Alberta Government

Bow River Phosphorus Management Plan:

Scenario Modeling Results for Crowfoot Creek

November 12, 2013

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The SWAT (Soil Water Assessment Tool) model was selected to simulate different agricultural practices and BMP options in Crowfoot Creek. The Crowfoot Creek watershed was selected as a pilot study area for rural non-point source BMP scenario modeling in Bow River Basin. Seven scenarios were run with the SWAT model to support the PMP. These included: protection of existing wetlands; restoration of degraded/drained wetlands; manure management and spreading; cropland conversion to perennial forage in riparian zones or in-field gullies/waterways; and riparian fall grazing within cultivated lands.

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Bow River PMP: Scenario Modeling Results for Crowfoot Creek using Non-point Source Watershed Model, SWAT

1. Background

The Crowfoot Creek watershed was selected as a pilot study area for rural non-point source BMP scenario modeling in Bow River Basin. This watershed is located approximately 85 km east of Calgary in Wheatland County, Alberta, Canada. The watershed covers an area of 1191.85 km2 and is predominantly agricultural in nature.

The Crowfoot Creek watershed was identified as an area of concern by the Bow River Water Quality Task Force (1991) due to excessive levels of nutrients and coliform bacteria within the reach of the Bow River where the creek discharges (Ontkean et al. 2003). Natural flows in the creek are provided by snowmelt runoff in the spring and runoff from rainfall events during the remainder of the year. Flows are maintained from May to early October by the addition of return flows from the Western Irrigation District (WID). Nutrient concentrations during spring runoff were in excess of the Alberta Water Quality Guidelines (AWQG) for surface water of 0.05 mg/L for phosphorus (AEP 1999). Ontkean et al. (2005) conducted research during 1997-99 and also confirmed that phosphorus concentrations exceeded Alberta surface water quality guidelines most of the time.

Water quality samples are taken just North of Highway 1 near the existing water surveys of Canada flow monitoring station that record daily flows in Crowfoot Creek. Confluence of Crowfoot and Bow River located about 10 Km further downstream of monitoring site. Table 1 shows the number of Total Phosphorus samples as well as period of data availability. As can be seen in Table 1, limited number of samples is available most of the time, however, there is no observed data from November to January.

Table 1. Frequency of sampling, period of available monitoring data, and monthly median observed Total Phosphorus (TP) at Crowfoot Creek (W-R2 station at Highway 1).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	-	-	-	4	2	3	1	2	1	1	-	-
1996	-	-	3	4	1	1	1	2	2	1	-	-
1997	-	-	-	5	4	4	3	1	1	-	-	-
1998	-	-	2	5	4	3	2	1	1	-	-	-
1999	-	-	1	2	2	2	2	1	3	2	-	-
2000	-	-	4	4	2	2	2	1	2	2	-	-
2001	-	-	4	2	3	3	2	1	1	1	-	-
2002	-	-	-	6	3	2	2	1	1	1	-	-
2003	-	-	4	5	3	2	3	4	2	2	-	-
2004	-	-	6	2	2	3	4	2	2	2	-	-
2005	-	-	6	2	3	3	2	2	2	4	-	-
2006	-	-	-	8	4	3	2	2	2	1	-	-
2007	-	-	6	6	4	2	2	1	1	-	-	-
Median TP (mg/l)	-	-	0.45	0.21	0.13	0.11	0.13	0.09	0.07	0.06	-	-

2. SWAT Model

SWAT (Soil Water Assessment Tool) model was selected to simulate different agricultural practices and BMP options in Crowfoot Creek. The SWAT model is a river basin scale, continuous time model that operates on a daily time step. The model can simulate a basin subdivided into sub-basins, and includes hydrology, weather, sediment yield, nutrients, pesticides, soil temperature, crop growth, tillage and residue and agricultural management practices components (Arnold et al., 1995). Model setup is defined based on sub-basins connected with the river network and smaller units called Hydrologic Response Units (HRUs), which represent a combination of land use, soil and slope. Areas with the same soil type, slope, and land use form a HRU, a basic computational unit assumed to be homogeneous in hydrologic response to land cover change. HRUs are non-spatially distributed assuming there is no interaction and dependency (Neitsch et al. 2005). SWAT simulates runoff, nutrients, and land management separately for each HRU, aggregated to the sub-basin level, and then routed to calculate total runoff and pollutant delivery at the outlet of each sub-basin and whole watershed. More detail on SWAT model descriptions and methodologies can be found in SWAT model documents at http://swat.tamu.edu/documentation/.

