5 - 1.5	0.5	0.8	1.5
Upper limit of curve number retention	1.0 - 2.0	2.0	1.2	1.5
Maximum canopy rainfall interception	2.0 - 15	2.0	10.0	2.0
Rainfall interception coefficient	0.05 - 0.3	0.3	0.3	0.1
Soil water tension factor	0.0 - 1.0	0.8	0.8	0.8
Snowmelt timing factor	10 - 20	20.0	16.0	12.0
Maximum groundwater storage	5 - 200	100.0	100.0	110.0
Groundwater residence time in days	0 - 365	30.0	30.0	30.0
Return flow	0.0 - 1.0	0.3	0.3	0.1
Potential evapotranspiration equation		B.-R.[y]	B.-R.	Hargreaves
Soil loss equation		RUSLE2[x]	MUSS[w]	MUSS[w]
TSS routing exponent	1 - 1.5	1.0	1.5	1.5
TSS routing coefficient	0.01 - 0.05	0.01	0.01	0.05
TSS routing travel time coefficient	0.5 - 10	3.0	3.0	3.0
RUSLE C-factor residue coefficient	0.5 - 1.5	1.1	1.0	1.4
RUSLE C-factor crop height coefficient	0.5 - 1.5	1.0	1.0	0.6
Water storage N leaching	0 - 1	0.7	0.6	0.5
Nitrate leaching ratio for surface runoff	0.1 - 1	0.5	0.2	0.5
Soluble phosphorus runoff exponent	1 - 1.5	1.4	1.4	1.3
Organic N and P transport exponent	1 - 1.2	1.2	1.0	1.0
Manure erosion equation coefficient	0.1 - 0.5	0.1	0.5	0.25
Manure erosion exponent	0.1 - 1.0	0.1	0.1	0.5
Manure erosion coefficient	1.0 - 1.5	1.5	1.5	1.0
Volatilisation/nitrification coefficient	0.05 - 0.5	0.5	0.5	0.05
Nitrate leaching ratio for return flow	0.01 - 0.05	0.05	0.05	0.01

[z] PET: Potential evapotranspiration.

[y] B.-R.: Baier-Robertson equation.

[x] RUSLE2: Modified revised universal soil loss equation.

[w] MUSS: Modified universal soil loss equation for small watersheds.

parameters in the 2009 calibrations were carried over to the 2010 calibrations without major changes (Olson and Kalischuk 2010). One exception was the SURLAG.bsn parameter for the IFC Watershed. The 2009 value was considered to be out of the recommended range of acceptable values and it was changed from 0.05 to 1.0. Table 6.2 includes a list of parameters that were calibrated, their acceptable range of values, and the values for IFC, WHC, and LLB.

The selection of these parameters was based on the sensitivity of these parameters on the model output. Initially, the default values were adjusted in order to match the APEX predicted flow, sediment, and nutrient values with the measured data. The parameter values shown in Table 6.2 are the result of calibration efforts for the three watersheds and represent the tentative final values to be used in scenario simulations based on water monitoring data received through 2009. Subsequent refinements in the calibration of APEX and SWAT will yield improved values for these parameters for simulating the BMP scenarios. It is anticipated the parameter values that result from the model calibration efforts will be more appropriate for conditions in the entire province than the model defaults. In addition to the parameters shown in Table 6.2, a number of other parameters were used in APEX and SWAT and were set to their default values. No model parameters or routines were specifically excluded from the current assessments.

The APEX model allows evaluation of groundwater table fluctuation on runoff. The user has the option of entering the minimum (min.), maximum (max.), and initial (init.) water depths or use model default values. In the current calibrations, a range of water table values were used based on model defaults (min. = 50 m, max. = 100 m, and init. = 75 m), as well as the available data, where applicable. However, in the final calibration, more recent groundwater data will be used to refine the water depths used in the model for both watersheds.

6.2.1.3 Results and Discussion for Indianfarm Creek Watershed

Similar to the flow calibrations reported for 2009, the R^2 and E values were generally better for the main channel stations (Stations 1, 5, and 11) than for the stations at the BMP sites (Stations 2, 4, 8, 9, 15, 18, and 21; Table 6.3). For the environmental indicators (i.e., flow, TSS, and nutrients), the R^2 values ranged from 0.64 to 0.99 at the main channel stations, and from 0.02 to 1.0 for the stations at BMP sites. Similarly, the E values ranged from 0.47 to 0.99 at the main channel stations; whereas, the range in E values was -3.21 to 0.92 at the BMP site stations. The SWAPP model predicted the IFC outlet relatively well, where all R^2 values were generally greater than 0.6 and all E values were greater than 0.5, with the exception of the ON load (E = 0.47). The predictions of flow and TSS loadings were acceptable for the majority of field-scale stations. However, the predictions of nutrient loads were less accurate at most stations and E values were often less than 0.5 or in many cases negative.

A satisfactory performance of SWAPP at the main channel IFC stations can be attributed to the larger flow volumes and more prolonged periods of flow. For example, the main channel stations experienced flow during 4 mo in 2007, and 6 mo in 2008 and 2009, and the maximum average monthly flow at the IFC outlet was 1.35 $m^3 s^{-1}$ (Figure 6.3a). In addition, the main channel stations flowed during snowmelt and rainfall events in each of the 3 yr. During these longer periods of flow, the TSS and nutrient loadings had a better chance of achieving equilibrium with flow rates, and this resulted in satisfactory model performance.

Field-scale stations had much lower flow rates in comparison to the main channel stations. For example, the maximum average monthly flow at Station 18 was 0.008 $m^3 s^{-1}$ during the 3-yr study period (Figure 6.4a). Snowfall data are largely taken from Environment Canada's Pincher Creek AUT station because the snowfall measurements at the ARD weather stations were often unreliable. In SWAPP, it is assumed that the end-of-winter snow distribution is uniform throughout

Table 6.3. Summary R^2 and E values from SWAPP calibration at Indianfarm Creek Watershed (March 2007 to August 2009), Whelp Creek Sub-watershed (January 2008 to December 2009), and Lower Little Bow River Field site (January 2008 to December 2009). Bold values represent main channel or major tributary stations, while the remainder are edge-of-field stations.

	Average flow		TSS		Nitrate N		Phosphate P		Organic N		Organic P		Total N		Total P	
Station	R^2	E	R^2	E	R^2	E	R^2	E	R^2	E	R^2	E	R^2	E	R^2	E
								Indianfarm Creek Watershed								
1	**0.76**	**0.59**	**0.97**	**0.53**	**0.95**	**0.86**	**0.64**	**0.61**	**0.97**	**0.47**	**0.99**	**0.73**	**0.98**	**0.52**	**0.99**	**0.75**
2	**0.74**	**0.52**	**0.65**	**0.39**	**0.87**	**0.25**	**0.41**	**0.20**	**0.77**	**-0.16**	**0.66**	**0.09**	**0.88**	**0.06**	**0.46**	**0.36**
4	0.53	0.40	0.44	0.42	0.70	0.09	0.47	0.30	0.22	0.16	0.28	-3.21	0.72	0.36	0.37	0.27
5	**0.70**	**0.60**	**0.97**	**0.80**	**0.93**	**0.93**	**0.73**	**0.73**	**0.97**	**0.59**	**0.98**	**0.97**	**0.97**	**0.65**	**0.98**	**0.97**
9	0.30	0.23	0.23	0.17	1.00	0.22	0.95	0.71	0.46	-0.06	0.47	-0.05	0.99	0.07	0.97	0.48
11	**0.70**	**0.60**	**0.98**	**0.56**	**0.98**	**0.90**	**0.95**	**0.92**	**0.98**	**0.62**	**0.98**	**0.98**	**0.98**	**0.65**	**0.99**	**0.99**
15	0.58	0.54	0.33	0.26	0.32	-0.08	0.99	0.73	0.83	-0.09	0.41	-0.09	0.68	-0.10	0.80	0.78
18	0.75	0.71	0.47	0.35	0.66	0.61	0.02	-0.86	0.89	-0.09	0.63	0.04	0.89	0.11	0.03	-0.48
21	0.67	0.92	0.54	0.60	0.03	-0.06	0.69	0.51	0.49	-0.07	0.53	0.02	0.57	-0.03	0.69	0.44
								Whelp Creek Sub-watershed								
301	**0.88**	**0.72**	**0.91**	**0.82**	**0.10**	**-8.86**	**0.58**	**0.56**	**0.87**	**0.20**	**0.75**	**0.64**	**0.69**	**0.66**	**0.64**	**0.62**
303	**0.90**	**0.90**	**0.89**	**0.70**	**0.07**	**-0.73**	**0.58**	**0.55**	**0.77**	**0.41**	**0.72**	**0.66**	**0.41**	**0.38**	**0.65**	**0.61**
307	0.79	0.75	0.99	0.94	0.92	-0.01	0.58	0.36	0.93	0.13	0.99	0.20	0.93	-0.01	0.63	0.34
309	0.94	0.60	0.86	0.85	0.81	0.63	0.94	0.72	0.76	0.01	0.85	0.30	0.94	0.37	0.94	0.85
311	0.03	-0.54	0.00	-0.31	0.04	-0.92	0.03	-2.76	0.00	-0.07	0.00	-0.08	0.01	-0.05	0.02	-1.34
314	0.95	0.94	0.94	0.92	0.69	-5.42	0.91	0.53	0.97	0.62	0.97	0.71	0.96	0.79	0.95	0.58
318	0.92	0.44	0.99	0.05	0.78	0.15	1.00	0.53	0.99	-0.04	1.00	-0.04	0.84	0.03	1.00	0.35
319	0.56	0.54	0.50	0.48	0.24	0.19	0.74	0.15	0.86	-0.23	0.73	-0.16	0.30	0.17	0.74	0.72
324	0.99	0.65	0.99	0.74	1.00	0.70	1.00	0.41	1.00	0.06	1.00	0.07	1.00	0.31	1.00	0.37
								Lower Little Bow River Field								
101	0.68	0.54	0.84	0.78	0.58	0.54	0.68	0.50	0.29	0.12	0.54	0.47	0.65	0.20	0.90	0.43

