

MODELLING WATERSHED RESPONSES TO AGRICULTURE AND
FORESTRY IN THE POTATO BELT OF NORTH-WESTERN NEW
BRUNSWICK

by

F. Craig Fowler

BSc, University of Alberta, 2000

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of

Master of Science in Forestry

in the Graduate Academic Unit of Forestry and
Environmental Management, University of New
Brunswick, Fredericton, N.B.

This thesis is accepted.

.....
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

May 2003

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ABSTRACT

The objective of this Thesis was to model measured impacts of agriculture and forestry **on stream discharge, sediment loads, and chemical loads** in the potato belt region of north-western New Brunswick. The area that was chosen is the dominantly forested Little River basin (143 km²) which includes the Black Brook basin (14.5 km²) at St. Andre. This smaller basin is one of the experimental watersheds of the Agriculture and Agri-Food Canada, and is mainly used for potato cropping. For the smaller basin, detailed records about land management, weather, stream discharge as well as sediment and nutrient loads have been collected since 1990. Similar records for the forested portion of the larger basin are sparse, and only cover the period from **October 2000 to December 2001**. Based on these records, it was found that sediment loads and N and P losses as generated from the upland soils within the Black Brook basin were generally higher by an order of magnitude than similar losses from the forested portion of the Little River basin.

The SWAT modelling framework (SWAT: Soil and Water Assessment Tool) was used to estimate the impacts upland operations on stream discharge, on soil erosion losses and subsequent stream sediment loads (N and P). In this framework, upland conditions are represented by spatially homogeneous hydrological response units that represent each specific soil type and land use combination. With SWAT, discharge, sediment loss and nutrient losses are calculated for each of these units and are routed down-stream according to the local flow accumulation network, from the sub-basin level to the main stem of the stream. The spatial resolution of the hydrological response units depends on diversity of land-use, and number of recognized soil types. A decrease in field and soil differentiation leads to a decrease in specific hydrologic response unit assignments.

This Thesis provides a brief review and outline of the SWAT model and its application to the Black Brook and Little River Basins. This involves applying SWAT to the Black Brook Basin without calibration, to determine which parameters need site-specific calibration, and which parameters do not in terms of predicting stream discharge, sedimentation and N and P losses. A sensitivity analysis was done to determine whether a change in soil resolution would affect the SWAT calculations. The calibrated model was then applied to: the forested part of the Little River Basin, and the entire Little River basin, including the Black Brook Basin. All calculations were summarized at the monthly and annual scale. The following was found:

- Stream discharge calculations were somewhat affected by method used to estimate rates of evapotranspiration.
- Sediment losses required no additional calibrations but were based on the assumption that no soil conservation practices were put in place.
- Estimated values for N and P leaching were generally too low in comparison with the actual field observations.

- Reducing the resolution of the soil information from 7 to 2 soil types increased the calculated sediment yields by a factor of 7; in contrast, stream discharge increased by a factor of 1.2.
- For hardwood and mixed wood forests, SWAT simulated lower stream discharge and sediment yields than what was measured. For softwoods, these estimates were even lower.
- In reference to the entire LRB, stream discharge was underestimated by approximately 43 mm, and sediment yields were overestimated by approximately 7 t ha⁻¹.

Discrepancies between model calculations and field observations are mainly due to a number of key assumptions and related model formulations, as follows:

- Soil and land use within each hydrological response unit are not entirely uniform.
- SWAT calculates soil losses based on surficial sheet erosion; line sources such as stream channels, rills and gullies and point sources such as lagoons, ponds, and manure piles are not part of the SWAT algorithm.
- Failure to include nutrient point sources leads to strong underestimates of N and P losses from the agricultural basin.
- Failure to include line sources underestimates total sediment loads from forests and fields.
- Calibrating SWAT with the no soil conservation practice assumption leads to unrealistically high rates of sheet erosion estimates in order to compensate for essentially equivalent sediment losses from streams, rills and gullies.
- Since soil conservation practices are in place in many areas of the Black Brook Basin, it follows that actual sediment loss from this basin would be even higher otherwise.

Applying the SWAT model to any particular watershed with multiple land uses is a time consuming task. Time consuming matters deal with assembling and compiling relevant data and other pieces of information from varying sources. Pre-processing requirements for SWAT are also considerable in the sense that considerable efforts were involved for developing an artifact-free digital elevation model for the area. Since this is the first comprehensive application to SWAT to watersheds involving forestry and/or agriculture, much time was spent in the proper calibration of various SWAT parameters. Even at this stage, further testing and calibration activities are recommended before the SWAT model can be used to make reliable predictions regarding land-use dependent impacts on watershed-wide stream discharge, sediment loads and nutrient losses. Top that end, the model formulation needs to include year-by-year change in land use as forced by local crop rotations, and quantitative assessments regarding: soil erosion from line sources (stream channels, rills, and gullies), and nutrient losses from point sources (lagoons, ponds).

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ACKNOWLEDGEMENTS

Many thanks are owed to my supervisor Dr. Fan- Rui Meng and my advisors (Dr. Charles Bourque and Dr. Paul Arp) for their support and guidance. I also thank Dr. T.L. Chow and Mr. H.W. Rees from the Research Branch, Agriculture and Agri-Food Canada for providing me with resources for the Black Brook Basin. My appreciation is extended to W. Richards from the Meteorological Service of Canada, Environment Canada for weather data, C.F. Zhang for his help with land classification, and Mark Castonguay for his technical support. Finally, I am grateful to Karen O’Leary, my parents (Evelyn and Darrell), and brother (Christopher) for their continuing support and encouragement of my personal and academic endeavours over the years.

Agriculture and Agri-Food Canada and Fraser Paper Inc. funded most of the research that is described in this Thesis. Additional support was received from the Faculty of Forestry and Environmental Management, and from the Nexfor/Bowater Forest Watershed Research Centre at UNB.

CHAPTER 1

INTRODUCTION

1.1 Background

The goal of this thesis is to provide a means to estimate soil and nutrient losses from forested and non-forested watersheds within the Upper Saint John River Basin in New Brunswick. In this area, the terrain is undulating, with long and sustained slopes, and these slopes are overlain by easily eroded soils. Prior to settlement, soil erosion from this area was not a factor due to complete forest cover, ranging from softwoods in the valleys, to mixed woods and pure tolerant hardwoods on the slopes and ridges. After settlement, these soils were recognized for their excellent qualities for mixed farming, and for potato cropping in particular. Today, potato cropping is extensive, while the forest is (i) absent in the most intensively managed areas, (ii) fragmented in the marginal areas, (iii) still complete in the surrounding areas. Streams that drain the more intensively managed areas receive high quantities of soil sediment, such that streambeds are covered with a thick layer of silt near the end of the growing season. High flow rates in spring, however, flush these streambeds clean, but the silt that was temporarily stored there is moved further downstream into the St. John River.

1.2 Literature Review

Soil erosion from potato fields within has already been a subject of many studies, including studies within the Upper Saint John River Basin. For example, row

cropping of potatoes with stone removal, and lack of soil conservation measures has been demonstrated to exacerbate sheet and rill erosion, and loss of high-quality topsoil (Coote et al., 1981, Stephens et al., 1982; Saini and Grant, 1980). Studies have shown that average annual soil losses from potato (*Solanum tuberosum* L.) production ranges from 17-40 t ha⁻¹ (Chow et al., 1999; Chow et al., 1990; and Saini and Grant, 1980). Soil losses may translate into crop yield reductions of more than 30% (Cao et al., 1994, Chow, 1990). Economic costs resulting from reduced crop yields range from \$10-12 million dollars annually (Fox and Coote, 1986). Detrimental impacts of sediments and chemical loads on aquatic fish habitat and water quality have also been documented (Chow et al., 1995; International Joint Commission, 1983).

Soil erosion and stream pollution also occurs on forested land, but is less prevalent, and the processes involved differ from agricultural areas. For example, White and Krause (1993) stated that sedimentation is not directly related to forest harvesting, but is rather a function of the activities associated with the harvest transportation, e.g. road building, road maintenance (or the lack thereof), access trails, skidding, and tree processing. Krause (1974) also found elevated SO₄²⁻ levels with increased stream sedimentation loads. Rice et al. (1979) determined that watershed-wide annual sediment yield during four years subsequent to logging and road building amounted to 0.1 mm per year, and increased to 0.3 mm per year during logging operations. Sullivan (1985) and Fredriksen et al. (1975) found that slope steepness increased forest stream sedimentation. The effects of soil erosion are long lasting on stream habitat (Eidt, 1982).

This thesis focuses on studying soil erosion within the Little River Watershed (LRW) of the Upper Saint John River Basin. This study is facilitated by the availability of

- (i) intensive temporal and geo-spatial data useful for quantifying soil erosion by land-use and by watershed area,
- (ii) the Soil and Water Assessment Tool (SWAT).

The SWAT model has already been used in New Brunswick on at least two prior occasions: Yang (1997) used SWAT to estimate stream discharge, sediment loadings, nutrient loadings, and stream pesticide concentrations in the Black Brook Watershed (part of LRW). It was found that SWAT underestimated annual water yields and overestimated annual sediments. The model also overestimated annual and monthly losses of $\text{NO}_3\text{-N}$ and soluble P. The second study used SWAT to estimate non-point source pollution in three predominately-forested watersheds (Jacobs, 1996). It also concluded that SWAT over-estimates evapotranspiration, and that it is not well suited for simulating sediment yield from forestry land use. There were, however, a number of limitations in this study. Firstly, the same weather data were used to assess each of the three basins. Secondly, input data regarding land use and physical characteristics of the basin were poorly resolved. Thirdly, the “forestry” land use did not specify forest type or any other details. Lastly, any potential pollution point sources within the watersheds were ignored.

1.3 Objective

The objective of this study is to assess land use impacts on surface water quality in basins with agriculture and forest lands. Specifically, the SWAT model will be used to assess water quality in the Black Brook Basin (BBB, mainly agriculture), a predominately-forested sub-basin of the Little River Basin (LRB), and a basin with mixed forestry and agriculture.

Data for model calibration and particle verification were readily available from existing monitoring stations. Digital maps dealing with basin characteristics, soil type, and land use were used for the geo-spatial component of the required SWAT input. The compiling and characterizing the geo-spatial and temporal data, the building of the appropriate geo-spatial-SWAT input database, and the calibrating and checking the SWAT model output regarding stream discharge represent the main activities of this study. These activities are described in Figure 1.1.

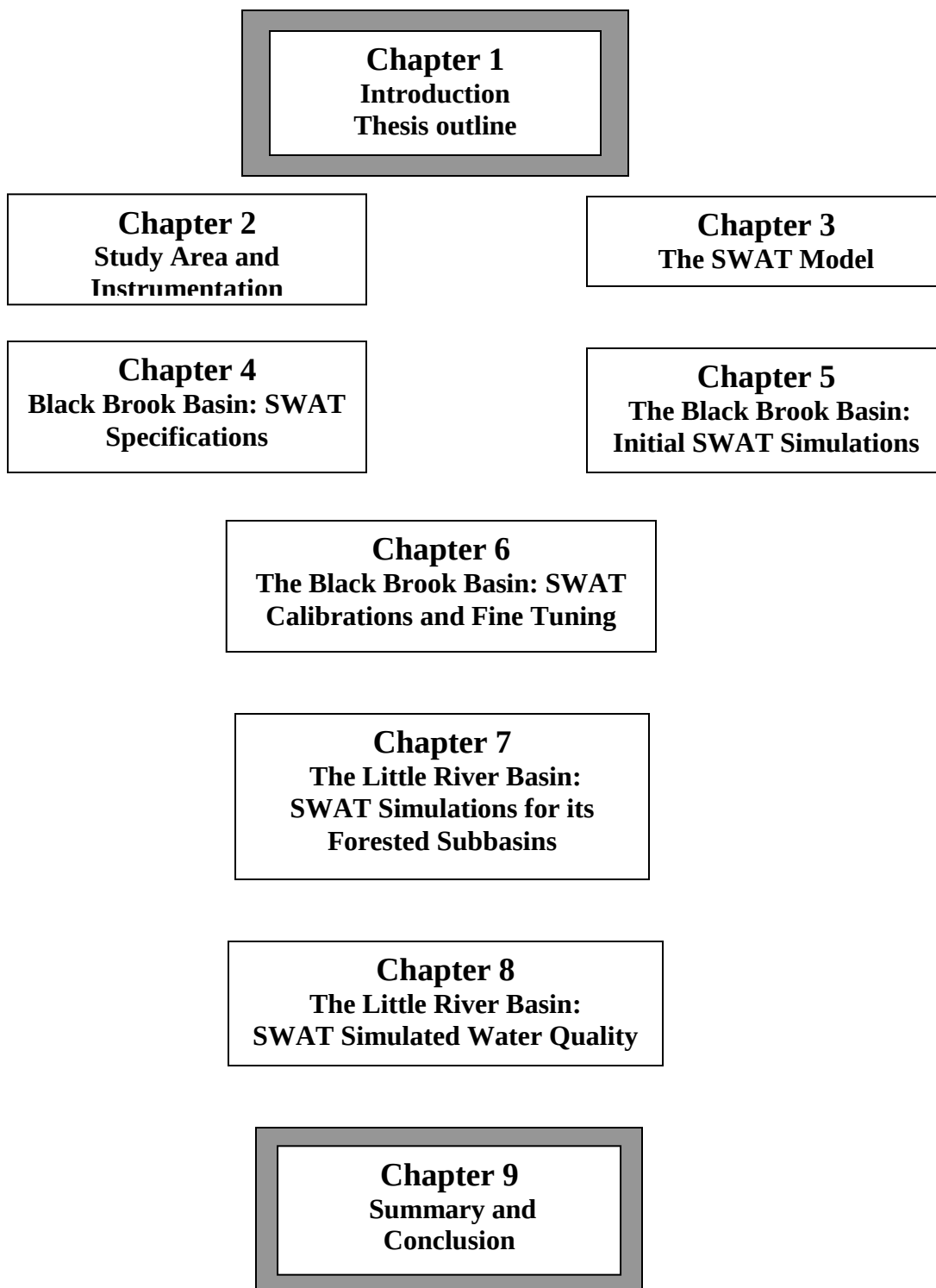


Figure 1.1. Thesis Structure....Revise this figure, titles of Chapters need to be revised

CHAPTER 2

THE STUDY AREA AND INSTRUMENTATION

2.1 Introduction

The Black Brook Basin (BBB) within the Little River Basin (LRB) has been a national benchmark basin to record and analyze relationships between soils, stream discharge, sediment yields, chemical loading, topographical features and potato cropping practices. As such, land-use, soils, stream discharge, soil and stream water quality and weather have been monitored since 1989. The resulting data are ideal for the SWAT modelling effort of this Thesis. This Chapter provides information on various geo-spatial features of the LRB and BBB, and on instrumentation.

2.2 Geography

The LRB straddles the Madawaska and Victoria county lines in New Brunswick. The Little River Basin (LRB) is approximately 380 km² and drains into the Saint John at Grand Falls, New Brunswick (Figures 2.1 and 2.2). It is located between 47°03' and 47°20'N and between 67°31' and 67°49'W. The Black Brook Basin (BBB), which is a subbasin of the LRB, is approximately 14.5 km² and is located between 47°05' and 47°09'N and between 67°43' and 67°48'W (Mellerowicz et al., 1993).

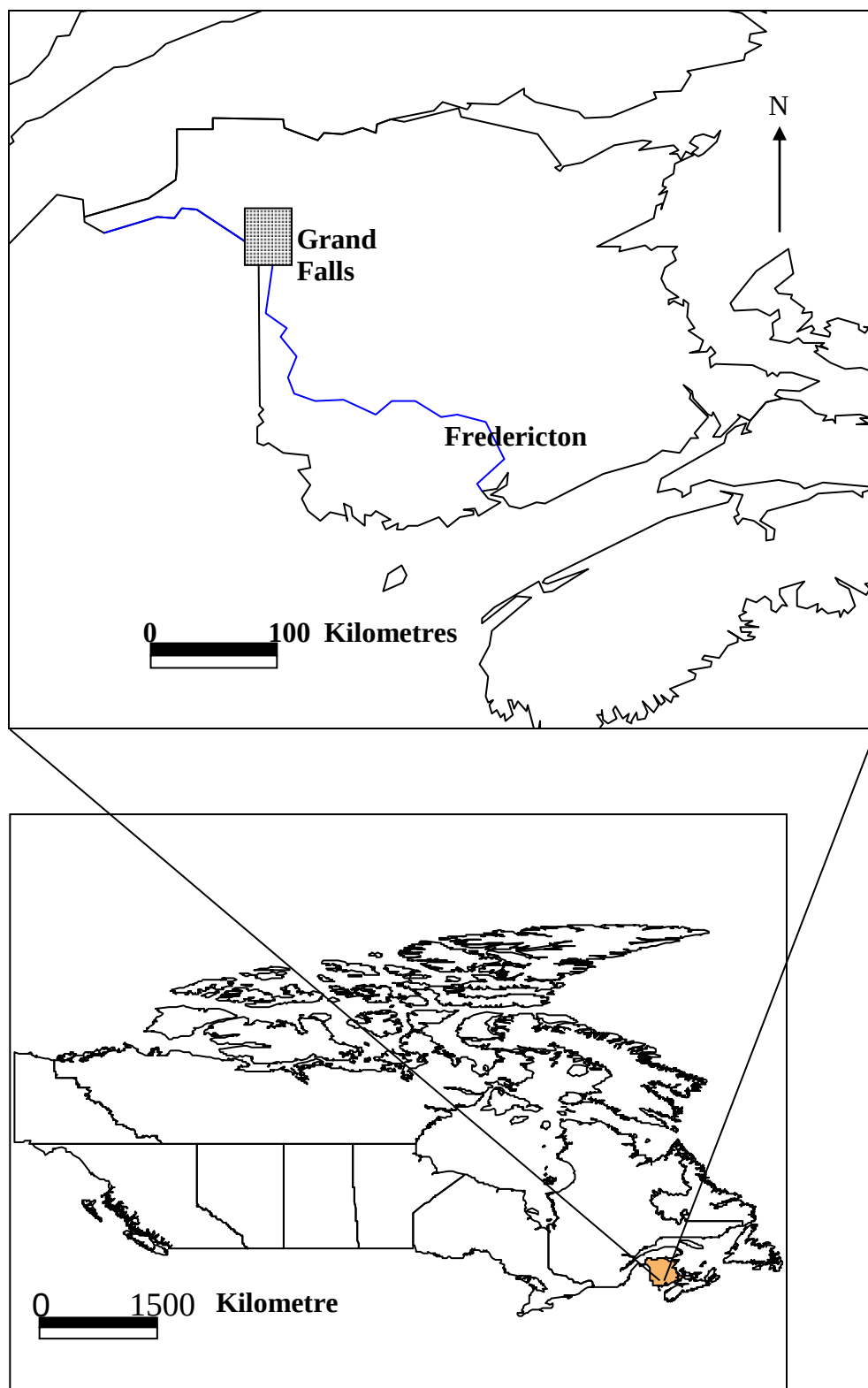


Figure 2.1. Site location of Little River Basin, north of Grand Falls, New Brunswick, Canada.

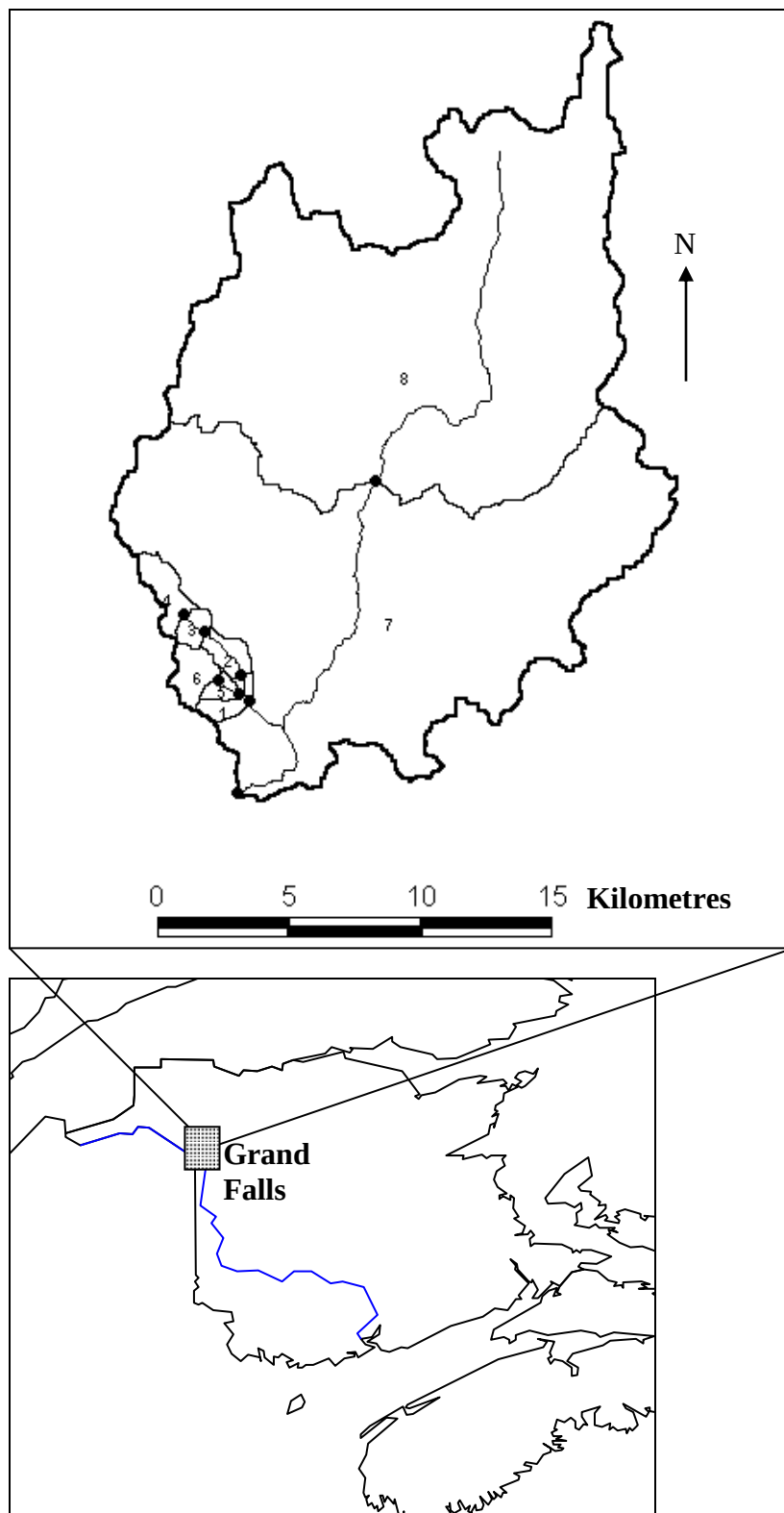


Figure 2.2. Subbasins, outlets (weir stations), and model generated stream network of Little River Basin.