The SWAT model was calibrated for Crowfoot Watershed for the period of 1990-2011. Figure 1 shows the division of Crowfoot Creek into 21 sub-basins. A total of 76 HRUs was defined for this watershed. The current model setup (21 sub-basins and 76 HRUs) was defined based on limited available information on climate, hydrology, water quality, and agricultural management practices.

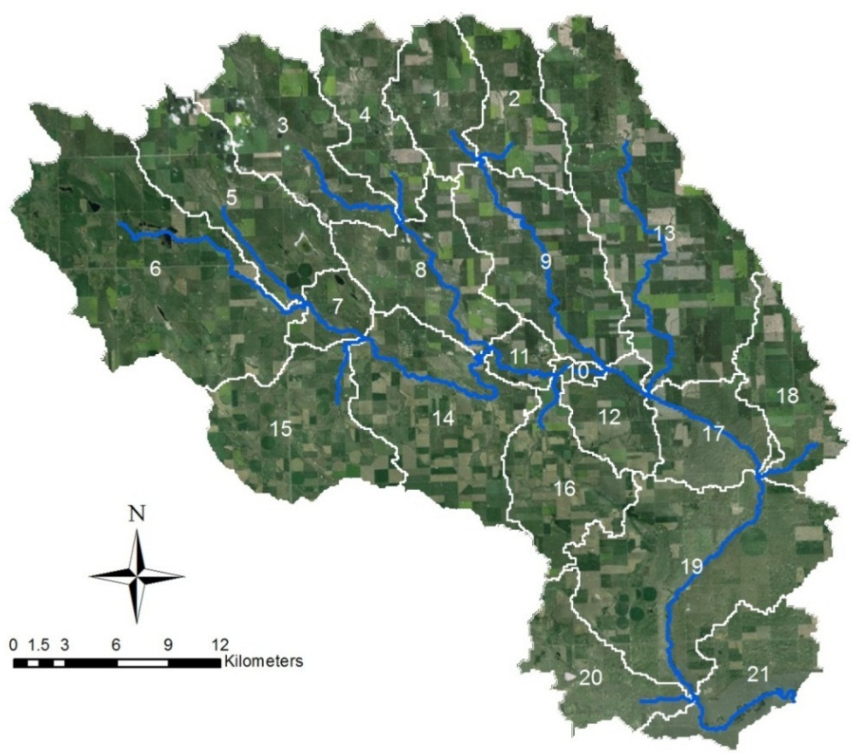

Figure 1. Delineation of Crowfoot Creek Watershed into 21 sub-basins.

3. BMP Scenario Options

1. Protection of Existing Wetlands

The Alberta Wetland Inventory layer was used in order to understand the status of existing wetlands in the Crowfoot Watershed. These inventories include a high resolution layer based on air photography (years of 2004-2007 and spatial resolution of 0.5 meter) and Spot layer based on satellite imagery (years of 2006-2008 and spatial resolution of 10 meters). Figure 2 shows the distribution of wetlands in the study area based on the Alberta Wetland Inventory layer, indicating that the majority of wetlands in this watershed are small and scattered across the watershed. In the SWAT model, each sub-basin can have one wetland (or pond). Therefore, all individual wetlands were aggregated as one single wetland function in each sub-basin. SWAT model calibration (base case) has been done based on these existing wetlands in the model. Therefore, in this exercise this option will be considered as the base case scenario for comparisons.

There is a lack of information on wetland characteristics including water quality information. Therefore, wetland function in SWAT should be defined based on some assumptions. The only information that was extracted from the Alberta Wetland Inventory GIS layer is the area of wetlands, which are shown in Table 2. Other necessary physical information such as wetland depth, volume of water at normal level and maximum conditions were estimated or assumed for the base case scenario. This option was considered the base case scenario and will be used for comparing impacts of the other proposed options on phosphorus reduction. Figure 3 shows simulation results for Total Phosphorus (mg/l) at Crowfoot Creek over the period of 1990 to 2007.