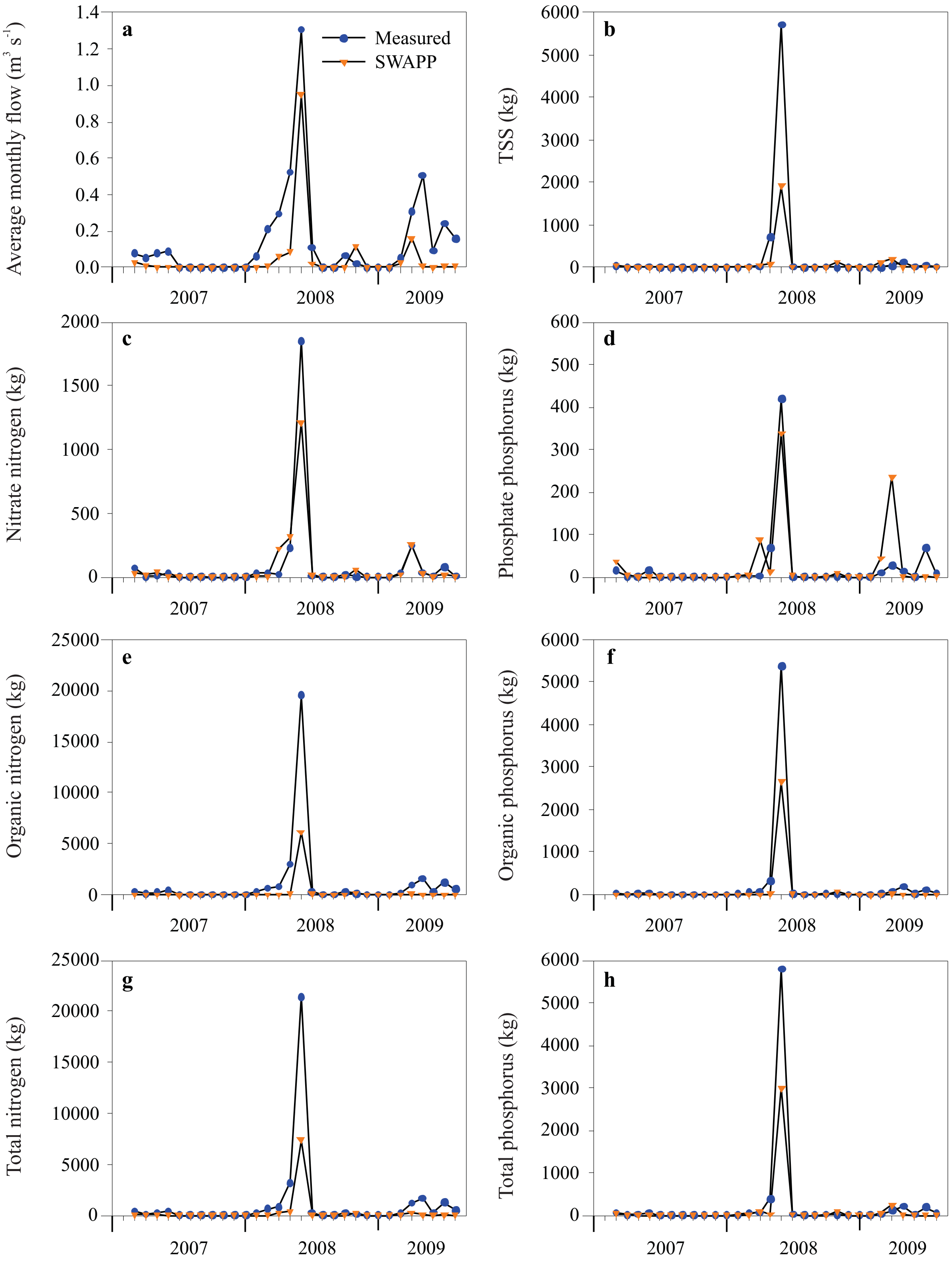


Figure 6.3. Measured and SWAPP-predicted values for (a) average monthly flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phsophorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the Indianfarm Creek Watershed outlet (Station 1) from 2007 to 2009.

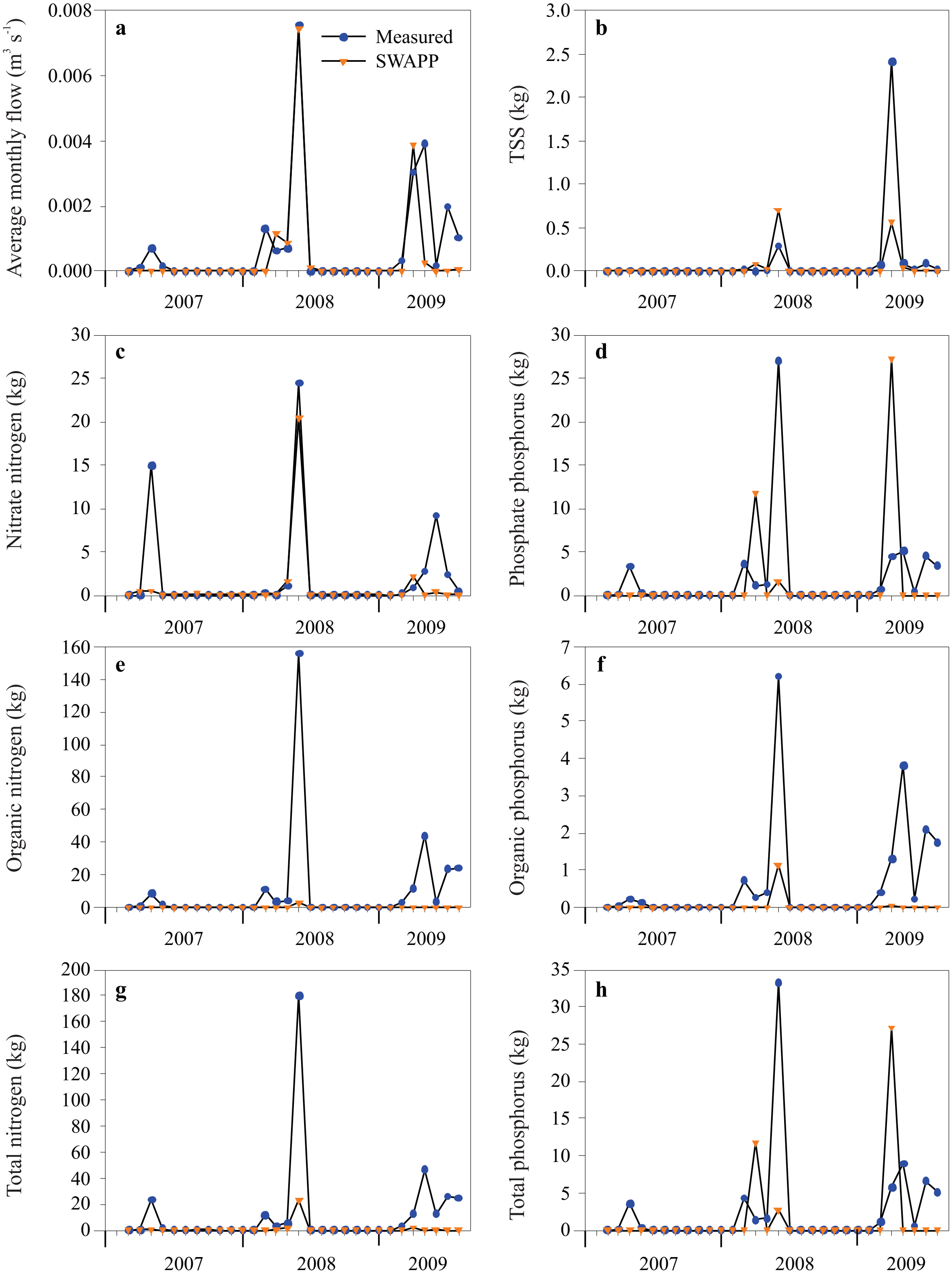


Figure 6.4. Measured and SWAPP-predicted values for (a) average monthly flow (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphous, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at Station 18 in the Indianfarm Creek Watershed from 2007 to 2009.

the watershed; however, the snow tends to accumulate in local depressions and primarily in the stream channel at IFC. As a result, the majority of small snowmelt events were commonly overestimated by SWAPP. Snowmelt and rainfall runoff events were also often separated by 1 or 2 mo of dry periods at the field-scale stations. These short duration events and associated very low flow volumes have proved to be difficult for SWAPP to predict with accuracy. During calibration runs, it was also discovered that minor changes in precipitation amounts (i.e., < 5 mm) had very large effects on field-scale flow predictions. The majority of gauging stations did not have precipitation measurements, which are derived from the weather stations that are often a few kilometres away. Therefore, there is a possibility that the precipitation inputs may affect predicted flow at the field-scale stations.

The preliminary calibration showed that SWAPP underestimated flow volumes at the outlet of IFC during snowmelt and precipitation events (Figure 6.3a). As a result, SWAPP generally underestimated TSS (Figure 6.3b) and nutrient (Figure 6.3c-h) loads. However, the most notable exception was an overestimation of NO_3-N and PO_4-P loads during the snowmelt in 2009. At the field-scale stations, there was more variability in TSS and nutrient load predictions (Figure 6.4b-h). For example, at Station 18, the predicted flow volume was satisfactory, but the TSS load was overestimated in 2008 and underestimated in 2009. The ON and OP loads were commonly underestimated at the field stations, and this resulted in poor predictions of TN and TP because the organic fractions tended to dominate nutrient exports at IFC.