The climate associated with the watershed is moderately cool boreal (Langmaid et al., 1980) with a humid to perhumid moisture regime with approximately 120 frost-free days per year. Average annual rainfall, snowfall, and daily temperatures are 730.7mm, 306.7cm, and 3.7°C respectively (Mellerowicz et al., 1993).

Elevation ranges from 160 to 410 m above mean sea level in the LRB (Figure 2.3) and ranges from 180 to 260 m above mean sea level in BBB. Most of the area is on a plateau that is characterized by gently rolling and undulating topography. Most of the BBB is undulating to gently rolling with slopes of 1-6% in the upper portions and slopes of 4-9% in the central parts. In the lower portions, slopes are more strongly rolling at 5-16% (Mellerowicz et al., 1993).

The geological material of the area is mostly Ordovician and/or Silurian calcareous and argillaceous sedimentary rocks (shale, slate, limestone). Volcanic rocks also exist. The major glacial influence on the area resulted from the Wisconsin ice sheet. Surface deposits are glaciofluvial and morainal containing mixed sand, gravel, silt, and stones (Mellerowicz et al., 1993; Langmaid et al., 1980; Langmaid et al., 1976).

Figure 2.4 illustrates the spatial extent of the soil types found within LRB. The following soil associations were mapped in the LRB: Caribou, Carlingford, Glassville, Grand Falls, Holmesville, McGee, Muniac, Ogilvie lake, Siegas, Thibault, Undine, Victoria, and Waasis. The soils within the area were mapped at a scale of 1:50000 (Langmaid et al., 1980) or 1:63360 (Langmaid et al., 1976). At the scale of

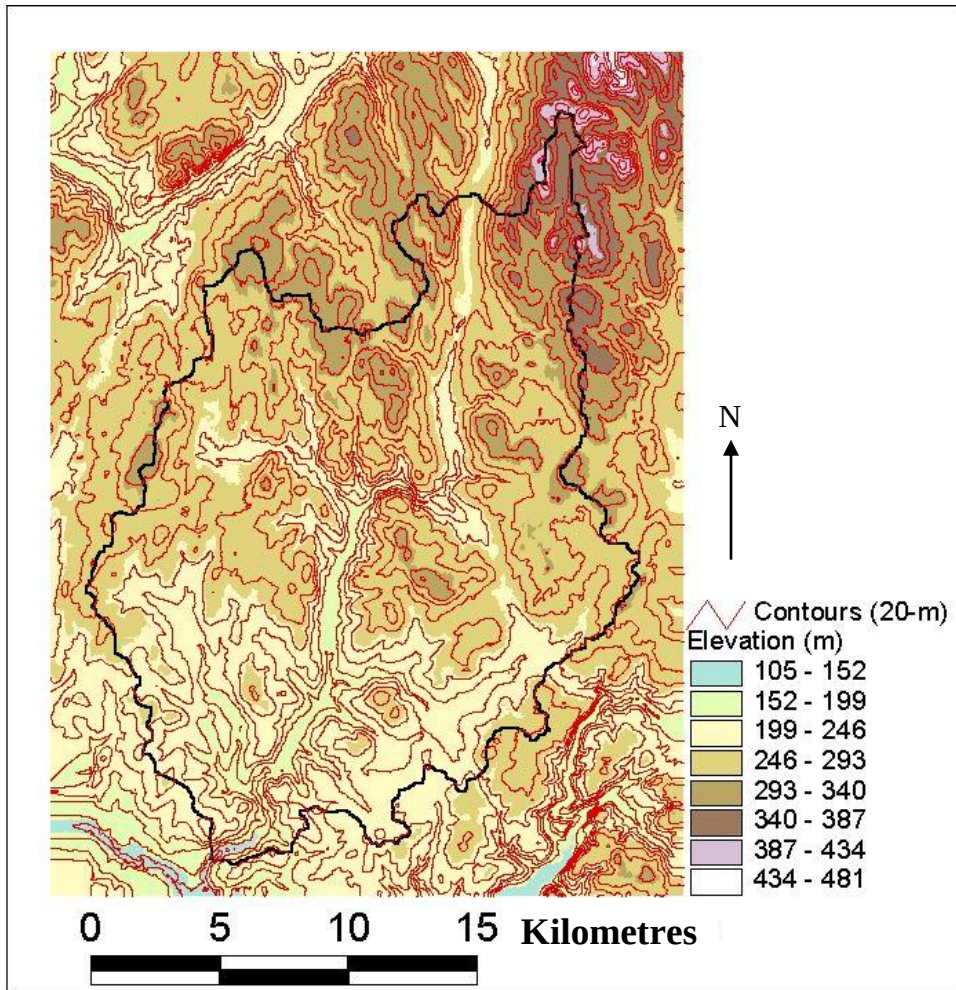


Figure 2.3. Topography and elevation of the Little River Basin.

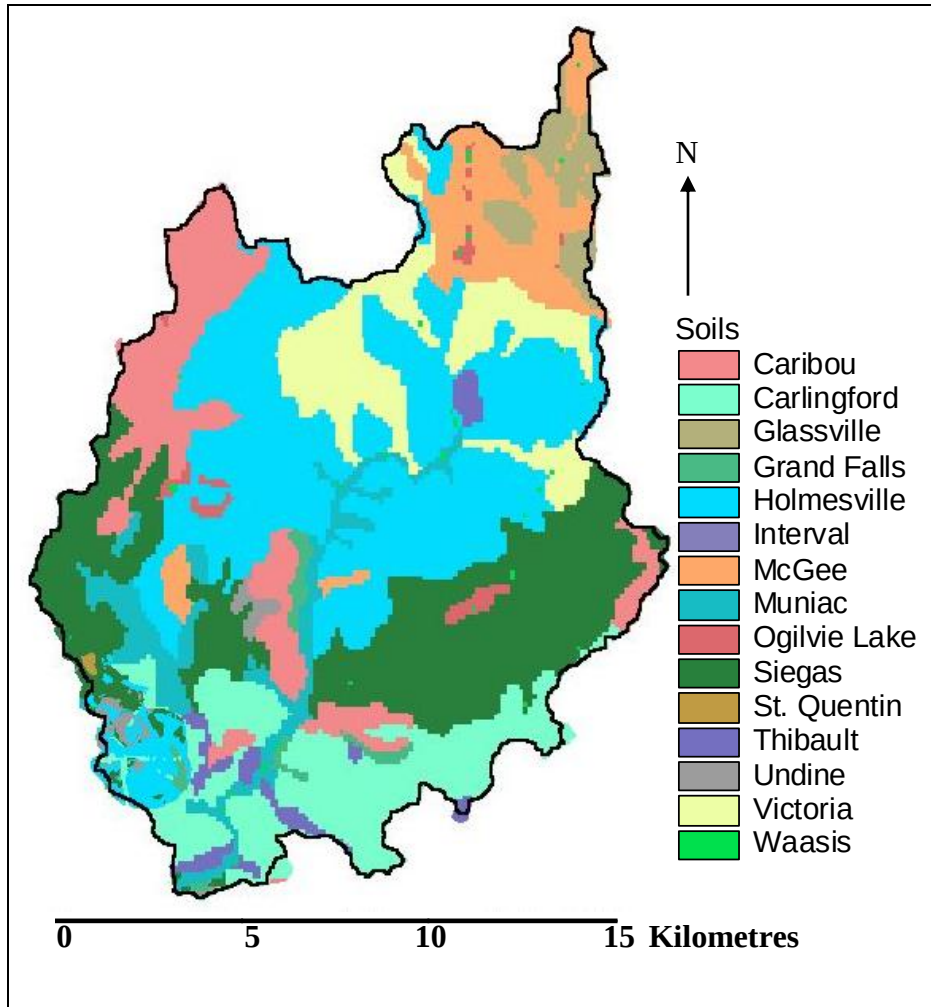


Figure 2.4. Distribution of soil series in Little River basin.

1:50000, only the Siegas and Carlingford associations occur in the BBB subbasin. However, a detailed soil inventory at a scale of 1:10000 identified six mineral soils and one organic soil for BBB (Figure 2.5) (Mellerowicz et al., 1993). They are: Grand Falls, Holmesville, Interval, Muniac, Siegas, Undine, and St. Quentin (organic). All soils within LRB are classified as mineral soils and derived from various geological parent materials.

According to Mellerowicz et al., (1993), a number of tree species can be found in the forested areas. Dominant species include eastern cedar (*Thuja occidentalis*); black spruce (*P. mariana*), white spruce (*P. glauca*), and red spruce (*Picea rubens*); balsam fir (*Abies balsamea*); white (*Betula papyrifera*) and yellow birch (*Betula alleghaniensis*); red maple (*Acer rubrum*); sugar maple (*Acer saccharum*); beech (*Fagus sylvatica*); balsam poplar (*Populus balsamifera*); and trembling aspen (*Populus tremuloides*). Larch (*Larix decidua*), striped (*Acer pensylvanicum*) and mountain maples (*Acer glabrum*), speckled alder (*Alnus rugosa*), pin cherry (*Prunus pensylvanica*), beaked hazel (*Corylus cornuta*), shadbushes (*Amelanchier arborea*, *laevis*) and willows (*Salix sp.*) are also present. Ground vegetation includes wood sorrel (*Oxydendrum arboreum*); starflower (*Teientalis borealis*); goldthread (*Coptis trifolia*); twinflower (*Linnea borealis*); yellow clintonia (*Clintonia borealis*); false lily of the valley (*Maianthemum sp.*); bunchberry (*Cornus canadensis*); blackberry (*Rubus argutus*); raspberry (*Rubus idaeus*); sphagnum (*Sphagnum cuspiatum*); mountain-fern (*Oreopteris limbosperma*); Schreber's (*Pleurozium schreberi*), plume (*Ptilium crista-castrensis*), broom (*Dicranum sp.*), and mniium (*Mnium hornum*) mosses; shining clubmoss (*Huperzia lucidula*); and bracken

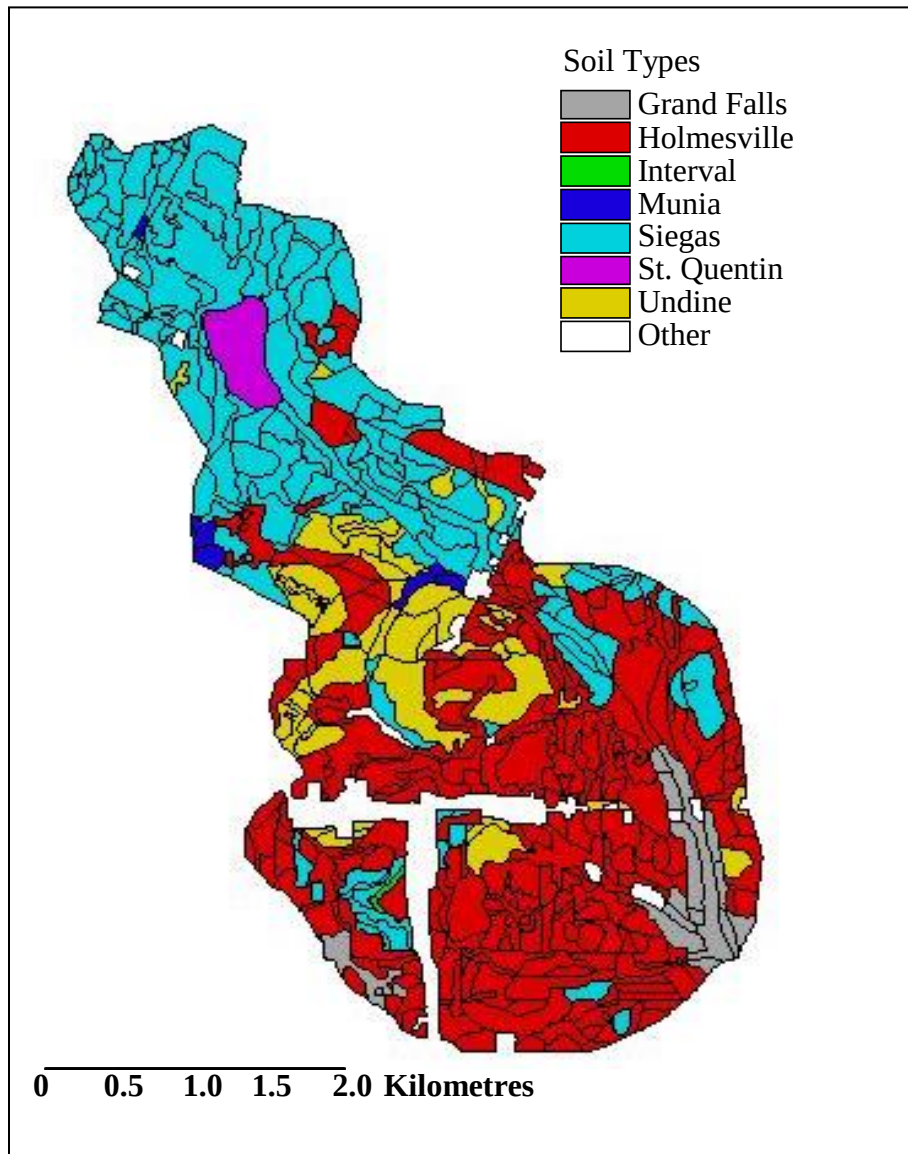


Figure 2.5. Distribution of soil series in the Black Brook Basin (after Mellerowicz *et al.*, 1993).

(*Pteridium aquilinum*), wood (*Dryopteridaceae*), and ostrich ferns (*Matteuccia struthiopteris*).

Forestry activities dominate the Little River Basin (LRB) with approximately 15% of the area is allocated to agriculture including the Black Brook Basin (BBB). The major land use within the BBB is agricultural and approximately 1050 ha out of the total area of 1450 ha are devoted to farming. The major cash crop is potatoes, followed in rotation with grain, peas, and hay for forage (Mellerowicz et al., 1993).

2.3 Instrumentation

Five weather stations within BBB (Figure 2.6) have monitored climatic since 1992. Variables measured are air temperature, relative humidity, rainfall amount and intensity, incoming radiation, and solar radiation.

Locations of weirs were determined by topographical attributes, soil conditions, and cropping and management practices (Chow et al., 1995). Each weir has an associated stilling well connected to it by subsurface piping. The stilling well prevents extraneous sources of disruption that may cause turbulence and affect the measurement of stage height.

Weirs consist of a composite triangular V-notch with a rectangular profile. The opening of the notch is 90° with the sides of the notch are orientated 45° from the vertical. Figures 2.7 through 2.10 show weir stations located in BBB and illustrate the V-notch design. This design is intended to capture accurate baseflow measurements while at the same time, have the capacity for peak flow periods. The

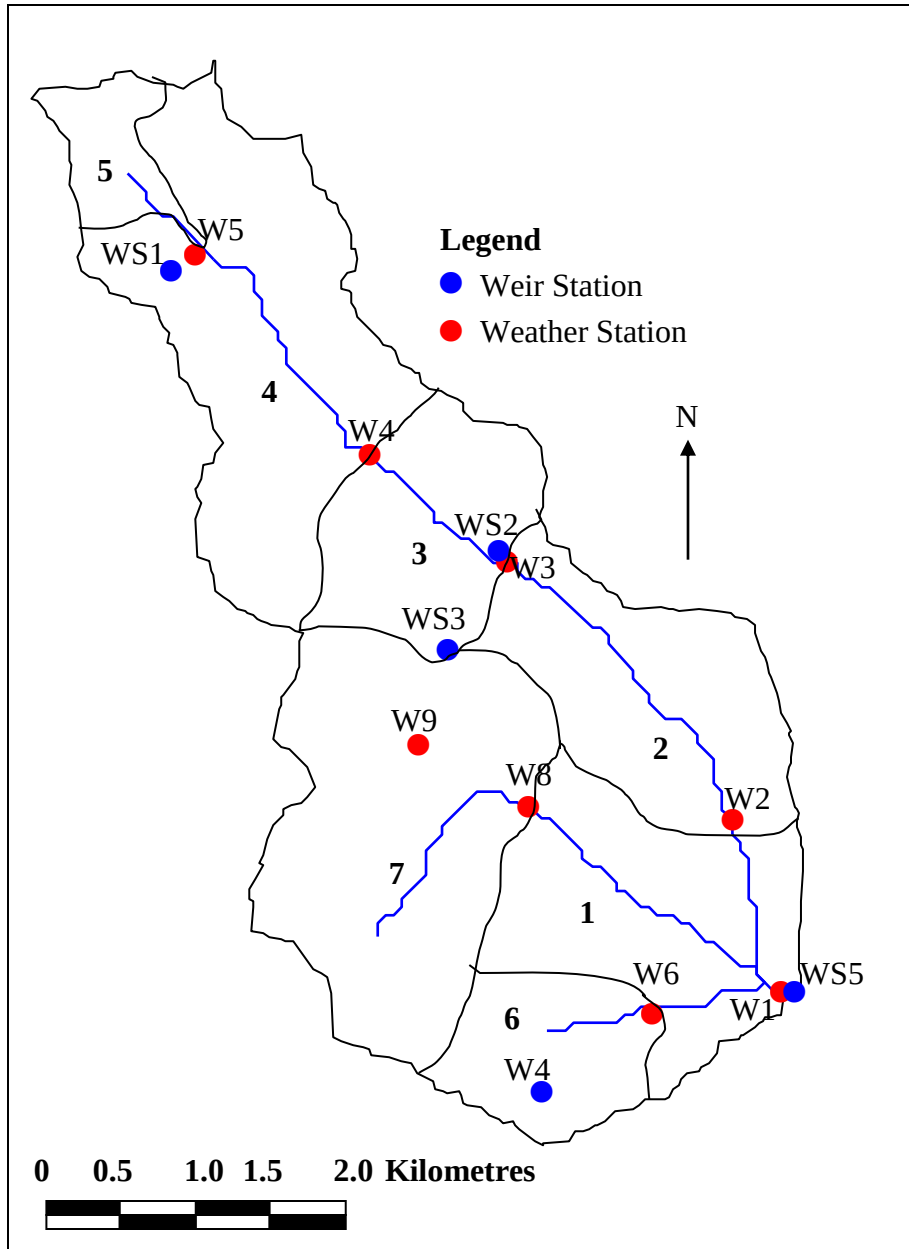


Figure 2.6. Monitoring network within the Black Brook Basin.



Figure 2.7. Example of composite V-notch and rectangular weir design.

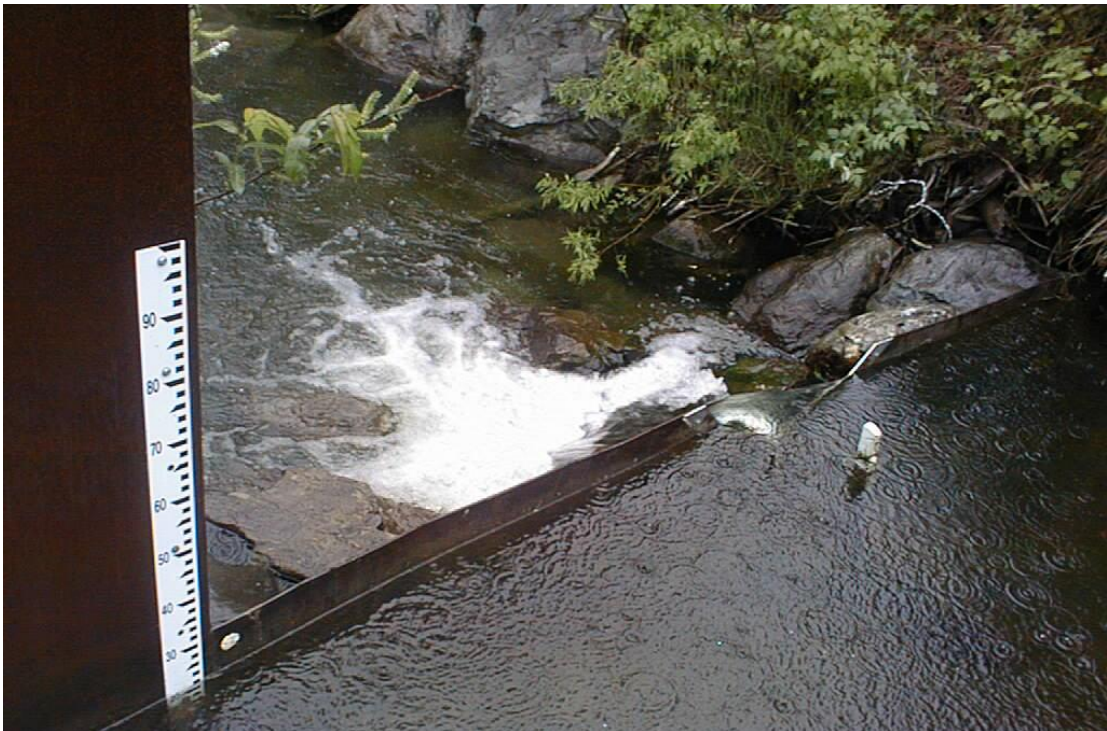


Figure 2.8. Example of composite V-notch and rectangular weir design.