Table 2. The area (ha) of wetlands for each sub-basin in Crowfoot Creek Watershed based on Alberta Wetland Inventory Layer

Sub-basin	Surface area of wetlands at normal water level (ha)	Sub-basin	Surface area of wetlands at normal water level (ha)
1	30.58	12	49.38
2	77.40	13	476.18
3	166.28	14	195.25
4	176.99	15	183.84
5	305.54	16	142.23
6	413.20	17	95.61
7	86.01	18	169.85
8	126.45	19	413.44
9	195.04	20	186.32
10	6.55	21	85.03
11	19.65		

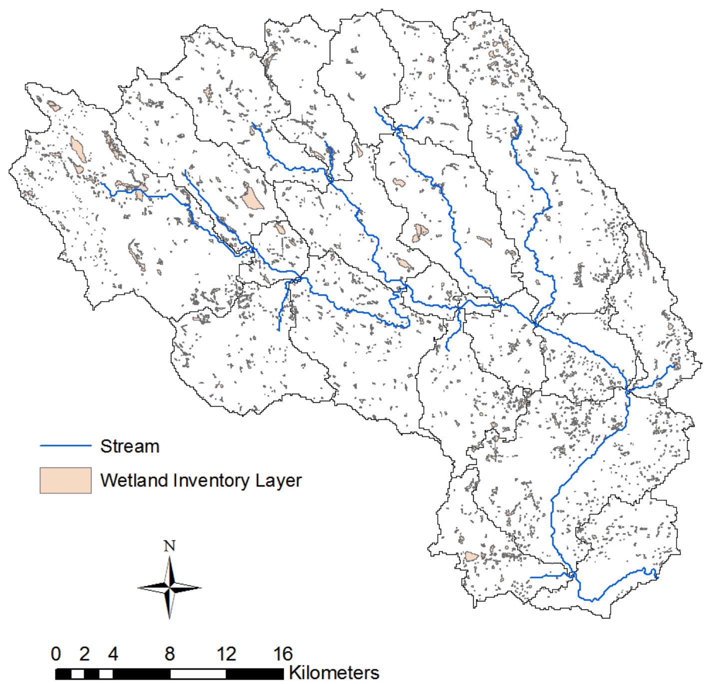

Figure 2. Distribution of wetlands in Crowfoot Watershed based on Alberta Wetland Inventory Layer

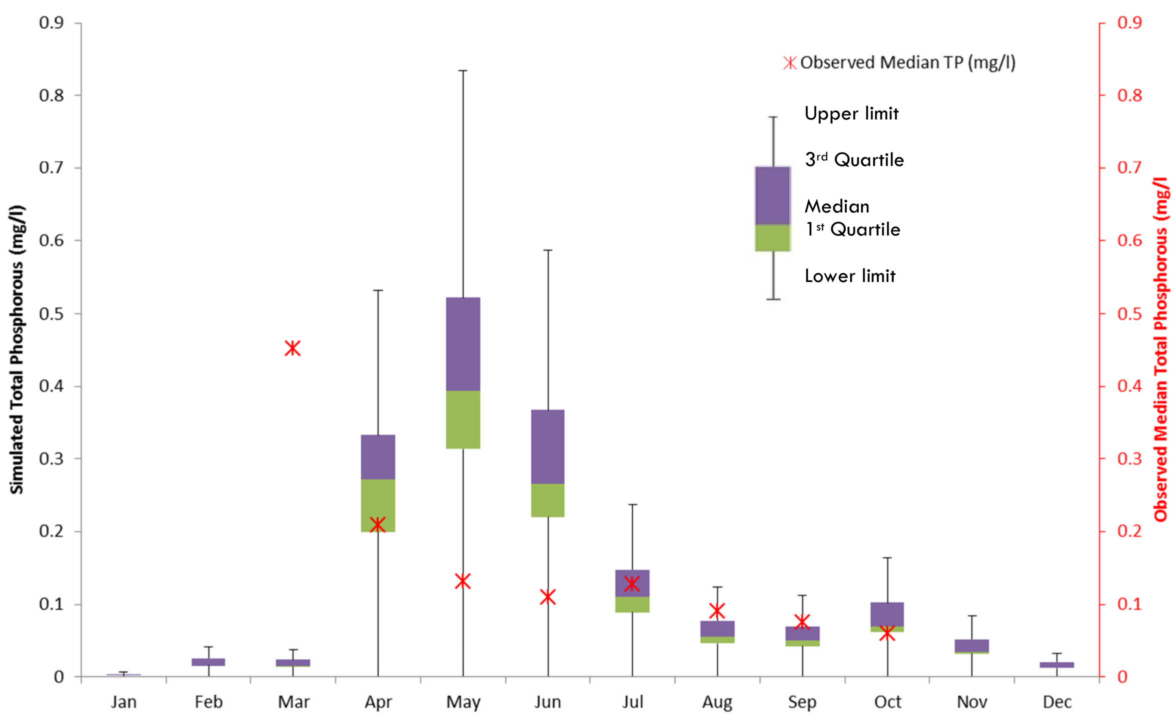

Figure 3. Simulated Total Phosphorus (mg/l) at Crowfoot Creek over simulation period of 1990 to 2007 using SWAT Model. Observed median TP (mg/l) in the period of 1995-2007 was used for comparison.