6.2.1.4 Results and Discussion for Whelp Creek Sub-watershed

The WHC calibration results had higher R^2 and E values at the main channel stations (Stations 301 and 303) than at the field-scale stations (Stations 307, 309, 311, 314, 318, 319, and 324; Table 6.3). With the exception of NO_3-N ($R^2 = 0.10$), the R^2 values were generally greater than 0.5 at the watershed outlet. The field-scale stations had a wide range of R^2 values, but results were acceptable ($R^2 > 0.5$) for the stations with well calibrated flow ($R^2 > 0.60$; Stations 307, 309, 314, 318, and 324). For the field-scale Station 311, where flow was not well calibrated ($R^2 = 0.03$), the R^2 value for TSS and nutrient loadings was also less than 0.1. Similarly, with the exception of NO_3-N (E = -8.9), the E values were often greater than 0.5 at Station 301. The E values were much more variable at the field-scale stations in comparison to R^2 values. In general, the E values for TSS loads were better for field stations with well calibrated flow.

The SWAPP model performed better at the main channel stations, and this can be attributed to the greater flow volumes and longer duration of flows than at the field-scale stations. For example, the WHC outlet (Station 301) had a maximum average monthly flow of 0.034 $m^3\ s^{-1}$ and flowed during 5 mo in 2008 and 1 mo in 2009 (Figure 6.5a). The field-scale Station 309 had a maximum average monthly flow of 0.0017 $m^3\ s^{-1}$ and only flowed during 1 mo or less in 2008 and 2009 (Figure 6.6a). Similar to IFC, it appears that the TSS and nutrient loadings had a better chance of achieving equilibrium with flow rates during longer periods of flow, and this was reflected in the SWAPP predictions. Predicting flow at the field-scale stations was also hindered by errors associated with field measurements of very small flow volumes. The majority of runoff events at the field-scale stations were generated by snowmelt and the observed flow rates were directly related to the distribution of snow within each sub-basin. Field observation showed that the distribution of snow was not uniform within sub-basins. However, the WHC snowfall input data were largely derived from a few kilometres away at Environment Canada's Lacombe CDA2 weather station, and was assumed to be uniform for the entire watershed. This assumption did not represent the actual snow distribution among sub-basins and most likely had a negative effect on the SWAPP output, particularly for the field-scale stations.

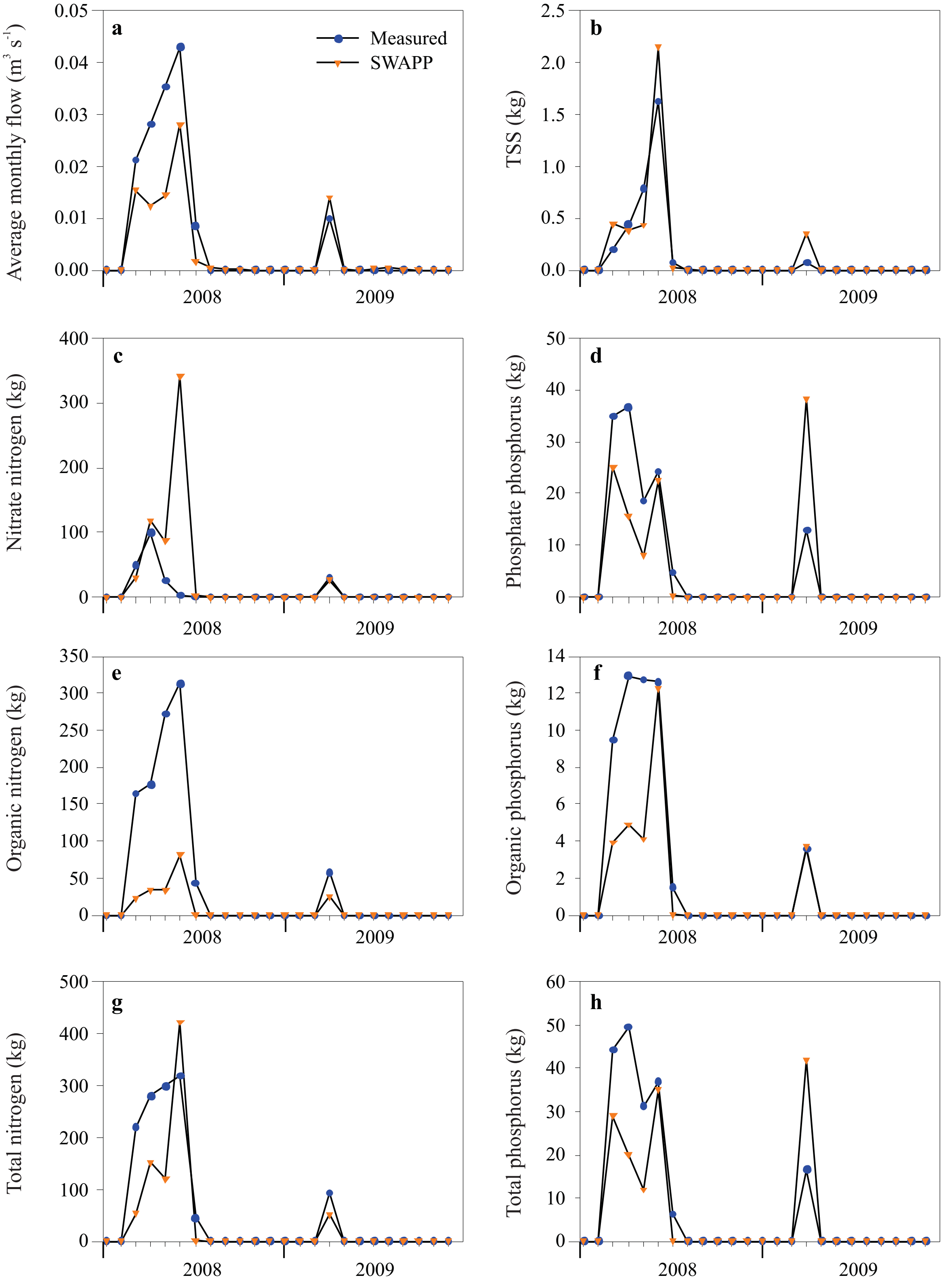


Figure 6.5. Measured and SWAPP-predicted values for (a) average monthly flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at the outlet (Station 301) of the Whelp Creek Sub-watershed in 2008 and 2009.

The WHC Sub-watershed is characterized by wetlands, ponds, impoundments, and local depressions, and these greatly affect flow volumes at the field stations and eventually the main channel stations. It was difficult to accurately predict the storage capacity of these depressions, which often dry up and need to fill with water before flow continued downstream. For minor flow events, the depressions will often not fill to capacity and flow disconnects between field stations and/or sub-basins. During these small events, flow was often generated from close proximity at the field-scale station, and without accurately estimating every small depression, SWAPP often predicted incorrectly that there was flow at the downstream station. These water storage issues are likely compounded downstream in WHC and have an influence on flow predictions at the WHC outlet. It is expected that SWAPP would predict larger flow events with better accuracy because the storage depressions would fill and water would flow more freely through WHC.

Further analysis at Station 301 showed that in 2008 SWAPP underestimated flow and overestimated the TSS load, but in 2009 it overestimated flow and TSS loading (Figure 6.5a-b). In 2008, SWAPP overestimated NO_3-N (Figure 6.5c) and underestimated PO_4-P (Figure 6.5d), ON (Figure 6.5e), and OP (Figure 6.5f). However, in 2009, SWAPP overestimated PO_4-P and underestimated ON. Most of the variability can be attributed to the effects of the ponds, wetlands, and reservoirs present in WHC and the runoff events were of low magnitude. Using Station 309 as an example of a field-scale station, the predicted flow and TSS were overestimated in 2008 and underestimated in 2009 (Figure 6.6a-b). In addition, SWAPP underestimated NO_3-N (Figure 6.6c) and ON (Figure 6.6e) in both years and overestimated PO_4-P (Figure 6.6d) and OP (Figure 6.6f) in 2008. In 2009, SWAPP overestimated PO_4-P and underestimated OP. Most of this variability can be attributed to very low runoff evens because the maximum average monthly flow was only 0.0017 $m^3\ s^{-1}$.

6.2.1.5 Results and Discussion for BDF and LLB Sites

Battersea Drain Field site. The SWAPP model calibration was attempted at three irrigated field stations at the BDF site; however, satisfactory results were not attainable. The R^2 values for Stations 203, 204, and 206 were less than 0.1, and E values were less than zero after calibration. These stations proved difficult to calibrate because of very low average monthly flow rates (Figure 6.7), and the discrepancy between flow volumes at the three BDF stations. The three sub-basins of the monitoring stations had the same inputs (soil, topography, climate, farming operations, etc.); however, the annual pattern in average monthly flow volumes at Station 203 was markedly different than Stations 204 and 206 (Figure 6.7). Even after disregarding Station 203, attempts that were made to calibrate Stations 204 and 206 were unsuccessful. With further calibration efforts, it may be possible to marginally improve on these results, but currently there are no plans to continue calibration and modelling for BDF. The calibration work at LLB will be sufficient for characterizing irrigated field sites in the moist mixed grasslands.