Figure 2.9. Example of composite V-notch and rectangular weir design.



Figure 2.10. Example of composite V-notch and rectangular weir design.

larger capacity rectangular section of the weir accommodates higher flow conditions. Weirs were positioned adjacent to existing culverts when possible. Here, the design is different in that it utilizes a 152° opening, which was used to minimize problems with reducing flow through the culvert (Chow et al., 1995).

Two stream monitoring stations (Weirs 12 and 14) were constructed in September 2000 on the Little River (Figure 2.11). Discharge at these sites was determined by measuring changes in stage height, stream velocity, and determining the cross-sectional area of the stream. Velocity is measured with a current meter and is positioned at 70% depth of the stream. A stage-discharge rating curve was created and the area under the curve was integrated to determine discharge. Stilling wells with float operated water recorders are also utilized at all sites, and are automated using a transducer. Heated instrument shelters were constructed to protect instrumentation.

2.4 Sampling Frequency

Samples were collected at a predetermined rate of one sample every 72 hours. Sampling frequency increased with one sample for change of stage height greater than 5 cm. Data is collected and stored using a Campbell-Scientific CR10X data logger (Figure 2.12). Water samples were collected with an ISCO automatic sampler (Figure 2.13). Samples were analyzed for concentrations of calcium, sediments, nitrates, phosphorous, potassium, and magnesium at the Potato Research Centre in Fredericton.

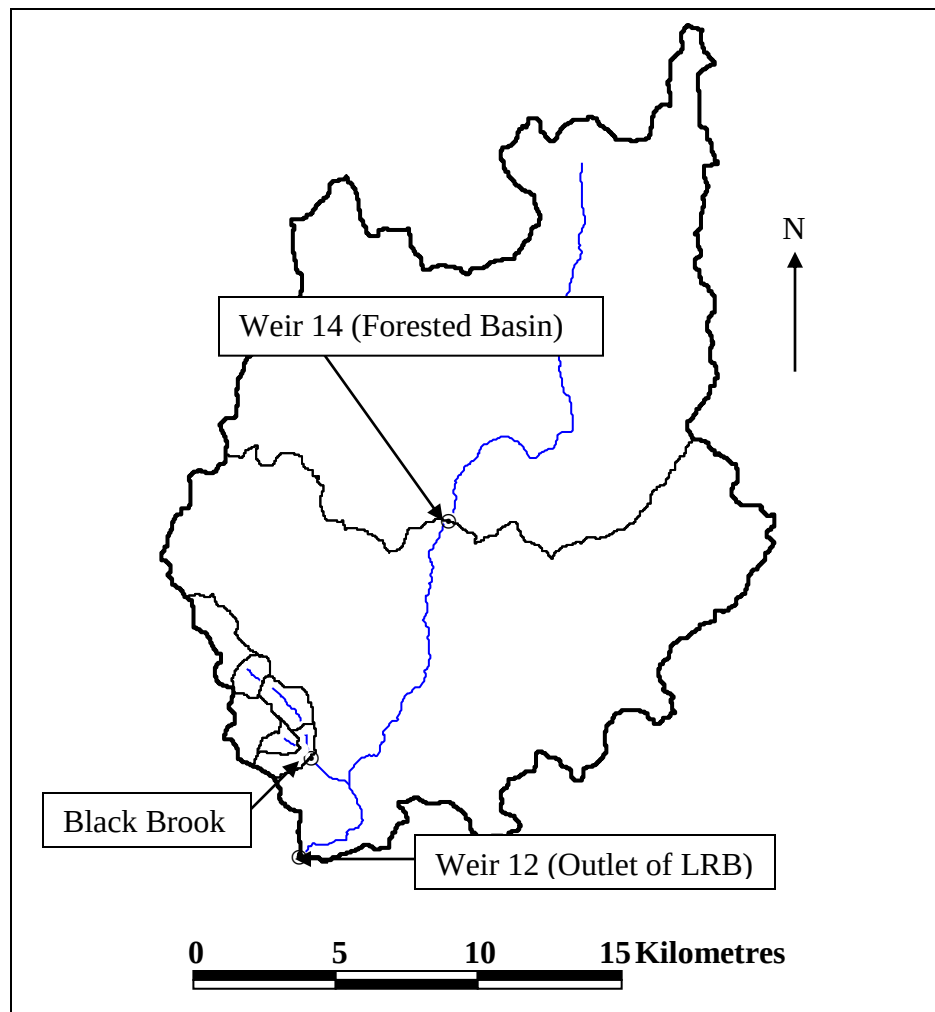


Figure 2.11. Installation location of weirs 12 and 14.

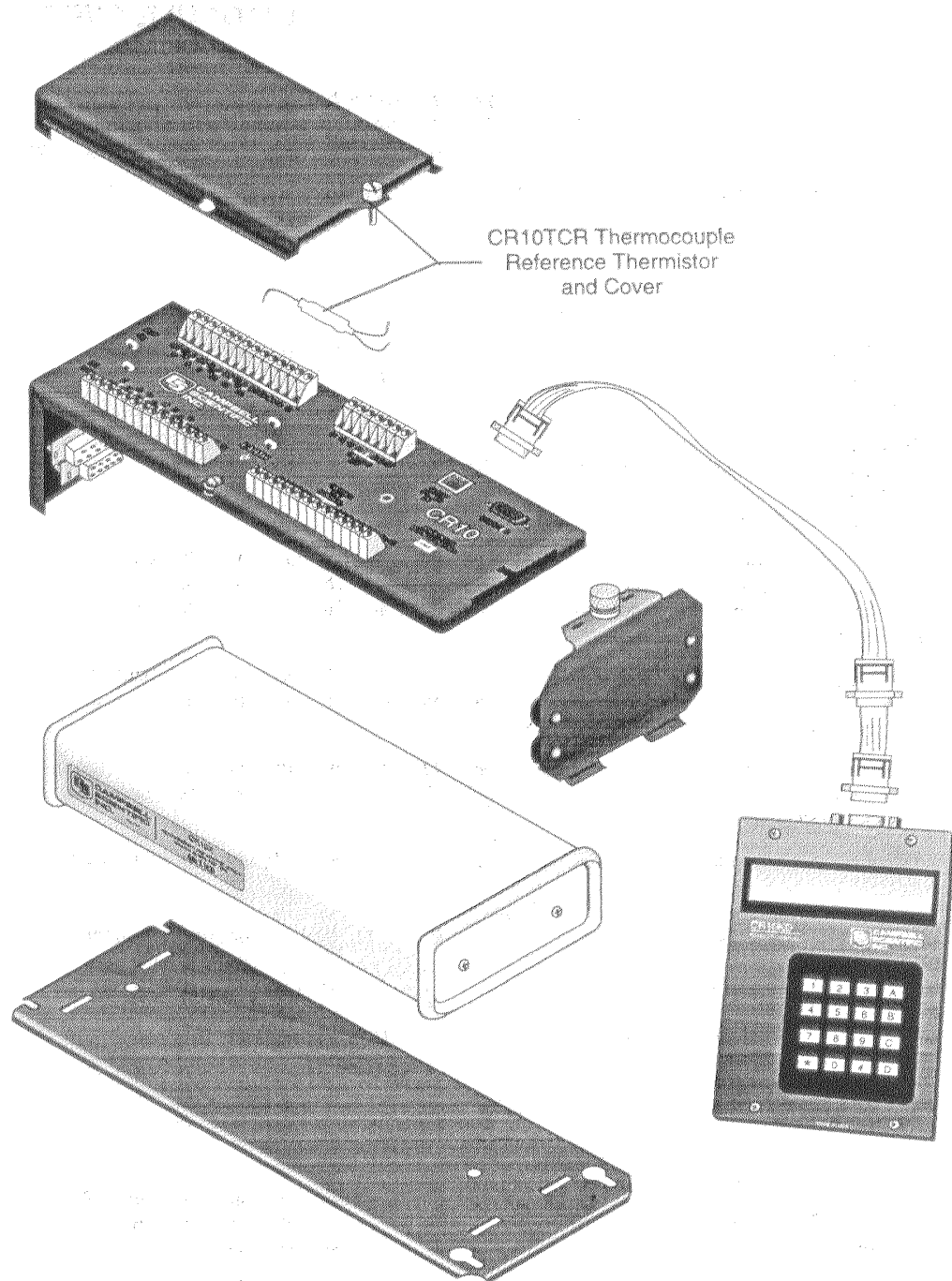


Figure 2.12. Diagram of Campbell Scientific CR10X data logger (Adapted from the User's Manual by Campbell Scientific)



Figure 2.13. Representation of typical ISCO automated water sampler used at monitoring stations (Internet, 2003).

2.5 Results

Data organization, synthesis, and summarization have been an ongoing process in BBB and LRB. Tables 2.1 and 2.2 present data not previously published and are a direct result of the research done by the team headed by Dr. Chow of Agriculture and Agri-Food Canada in Fredericton, New Brunswick, Canada. Stream discharge from the BBB for 1995 to 2001 ranges from 386.86 mm (2001) to 750.13 mm (1996) (Table 3.1). Sediment yield for the 15-month period is the most concentrated from the agricultural basin at 2.352 t ha^{-1} (Table 3.2), while at the outlet of the forested portion, the sediment yield is 0.232 t ha^{-1} .

Table 2.1. Stream discharge at outlet of Black Brook Basin (14.5 km²) from 1995-2001.

		Discharge (mm)							
Year		1995	1996	1997	1998	1999	2000	2001	Average
Month	1	34.32	93.08	15.13	127.75	22.07	17.7	18.36	46.92
	2	13.99	118.98	16.44	126.61	18.07	12.41	11.31	45.40
	3	24.11	81.65	19.32	152.69	174.34	110.46	19.81	83.20
	4	168.8	112.04	122.43	121.24	105.55	181.54	166.51	139.73
	5	112.86	73.62	105.57	37.66	29.55	46.58	45.64	64.50
	6	34.22	38.55	43.51	9.11	9.9	26.48	24.43	26.60
	7	11.75	36.69	51.99	27.33	4.99	25.13	25.32	26.17
	8	5.33	14.75	34.99	5.62	4.85	14.99	15.15	13.67
	9	2.39	15.96	33.43	6.88	21.13	11.66	15.32	15.25
	10	3.89	30.59	30.07	20.2	31.4	12.33	13.26	20.25
	11	32.06	61.68	47.33	16.98	45.48	19.59	13.54	33.81
	12	24.54	72.55	41.64	34.11	56.52	39.58	18.22	41.02
Total		468.25	750.13	561.84	686.18	523.86	518.44	386.86	556.51

Table 2.2. Summary of measured data collected in agricultural basin (14.5 km²) forested portion of LRB (180 km²) and at the outlet of LRB (357 km²) (Chow, 2002).

		Agricultural Basin (BBB)		Forested Portion		Outlet of LRB	
Year	Month	Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)	Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)	Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)
2000	10	12.33	0.013	20.08	0.001	17.28	0.004
	11	19.59	0.021	33.26	0.003	31.16	0.050
	12	39.58	0.390	76.05	0.010	91.32	0.042
2001	1	18.36	0.006	57.87	0.018	58.32	0.002
	2	11.31	0.005	48.00	0.003	59.05	0.002
	3	19.81	0.007	50.37	0.005	63.37	0.002
	4	166.51	1.675	85.87	0.010	68.83	0.162
	5	45.64	0.122	112.31	0.012	112.59	0.014
	6	24.43	0.008	48.27	0.006	40.75	0.005
	7	25.32	0.065	48.16	0.147	43.92	0.154
	8	15.15	0.007	22.98	0.003	17.53	0.021
	9	15.32	0.009	21.58	0.002	16.94	0.005
	10	13.26	0.010	23.25	0.005	21.54	0.008
	11	13.54	0.010	26.32	0.003	19.09	0.005
	12	18.22	0.004	36.33	0.004	33.11	0.009
Total		458.36	2.352	710.70	0.232	694.8	0.483

CHAPTER 3

THE SWAT MODEL

3.1 Introduction to SWAT

With the advent of the Clean Water Act in the United States in the 1970's – and similar legislation in the rest of the world - many Hydrologic Water Quality (HWQ) models have been developed to improve predictions of local stream discharge, surface runoff, sediment and chemical loadings, and pesticide routing in response to upland variations in soils, climate, and land use. Among these models, SWAT is perhaps the most frequently used modelling framework for general watershed assessments, especially in agriculture.

SWAT was developed in the early 1980's by the Agricultural Research Service branch of the United States Department of Agriculture (Neitsch et al., 2000). Five new versions have been released since then. The most recent versions are compatible with the Windows computing platform (Visual Basic), and with ArcView by way of an ArcView extension. This extension allows the user full access to the ArcView program, to facilitate ready visualization of topography and other geo-spatial variations (Luzio et al. 2002).

SWAT is, essentially, a generic modelling frame for conducting geo-spatial analysis of water flow from uplands to streams. As such, SWAT development is an ongoing upgrading process, and incorporates many modelling components as summarized below and as illustrated in Figure 3.1:

- AGNPS (Agricultural Non-Point Source model; Young et al., 1987)

- CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems; Knisel, 1980)
- GLEAMS (Groundwater Loading Effects on Agricultural Management Systems; Leonard et al., 1987)
- EPIC (Erosion-Productivity Impact Calculator; Williams et al., 1984)
- SWRRB (Simulator for Water Resources in Rural Basins; Williams et al., 1985; Arnold et al., 1990)
- ROTO (Routing Outputs to Outlet; Arnold et al., 1995).
- GRASS (Geographic Resources Analysis Support System; US Army, 1988, , with geographic display interface)
- MUSLE (Modified Universal Soil Loss Equation; Williams and Berndt, 1977) has also been incorporated into SWAT
- incorporating the Penman-Monteith potential evapotranspiration equation and other evapotranspiration formulations
- improving snow melt routines, weather generator routines, and nutrient cycling routines.

SWAT has been applied to various watershed and water quality studies around the globe, including forestry (Saleh et al., 2000; Srinivasan et al., 2000; Rosenberg et al., 1999). Thus far, SWAT recognizes five tree types as individual land covers, and four land cover types. Tree types refer to apple (*Malus domestica* Borkh.), pine (*Pinus*), oak (*Quercus*), poplar (*Populus*), and honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*); land cover types refer to forest-mixed

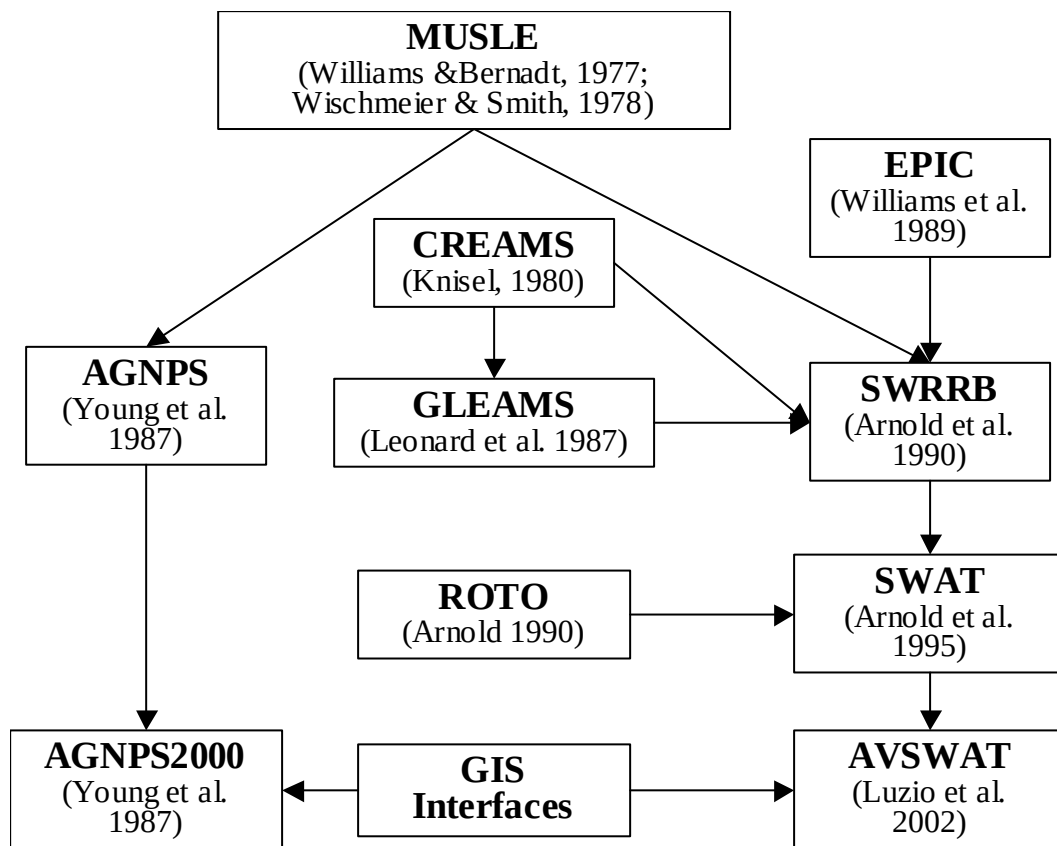


Figure 3.1. Evolution of SWAT model (Adapted from Yang, 1997).

(oak), forest-deciduous (oak), forest-evergreen (pine), and wetlands-forested (oak) (Neitsch et al. 2000).

The following sections provide information and detail about the basic SWAT modelling process, and this is presented in terms of five sections, namely

- Data pre-processing (3.2)
- Watershed delineation (3.3)
- Land use and soil characterization (3.4)
- Hydrological response unit formulation (3.5).
- Generating SWAT- ArcView interface files (3.6)
- Running SWAT (3.7)
- Generating output files (3.8)

3.2 SWAT Pre-processing

Pre-processing of data is required before a project can be created. For example, to create a SWAT database, ArcView themes and database files must be already compiled. ArcView map themes that are required are a digital elevation model (DEM), land cover, land use, and soil type. The DEM needs to be in ArcInfo-ArcView GRID format, while the land use and soil themes can be either ArcInfo-ArcView GRID or Shape format, but all themes are eventually converted to a raster format by the model interface. A DEM mask (concentration area on the DEM) or stream definition theme is optional. The current SWAT-user interface allows the option of having database information in either a *.dbf or *.txt format. The SWAT

formatting requirements are described in the ArcView interface manual for SWAT (e.g., The model operates within ArcView™ GIS 3.2a ; Diluzio et al. 2001).

The local requirements and scope of the project determine which tables need to be compiled. Figure 3.2 illustrates the interrelationships among the different parts involved with a SWAT project.

Two phases are involved with the SWAT modelling (Neitsch et al. 2000):

- Phase 1 deals with the structure and spatial relationships of the catchment.
- Phase 2 emphasizes the routing of specific soil, stream, climatic, and management (land use) impacts that ultimately determine the specific yield or loading of streams in terms of sediments, nutrients, and pesticides. By delineating each catchment into subbasins, and each subbasin into hydrological response units (HRUs), relative magnitude and distribution of stream discharge, sediment and nutrient loading can be modelled throughout each watershed.

3.3 Watershed Delineation

How the basin is delineated and discretized or subdivided depends on the complexity of the basin with regards to topography and to specific objectives of a project. The purpose of watershed discretization into subbasins and HRUs is to enable the routing of sediment and nutrient loadings within each subbasin or HRU. The technique that SWAT uses is the Subwatershed technique. This technique configures the basin in such a way that it focuses on natural flow paths or channels of the watershed. In this regard, watershed delineation can be done in several ways:

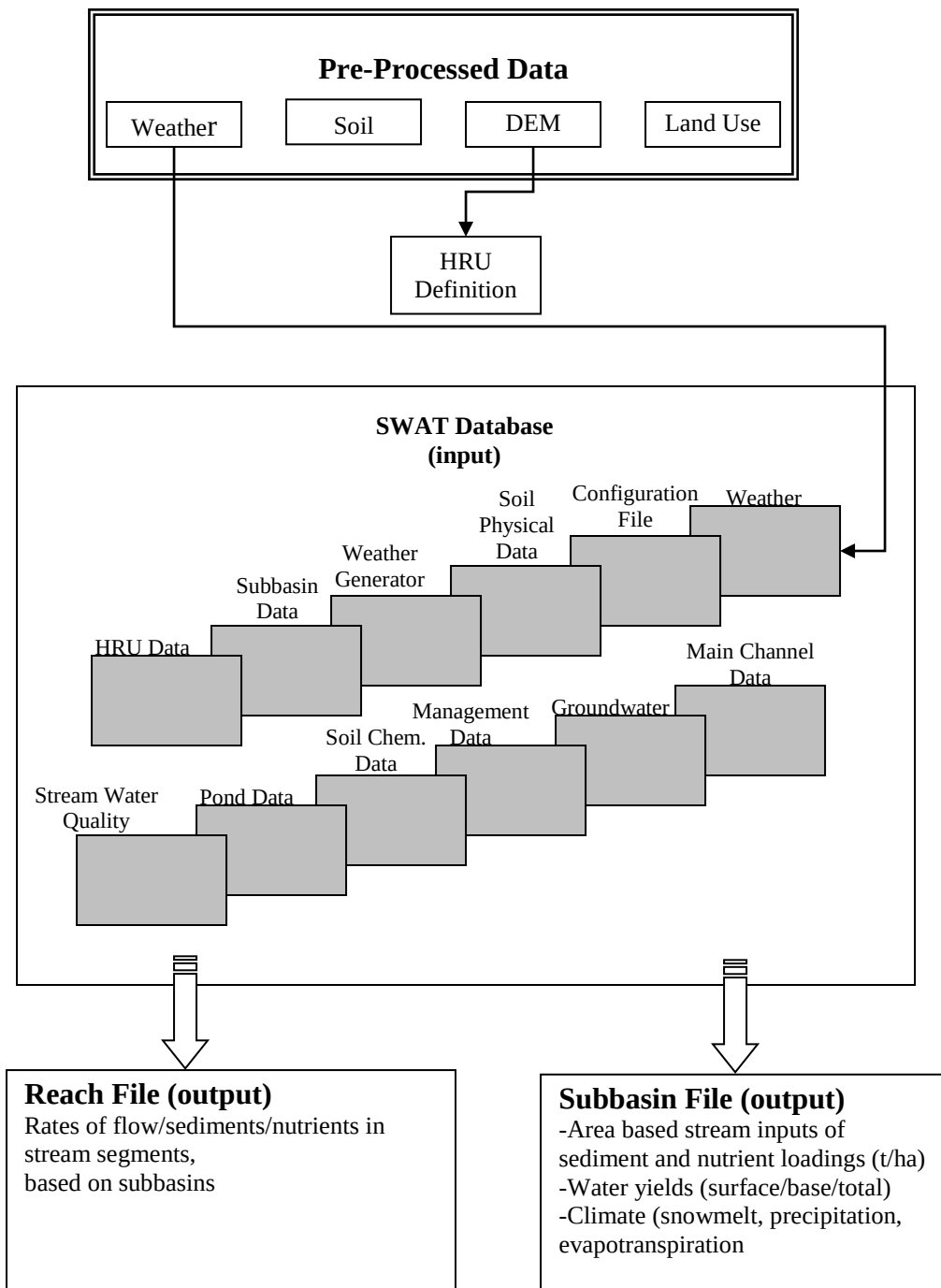


Figure 3.2. Diagram depicting SWAT inputs and main output files.