2. Restoration of Degraded/Drained Wetlands

To define wetland restoration options in the SWAT model we need to make assumptions on different wetlands characteristics such as physical properties, nutrients (phosphorus, etc.) and sediment settling rates, retention time, initial concentration of constituents, etc. These assumptions might be unrealistic due to the lack of sufficient information. Referring to literature and previous studies (i.e. Gehrels and Mulamoottil 1989; Ontkean et al 2003; Fisher and Acerman 2004; Braskerud 2005; Bruland and Richardson 2006; Montgomery and Fames 2008), wetlands might act as a phosphorus sink or source, depending on local conditions.

Following is a brief literature review on wetland functions.

Ontkean et al (2003) conducted a three-year study to examine the effects of a prairie wetland enhanced for waterfowl habitat on surface water quality in the Crowfoot Creek watershed. Monitoring was carried out at the Hilton wetland from mid-March to the end of October in 1997 to 1999 at two inflow sites and one outflow site. Data were collected on flow, total phosphorus (TP), total nitrogen (TN), total suspended solids (TSS), and fecal coliform (FC) bacteria. They showed that TSS concentrations decreased significantly from inflow to outflow, indicating sedimentation occurred in the wetland, but there was no significant change in nutrient status. The wetland acted as both a source and a sink for nutrients, depending on flow volumes. Comparisons of median TP levels between Inflow 1, Inflow 2, and the outflow showed concentrations decreased between Inflow 1 and the outflow in 1997, but increased in 1998 and 1999. However, variations in TP median concentrations were significant only in 1998. Median concentrations of TP increased significantly ($p < 0.05$) between Inflow 2 and the outflow in all three years. The lack of a significant reduction may be the result of insufficient residence time in the wetland for microbial and plant uptake to occur. Mitsch et al. (1995) suggested that low flow wetlands appeared to decrease TP concentrations more effectively than high flow systems.

The wetlands effectively trap suspended solids, but for nutrients it is difficult to generalize the fact for all wetlands. High initial removal rates of phosphorus by freshwater wetlands will be followed by large exports of P in a few years. Studies show wetlands had considerably different P sorption capacities (Bruland and Richardson, 2006). Montgomery and Fames (2008) showed that wetlands effectively trap suspended solids but act as a source of soluble reactive and total phosphorus to the river both during the growing and non-growing seasons. A case study in Ontario showed P export over the study period was 22% greater than imports to the wetland (Gehrels and Mulamoottil 1989). This could be due to releasing P during mineralization of organic matter and also by accumulation and release of bacterial P.

Another case study on 57 wetlands around the world showed 50% of the wetlands exhibited soluble P reduction, while 25% exhibited soluble O increase in P loading to receiving waters (Fisher and Acerman 2004). The fact is some of the wetlands may act as a P source, some others as sinks. The average total phosphorus retention in constructed wetlands varied from 1 to 88%, and dissolved reactive phosphorus retention from -19 to 89%. Retention varied substantially from site to site, indicating the existence of site-specific factors in the catchment and wetlands that influenced the P retention. Dissolved reactive phosphorus retention was higher in new than in old wetlands, while increasing age did not influence PP retention negatively (Braskerud, 2005). As a result, wetlands roles depend on many factors including flow conditions, wetland age, water residence time, and season etc.

3. Increase the adoption of livestock grazing and offsite watering systems in or near riparian areas

Filter (buffer) strip parameter was used in the SWAT Model to implement this option. Filter strips can be defined as vegetated areas that are situated between surface water bodies and cropland or grazing lands. Field buffer strips are installed along the edge of main channel. They are generally in locations where runoff water leaves a field with the intention that sediment, organic material, nutrients, and chemicals can be filtered from the runoff water. Figure 4 shows a hypothetical filter strip in the field that can be defined in the SWAT Model. Substantial over-wintering and grazing occurs adjacent to and within the creek bed, which is seen as a major source of summer constituents in the creek (Bonnell et al. 1999). Therefore, this option could be an effective scenario for phosphorus reduction in Crowfoot Creek.
Application of specific distance as field buffer strips on arable and pasture land can be defined in the SWAT model.