Lower Little Bow River Field site. Despite low average monthly flow volumes (Figure 6.8a), the preliminary flow, TSS, and nutrient calibrations at Station 101 at the LLB were relatively successful (Table 6.3). The R^2 and E values for average monthly flow calibration were 0.68 and 0.54, respectively. With the exception of ON ($R^2 = 0.29$), the R^2 values for TSS and nutrient loadings were generally acceptable for preliminary results ($R^2 > 0.5$); whereas, E values were generally greater than 0.4, with the exception of ON (E = 0.12).

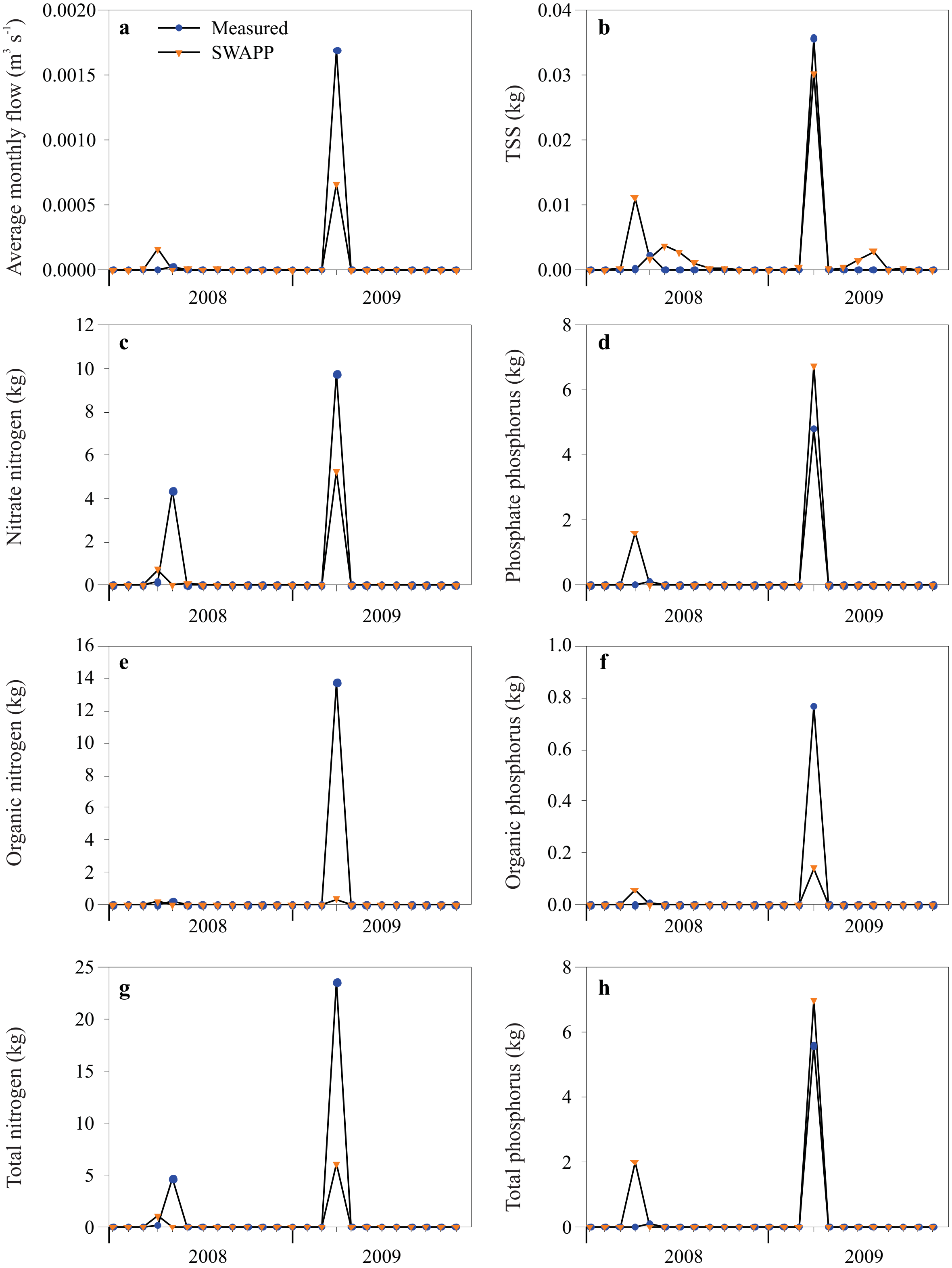


Figure 6.6. Measured and SWAPP-predicted values for (a) average monthly flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, (h) total phosphorus at Station 309 in the Whelp Creek Sub-watershed in 2008 and 2009.

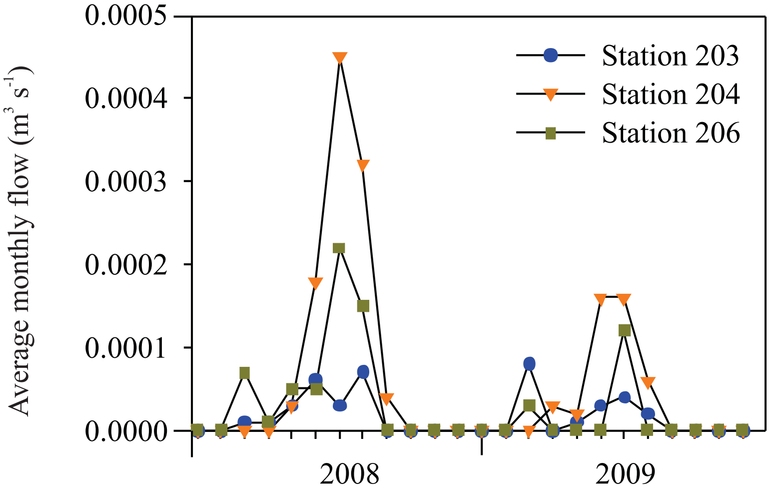


Figure 6.7. Measured average monthly flow at Stations 203, 204, and 206 at the Battersea Drain Field site in 2008 and 2009.

In 2008, there was almost no spring runoff from snowmelt at LLB, and summer runoff was largely the result of irrigation. In contrast, there was a relatively large snowmelt runoff event in 2009, and the majority of runoff during the summer was mostly the result of rainfall, which was at times combined with irrigation. With the current calibration, SWAPP predicted the snowmelt events quite well, but summer runoff was underestimated, particularly in the summer 2009 (Figure 6.8a). The SWAPP model predicted TSS loadings reasonably well (Figure 6.8b); however, further parameter adjustments will be necessary once the flow is readjusted with the addition of the 2010 data. The NO_3-N and ON loadings (Figure 6.8c,e) were generally underestimated, with the exception of NO_3-N during the snowmelt event in 2009. As a result, the TN loadings were considerably underestimated (Figure 6.8g). The PO_4-P loads were underestimated during spring and summer runoff events (Figure 6.8d); whereas OP was underestimated during the irrigation generated runoff events in 2008, and overestimated during the rainfall events in 2009 (Figure 6.8f). Since PO_4-P loadings were greater than OP, TP loadings were also underestimated (Figure 6.8h).

Calibration work will continue for the LLB site and it is expected the flow, TSS, and nutrient calibrations will improve.

6.2.1.6 Summary of Calibration Results

Preliminary calibration results were reasonably successful for IFC, WHC, and LLB. Model calibrations will continue for the two watersheds and the LLB site. Model calibration was not successful for the BDF site, and therefore, calibration work will be discontinued for this site.

It is important to note that environmental models such as SWAPP are designed to evaluate the effects of management practices on water quantity and quality at locations with significant runoff (average monthly flow > 0.2 $m^3 s^{-1}$). Field measurement equipment accuracy is higher for storm events with greater water quantity. Cold temperatures during spring snowmelt may result in frozen measurement equipment and/or the accumulation of ice and snow at or close to sampling stations. The lack of rainfall gauges at some of the sampling stations (especially under very low runoff conditions) could result in precipitation input data inaccuracies. For example, a thunderstorm passing over one station could initiate a small runoff event; whereas, the weather station a few kilometres away may show no rainfall for the same period. When there are such low flow volumes