- By obtaining a digitized geo-referenced stream delineation network (stream theme)
- By obtaining geo-referenced digital elevation grid (DEG), with xyz coordinates (longitude, latitude, elevation)
- By generating a digital elevation model (DEM) to define stream and watershed boundary locations based on the DEM flow accumulation pattern
- By adjusting the DEM in such a way that DEM-generated streams complies with the already existing stream delineation network for the study area.

The initial stage is to subdivide each watershed of interest into separate entities or subbasins. SWAT utilizes ArcView and Spatial Analyst functions (Diluzio et al., 2001) to perform the delineation of the watershed, which is based on the corrected DEM. In all of this, the interpolation methods and resolution of DEM have major impact on the accuracy of all calculations. The particular method for determining the optimal interpolator and grid cell size for the DEM is outlined in Appendix A.

Within SWAT, users can access U.S. stream network delineations by selecting Reach File V1, Reach File V3, and the National Hydrography Dataset). For areas outside the USA, digitized stream delineation networks need to be supplied through SWAT external means. DEGs also need to be supplied, and these grids need to be pre-processed, as shown in Appendix A, to ensure that the resulting DEM conforms as closely to the actual topography of the study area. Among other things, pre-processing means eliminating DEG-produced artefacts related to “ridging”.

Formally, 5 separate components are associated with SWAT watershed delineation:

- DEM set-up
- Stream definition;
- Outlet and inlet definition;
- Main watershed outlet(s) selection and definition;
- Reservoir identification.

In SWAT, the DEM-generated stream and watershed definitions are accessed through the Watershed Delineation window, to determine stream network and number of subbasin outlets. The model then sets minimum and maximum suggested subbasin areas in hectares. With this information, the DEM threshold area or critical source area per subbasin can be determined. This value defines the amount of upslope drainage area that is required for a stream to begin. After entering this threshold area, themes containing the synthetic stream network and subbasin outlets are created. In addition, SWAT recognizes point-source discharges or drainage points in the watershed as an additional drainage inlet type. There is also an option to modify the subbasin outlet locations: using a look-up table, the outlets can be added to the stream network that corresponds to the gauging stations. This is useful for comparing measured flow rates, sediment loads, and nutrient yields with SWAT generated values. It is important that outlets or inlets not be placed at a junction cell (convergence of two streams) because doing so will generate error messages when the model delineates the subbasins. Also, point source discharges cannot be changed or modified within the watershed. Adding or removing reservoirs along the main

channel is optional. Only one reservoir can be added for each subbasin. The model does not distinguish between man-made and natural reservoirs. Subbasins upstream of water bodies influence all reservoirs.

The DEG can be selected directly from the Watershed View, or it can be acquired separately. The DEM properties are verified after the DEG has been loaded. The properties that are checked are the X- Y- Z- coordinates, to ensure that the units of these coordinates are what they are supposed to be. The geographic projection type also has to be selected. Three pre-defined projections are available: Geographic (decimal degrees), Albers Equal-Area (conterminous US), and Wisconsin Transverse Mercator.

The DEM set-up allows for a Mask to be applied to the DEM. A mask is a focused area that will limit the functions performed by the SWAT ArcView interface to the area defined by the mask. An actual stream network (polyline theme) can be superimposed on the DEM when the lack of relief prevents the interface from accurately placing stream locations.

3.4 Land Use and Soil Characterization

After the desired number of outlets and inlets has been determined, and the appropriate DEG has been entered, SWAT can be activated to delineate the desired sub-watersheds and the related stream patterns. Thereafter, the calculation of various subbasin parameters can begin. To this end, it is essential that the DEG, land use, and soil themes all have the same projection. If they are not in a common projection the

map themes will not be clipped to each other and an error will occur specifying that the themes do not overlay the basin.

SWAT uses its land use and soil themes to determine the area and hydrologic parameters of the basin, the subbasins, and each HRU, where each HRU is a unique combination of land use and soil type. Land use and soil type coverage is cross-tabulated to provide a report that describes the percentage of the total area that each HRU occupies in a basin and its subbasins. Land use and soil themes can be in shape or grid format, but are ultimately converted to grid format so the operations can be performed by the Spatial Analyst extension of ArcView GIS. The cell size of the two themes is automatically converted to the grid cell size of the DEG.

The land use data layer requires a look-up table for land use and land cover for each HRU, and these assignments are entered manually (Figure 3.3), using specific land use codes, either as prescribed by the United States Geological Survey. Entering the land cover manually is accomplished by double-clicking in the *Joining Attributes* box. Each land cover and plant type has a corresponding four-letter SWAT code that provides the model with hydrologic parameters and physical characteristics related to each land cover. Entering these land use codes produces the SWAT land use theme. Any land use that is not yet in SWAT's Land Use and Plant Growth database should be entered into that database before generating the land use theme.

Loading the soil data layer into the SWAT database follows the same procedure. If the theme is already in shape format, then this theme will be converted to grid format using the resolution of the DEM for the base grid cell size. When

Definition of LandUse and Soil Themes

Land Use data layer

Landuse Grid

 c:\avs2000\new7\watershed\grids\LusGr3

 Lookup Table Grid Values --> Land cover classes

Grid Field
Value

Joining Attributes

Value	Area[%]	LandUseSwat
1	22.56	RNGB
2	38.29	FRSE
3	15.30	POTA

Reclassify

Soil data layer

Soils Grid

 c:\avs2000\new7\watershed\grids\SolGr4

 Lookup Table Grid Values --> Soils attributes

Grid Field
Value

Joining Attributes

Value	Area[%]	S5id
1	20.56	me0031
2	5.18	me0021

Options:

☐ Stmuid
 ☒ S5id
 ☐ Name

☐ Stmuid + Seqn
 ☐ Stmuid + Name

Reclassify

Overlay

Help Exit

Figure 3.3. Computer screen for entering land use and soil data layers.

loading the soil file, SWAT automatically looks first for *Muid*, *Stmuid*, *Name*, *S5id*, and *Seqn* fields in the file, to register each soil type. If these headings are not present, then the interface will search for an integer or string field type. If the theme has none of these fields, an error message will occur.

If a look-up table is not used, these fields and the associated soil types can be manually entered. The soil types are either derived from the United States Soil Geographic (STATSGO) database or are obtained from a User Soil database. The fields mentioned are soil map categories that serve as a link to the STATSGO database. United States soil types not included with the interface can be downloaded from the internet (<http://www.brc.tamus.edu/swat/swatsoils.html>). The *Name* map category is indicated when the User Soil database is to be used. Any soil types not found in the STATSGO database should be compiled into the User Soil database before the soil theme is reclassified. If the soil theme is not projected or does not lie within a portion of the watershed, then map processing will stop. After the joining attribute codes have been added, the file is ready to be reclassified or loaded by the interface and a new soil theme is added to the View.

After both themes have been reclassified, the two themes are overlaid and the interface generates a detailed report of the distribution of each within the watershed. This also includes the distributions within the subbasins

3.5 Hydrologic Response Unit (HRU) Specifications

After the land use and soil themes have been reclassified and loaded by the interface, the number of HRUs that occur within the basin can be specified. The

potential number of HRUs that are modeled within the basin is a function of the number of land uses and soils that occupy the basin. The rationale for having many HRUs is that runoff responses from watersheds are much improved if the runoff predictions are done for each HRU separately. In this, HRUs are newly created polygons that have a unique soil type and land use. This polygonization allows for a systematic delineation of the main heterogeneity features of the landscape as defined, e.g., by elevational gradients, crop type, and specific management practices. These features, in turn, influence how water moves into the soil and over a landscape, and how much run-off and soil erosion is likely to occur in each HRU-specific context.

Within each subbasin there is one of two methods for characterizing HRUs. The first method will select the dominant land use and soil type within the subbasin, which produces one HRU for the entire subbasin. The other method allows for multiple HRUs within the subbasin. This is accomplished by first determining a threshold value, which is a percentage of the total area in the subbasin that the land use must occupy to be considered in the creation of a HRU. For example, if corn occupies 15 percent of the land area in a subbasin and the threshold is 20 percent, then corn will not be considered for creating HRUs. The second step is to define the threshold for area of soil types on a particular land use. This will remove minor soil types. The interface will reapportion the land uses and soil types so that all of the area within the subbasin is considered. As the threshold lowers for both, it potentially increases the total number of HRUs that will be created within the subbasins and ultimately the entire basin. As it increases, it essentially becomes more similar to modeling the dominant land use and soil type (method 1). The interface creates a

report that lists all land use and soil type combinations and the spatial extent of each within each subbasin and for the basin as a whole. After the HRUs have been defined the *SWAT View* is automatically created.

3.6 SWAT-ArcView Data Files

All of the above information is formatted and compiled in SWAT database files (input), and these files also provide direct linkage to the ArcView interface. These input files are created in sequential order. If, for example, HRU assignments are modified, then the SWAT process of generating these files needs to be repeated. Diluzio et al. (2001) suggest that the SWAT *Write All* command will be most useful for updating and debugging purposes. Another method allows files to be written sequentially, one at a time.

3.6.1 Weather Stations

This is the first input file that is written and provides hourly or daily weather data for the basin. The five weather variables are Rainfall, Temperature, Solar Radiation, Wind Speed, and Relative Humidity. There can be a maximum of 18 temperature and precipitation files and each file can have data for 300 weather stations. Radiation, wind speed and relative humidity files can hold data for up to 300 stations. Any missing records for measured data are inputted as -99.0 and the weather generator will simulate a value for the missing values. Also, the period to be simulated, using measured data, has to coincide with the beginning and end dates in the weather records. Weather stations can be assigned to a particular subbasin.

3.6.2 Weather Generator Data (*.wgn)

The WXGEN weather generator within SWAT can be used to simulate daily values for all five-climate variables when measured data are not available or are missing (Sharpley and Williams, 1990). This generator uses weather normals to generate hourly or daily weather predictions. Weather normals for North America (?) are already part of the SWAT database, and these are based on 20-years of data records containing 19 weather variables. There is also an option for adding custom weather normals to the SWAT database.

3.6.3 Watershed Configuration File (*.fig)

The watershed configuration file describes the connectivity or spatial arrangement of the stream network. SWAT utilizes a similar command language that William and Hann (1973) developed for a hydrologic model named HYMO. There are 14 commands used in the watershed configuration file, which is created from information provided during the automatic delineation phase.

3.6.4 Subbasin General Data (*.sub)

This input file pertains to a host of physical attributes specific to the subbasins. The file contains information about stream channels within the subbasin, the effect of topographic relief on climate and climate change within the subbasins, and the names of input files and number of HRUs within the subbasins. There are 25 variables contained within the subbasin general data input file.

3.6.5 Soil Physical Data File (*.sol)

There are 19 variables used in this file, but one is inactive (electrical conductivity). Soil physical data refer, e.g., to soil bulk density, porosity, texture, depth, etc. The physical characteristics of the soil determine how water moves through and over the soil. This in turn, determines the erodibility of the soil.

3.6.6 Soil Chemistry Data (*.chm)

Chemical characteristics of the soil are optional. However, the user cannot modify or set default values via the ArcView interface. Instead, Chemical parameters can be changed in the *scenarios/default/tables* folder of the project, which is the location of the *chm.dbf* input file and all the other input files. If known, concentrations of nitrates, organic nitrogen, soluble phosphorous, and organic phosphorous need to be entered in this file.

3.6.7 Management Data (*.mgt)

The management data input file details land management practices within the HRUs. These practices are a result of anthropogenic decisions regarding planting, harvest operations, irrigation practices, nutrient application, pesticide applications, and tillage operations. Particular variables within the file characterize runoff response within the HRUs, sediment erosion, biological mixing, and the timing of management practices.

3.6.8 General HRU Data (*.hru)

Data contained within this input file pertain to specific parameters characteristic of each HRU. For each HRU, there is information regarding area of the polygon, flow of surface water and ground water, and erosion and management parameters. There are 32 variables within the HRU input file, but one is not active.

3.6.9 Pond Data (*.pnd)

The pond data input file is for modeling the water balance, sediments and nutrients for ponds and wetlands. SWAT considers ponds and wetlands as impoundments for water, nutrients, and sediments.

3.6.10 Groundwater Data (*.gw)

SWAT models groundwater flow as a shallow unconfined aquifer or as a deep confined aquifer. Shallow unconfined aquifers are considered to contribute to stream flow within the basin, while deep confined aquifers contribute to stream networks outside the subbasin. How and where the groundwater moves in both systems is a result of the groundwater input file, which contains 13 variables.

3.6.11 Main Channel Data (*.rte)

The main channel input file is used by the model to provide information about physical processes that occur within the reach. It particularly deals with water flow, and sediment loading within the stream network. It is different than the watershed configuration file because parameters such as stream width and depth, and channel length are computed. Watershed configuration data emphasizes the spatial arrangement or position of the streams in the subbasins. There are 11 variables associated with this input file.

3.6.12 Stream Water Quality Data (*.swq)

The aspects of stream water quality that SWAT considers for simulations are related to organic chemicals and nutrients from agricultural and industrial processes, heavy metals, bacteria, and sediments. SWAT also uses data from the general water quality input file (*.wwq), but this file is not accessible from the *Subbasin Inputs* menu in the ArcView interface.

3.6.13 Water Use Data (*.wus)

The purpose of the water use input file is to address water losses from the basin. These losses are from management decisions regarding irrigation practices or from urban and industrial uses. The model has the ability to measure losses from the shallow aquifers, deep aquifers, streams, reservoirs, and ponds. Daily average water losses are required, but can vary monthly. This input file has five variables.

3.7 Model Operation

Upon completion of writing the above SWAT input files, or editing them as required, the model is ready to be used for simulation. On the menu bar of the SWAT View, the *Simulation* command allows for

- Starting model runs,
- Reading simulation results,
- Applying a calibration tools (ability to change parameter values), or
- Making a delivered load tables (ability to determine sediment and nutrient loadings at any point in stream network).

These commands are inaccessible until all prior steps have been completed correctly.

When the option to run the model is selected, a dialog box appears that requires specification of certain parameters. The start and end date that the simulation will span must be specified. These dates must coincide with the start and end dates of one of the weather inputs, but it is not required that they be taken from the same file.

Three options are available for selecting the precipitation time step, runoff calculation method, and the routing time.

- Option 1 computes daily rainfall, uses the curve number runoff, and calculates daily routing.
- Option 2 uses sub-hourly rainfall and the Green and Ampt method of calculating runoff at the daily level.
- Option 3 is similar to Option 2 but simulates hourly routing.

If the second or third options are to be used, precipitation data must be collected sub-hourly. The option that is selected will depend on the method used to collect measured rainfall. To calculate the distribution or amount of sub-hourly rainfall, either skewed normal or mixed exponential can be selected. The mixed exponential method is a better approach when precipitation data are limited.

Four methods are available for calculating potential evapotranspiration. They are:

- The Penman-Monteith method (Allen et al., 1989; Allen, 1986; Monteith, 1965);
- The Priestly-Taylor method (Priestly and Taylor, 1972);
- The Hargreaves method (Hargreaves et al., 1985); and
- The read-in option, which is available if yet another method of calculating evapotranspiration, is used.

There are four different sections that pertain to stream flow.

- **Section 1, crack flow:** this section asks the user whether or not to model crack flow. If the crack flow option is selected, then surface water will be allocated to the filling of crack volume. When the crack volume is filled, more surface runoff will be generated. This option is useful for vertic soils, or soils with high amounts of clay, which exhibit cracking and swelling during wetting.
- **Section 2, variable water storage:** this section of using the variable storage method or the Muskingum method (Chow et al., 1988) to simulate the routing

of water and water storage in the stream network. Both methods are a variation of the kinematic wave flood routing model (Chow et al., 1988).

- **Section 3, channel degradation:** this section allows for simulating channel degradation. The two aspects of degradation that are considered: channel downcutting and channel widening. Changes in bankfill depth, channel width and channel slope are allowed to vary.
- **Section 4, water quality transformation:** this section allows for change of stream water quality due to processes that affect nutrient transformations within the stream network.

For each model run, the user has the ability to edit the basin input file (*.bsn), the water quality input file (*.wwq), and the SWAT default settings file within the *installationdir/avswatdb* directory. The model can be used to check whether any of the values of the input parameters are out of range. After making the appropriate selections, SWAT re-sets all files automatically.

3.8 Generating Output Files

SWAT output can be daily, monthly, or yearly. Output is generated by converting SWAT internal ASCII format files to dBase tables that interface with ArcView. Specific output files refer to

- HRU Output File (*.sbs),
- Subbasin Output File (*.bsb),
- Main Channel Output File (*.rch),
- HRU Impoundment Output File (.wtr),

- Reservoir Output File (*.rsv).

The last two files are optional. All other output can be viewed using the *Show list* command in the *Reports* menu.

After performing a simulation, the *Calibration Tool* can be used, which is under the *Simulation* menu. This allows the modification of 27 different parameters within different input files. Multiple parameters can be modified as desired. Some parameters are modified or varied by a value or percentage change of the default or edited value. The change can be negative or positive. If the change is outside the allowable limits, there is the option to override the existing limits. Another benefit of the calibration tool is that the effect of modifications to certain parameters can be tested on specific subbasins. This option has not been available on prior versions of the model. Different scenarios can be saved and applied to the most recent simulation. The last command is the *Make Delivered Load Table*. This command allows the amount of load to be calculated at any point along the stream network, which is useful for anticipated areas of high concentration levels. This option is only available if the *Yearly* printout frequency is selected. Using the *Map-Chart* command in the *Reports* menu can create ArcView maps of the SWAT output.

CHAPTER 4

BLACK BROOK BASIN: SWAT SPECIFICATIONS

This chapter provides details about how the Black Brook Basin Black Brook Basin is digitized to enable SWAT simulations. These details are generated by following the steps of the preceding Chapter.

4.1 Watershed Discretization and Stream Definition

The DEM of the BBB was created from map tiles 3427 and 3428 from the New Brunswick Department of Natural Resources (Crain, 2001). The IDW method of interpolation was used with a 50-m resolution (see Appendix A). Existing data for the boundary of the BBB were used as the DEM mask. The DEM was then processed remove any sinks to enable continuous stream network definition from uplands to lowlands and the main stream stem. The threshold area for stream definition was 25 hectares, or 100 cells at 50-m by 50-m resolution. This threshold area closely resembles the actual stream configuration within BBB.

The watershed was divided into a total of seven subbasins, which also corresponds to the number of gauging stations, as shown in Figure 4.1. Table 4.1 summarizes the physical attributes of each of these subbasins and the stream network. The modeled area does not incorporate residential area as a land use. Doing so decreases the total area considered by approximately 2 km².