In this option, a 20 meter filter strip was defined in the model for 50% of the total length of all creeks in riparian areas with perennial forage land cover. The main assumption in this option is that target 20m buffer adjacent (in 50% of the areas) to flowing water will be applied only in 4% of areas dominated by perennial forages. Model simulation for this option shows a reduction of about 0.83% in total phosphorus and total dissolved phosphorus at the watershed outlet.

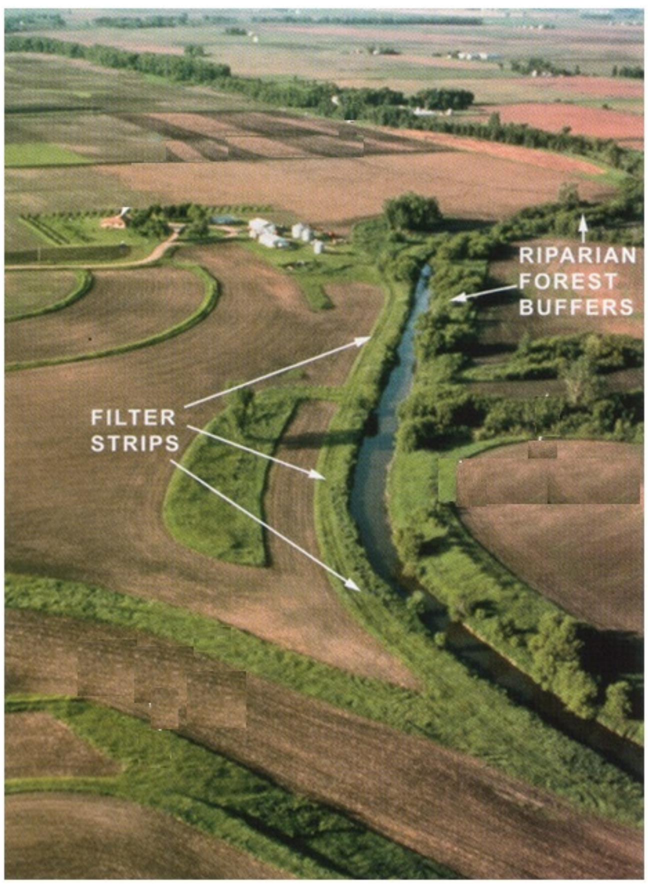

Figure 4. Hypothetical filter strip that can be defined in SWAT Model.

4. Manure Management and Spreading

The definition of manure spreading with specific proximity is an action at farm scale. The assumption for this option is that there should be rotation for spreading locations on 10% of average cultivated farms (1,500 acres). Current SWAT model configuration for Crowfoot Creek has been designed to simulate agricultural practices at HRUs or sub-basin scales and it is not practical to implement farm scale scenarios.

5. Cropland Conversion to Perennial Forage in Riparian Zone

The assumptions for this option is to Implement a cropland conversion to grass program adjacent to riparian areas, including set-back 20m from 50% of total length all creeks, streams and rivers in only 3% of currently cultivated areas. In this option, 20 meter filter strip was defined in the model for 50% of total length all creeks and streams in all converted croplands into perennial forage. Current crops in riparian zones were converted to perennial forage (alfalfa) at HRUs level. Model simulation for this option shows reduction of 3.5% and 3.6% in total phosphorus and total dissolved phosphorus, respectively, at the watershed outlet.

6. Cropland Conversion to Perennial Forage of In-field Gullies-Waterways

The assumption for this option is to implement a cropland conversion on gullies/waterways to perennial forage on cultivated farm size of 1500 acres. The 1% of total cultivated areas assumed are gullies which would be converted to perennial forage. Considering the assumption of 1% of total cultivated areas are gullies in the basin, this option as cropland conversion to perennial forage (alfalfa) was defined in only three HRUs (about 1% of total cultivated lands) in the model (total number of HRUs in the model setup is 76). Model output considering this land use conversion at the watershed outlet shows a reduction of 0.2% in total phosphorus and total dissolved phosphorus. Larger reductions might occur at specific sites (selected HRUs), but the percentage of reduction seems small for this option when we compare the results at the watershed outlet. Current SWAT model configuration for Crowfoot Creek is not ideal to simulate this option. However, a more detailed farm scale model is needed to accurately simulate small scale practices.