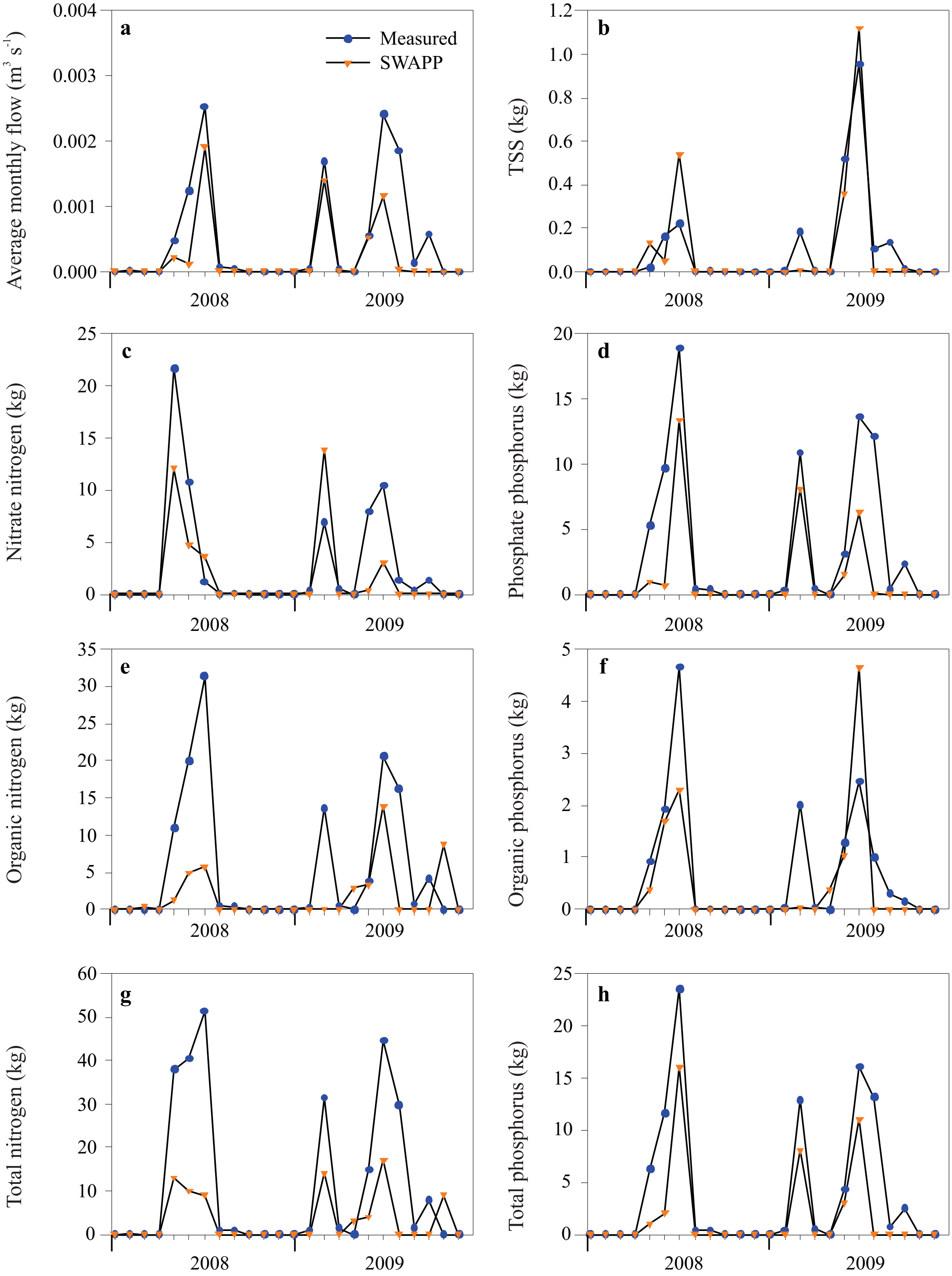


Figure 6.8. Measured and SWAPP-predicted values for (a) average monthly flow, (b) total suspended solids (TSS), (c) nitrate nitrogen, (d) phosphate phosphorus, (e) organic nitrogen, (f) organic phosphorus, (g) total nitrogen, and (h) total phosphorus at Station 101 at the Lower Little Bow River Field site in 2008 and 2009.

at the field stations, these types of events can have large effects on SWAPP predictions. In other studies, such as Saleh et al. (2000), model performance is better under larger flow volumes than under low flow volumes. Larger runoff volumes at the outlets of IFC and WHC resulted in more accurate field measurements and more reliable results from SWAPP. This is well demonstrated by better E values obtained where more significant runoff volumes, TSS loadings, and nutrient loadings were measured and predicted.

6.2.2 CEEOT BMP Simulations

6.2.2.1 Scenario Preparations for IFC and WHC

The environmental impacts of a significant number of the monitored BMPs are largely attributable to field locations. For example, part of the BMPs implemented at the IFC Wintering site entailed the relocation of a cattle wintering site to a new location further away from the creek. The longer flow path would result in the attenuation of nutrient concentrations and loadings entering the creek. To evaluate the environmental impacts of such BMPs, the sequence of flow routing between fields in each watershed must be ascertained. Since the default flow routing sequence in APEX may not accurately represent actual occurrences, use of these defaults may result in incorrect assessments. Consequently, the routing scheme was first determined for each watershed prior to simulation of the base line and BMP scenarios.

Routing schemes. The natural flow sequence from field to field within each sub-basin was delineated by visual inspection of GIS maps for each of the sub-basins coupled with the expert opinion of researchers familiar with the area. Field routing sequences were initially developed only for fields that were directly impacted by or impacting the monitored BMP sites. Subsequent routing schemes were also developed for all the other fields within sub-basins that were large enough to have a measurable impact on the water quality of IFC or WHC. Specifically, the fields for which routing sequences were developed were larger than 0.5 ha in size, and most were larger than 2 ha.

Special considerations and subarea delineation. The unit of land area simulated in APEX is called a subarea. Traditionally, CEEOT simulations in APEX are performed by representing each SWAT hydrologic response unit (HRU) as a single subarea in APEX. However, due to the more refined nature of the locations and spatial extent of the monitored BMPs it was necessary to redefine the APEX subareas using HRU designations and actual field polygons used to capture land use data with AgCapture (Sub-section 2.3 for IFC and Sub-section 3.3 for WHC). In particular, the GIS layer of field polygons was overlaid on the HRU distributions to determine the new definition of APEX subareas. This procedure resulted in an increase in the number of subareas to be simulated in APEX. However, it provided the opportunity to assign unique management files to each field-HRU intersection rather than just at the HRU level.

In addition to defining subareas as the intersections of fields and HRUs, additional subareas were developed by creating new polygons within existing subarea polygons. These new polygons were necessitated by the fact that some BMP sites included special practices on land parcels that did not coincide with the boundaries of the field-HRU intersections. For instance, whenever manure application setbacks were called for, the setback was normally a narrow strip of land adjacent to a creek or other sensitive resource. In such cases, it was often necessary to create a new polygon representing the setback area.

When compared to the previous routing process for HRUs in APEX, the new routing sequence is relatively complex because it is necessary to route many more subareas in order to properly assess BMPs. The previous routing process was strictly sequential; whereas, the new routing scheme involves multiple simultaneous flow paths for each sub-basin. Fortunately the APEX model includes a routine (APSUBLDM) that automatically generates sub-basin files regardless of the complexity of the routing sequence, and this will be crucial to applying APEX to other watersheds in the future.

BMP simulation procedure for IFC and WHC watersheds. Once the routing schemes were developed, BMP simulation and evaluation were performed using the following three primary steps: (1) simulation of base line conditions using routing scheme developed for each watershed, (2) simulation of a single scenario consisting of the distribution of the monitored BMPs in their locations using the same routing sequence that was used for base line simulation, and (3) comparison of base line and BMP scenario loads.

6.2.2.2 Simulation of BMPs for the Indianfarm Creek Watershed

The following is a description of the preliminary simulation of BMP implementation at six sites in the IFC Watershed. Further details about the BMPs are reported in Section 2. In some cases, preliminary simulations did not exactly reflect actual BMP implementations used in the field. Future CEEOT simulations will reflect updated information on actual or planned BMP implementation at each site.

Impoundment site (IMP). To simulate the BMP at the IMP site, conventional practices (primarily grazing) were simulated for all subareas during the base line scenario. A 'no grazing' management file was substituted for the management files that were used on areas immediately surrounding the IMP lake in the base line scenario (Figure 2.20). This represented the installation of fencing to exclude cattle from the IMP lake and off-stream watering.

North Manure Field site (NMF). Conventional practices were simulated on all subareas in the base line scenario. For the preliminary simulations of this BMP, a “no-grazing” management file that entailed minimal application of inorganic fertilizer and no manure application were simulated on either side of the drainage channel to mimic a manure application setback (Figure 2.26). However, further detailed information on this BMP indicates that cattle exclusion from the channel is the main feature of this BMP rather than a manure setback. Future simulations will be revised to capture the impact of cattle exclusion rather than a manure setback.

Pasture site (PST). Pre-BMP management practices were simulated as base line grazing conditions during the base line scenario simulation. During BMP scenario simulation, the majority of the subareas were simulated with alternative grazing schedules to reflect improved management practices (Figure 2.37). In particular, cattle were moved between several pastures to minimize overgrazing and improve vegetative cover. On a few of the subareas at this site, a “no-grazing” management practice was simulated to reflect instances when cattle were excluded from that area or were moved to other fields for grazing.

Wintering site (WIN). The WIN site BMP entailed relocation of a cattle wintering site to a new site further away from the creek in order to minimize direct runoff losses to the creek (Figures 2.54 and 2.55). Fencing and off-steam watering was also used to create a riparian pasture and rotational grazing was implemented to limit cattle access to the creek and riparian area. Special management files were created for various subareas to simulate post-BMP implementation practices.

South Manure Field site (SMF). Five unique subareas were delineated based on the intersections of fields and HRUs for this site. Specific field routing was determined for each of the subareas and a manure setback was simulated for either side of the drainage channel (Figure 2.64). The setback received very little inorganic fertilizer and no manure applications.

Dairy Manure Field site (DMF). Nineteen unique subareas were delineated for this area based on the intersections of fields and HRUs. While this BMP site is not a very large area, as many as nineteen subareas were delineated in this site as a result of additional field overlaying procedures that were performed to enhance the reliability of the computer model output. A significant component of this BMP is that a manure application setback was simulated along the drainage channel (Figure 2.68). As with the other manure field BMP sites, the manure setback was simulated by replacing the base line management file with a no grazing management file that entailed pasture grass cover with very little inorganic fertilizer application and no manure applications. However, further details about this BMP indicate discontinuation of manure application is the main feature of this BMP rather than only a manure setback.

6.2.2.3 Simulation of BMPs for the Whelp Creek Sub-watershed

The following is a description of BMP implementation at five sites in the WHC Sub-watershed. Further details about the BMPs are reported in Section 3. the North Field site was not included because the flow data were not reliable for model calibrations.

West Field site (WFD). Six unique subareas were created at the WFD site after overlaying the field boundaries with the HRU distributions. A manure setback was simulated for both sides of the drainage channel to Station 309 (Figure 3.29). As with the IFC setbacks, the manure setbacks in WHC received no manure applications, and a very low rate of inorganic fertilize. Poultry manure was applied based on 3 to 4 yr of crop P removal.