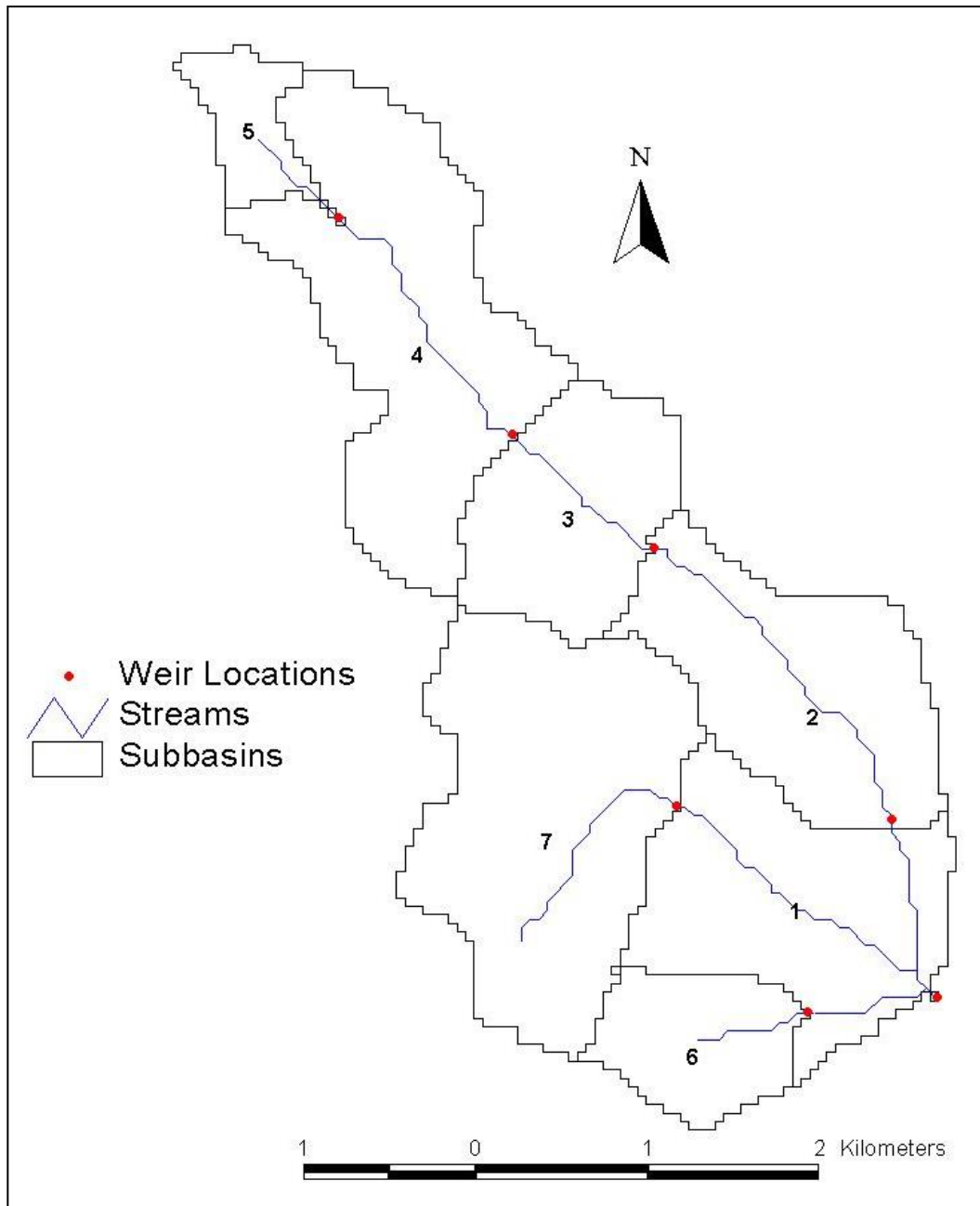


Figure 4.1. Simulated subbasins, outlets (weir stations), and stream network of Black Brook Basin.

Table 4.1. Physical characteristics of subbasins and stream attributes of Black Brook Basin (12.5 km²).

Subbasin Number	Subbasin Area (ha)	Fraction of Total Area	HRU Total	Main Channel Width (m)	Avg. Slope of Channel (m)	Main Channel Length (km)	Channel Width:Depth Ratio
1	210	0.17	15	5.9	0.025	1.1	16.5
2	207	0.17	19	4.0	0.012	2.4	14.5
3	139	0.11	13	3.2	0.009	1.1	13.5
4	278	0.22	21	2.6	0.010	1.8	12.5
5	45	0.04	6	0.8	0.017	0.8	8.4
6	84	0.07	4	1.2	0.020	0.7	9.6
7	295	0.24	16	2.5	0.013	1.5	12.3

Coordinates of the gauging stations were determined with GPS. The coordinates were converted to the common projection (StereoG. NAD83, 20, 74, 7, -66.5, 46.5, 0.999912, 2500000, 7500000) used in the project by MapInfo. This is the same projection as the DEM, soil theme, and land use theme. SWAT clips the outlets to the nearest location on the synthetic stream network. The ArcView Interface User's Guide (Diluzio et al., 2001) recommends that actual gauging stations or stream outlets be used when comparisons are made between simulations and measured data.

4.2 Land Use, Soil and HRU Characterization

Soil and land use themes were imported, were converted to the same geographic projection of the DEM, and were overlaid on the DEM (Appendix B) to determine the various HRUs polygons within BBB. Crop type distribution and field boundaries (Figure 4.2) are based on 1994 data (Crain, 2001), and on the existing attribute table for management practices for each crop (Rees, 2002). Crop type and field boundaries are assumed to be the same for each year. Up to three crops can be grown in one year, but the initial crop was used for the entire growing season, as is typical under the local management.

There are a total of 11 different crop types or land uses within BBB. Table 4.2 summarizes the crop types and corresponding four-letter crop name that is used by SWAT. Table 4.3 summarizes the crop type and the associated management practices. Land uses with the same management practices were grouped together. The hydrological parameter or surface runoff curve number (CNII) for each crop was determined by: the condition i.e. fallow or row crop; crop i.e. row crop, contour, or

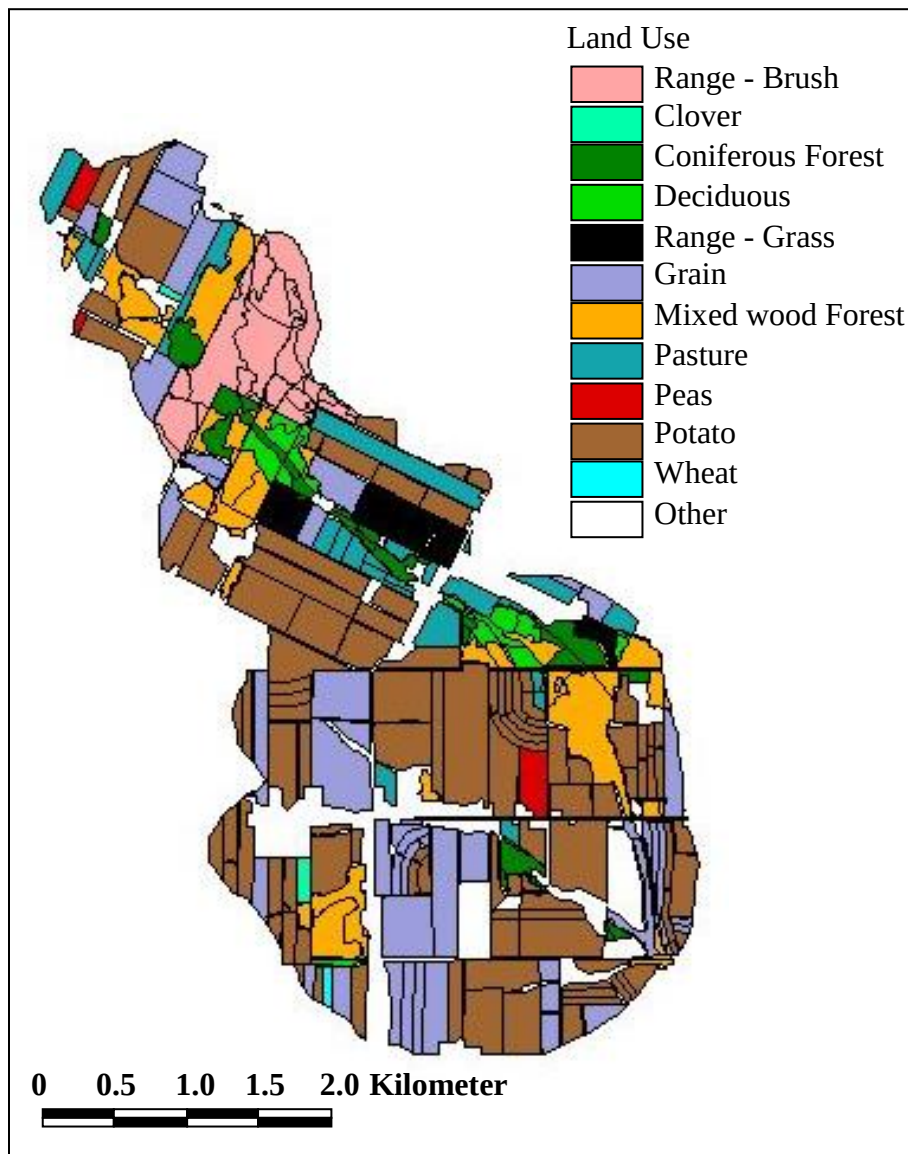


Figure 4.2. Land use distribution within Black Brook Basin

Table 4.2. Summary of crop types modelled in Black Brook Basin and their percentage cover (12.5 km²).

Land Use	SWAT Code	% of Watershed
Grain Sorghum	GRSG	18.4
Range-Brush	RNGB	5.6
Pasture	PAST	6.0
Range-Grasses	RNGE	2.9
Field Peas	FPEA	1.2
Red Clover	CLVR	0.40
Forest-Deciduous	FRSD	2.6
Forest-Evergreen	FRSE	4.2
Potato	POTA	45.3
Forest-Mixed	FRST	13.0
Winter Wheat	WWHT	0.3

Table 4.3. Summary of crop types and respective management practices.

Land Use	Initial CNII	Management Operation	SWAT Code	Date of Operation	Condition	Crop	Cover	Adjusted CNII	Fertilizer (N:P:K)	Fertilizer App. Rate (kg ha ⁻¹)
Grain Sorghum	83	Tillage operation	SPRGLOW	15-May	Small grain	Straight Row	Poor	84		
Winter Wheat		Plant/begin growing season		16-May	Small grain	Straight Row	Poor	84		
		Fertilizer application	33-00-00	1-Jun					33-00-00	250
		Harvest and kill operation		15-Oct	Small grain	Straight Row	Poor	84		
		Tillage operation	FALLFLOW	16-Oct	Small grain	Straight Row	Poor	84		
Pasture, Red Clover, Range-Brush, Range-Grasses	79	Tillage operation	SPRGLOW	15-May	Pasture or range	N/A	Poor	86		
		Plant/begin growing season		16-May				86		
		Kill/end growing season		15-Oct						
		Tillage operation	FALLFLOW	16-Oct	Pasture or range	N/A	Poor	86		
Field Peas	83	Tillage operation	SPRGLOW	15-May	Row Crop	Straight Row	Poor	88		
		Plant/begin growing season		16-May	Row Crop	Straight Row	Poor	88		
		Fertilizer application	33-00-00	1-Jun					33-00-00	340
		Harvest and kill operation		15-Oct	Row Crop	Straight Row	Poor	88		
		Tillage operation	FALLFLOW	16-Oct	Row Crop	Straight Row	Poor	88		
Potato	83	Tillage operation	SPRGLOW	15-May	Row Crop	Straight Row	Poor	88		
		Plant/begin growing season		16-May	Row Crop	Straight Row	Poor	88		
		Fertilizer application	15-15-15	1-Jun					15-15-15	500
		Fertilizer application	15-15-15	1-Jul					15-15-15	500
		Harvest and kill operation		15-Oct	Row Crop	Straight Row	Poor	88		
		Tillage operation	FALLFLOW	16-Oct	Row Crop	Straight Row	Poor	88		
Forest-Mixed, Forest-Deciduous, Forest-Evergreen	83	Plant/begin growing season		15-May	Woods	N/A	Poor	77		
		Kill/end growing season		15-Oct						

contour and terraced; and cover i.e. poor or good. The highest CNII number was used for the respective crop condition to give a “worst case” scenario.

Dates at which spring and fall tillage, planting, fertilization, and harvesting occur are the same for all crops if needed. For example, no fertilizer is applied to land devoted to clover. Also, two fertilizer applications (June 1 and July 1) are applied to fields that grew potatoes because typical fertilizer application rates in the area are in excess of 1000 kg ha⁻¹. SWAT only allows a maximum rate of 500 kg ha⁻¹ and therefore necessitated two applications. Table 4.3 also includes the type of fertilizer (ratio of N:P:K) and the application rate (kg ha⁻¹).

The soil type theme represents the spatial distribution of Canadian soil classes within the BBB (Figure 2.5). A total of seven different soils were overlaid on the land use theme. The United States (Maine) soil equivalents were assigned to similar Canadian soil types. The reason for this is that the State Soil Geographic Database (STATSGO) used by the model has the detailed soil physical and chemical data that is required as input. Soil types were deemed equivalent based on the soil erodibility (K) factor (Source: Unknown). Within the STATSGO database, the S5id field linked the Maine soils. This is an alphanumeric code, which links the data of the soil series with corresponding soil polygon(s). Table 4.4 summarizes the U.S. soil equivalents and the percent coverage within BBB.

For BBB, Multiple HRUs were generated based on a minimum threshold of one percent was used for soil and land use. This threshold yielded 94 HRUs, as summarized in Appendix C.

Table 4.4. Soil type distribution and U.S. equivalents in BBB (14.5 km²).

Soil Series	Canadian Soil Sub Group	US Equivalent	SWAT Code (S5ID)	% of Watershed
Grand Falls	Orthic Humo-ferric Podzol	Machias	ME0033	3.8
Holmsville	Orthic Humo-ferric Podzol	Plaisted	ME0007	49.0
Interval	Orthic Regosol	Fryeburg	ME0080	0.2
Muniac	Orthic Humo-ferric Podzol	Stetson	ME0021	0.4
Siegas	Gleyed Podzolic Gray Luvisol	Daigle	ME0031	31.5
St. Quentin	Terric Mesisol	Wonsqueak	ME0121	2.2
Undine	Orthic Dystric Brunisol	Mapleton	ME0025	13.1

4.3 Importing Weather Data

Actual weather data for precipitation, minimum and maximum temperature, solar radiation, wind speed, and relative humidity were used for BBB weather input. Weather data were obtained from the weather station records at the Saint-Leonard Airport [International Civil Aviation Organization (ICAO) code – CYSL], from 1990 to 2001 (c/o Environment Canada; Richards, 2002). From these data, daily values were derived.

The amount of precipitation required for measurement on a given day was 0.2 mm. When data was missing the model used a Markov chain-skewed (Nicks, 1974) or Markov chain-exponential model (Williams, 1995). On days where measured data was missing, a first-order Markov chain was used to determine if the day was wet or

dry. For all simulations, the skewed distribution scheme was used to determine the amount of precipitation generated.

Daily values for maximum temperature, minimum temperature, and solar radiation are simulated based on work done by Matalas (1967). Multiplying the residual element by the standard deviation and adding the monthly average value determined the daily values. For a more detailed explanation, the reader is referred to Chapter 4 of the SWAT User's Manual (Neitsch et al., 2000). Solar radiation was simulated by SWAT for the entire 12 years because measured data was not available.

Relative humidity and wind speed data are required by SWAT if the Penman-Monteith method of calculating evapotranspiration is to be used. Wind speed data collected at the Saint-Leonard Airport would typically be higher than compared to an area with more land cover i.e. forested landscape. No correction factor was applied to the wind speed data.

Actual data were used for all SWAT weather variables, except solar radiation, which was created by the weather generator. Generated daily solar radiation was derived from monthly solar radiation normals. Monthly normals were based on solar radiation data at Maine Airport (ICAO code – KCAR, see Appendix D for further details).

4.4 Constructing the Default Database

After the soil, land use, HRU and weather data import, SWAT creates the BBB database. At this stage, the management input file was edited to reflect local tillage, planting, and fertilizer practices (Table 4.3). Editing the management input

file (*.mgt) was done by *Edit Inputs/Subbasin Data* in the ArcView interface. The required plant growth heat unit specifications were calculated using United States climate data. No point sources, inlets, or reservoirs were modelled. Default values were used for the Manning's Roughness "n" Factor (0.014) when the subbasin general input file (*.sub) and main channel input (*.rte) were written.

CHAPTER 5

THE BLACK BROOK BASIN: INITIAL SWAT SIMULATIONS

5.1 Introduction

This chapter describes the SWAT calculations process, starting with the SWAT default values for BBB. Also provided in this Chapter are BBB field data (Table 5.1) to determine

- whether the default values for the SWAT parameters are adequate to calculate stream discharge as well as sediment, nitrate and soluble P yields
- to what extent the default values for some of the model parameters need to be calibrated to bring about a closer agreement between the simulations and the field observations.

5.2 Stream Discharge

Default settings for the initial monthly SWAT simulations are illustrated in Figure 5.1. Simulations were done using the Penman-Monteith (PM), Priestly-Taylor (PT) and Hargreaves (HG) models for evapotranspiration. For the PM and PT methods, solar radiation values are required. Figures 5.2, 5.3, 5.4 and 5.5 show the results. Figures 5.6 through 5.9 depict annual comparisons of simulated and measured data.

Table 5.1. Measured monthly sediment, nitrate-N and soluble P loadings for Black Brook Watershed (14.5 km²).

Year	Month	Sediment Loadings (kg ha ⁻¹)	NO3-N Loadings (kg ha ⁻¹)	Soluble P Loadings (kg ha ⁻¹)
1992	1	0.092	2.196	0.008
	2	0.006	0.66	0
	3	0.023	0.619	0
	4	3.842	7.614	0.101
	5	0.074	1.948	0.021
	6	0.043	1.003	0.007
	7	1.221	1.507	0.013
	8	0.074	1.672	0.008
	9	0.01	0.645	0.003
	10	0.054	2.251	0.013
	11	0.051	2.425	0.017
	12	0.039	1.567	0.006
Total		5.529	24.107	0.197
1993	1	0.038	1.549	0
	2	0.014	0.796	0.001
	3	0.017	0.63	0.008
	4	2.648	9.61	0.203
	5	0.386	2.033	0.013
	6	0.256	1.001	0.01
	7	0.062	0.27	0.001
	8	0.038	0.157	0.001
	9	0.008	0.204	0.003
	10	0.143	1.532	0.016
	11	0.04	2.332	0.018
	12	0.092	3.763	0.036
Total		3.742	23.877	0.31
1994	1	0.012	0.634	0.005
	2	0.009	0.748	0.009
	3	0.004	0.317	0.004
	4	2.369	8.223	0.605
	5	0.345	3.23	0.049
	6	0.658	1.557	0.024
	7	0.487	0.755	0.014
	8	0.169	0.839	0.008
	9	0.133	1.435	0.015
	10	0.021	0.964	0.01
	11	0.034	1.361	0.01
	12	0.009	0.385	0.009
Total		4.25	20.448	0.762

Set Up and Run SWAT model simulation

Period of simulation: Starting date Ending date

January 1 1990 December 31 2001

Month Day Year Month Day Year

Rainfall/Runoff/ Routing: Rainfall distribution: Potential ET method:

Daily rain /CN / Daily

Skewed normal

Mixed exponential

Priestley-Taylor method

Penman-Monteith method

Hargreaves method

Read in

Crack flow: Channel water routing method: Channel dimensions: Stream Water Quality Processes: Lake Water Quality Processes:

Not active

Variable Storage

Not Active

Not Active

Active

Muskingum

Active

Active

Active

Printout frequency: Routing Pesticide: Watershed parameters:

Daily

Monthly

Yearly

Basin Input File: Bsn

General Water Quality Input File: Wwq

Help Exit Setup SWAT Run Chek Input Ranges Run SWAT

Figure 5.1. SWAT default settings for BBB.

As shown, monthly peaks of stream discharge during spring melt in April and May are poorly represented by SWAT: there is an overestimation of stream discharge during March and an underestimation during April and May. The amount and timing of snowmelt within BBB is the most likely reason for lower monthly water yields in April and May.

Annual stream discharge was generally underestimated with all three methods. However, PT overestimated annual stream discharge for the years 1995, 1998, and 1999. Measured average stream discharge was 652.97 mm for eight years. Simulated average stream discharges were 603.12 mm, 518.76 mm, and 487.98 mm for the PT, PM, and HG methods respectively. The lower annual predictions of water yields are most likely the result of overestimated evapotranspiration. The Priestly-Taylor method will be used in all subsequent simulations because this method approximated the actual values the best.

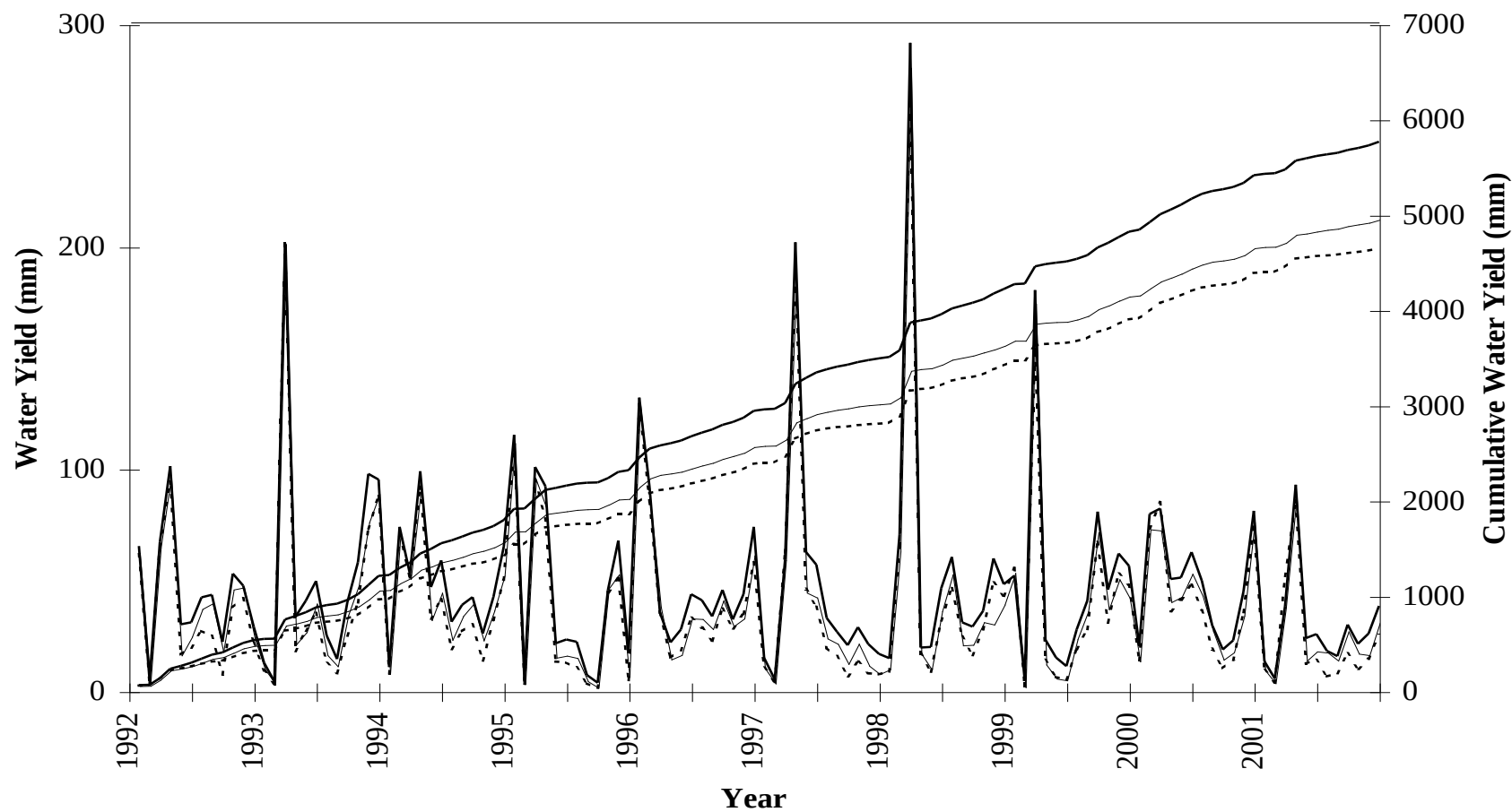


Figure 5.2. Impact of Priestly-Taylor (—), Penman-Monteith (—), and Hargreaves (----) methods of calculating evapotranspiration on monthly water yield in BBB.