7. Riparian Fall Grazing within Cultivated Lands

This option is to limit grazing of riparian areas in predominately cultivated areas. It aligns with riparian grazing programs on smaller acreages, and is based on riparian grazing restriction within cultivated quarter sections. This option also looks at action at the farm scale, rather than HRUs or sub-basin level. It was not possible to apply this option to a specific area within HRUs or Sub-basins in the SWAT Model.

4. Comparison of BMP Options

In summary, four BMP options (scenario 1, 3, 5, and 6) were defined and modelled in the SWAT Model in this exercise. Figure 5 shows a comparison of the three options with regard to the base case scenario. Option 3 has the highest phosphorus reduction in comparison with base case scenario (about 3.5%). Phosphorus reduction in options 3 and 6 are lower than option 5 (0.83% and 0.2% phosphorus reduction, respectively).

It should be noted that percentage reduction was calculated based on average yearly reduction in loading, as there are variations in phosphorus reductions in different years (Figure 6). Figure 7 also shows monthly variation of phosphorus reduction (%) for different BMP options using 2007 as a sample. Therefore, scenarios are effective only in some of the years and months, and percentage of reduction is the overall average of annual reduction over simulation period of 1990-2007.

The following considerations should be noted before final conclusion based on the results of this modelling exercise.

First, the accuracy of these scenario modelling results depends on the scale in which scenarios were implemented. In fact, different scales are considered in the current model configuration and scenario definitions by stakeholders. Therefore, some differences between SWAT model scenario simulation and assumptions in the INFFER approach is expected. As a result, a more detailed farm scale model is needed to accurately simulate small scale agricultural practices.

Second, there is lack of enough observed data on irrigation return flow, water quality monitoring, wetland characteristics, and land management practices, etc. This will result in increased modelling errors, as the model is not able to capture all watershed processes properly. For example, flow and nutrient loadings are affected by irrigation return flow in this watershed. This will provide more complexity for the model to integrate natural processes (rainfall-runoff, hydrology, and nutrient transport) with human-made interruptions (irrigation diversion, return flow and loading) into the river system.

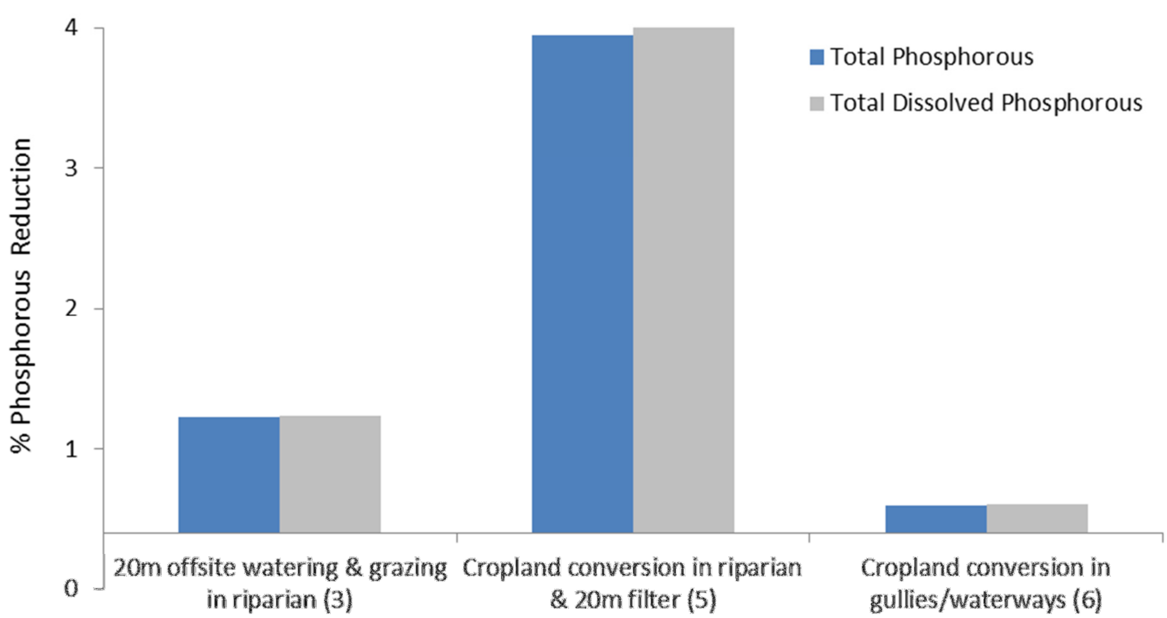

Figure 5. Phosphorus reduction (%) for BMP options in comparison with base case scenario for Crowfoot Creek. This graph is based on average of all simulated values over period of 1990-2007.