East Field site (EFD). The EFD BMP site in WHC covers five fields and seven subareas. During preliminary simulations, manure setbacks were simulated on the north side of the channel (Figure 3.40). Subsequent simulations will be revised to more accurately reflect the management practice of applying liquid manure on a forage crop.

South Field site (SFD). The SFD BMP site involves four fields, with eight unique subareas. Manure setbacks were simulated directly south of Station 314 (Figure 3.43). As with the other setbacks, these manure setbacks also entailed a pasture field with no manure applications and minimal inorganic fertilizer application to maintain vegetative cover. Liquid hog manure was applied based on crop N requirements.

North Pasture site (NPS). The NPS site covers six unique subareas. In contrast to the base line, rotational grazing was simulated for all subareas except for a small area (about 10 by 15 m) near Station 303 (Figure 3.48). This 10 by 15 m area is a bioengineering site that received no grazing by simulating a “no grazing” pasture management file. Cattle were rotated between the original NPS site and an adjacent pasture of about the same size.

South Pasture site (SPS). The SPS site covers four unique subareas. The pasture was divided into three paddocks and a rotational grazing management plan was implemented. Rotational grazing was simulated on all four subareas under the BMP scenario (Figure 3.56).

6.2.2.4 Results and Discussion

The environmental output from CEEOT simulations will show the simulated environmental impacts of each monitored BMP; however, the preliminary results presented here only show the environmental impacts of concurrent BMP implementation at the outlet of each sub-basin.

The environmental indicators presented in this report are flow, TSS, ON, OP, NO_3-N, and PO_4-P. It is important to note that the results presented here are at the sub-basin level. Thus the impacts shown in the tables are not necessarily the impacts of the specific BMPs for at least two reasons. First, the portion of the sub-basin covered by the BMP is not indicated here. It is expected that the greater the portion of the sub-basin covered by the BMP the more closely will the sub-basin impact mirror that of the BMP, and vice versa. Second, because one sub-basin routes to another until the outlet of the watershed is reached, the impacts shown for various sub-basins are masked by the cumulative effect of flow, sediment, and nutrient loads from upstream sub-basins. To aid the reader in understanding the environmental results, the sub-basin routing schemes for the two watersheds are shown in Figures 6.9 and 6.10. The results obtained so far were deemed too preliminary to present BMP-specific impacts; however, future work will include BMP-specific assessments.

In general, sub-basins where BMPs were implemented showed varied impacts, with some sub-basins showing reductions in flow, TSS loads, and nutrient loads, while others indicated mixed impacts (Tables 6.4 and 6.5). It is worth noting that the BMPs listed for each sub-basin are the BMPs located in that sub-basin and in some cases one BMP management unit traversed more than one sub-basin and one sub-basin may contain multiple BMPs. Tables 6.4 and 6.5 show the

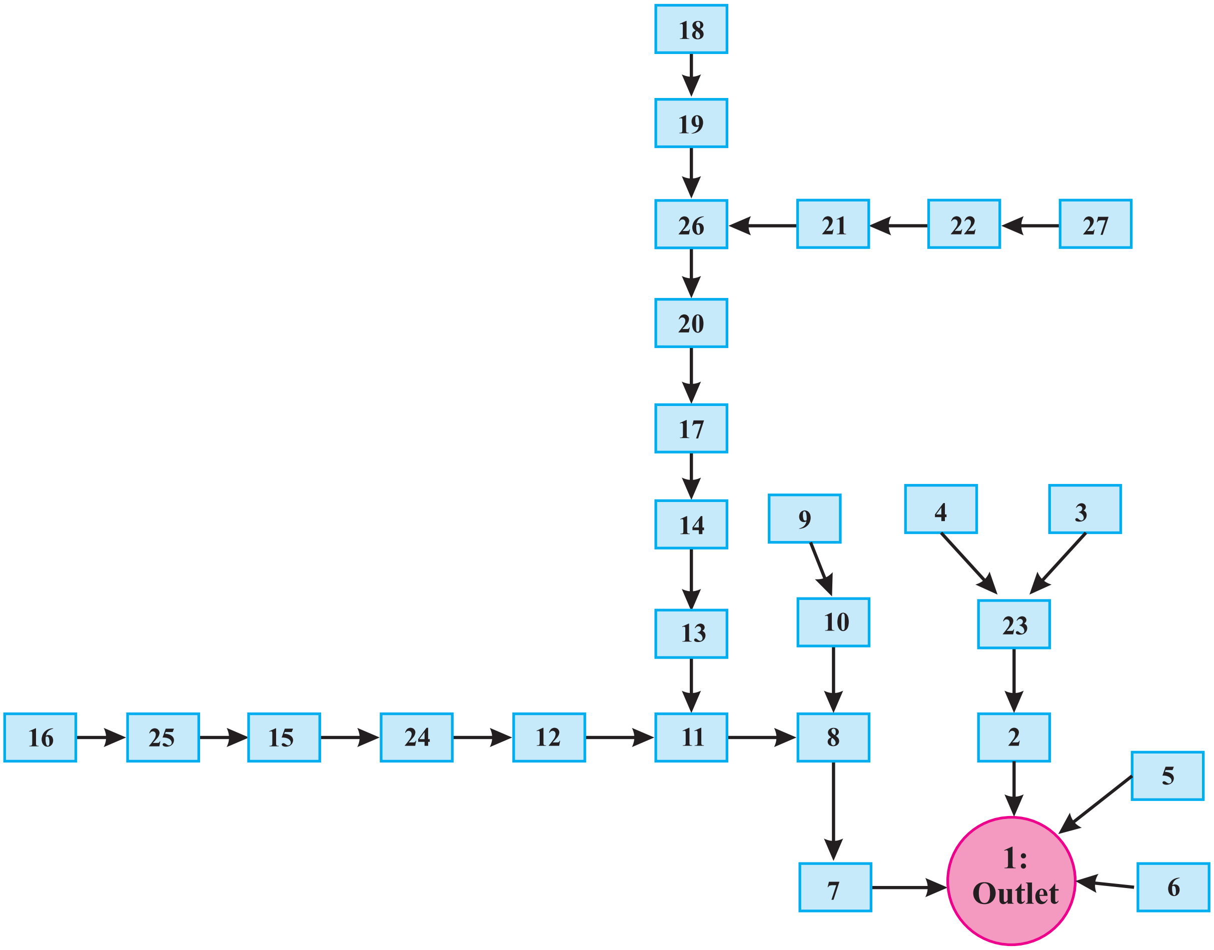


Figure 6.9. Sub-basin model routing sequence for the Indianfarm Creek Watershed.

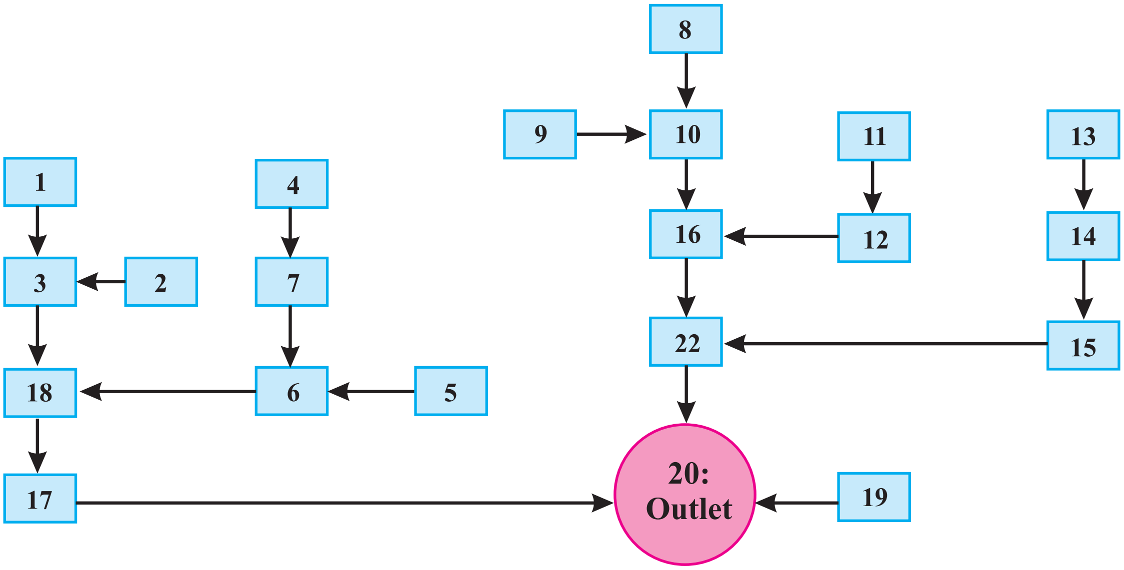


Figure 6.10. Sub-basin model routing sequence for the Whelp Creek Sub-watershed.

percentage changes in flow, TSS loads, and nutrient loads under each of the BMP scenarios when compared to base line conditions. For example, the BMP scenario for the IMP site (Sub-basin 2) predicted that flow, ON, OP, and PO_4-P increased, ranging from 0.3 to 6.1%; whereas, TSS decreased by 0.9% and NO_3-N decreased by 0.3%. For the DMF site, flow, TSS, and all of the nutrient parameters were reduced, with more than a 40% reduction predicted for NO_3-N. The BMP scenarios predicted large decreases for some parameters at the NMF and COR sites. It is also important to note that the results also reflect the improved calibration of the SWAPP model for IFC relative to WHC.

As indicated above, the environmental impacts of BMP scenario simulation were routed from one sub-basin to the next until the outlet was reached. Therefore, the predicted values for the outlets of IFC Watershed (i.e., Sub-basin 1) and WHC Sub-watershed (Sub-basin 20) represent the cumulative effect of all simulated BMPs in the scenario. The preliminary results showed that at the outlet of the IFC Watershed, flow, TSS load, and NO_3-N load were reduced by simulated BMP implementation; whereas, ON, OP, and PO_4-P loads were increased (Table 6.4). In contrast, implementation of BMPs in the scenario simulation of the WHC Sub-watershed resulted in no change at the outlet (Table 6.5).