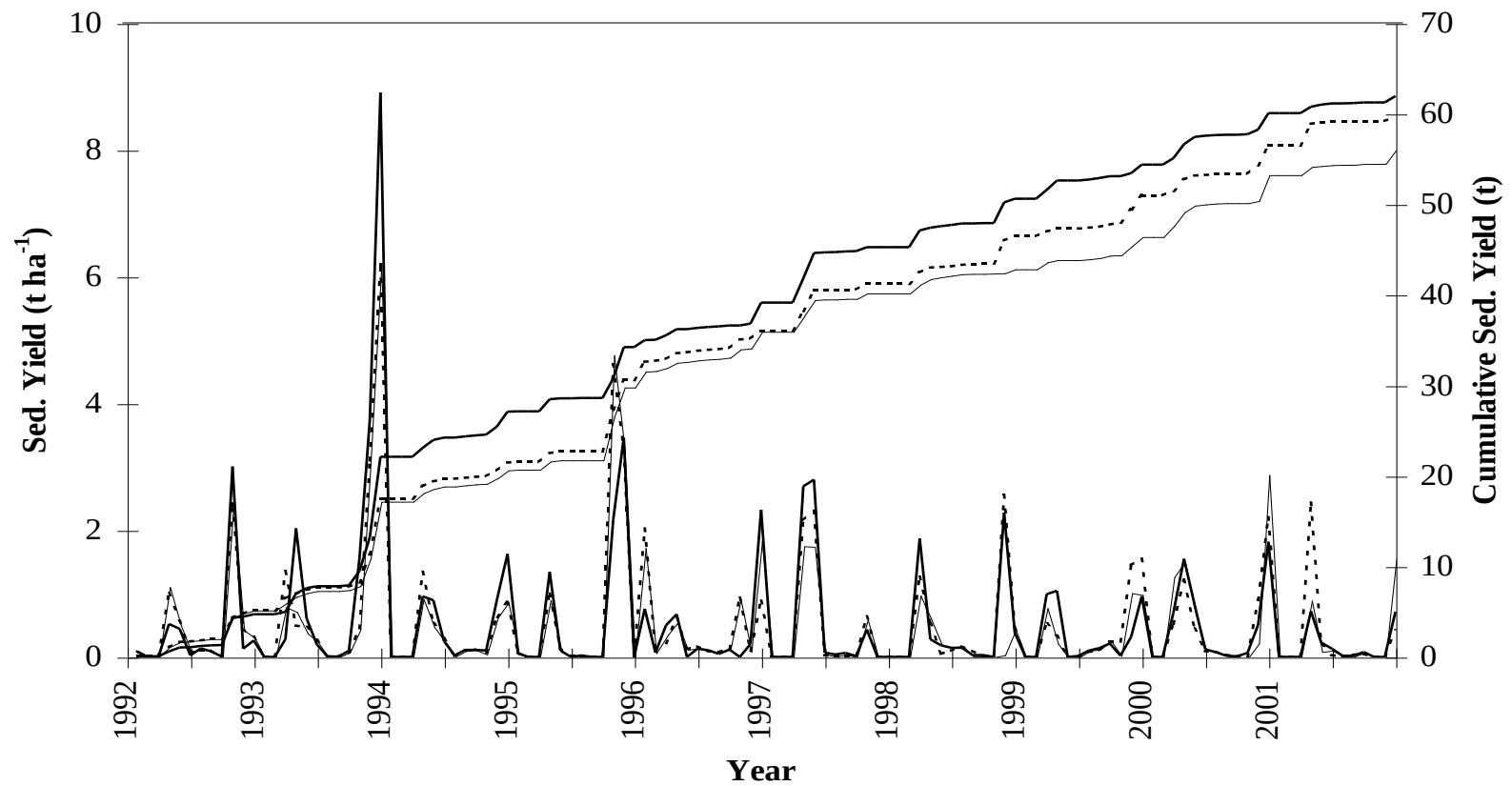


Figure 5.3. Impact of Priestly-Taylor (—), Penman-Monteith (—), and Hargreaves (----) methods of calculating evapotranspiration on monthly stream sediment yield in BBB.

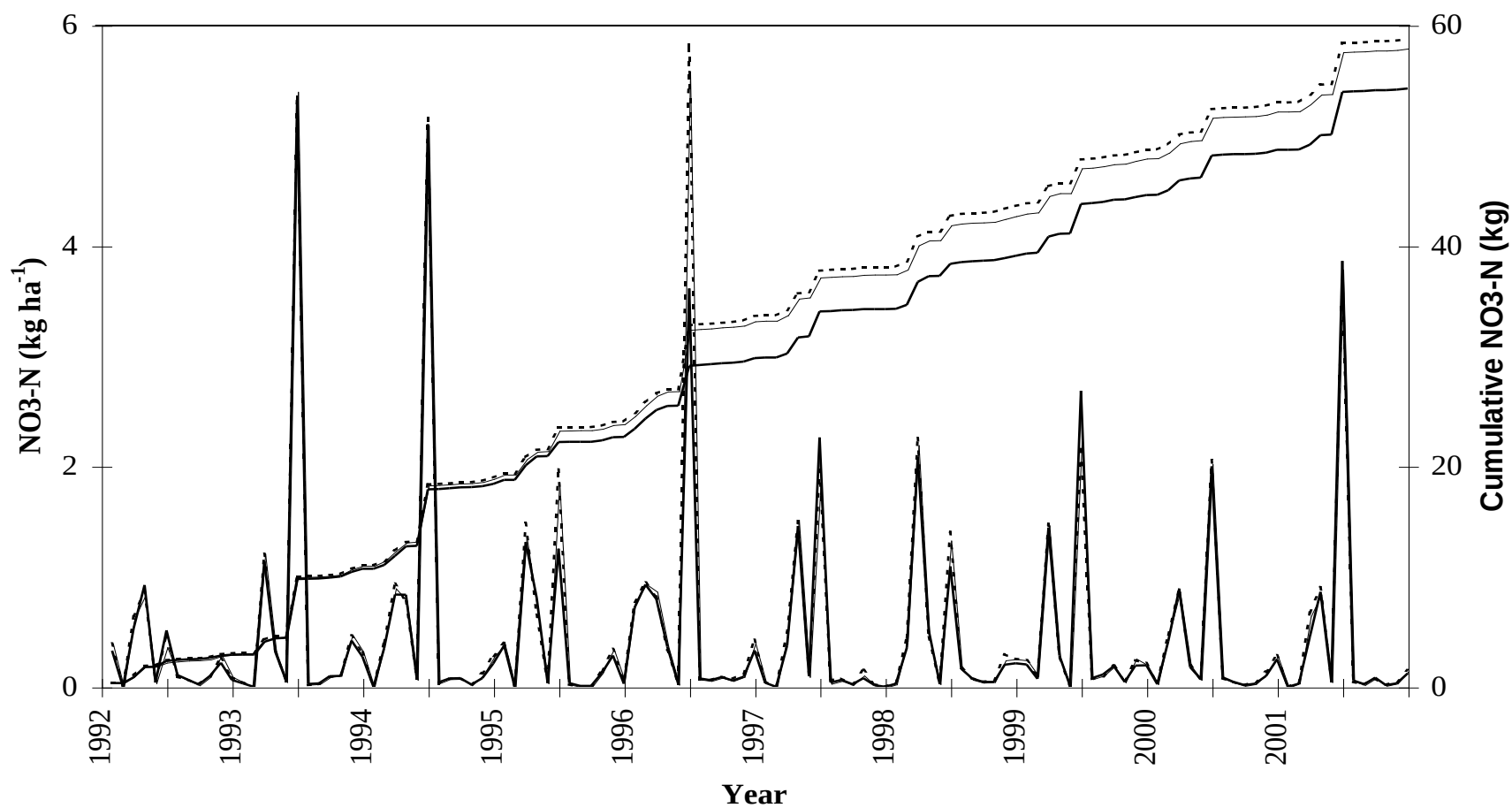


Figure 5.4. Impact of Priestly-Taylor (—), Penman-Monteith (---), and Hargreaves (· · · ·) methods of calculating evapotranspiration on monthly stream $\text{NO}_3\text{-N}$ yields in BBB.

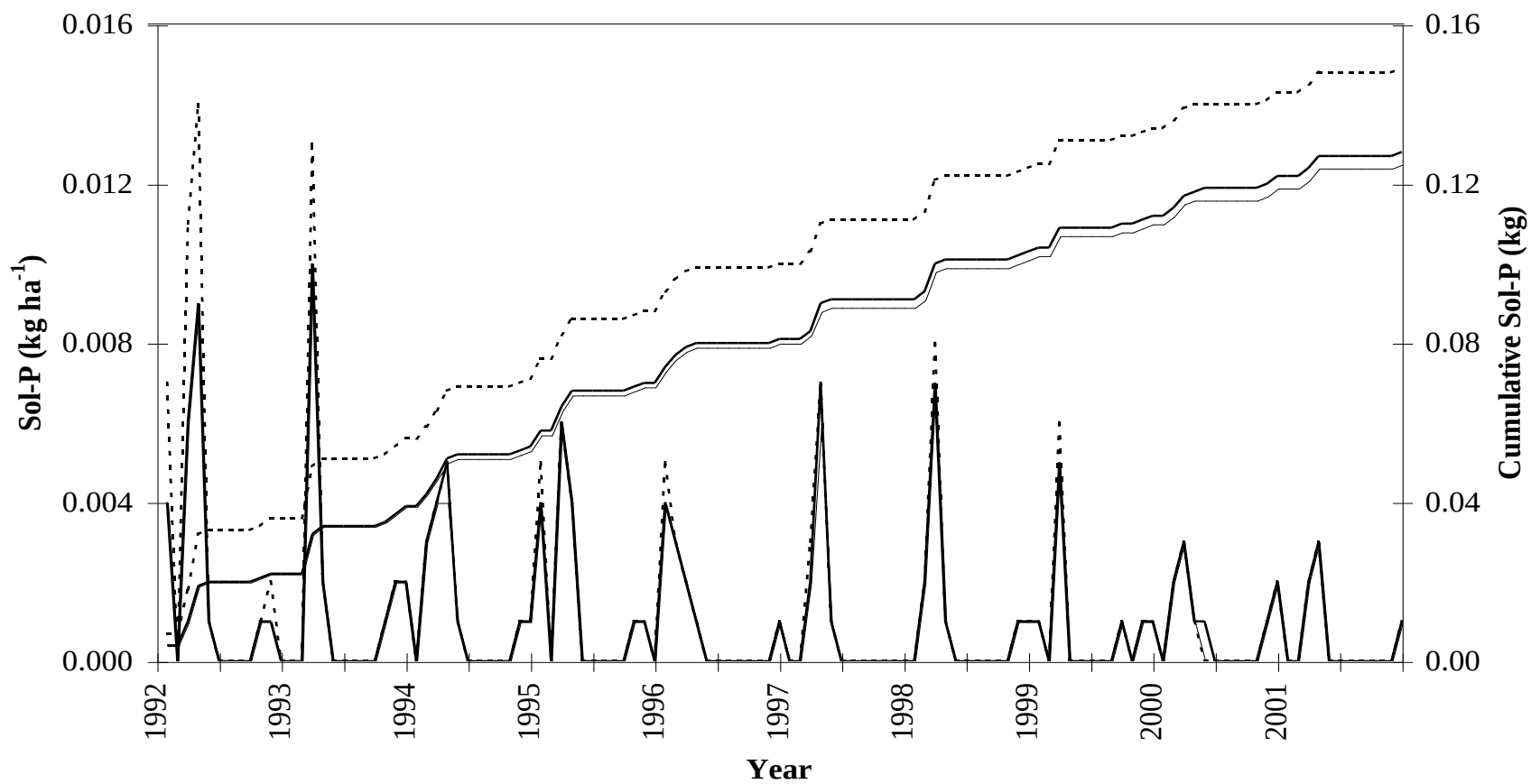


Figure 5.5. Impact of Priestly-Taylor (—), Penman-Monteith (—), and Hargreaves (---) methods of calculating evapotranspiration on monthly stream soluble phosphorous yields in BBB.

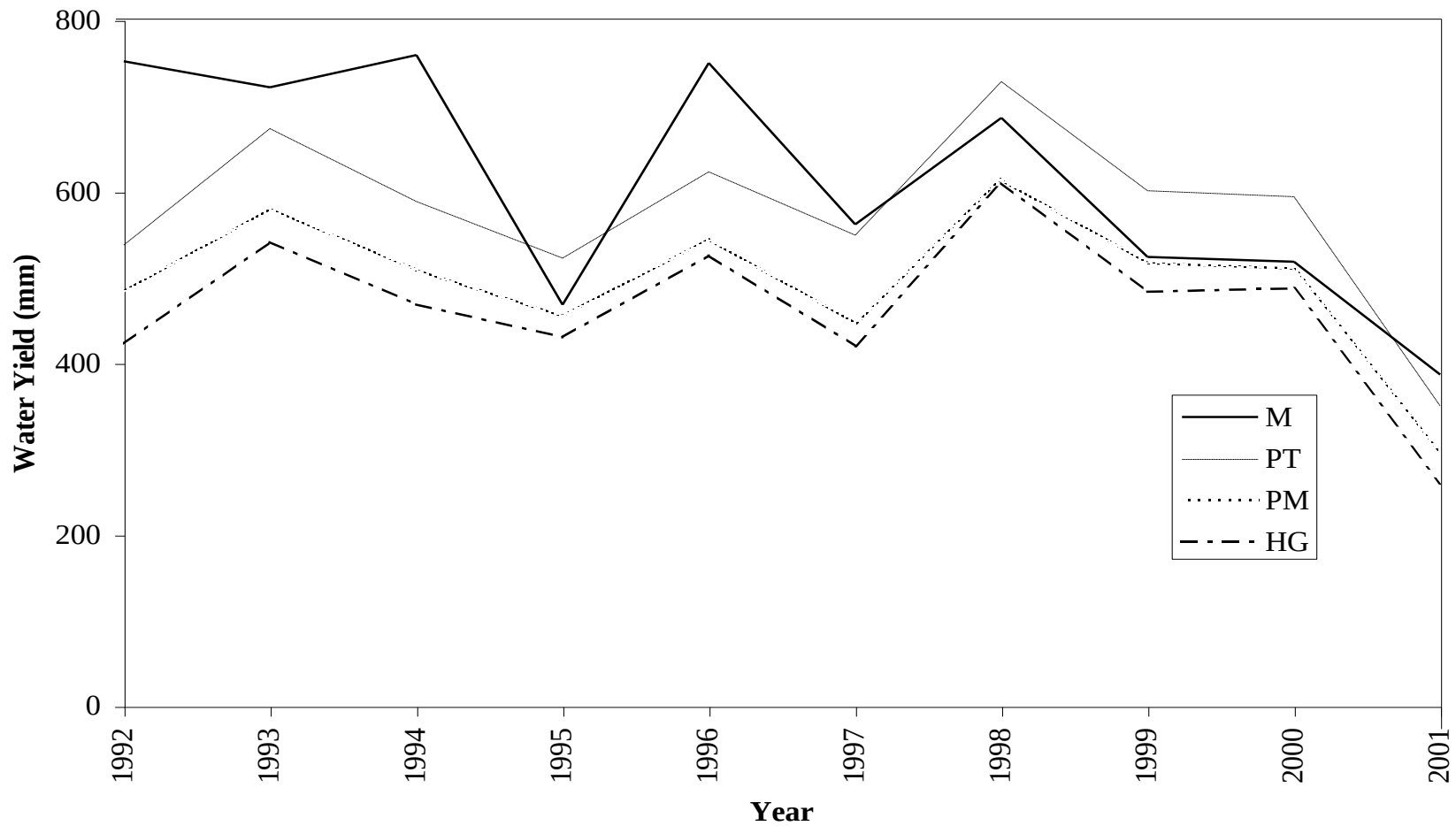


Figure 5.6. Comparison of annual measured (M) and simulated stream discharges resulting from the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration (ET).



Figure 5.7. Comparison of annual measured (M) and simulated sediment yields resulting from the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration (ET).



Figure 5.8. Comparison of annual measured (M) and simulated NO₃-N yields resulting from the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration (ET).

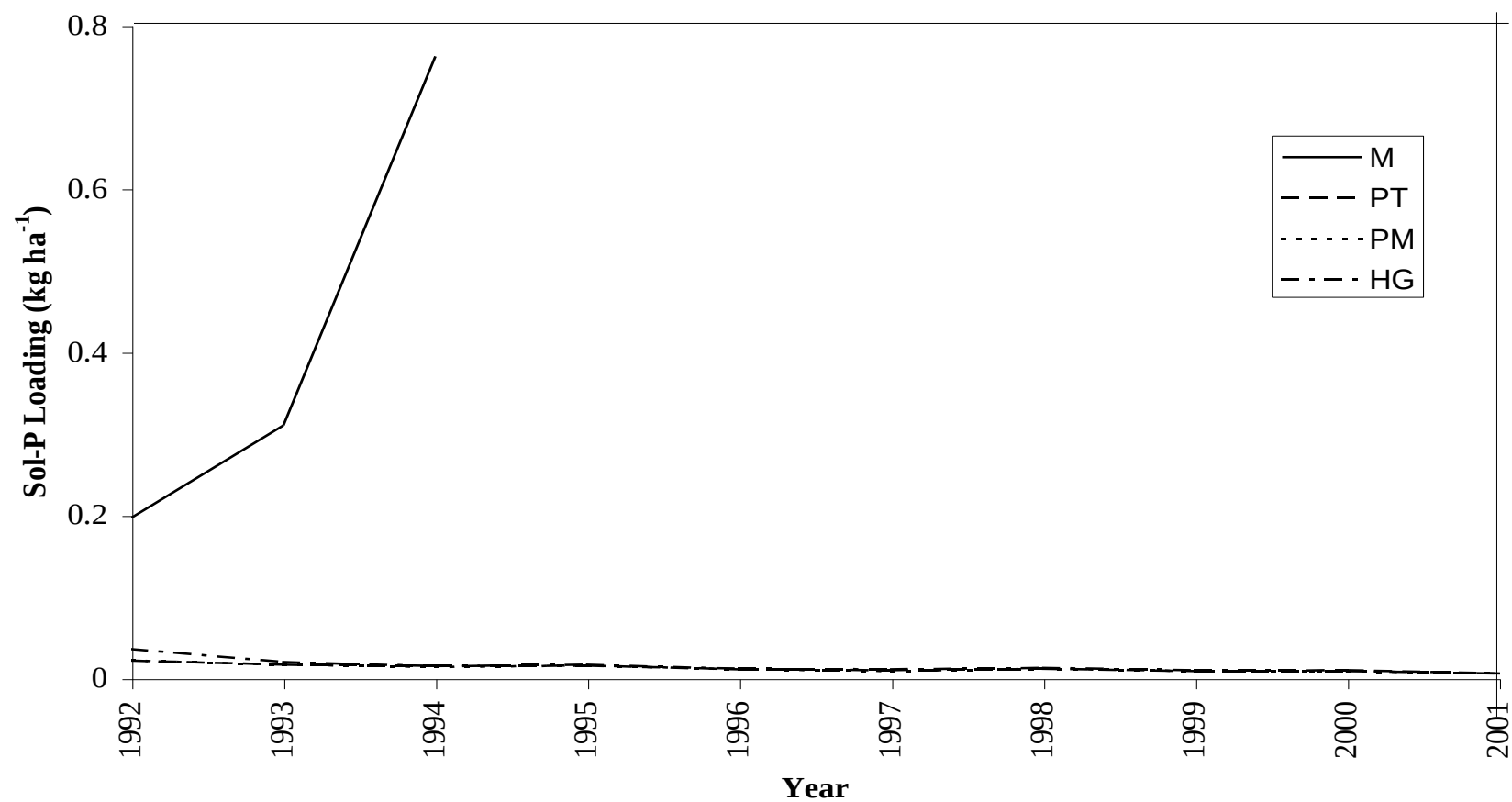


Figure 5.9. Comparison of annual measured (M) and simulated soluble phosphorous yields resulting from the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration (ET).