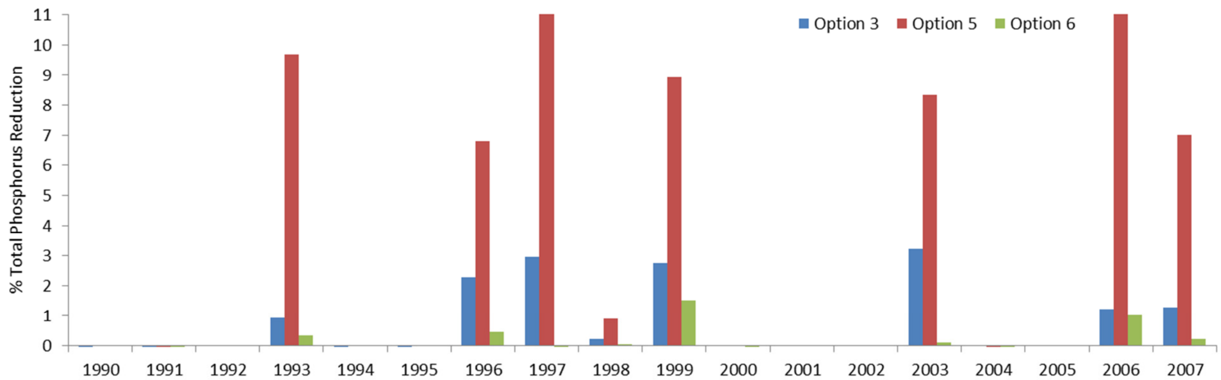

Figure 6. Annual Total Phosphorus reduction (%) for different BMP options

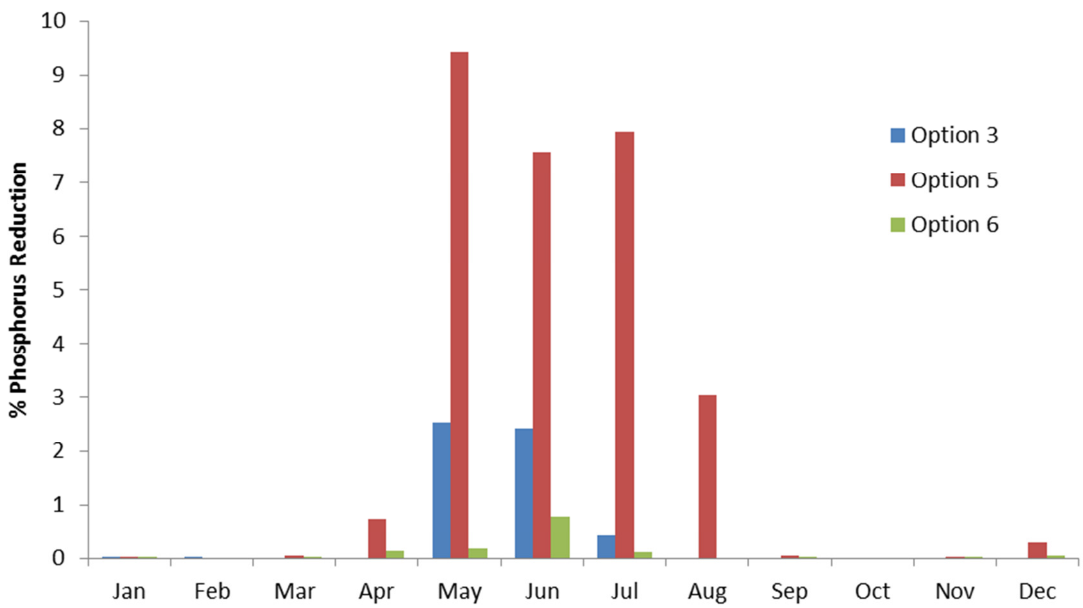

Figure 7. Monthly Total Phosphorus reduction (%) for different BMP options during year of 2007.

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