As would be expected, nutrient losses generally tracked flow and TSS loads reasonably well. Beneficial management practices that have noticeable impacts on TSS also have an impact on ON and OP loads as well. Beneficial management practices that had impacts on flow also impacted NO_3-N and PO_4-P losses. The model results indicate that BMP implementation did not seem to affect flow, TSS, or nutrient losses for many sub-basins, and this is largely attributable to one of three main reasons: (1) the BMP covered only a small portion of the sub-basin in question, (2) the BMP is truly not effective, or (3) the simulations did not adequately captured the essence of the BMP.

Table 6.4. Preliminary SWAPP output of key environmental indicators at the sub-basin level in the Indianfarm Creek Watershed. Percentage impacts of beneficial management practices (BMP) scenario relative to the base line.[z]

Sub-basin	Flow	TSS	Organic N	Organic P	Nitrate N	Phosphate P
1[y]	-0.7[x]	-7.2	4.1	4.0	-0.5	0.7
2	0.3	-0.9	4.4	6.1	-0.3	0.7
3	-3.2	-6.2	-0.2	-0.7	-42.5	-17.8
4	-8.5	-6.1	-6.2	-11.4	-42.4	-17.0
5	0.0	0.0	0.0	0.0	0.4	0.8
6	-59.9	-49.6	-97.8	-97.4	-1.3	-1.2
7	0.4	-2.8	-0.5	-0.7	1.1	1.0
8	0.4	-2.8	-0.5	-0.7	1.0	1.0
9	-9.0	-11.7	-69.9	-62.8	-0.1	-0.4
10	-8.7	-12.3	-69.9	-62.8	-13.6	-11.0
11	0.4	-0.9	-0.4	-0.6	-0.4	0.3
12	-1.3	-3.2	-1.7	-1.6	-1.3	-1.2
13	0.7	-0.8	-0.2	-0.3	1.1	1.0
14	0.7	0.0	-0.2	-0.3	1.0	1.0
15	-0.4	-0.9	0.1	0.1	-0.1	-0.4
16	-11.5	-16.3	70.7	68.4	-13.6	-11.0
17	0.1	0.0	0.0	0.0	-0.4	0.3
18	0.0	0.0	0.0	0.0	0.0	0.0
19	4.8	3.8	-0.8	-0.3	-22.5	4.5
20	0.1	0.1	0.0	0.0	-0.4	0.3
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0
23	0.3	-2.9	4.3	6.0	-10.9	5.5
24	-1.3	-3.2	-1.7	-1.6	-1.3	-1.2
25	-0.4	-0.7	0.1	0.1	-0.2	-0.4
26	0.1	0.1	0.0	0.0	-0.5	0.4
27	0.0	0.0	0.0	0.0	0.0	0.0

[z] A negative value indicates a percent reduction and a positive value indicates an percent increase relative to the base line.

[y] The following are locations of BMPs sites at the sub-basin scale: Pasture and Corral sites (Sub-basins 1, 7, 8, 9, 10, and 11), Impoundment site (Sub-basin 2), Dairy Manure Field (Sub-basin 4), North Manure Field (Sub-basin 6), Wintering site (Sub-basins 9, 11,12, 13, 14, and 24), Reference site (Sub-basins 16 and 24), and South Manure Field (Sub-basin 19).

Table 6.5. Preliminary SWAPP output of key environmental indicators at the sub-basin level in the Whelp Creek Sub-watershed. Percentage impacts of beneficial management practices (BMP) scenario relative to the base line.[z]

Sub-basin	Flow	TSS	Organic N	Organic P	Nitrate N	Phosphate P
1[y]	0.0[x]	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0
5	-16.9	-54.5	-71.3	-77.7	-31.8	-21.5
6	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0
17	-2.0	18.2	6.3	5.3	27.0	-6.1
18	-1.6	19.8	5.0	3.6	10.4	-0.1
19	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0

[z] A negative value indicates a percent reduction and a positive value indicates an percent increase relative to the base line.

[y] The following are locations of BMP sites at the sub-basin scale: North Field (Sub-basin 2), West Field (Sub-basin 4), East Field (Sub-basin 5), South Field (Sub-basin 10), Reference 1 site (Sub-basin 12), South Pasture (Sub-basins 13 and 14), North Pasture (Sub-basin 17), and Reference 2 site (Sub-basin 19).

The economic impacts of BMP implementation in IFC and WHC were based on farm-scale simulations of the total costs entailed in BMP installation and management. Preliminary results are shown for IFC and WHC as average annual costs and returns per farm (Table 6.6). Key cost components include machinery costs, principal and interest payments on borrowed capital, depreciation and cost of owner's equity, and facility maintenance costs. The primary economic indicator of interest is net returns, which is simply total revenue minus total cost. A BMP increases revenue if the total revenue impact is positive. Similarly a BMP increases cost if the total cost impact is positive. The bottom line profit of the farm is captured by the net returns value. From the perspective of the farmer or the one paying for BMP implementation, the BMP entails a net cost if the net returns impact is negative.

The economic impacts presented here are expressed as dollars per farm, and are the average annual economic impacts of the BMP scenarios implemented on the fields. For this economic assessment, the total cost of implementation was captured regardless of whether the cost was shared between the producer and the research project or whether it was borne entirely by one or the other. Similar to the preliminary environmental output results, revisions are expected for the predicted economic impact of the BMPs.

In general, most BMPs increase total costs primarily because of the BMP installation costs (Table 6.6). In addition, if a BMP caused a reduction in nutrient application, there may be a yield penalty that was reflected in a reduction in total revenue. Where there was a combination of BMPs on a single farm, the total economic impact was the sum of the combined effects of all the BMPs implemented on that farm.

It is important to note that these results are very preliminary, and changes are expected as work continues, and in some cases, more significantly than others. Base line and BMP scenario values used to calculate the percentage changes were annual averages of the SWAPP 10-yr output for each respective environmental indicator. Since the results are at the sub-basin level, the actual BMP impact at the field-scale where the BMP was simulated would be greater in magnitude than the impacts presented here.

Table 6.6. Preliminary FEM output for beneficial management practices (BMPs) sites in the Indianfarm Creek Watershed and Whelp Creek Sub-watershed.

BMP site[z]	Grain sales	Total revenue	Total cost	Net returns	Machinery cost	Principal and interest	Depreciation and cost of equity	Additional fertilizer cost	Crop supplies cost	Field labour cost	Facility maintenance
	($ $year^{-1}$)										
Indianfarm Creek Watershed											
IMP and REF	0	0	982	-982	-204	-929	1380	-14	-38	-18	800
PST	0	0	1716	-1716	0	80	1036	0	0	0	600
WIN	0	0	1641	-1641	0	80	1036	0	0	0	525
SMF and NMF	0	0	-901	901	-901	0	0	0	0	0	0
NMF and PST	-3600	-3600	-1260	-2340	-850	0	0	0	0	-410	0
Whelp Creek Sub-watershed											
NFD	-1051	-1051	-907	-145	0	0	0	-907	0	0	0
EFD	-2490	-2490	-494	-1996	6	0	0	-501	0	1	0
SFD and EFD	526	526	622	-96	0	0	0	453	168	0	0
WFD	-254	-254	-15	-240	0	0	0	-15	0	0	0

[z] IMP = Impoundment site, REF = Reference site, PST = Pasture site, WIN = Wintering site, SMF = South Manure Field, NMF = North Manure Field, NFD = North Field, EFD = East Field, SFD = South Field, WFD = West Field.

6.3 Red Deer River Watershed Project Activities

The objectives of this project are to: (1) estimate TSS and nutrient loadings from the middle Red Deer River (RDR) and its tributaries (Figure 6.11), (2) evaluate the impact that agricultural practices have on water quality and assess how BMPs could reduce TSS and nutrient loads, and (3) assess the impact that small agricultural watersheds have on a major river.

Sixty-nine sub-basins were delineated in the middle RDR (Figure 6.12) based on the location of water quantity and quality stations, and the boundaries of Prairie Farm Rehabilitation Administration (PFRA) watersheds, which in some cases were further subdivided for major tributaries. The size of each sub-basin is generally similar to the size of IFC (141 km^2) and WHC (46 km^2).

A list of datasets required for modelling the middle RDR was outlined in Olson and Kalischuk (2010). Addressing the data gaps required to calibrate flow in the middle RDR tributaries was the top priority in 2010. The data gaps included: (1) farm operations such as typical crop rotations, tillage intensities, and fertilizer applications, (2) water usage obtained through water licenses, (3) lake and large wetland outlet locations, surface areas, and storage capacities, and (4) reservoir outlet locations and water storage specifications.

The first task associated with applying farm operations to the annual croplands was to divide the area into manageable units (one-quarter townships), which reduced input data complexity while still maintaining a diversity of crops. Crop rotations were developed using 2001 Census of Agriculture data for each PFRA watershed along with the typical crop rotations that were developed for each ecodistrict by Dey (2000). The proportion of crops that made up greater than 10% of the cropland area in each PFRA watershed (typically barley, wheat, canola, corn, and occasionally oat) were used to develop one, 4-yr and one, 5-yr rotation for each PFRA watershed, and these were confirmed by checking the ecodistrict rotations. Finally, different combinations of each rotation were applied to the one-quarter townships so that all the units in a PFRA watershed were not growing the same crop each year.