5.3. Sediment Yields

Sediment load predictions for all three methods were quite similar to measured values for 1992 and 1994, but predictions for 1993 were high (Figure 5.11). The predicted sediment values for 1993 were 17.4 t/ha, 12.0 t ha⁻¹, and 12.4 t ha⁻¹ for the PT, PM, and HG methods, respectively. The most probable reason for these values is the unusually high amount of actual precipitation and simulated snowmelt that occurred in November and December. As such, 72.6 %, 77.5%, and 75.0% of the annual sediment loads occur in these two months, as calculated with the PT, PM, and HG, respectively. For measured values in all three years, the sediment loadings from November and December account for less than 4% of the annual total. Omitting sediment contributions from November and December of 1993 would change the three-year average from 9.0 t ha⁻¹ to 4.8 (PT), 6.9 t ha⁻¹ to 3.8 t ha⁻¹ (PM), and 7.2 t ha⁻¹ to 4.1 t ha⁻¹ (HG). The measured three-year average for sediment loading is 4.5 t ha⁻¹. Hence, the simulated annual sediment loading predictions are consistent with measured values. However, the observed peak that occurs in April is absent from the monthly simulations.

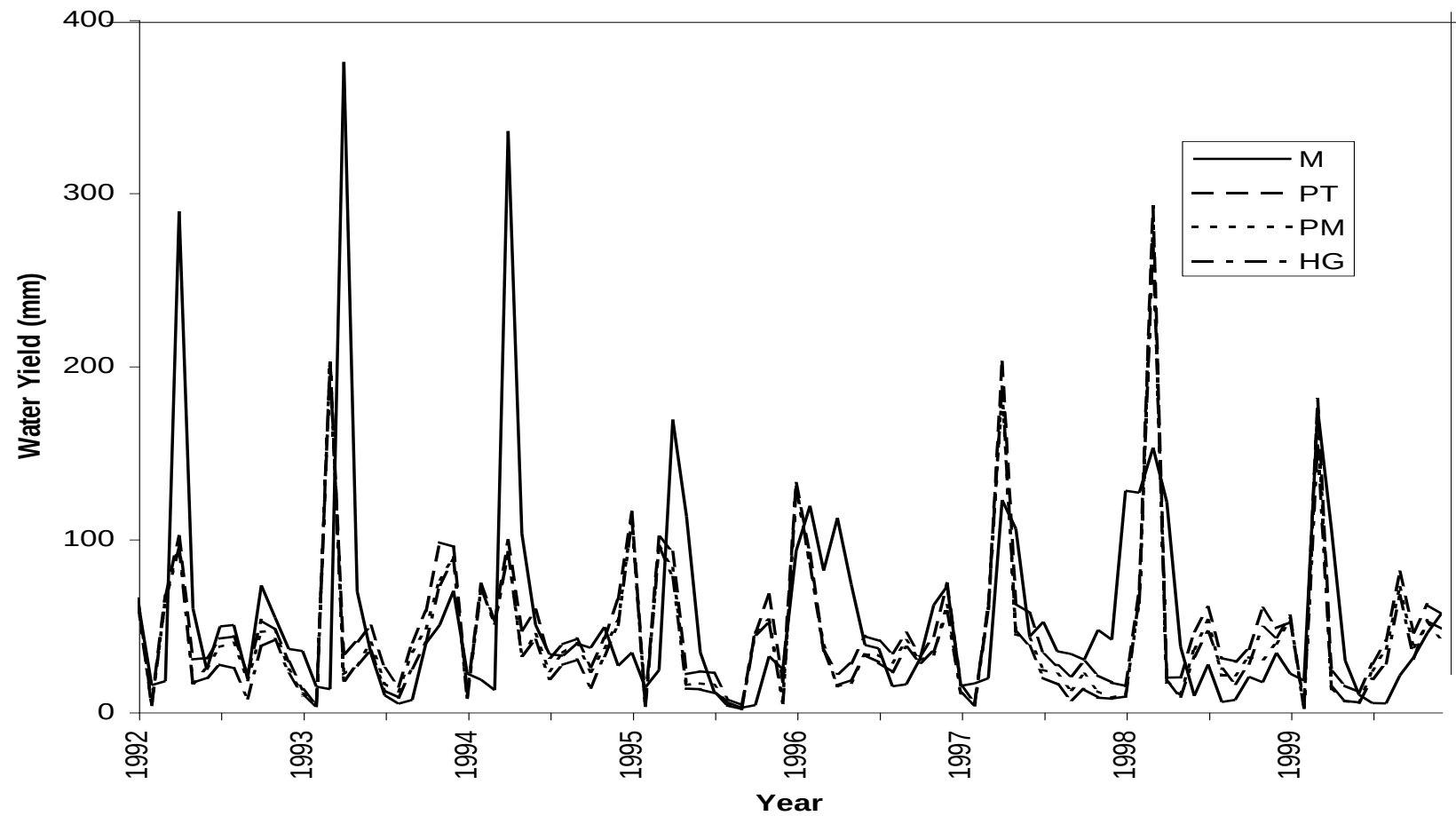


Figure 5.10. Comparison of monthly measured and simulated water yield data in the Black Brook Basin using Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration.

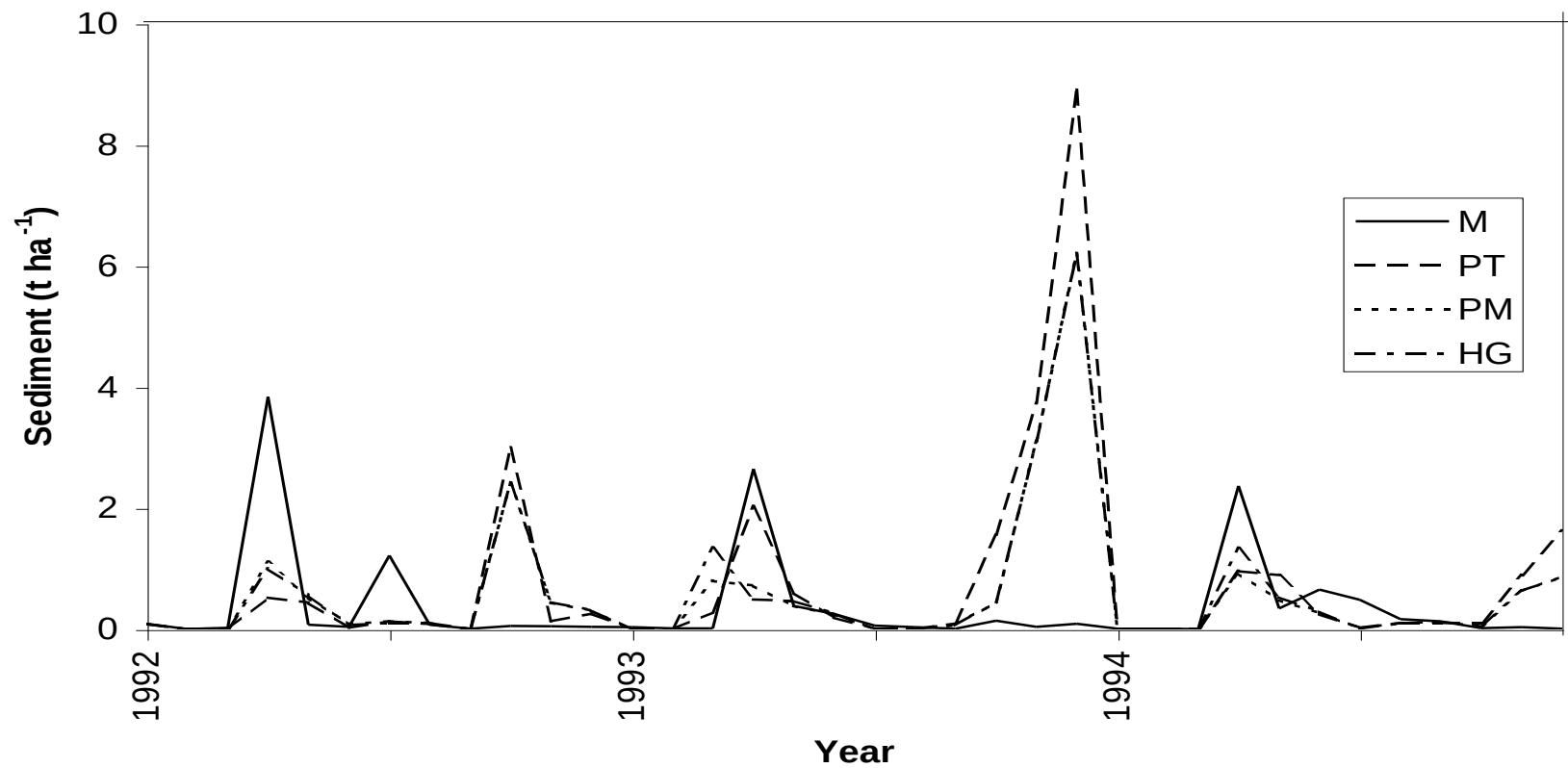


Figure 5.11. Comparison of monthly measured (M) and simulated sediment loadings in the Black Brook Basin using Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration.

5.4. Nitrate Yields

Initial soil concentrations of nitrate and soluble phosphorous were assumed to be zero. On the whole, simulated nitrate loadings are therefore underestimated (Figure 5.12). The measured three-year average is 22.8 kg ha^{-1} while the highest simulated value was 6.3 kg ha^{-1} , as generated with the Hargreaves method. The peak in nitrate that occurs in June from the simulated results is a magnitude of 5 higher than the measured values. The assumption is that most nitrates found in surface runoff is a result of fertilizer use. The model, therefore, needs to be calibrated to reflect measured concentrations.

5.5. Soluble P Yields

As with the simulated nitrate loadings, Sol-P loadings (Figure 5.13) were largely underestimated by a magnitude of approximately 10. Measured annual Sol-P ranged from 0.20 kg ha^{-1} to 0.76 kg ha^{-1} and had a three-year average of 0.42 kg ha^{-1} . The largest annual simulated result was 0.036 kg ha^{-1} and the largest three-year average was 0.024 kg ha^{-1} , based on the Hargreaves method.

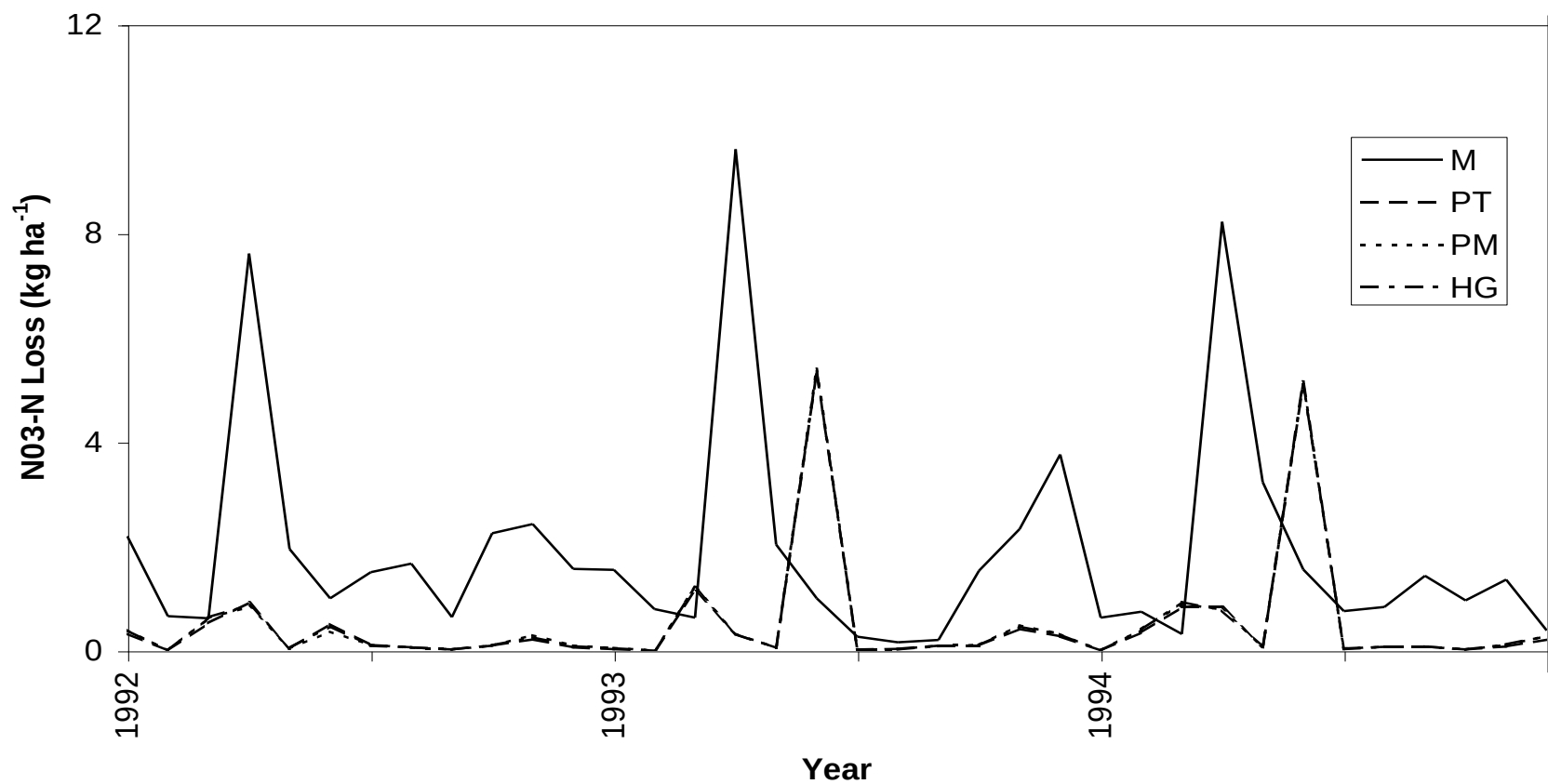


Figure 5.12. Comparison of monthly measured (M) and simulated nitrate loadings in the Black Brook Basin using the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration.

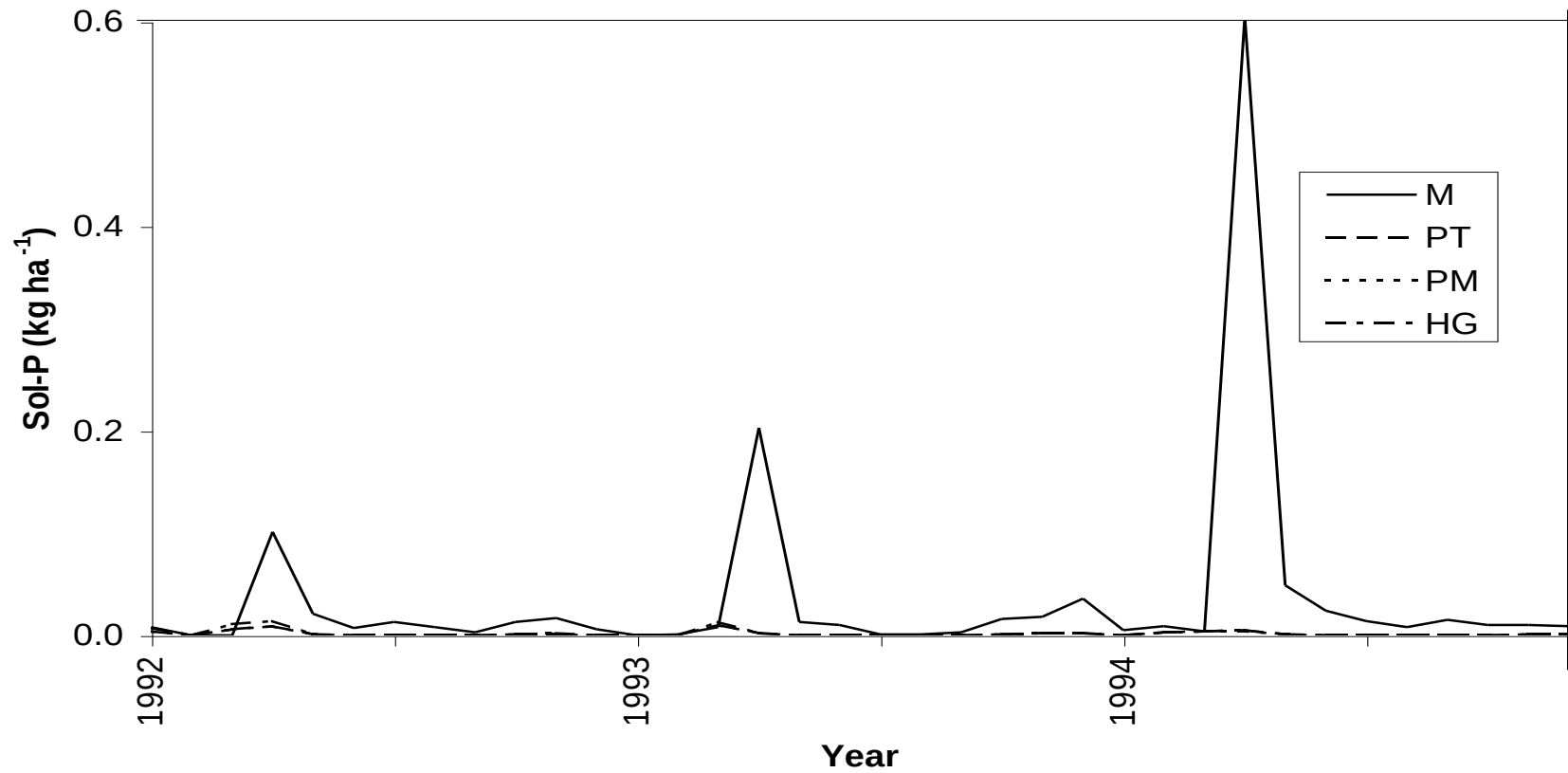


Figure 5.13. Comparison of monthly measured and simulated soluble phosphorous loadings in the Black Brook Basin using the Priestly-Taylor (PT), Penman-Monteith (PM), and Hargreaves (HG) methods of calculating evapotranspiration.

CHAPTER 6

THE BLACK BROOK BASIN: SWAT CALIBRATIONS AND FINE-TUNING

6.1 Introduction

While the initial SWAT simulations are generally close to the field observed values for stream discharge and the stream loadings for sediments, nitrate-N and soluble P, further adjustments are now described that enhanced the general performance of SWAT for BBB. All of this was done with the expectations that these adjustments will generate a well-calibrated SWAT model to model land and soil conditions similar to BBB elsewhere in Atlantic Canada and beyond. In this, the **SWAT calibration tool** facilitates any adjustments that would need to be made for the purpose of enhancing the overall model performance. For example, this tool allows changes to 27 parameters within the following input files: crop.dat, *.bsn, *.chm, *.gw, *.hru, *.sub, *.rte, *.mgt, and *.sol. Depending on the parameter, changes can be made by an absolute value, which decreases or increases the default value, or by a percentage of the default value. If the new value is outside the lower and upper limits that are determined by SWAT, one can specify that the value either remains in the range or exceeds this range. Also, alterations can be applied to a specific land use(s) within a basin. All parameters for the *.bsn and *.wwq input files can be accessed within the SWAT set up window (Figure 5.1).

6.2. Hydrological SWAT Adjustments

Several parameters are available to adjust the rate of snowmelt: SMTMP parameter, SNOCOV MX, SMFMX, SMFMN and FFCB. The role of these parameters is described below. Multiple iterations among these parameters are required to obtain optimal parameter values listed in Table 6.1.

The SMTMP parameter is the snowmelt base temperature in the *.bsn input file. Increasing this parameter from 1°C to, e.g., 5 °C causes the majority of snowmelt to occur in April, as observed. In the file, SMTMP is set to range from –5 °C to 5 °C. No snowmelt from the snow pack will occur until the measured or generated air temperature exceeds the base temperature. The specific SMTMP value likely depends on antecedent air temperatures, melting rates, and the amount of land covered by snow. By increasing SMTMP to 5 °C, the simulated annual average stream discharge increased from 603 mm to 647 mm, which is close to the measured annual average of 653 mm. Simulated peaks of stream discharge following this adjustment are also in agreement with observed peaks.

The SNOCOV MX parameter is the threshold value where the landscape is covered entirely by snow. It can also be defined as the minimum amount of snow water content that coincides with 100 percent coverage of snow across the landscape. Different values of SNOCOV MX influence the areal depletion of snow and the fragmentation of bare ground across the landscape.

The SMFMX parameter is the maximum snowmelt rate factor in mm H₂O per °C-day and is based on the amount of snow that would melt on June 21. The minimum snowmelt rate factor (SMFMN) is based on the amount of snow that would

Table 6.1. Calibrated output for water yield.

	Measured	Default	Calibrated
Input			
SMTTMP	N/A	0.5	5
SMFMN	N/A	4.5	1.5
SMFMX	N/A	4.5	6
SNOCOVMAX	N/A	1	30
FFCB	N/A	0	0.6
Output			
Snow Melt* (mm)	Not Avail.	359.70	361.44
Water Yield* (mm)	652.97	603.12	652.42
Sediment Yield** (t ha ⁻¹)	4.51	9.03	4.46
Nitrate Yield** (kg ha ⁻¹)	22.81	6.13	6.64
SolP Yield** (kg ha ⁻¹)	0.42	0.02	0.02
* Simulated and measured data based on average of years 1992-1999 inclusive			
** Simulated and measured data based on average of years 1992-1994 inclusive			

melt on December 21. These rates vary throughout the year and reflect the impact of snow pack density on snowmelt. By increasing SMFMX, more melt water can be produced in April and May as daily temperatures begin to rise. Decreasing SMFMN allows for the potential of a lower rate of snowmelt in the winter months.

The FFCB parameter refers to the initial amount soil water and is represented as a fraction of field capacity. The range of FFCB is from 0-1. The default setting of zero is unrealistic, because most soils in the region experience a certain amount of wetting. During the model simulations, surface runoff was first allocated to the soil until saturation occurs. This represents a significant amount of water that would otherwise have contributed to stream discharge.