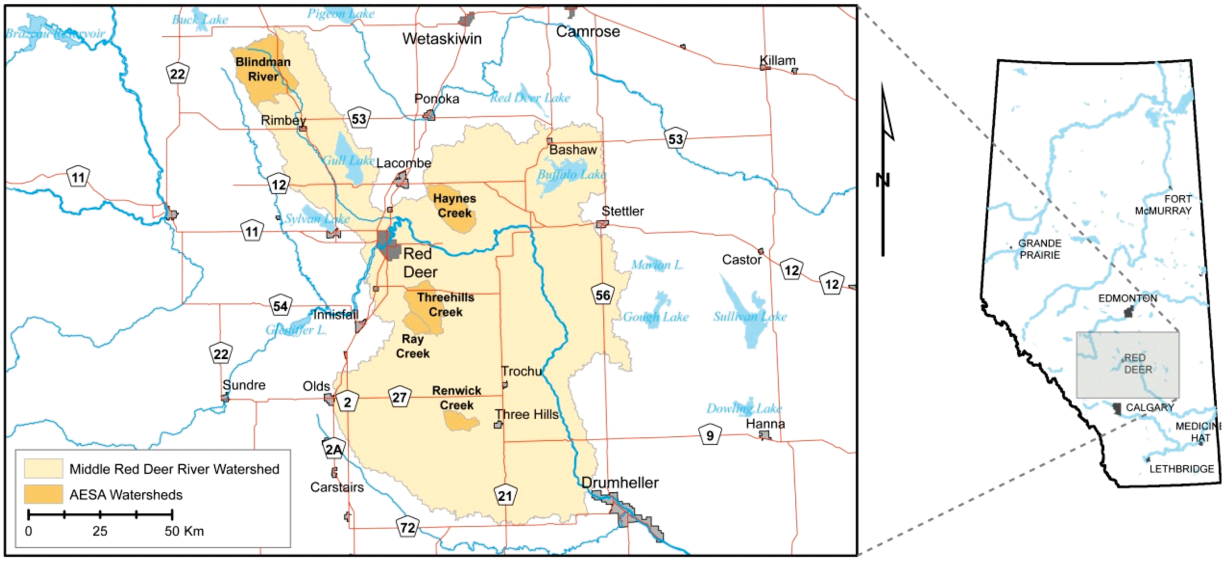


Figure 6.11. Location of the middle Red Deer River Watershed and five Alberta Environmentally Sustainable Agriculture watersheds: Blindman River, Haynes Creek, Threehills Creek, Ray Creek, and Renwick Creek.

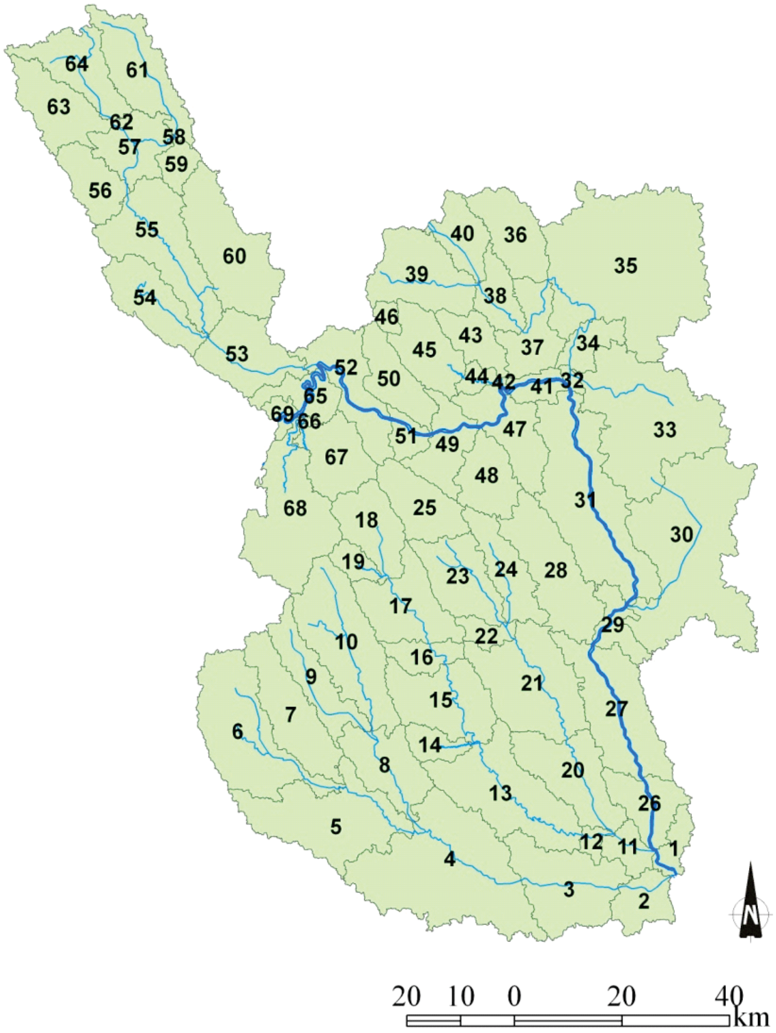


Figure 6.12. The 69 sub-basins in the middle Red Deer Watershed. The sub-basin number generally increases in the upstream direction.

Automated techniques are in development to input farm operation datasets for the various crop rotations and their different combinations. Typical tillage and fertilizer operations will be developed based on the 2001 Census and the operations will be applied to each type of crop in a given PFRA watershed.

Water withdrawn from the Red Deer River and its tributaries was estimated from the amount of water allocated for use by municipalities and industry (AENV 2010b). Actual water use in relation to the amount allocated has been approximated by Alberta Environment (AENV 2007). The percentage of actual use to amount allocated (Table 6.7) was then used to calculate the total amount of water withdrawn in each section of land where water was allocated.

Lake and large wetland outlets will be delineated from the 30-m resolution land use map obtained from Agriculture and Agri-Food Canada (AAFC 2008). Bathymetry and lake level data have been obtained to calculate the storage capacity for Buffalo and Gull Lakes, which are the two large lakes in the middle RDR. The surface area of small lakes and large wetlands will be estimated from the land use map, and storage capacity will be estimated from the digital elevation model.

Table 6.7. Percent of water usage relative to amount allocated by sector.

Sector	Sub-sector	Percent usage
Municipalities		74
Agriculture	Beef industry	70
	Private irrigation	97
Commercial		100[z]
Petroleum	Injection	3
	Gas / Petrochemical plants	97
Industry	Cooling	62
	Forestry	100
	Fertilizer plants	100
	Manufacturing	100
	Mining	100
	Other	100
Ecological	Water management	46
	Habitat enhancement	90

[z] Estimates of 100% usage are likely overestimates, but these sectors/sub-sectors use relatively low amounts of water.

Reservoir outlet locations were available from the land use map (AAFC 2008). Water storage specifications such as surface area and water volume at full supply level have been obtained for eight reservoirs from Alberta Environment and are ready to be input into SWAT.

6.4 Summary and Future Work

In 2010, significant progress was made on calibrating SWAPP outputs using the 2007 to 2009 measured data for IFC, WHC, and LLB. Calibration results were generally better for the main channel stations in comparison to the field stations. Preliminary results of BMP evaluations at IFC and WHC showed varied impacts. Reductions in flow, TSS loadings, and nutrient loadings occurred at some BMP sites; whereas, others preliminary results showed BMPs were less successful. The evaluation of economic impacts of BMP implementation, which estimates the total costs required for BMP installation and long-term management, was started in 2010. Further progress was also made in gathering datasets required to calibrate flow in the Red Deer River and its tributaries.

The 2011 to 2012 activities will focus on completing all deliverables listed in the General Services Contract between ARD and TiAER. The activity list includes: (1) completing CEEOT calibration/verification, (2) completing CEEOT BMP scenario simulation, (3) providing guidance for generating input databases to run CEEOT in other Alberta watersheds, and (4) developing a protocol for transferring simulation results from IFC and WHC simulations to other watersheds in Alberta.

The 2010 field data still needs to be entered into SWAPP for IFC, WHC, and LLB, and the 2007 to 2009 calibration results will be verified with the 2010 data. Additional groundwater table data needs to be entered into the model, and its impact needs to be evaluated. Pending the verification, some input parameters may need further calibration.

Once CEEOT calibration/verification is completed for IFC, WHC, and LLB, 30-yr simulations will be conducted for these watersheds to simulate the effectiveness of the monitored BMPs. The simulation will require the preparation of files for the pre-BMP and post-BMP scenarios, and will utilize the latest SWAPP validation/calibration results. In addition, a list of non-monitored BMPs will be prepared and a similar set of input files will be assembled for an additional 30-yr simulation.

The FEM base line scenarios will require input data verification. The FEM 30-yr scenario simulations will be conducted and verified for the monitored BMP sites and non-monitored BMP sites.

Another objective of evaluating CEEOT performance at each watershed is to assess the suitability of the model for Alberta conditions. The experience acquired during model calibrations will provide the basis for outlining the limits of CEEOT applications. Once model calibrations are complete, a list of the parameters that most influence flow, TSS, and nutrient outputs will be provided with a range of values that are applicable for Alberta conditions. In addition, instructions and guidance will be provided for creating new BMP scenarios in other watersheds.

To provide recommendations on future applications of CEEOT in other watersheds, the availability of existing model input databases has yet to be summarized and documented. This will provide the basis for filling data gaps and providing guidance to automate the process of generating data input files.

For the RDR project, the focus of the upcoming year will be to complete the tasks required to begin flow calibrations for the tributaries of the middle RDR. Automating the input of farm operations will be the priority task to complete. Once this is accomplished, flow calibrations will begin for the outlets of the Alberta Environmentally Sustainable Agriculture watersheds.