6.3 Sediment Yield Adjustments

SWAT uses the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975, 1995) to calculate erosion from rainfall and surface runoff. This equation is based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Sediment yield calculations were based on attributes of the subbasins and channel degradation was not considered in any of the simulations.

Simulated sediment loadings closely reflected the measured three-year average (Table 6.1) after stream discharge was calibrated: the calculated three-year average and measured value both amounted to 4.5 t ha^{-1} . In this, no additional sediment loss calibrations were needed. Yearly comparisons showed that the simulated sediment loadings were underestimated in 1992 ($\sim 0.7 \text{ t ha}^{-1}$) and

overestimated in 1993 ($\sim 0.2 \text{ t ha}^{-1}$) and in 1994 ($\sim 0.4 \text{ t ha}^{-1}$) compared to the annual measured values in Table 6.1.

Although the annual simulated values are in close agreement with to the measured values, most sedimentation is predicted to occur in May rather than in April. This is indicative of a problem with the snowmelt calculations. Also, in 1992 the model showed a spike in October whereas none was recorded. It is unsure as to why these discrepancies occur. However, one should note that SWAT and MUSLE calculations represent long-term averages better than short-term events. Short-term events such as bank-erosion, road wash-outs, failure of beaver dams, and other failures of land structures designed to alleviate storm run-off all contribute recorded stream sediment loads, but are - essentially – not part of the SWAT formulations.

It should be noted that the support practices factor P would have the most influence on calculated erosion loadings, as discussed in Chapter 33 of the Soil and Water Assessment Tool User's Manual (Neitsch et al., 2001).?????

6.4 Nitrate Loading Adjustments

To calibrate nitrate loadings, the nitrogen percolation coefficient (NPERCO) in the *.bsn input file was used to simulate more reasonable nitrate concentrations within surface runoff. It was found that increasing NPERCO from 0.2 to 0.9 increased the three-year simulated average from 6.1 kg ha^{-1} to 21.8 kg ha^{-1} , which is close to the three-year measured average of 22.8 kg ha^{-1} . Yearly comparison of values was not simulated very accurately. In 1992, the simulated amount was 8.06 kg ha^{-1} , i.e., much lower than the measured value of 21.1 kg ha^{-1} . Nitrate contributions

were predicted to be 29.0 kg ha⁻¹ (1993) and 28.3 kg ha⁻¹ (1994) compared to 24.4 kg ha⁻¹ and 20.5 kg ha⁻¹, respectively. The majority of nitrate loading occurred in the month of June, especially for 1993 and 1994, which coincides with the scheduling of fertilizer application. The month of June accounted for 80.2% (23.2 kg ha⁻¹) of the total nitrate in 1993 and 78.3% (22.2 kg ha⁻¹) in 1994. For the simulations, the fraction of nitrate that was applied to the top 10 mm of soil was set to one. This would significantly allow for much nitrate runoff to occur soon after application. The maximum value for the NPERCO is 1.0. The most probable reason for requiring such a drastic increase in the NPERCO is that initial soil concentrations of nitrate were assumed to be zero.

6.5 Water Soluble Phosphorous Loading Adjustments

The phosphorous sorption coefficient (PSP) and phosphorous soil partitioning coefficient (PHOSKD) in the *.bsn input file can be used for modifying the soluble P loadings. To bring about agreement between observed and simulated soluble P loadings it was required to change PSP to its minimum default value of 0.01. The adjusted value used for PHOSKD was 61.5. This value falls out of the default range (100-200). To change PHOSKD to 61.5, the variable must be changed directly in the *.bsn input file.

The calibrated three-year simulated average is the same as the three-year measured average (0.42 kg ha⁻¹) for soluble P. The model overestimated soluble P in 1992 and 1993 with 0.40 kg ha⁻¹ and 0.42 kg ha⁻¹, respectively, compared to the corresponding yearly measured values of 0.20 kg ha⁻¹ and 0.31 kg ha⁻¹, respectively.

Simulated peaks do occur in April as with the measured data. Also, both sets of monthly values are comparable.

6.6 Further Adjustments

Calibrating the nutrient loadings had an indirect effect on water and sediment yields. For example, the increase in the nutrient loadings caused the three-year average simulated sediment yields to increase to 4.6 t ha^{-1} (up from 4.5 t ha^{-1}), and three-average simulated water yield decreased to 651 mm (down from 653 mm). More model simulations were conducted to adjust these parameters. SNOCOVMX was increased to 30.5 mm, which decreased the three-year average to 4.6 t ha^{-1} and increased the three-year water yield to 651mm. After multiple iterations of changing SNOCOVMX and SMFMX, this was found to be in closest agreement with the three-year measured average. Nutrient yields remained unchanged from modifying SNOCOVMX. Table 6.2 summarizes the variables that were changed to produce the final output.

6.7 Sensitivity Analysis: From High to Low Soil Resolution

The simulations performed in the BBB were based on soil data collected at the 1:10000 scale. Soil data at this resolution is rare. Soil data in Canada is largely provided by the Canadian Soil Information System (CanSIS), with originating support from Agriculture and Agri-Food Canada and various provincial

Table 6.2. Final calibrated output for Black Brook Basin.

	Measured	Default	Calibrated
Input			
SMTTMP	N/A	0.5	5
SMFMN	N/A	4.5	1.5
SMFMX	N/A	4.5	6
SNOCOVMAX	N/A	1	30.5
FFCB	N/A	0	0.6
NPERCO	N/A	0.2	0.9
PHOSKD	N/A	175	61.5
PSP	N/A	0.4	0.01
Output			
Snow Melt* (mm)	Not Avail.	359.7	361.44
Water Yield* (mm)	652.97	603.12	651.26
Sediment Yield** (t ha ⁻¹)	4.51	9.03	4.58
Nitrate Yield** (kg ha ⁻¹)	22.81	6.13	21.78
SolP Yield** (kg ha ⁻¹)	0.42	0.02	0.42
* Simulated and measured data based on average of years 1992-1999 inclusive			
** Simulated and measured data based on average of years 1992-1994 inclusive			

departments and universities. The general resolution of this soil data is often at the 1:50000 scale.

Using SWAT, a simulation with the soil data compiled by CanSIS at the 1:50000 scale was used to determine how sensitive the output would be to using lower soil resolution data. At this resolution, there are only two soil types: the Siegas series at 404 ha or 32 % of BBB, and the Carlingford series at 852 ha or 68 % of BBB. The corresponding U.S. soil equivalents are the Daigle series (S5id-ME0031) and the Conant series (S5id-ME0042), respectively. Using only two soil types yielded 49 HRUs compared to the 94 HRUs for the initial simulation. Both soil themes were overlaid on the same land use theme. Appendix E summarizes the HRU classification in the BBB.

As shown in Table 6.3, using the lower resolution soil data produced annual stream discharges that were generally higher than the simulations using the higher resolution soil data: The eight-year average for the lower resolution soil data was 748 mm compared to 603 mm for the higher resolution soil data. Surface runoff between the simulated data was therefore increased by a factor of 1.24. There were only two years (1992 and 1994) that the annual simulations were lower than the measured values.

The simulated annual average for sediment yield increased from 9.0 t ha⁻¹ to 63.1 t ha⁻¹ for the years 1992 to 1993 inclusive (Table 6.3). This is an increase by a factor of 7.06 when using lower resolution soil data. The values for 1993 were extremely high, which follows the same trend that was observed for the high-resolution soil data.

Table 6.3. Annual simulated data using different resolution soil maps.

Year		Measured	Simulated	
			1:10000 (7 soils)	1:50000 (2 soils)
1992	Water Yield (mm)	752.3	537.7	700.5
	Sediment Yield (t ha ⁻¹)	5.53	4.70	43.81
	NO3-N Loading (kg ha ⁻¹)	24.10	2.90	6.37
	Sol. P (kg ha ⁻¹)	0.197	0.022	0.966
1993	Water Yield (mm)	721.8	673.8	796.4
	Sediment Yield (t ha ⁻¹)	3.74	17.42	96.22
	NO3-N Loading (kg ha ⁻¹)	23.9	7.80	10.78
	Sol. P (kg ha ⁻¹)	0.310	0.017	0.966
1994	Water Yield (mm)	759.4	588.7	734.9
	Sediment Yield (t ha ⁻¹)	4.25	4.96	51.1
	NO3-N Loading (kg ha ⁻¹)	20.40	7.71	8.00
	Sol. P (kg ha ⁻¹)	0.762	0.015	0.87
1995	Water Yield (mm)	468.2	522.7	692.2
	Sediment Yield (t ha ⁻¹)	Not Available	7.15	56.17
	NO3-N Loading (kg ha ⁻¹)	Not Available	4.28	10.62
	Sol. P (kg ha ⁻¹)	Not Available	0.016	0.709
1996	Water Yield (mm)	750.1	623.2	807.2
	Sediment Yield (t ha ⁻¹)	Not Available	4.92	58.08
	NO3-N Loading (kg ha ⁻¹)	Not Available	7.1	10.8
	Sol. P (kg ha ⁻¹)	Not Available	0.011	1.11
1997	Water Yield (mm)	561.8	549.3	636.2
	Sediment Yield (t ha ⁻¹)	Not Available	6.11	49.79
	NO3-N Loading (kg ha ⁻¹)	Not Available	4.4	9.7
	Sol. P (kg ha ⁻¹)	Not Available	0.010	0.742
1998	Water Yield (mm)	686.2	728.4	871.0
	Sediment Yield (t ha ⁻¹)	Not Available	5.35	44.45
	NO3-N Loading (kg ha ⁻¹)	Not Available	4.84	11.1
	Sol. P (kg ha ⁻¹)	Not Available	0.012	1.462
1999	Water Yield (mm)	523.86	601.0	743.7

	Sediment Yield (t ha^{-1})	Not Available	3.79	43.67
	NO ₃ -N Loading (kg ha^{-1})	Not Available	5.50	7.9
	Sol. P (kg ha^{-1})	Not Available	0.009	1.427
2000	Water Yield (mm)	Not Available	594.1	749.6
	Sediment Yield (t ha^{-1})	Not Available	5.67	60.45
	NO ₃ -N Loading (kg ha^{-1})	Not Available	4.09	6.12
	Sol. P (kg ha^{-1})	Not Available	0.010	0.975
2001	Water Yield (mm)	Not Available	350.1	472.6
	Sediment Yield (t ha^{-1})	Not Available	1.90	31.06
	NO ₃ -N Loading (kg ha^{-1})	Not Available	5.58	10.3
	Sol. P (kg ha^{-1})	Not Available	0.006	0.846

The nitrate loading was the only variable that was not above the measured three-year average when using the lower resolution input data (Table 7.4). The simulated three-year average increased from 6.1 t ha^{-1} to 8.4 t ha^{-1} , but was still below the corresponding measured three-year average of 22.8 t ha^{-1} .

The simulated three-year average for Sol-P loadings experienced the largest increase by using the lower resolution data (Table 6.3). The three-year average increased from 0.02 t ha^{-1} to 0.93 t ha^{-1} , which is a factor of 46.7. When comparing it to the measured three-year average, it is only a factor of 2.2 greater.

The most likely reason for the increase in all variables due to the lowered soil resolution relates to an overall decreased soil drainage assignment for the basin: the well-drained Siegas series occupies the upper 32% of the basin; therefore – this soil would have the least influence on surface run-off; in contrast, the imperfectly drained Carlingford series covers approximately 68 % of the lower part of BBB, where most of the extra water as well as sediment and nutrient loads are likely to originate.

Hence, high resolution mapping of soils is essential for increasing the accuracy of SWAT predictions.

6.8 Concluding Remarks

In summary, the percent of areal coverage of snow across a landscape and the base temperature and rate at which snow melts has a large influence on calibrating SWAT stream discharge during spring. Altering the timing of snowmelt, however, has little to no influence the annual total stream discharge simulations. Increased snowmelt rates and areal coverage of snow are calculated to increase soil erosion, and hence sediment yields, but without increasing nutrient transfers to the stream.

As to be expected, factors that influence sediment yields in particular are:

- tillage methods
- extent of soil conservation measures
- soil surface conditions
- topography

It is noted that the stream discharge calculations were calibrated without considering soil conservation measures. The highest CNII values were used for each crop type and the support practices (P) factor was assumed to be 1 (no soil conservation measures). The implication of this is that even though simulated sediment yields are similar to the field observations, SWAT most likely underestimates sediment yields.

Incorporating conservation measures such as strip-cropping or contour terracing should theoretically reduce erosion. However, while conservation measures such as strip cropping and contour terracing were installed in certain places, these

need to be fully effective and comprehensive across the basin. Field inspection showed that while conservation practices were in part effective, such practices are not applied not in all places. As a result, downslope soil motion towards the stream was observable in many places. In addition, sediment settling on stream bottoms during mid- to late summer further indicated that achieving and maintaining soil conservation practices to maximum effectiveness is very difficult in general, and would be very difficult in certain portions of the terrain, i.e., those portions of the terrain where water infiltration in the soil is reduced because of low top and/or subsoil permeability, and slopes are sustained over long distances. Further research is required to project and analyse surface run-off patterns more closely within each subbasin and each HRU, especially in relation to the flow accumulation concept, and actual rate of soil infiltration at the flow accumulation lines. Actual rate of soil infiltration can be assessed through detailed hydrological modelling, one day at a time, and one HRU at a time.

Considerable upward SWAT adjustments were required to get simulated nutrient yields to reflect measured values. Here, the adjustments should be more focussed more on setting proper fertilization rates rather than one adjusting the SWAT parameters. Also, nutrient contributions arising point sources could be more important than what arises from areal applications. This requires further research by answering the following questions: are there point sources with sustained nutrient discharge? If so, where are these sources, and what are the concentrations of soluble nitrates and P at these locations?

It is apparent that SWAT heavily relies upon soil input data in modeling processes involving stream discharge, sediment loadings, and nutrient loadings. Lower resolution data resulted in increases in output largely because of the physical characteristics of the soils, particularly drainage. However, lower soil resolutions may not always produce this effect, because the SWAT calculations also depend on the geo-spatial soil distribution within the basin.

CHAPTER 7

THE LITTLE RIVER BASIN: SWAT SIMULATIONS FOR ITS FORESTED SUBBASINS

7.1 Introduction

This chapter compares SWAT output for stream discharge and sediment loads with measured data in a forested subbasin in the middle to northern portion of the LRB. For this purpose, the BBB-calibrated SWAT model was applied as follows:

- Apply no change to the weather data, assuming that the same weather conditions apply across the forested LRB subbasin, and that the forest has no effect on these weather conditions
- Apply the same procedure for subbasin and HRU delineation
- Compare model simulations with 15 months of measured discharge and sediment data from October 2000 until December 2001 (Chow, 2002)
- Use the actual stream gauging station on the Little River to make the comparisons between the SWAT simulations and the measured data.

7.2 Watershed Discretization and Stream Definition

The DEM of the LRB was created from the following 24 DEG map tiles from the New Brunswick Department of Natural Resources (Crain, 2001):

3323	3423	3523	3623
3324	3424	3524	3624
3325	3425	3525	3625
3326	3426	3526	3626
3327	3427	3527	3627
3328	3428	3528	3628

The IDW method of interpolation was used to produce a DEM at a 50-m grid resolution. The threshold area for generating the individual streams was set at 300 hectares, or 1200 cells at the 50-metre by 50-metre resolution. The DEM mask was set on the forested portion of the LRB that drains to the weir station 12 (Figure 2.11). This portion represents approximately 180 km², or 50 % of the total 356 km² area of LRB. Table 7.1 describes the physical attributes of the stream network located within the forested portion of the LRB.

Table 7.1. Physical characteristics of subbasin and stream attribute of the modelled forest portion of the Little River Basin.

Subbasin Number	Subbasin Area (ha)	Fraction of Total Area	HRU Total	Main Channel Width (m)	Avg Slope of Channel (m)	Main Channel Length (km)	Channel Width:Depth Ratio
8	17,981	0.504	21	29.07	0.003	18.09	28.03

7.3 Land Use and Soil Characterization

Soil maps and data were obtained from the Canadian Soil Classification System (<http://sis.agr.gc.ca/cansis/intro.html>). Land use was determined from the LandsAT satellite image of the area, using PCI Geomatics software. This was done by orthorectification and image classification using the Focus routines within PCI. Orthorectification of the satellite image was required to remove distortions due to camera tilt and lens effects. Making the image planimetrically correct allows the resulting orthoimage to be used as a fully geo-referenced theme.

Image classification with PCI classifies colour pixels into a finite number of categories. Supervised image classification was performed to generate land use types based on specific colour criteria, as detailed elsewhere (Learning PCI OrthoEngine, 1996; Introduction to Geomatica, 1996. The specific land use classification algorithm was based on the maximum likelihood classification.

Average accuracy of the classification using six land use codes was 98.2 %. Omitting the results from the Background (the black area outside of the satellite image) reduced the average accuracy to 97.1 %. The overall accuracy of the confusion matrix was 98.8 %. For further details, see Appendix F.

The classified land uses refer to hardwood, softwood, clearcut and forest-plantation, as shown in Figure 7.1. The order of land use, in decreasing order of areal coverage, forest-evergreen or coniferous forest, forest-deciduous, range-brush, and agriculture. The forest plantation land code was given the SWAT code – AGRL. Table 7.2 summarizes the spatial extent of each land use in the subbasin.

Table 7.2 Summary of crop types modelled in forested subbasin of Little River Basin and percent coverage.

Land Use	SWAT Code	Area (ha)	% of Subbasin
Range-Brush	RNGB	2893.02	15.75
Forest-Evergreen	FRSE	8740.36	47.58
Forest-Deciduous	FRSD	5823.07	31.70
Forest-Plantation	FRSE	913.05	4.97

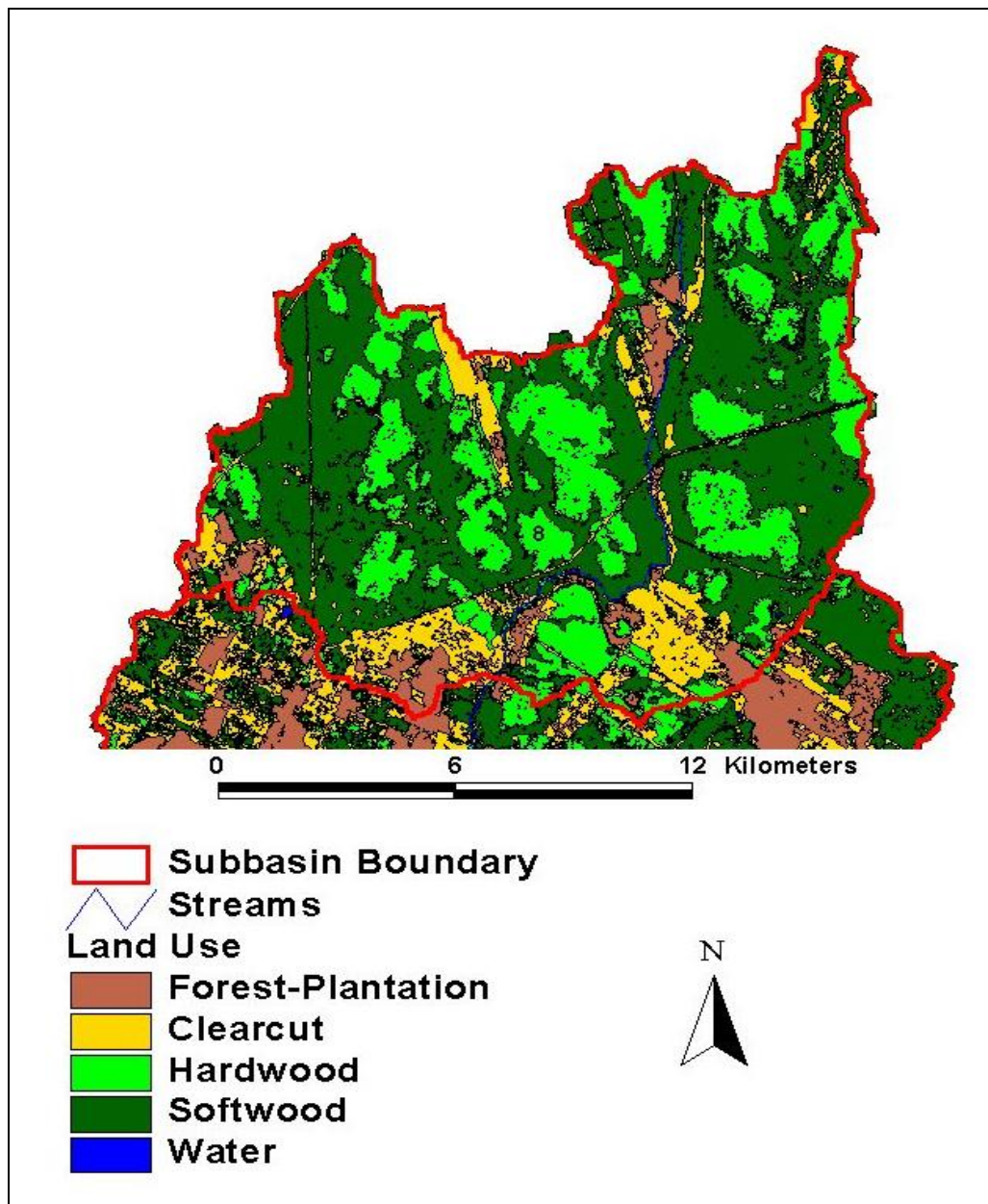


Figure 7.1. Land use distribution within forested subbasin of Little River Basin.

A total of seven soils cover the forested subbasin of LRB (Figure 7.2). The area that each occupies varies greatly. The order of predominant to minor soil series within the subbasin is Holmesville, McGee, Caribou, Siegas, Muniac, Ogilvie Lake, and Grand Falls. Table 7.3 summarizes the area that the soils within the basin, and also lists the corresponding U.S. equivalents.

Multiple HRUs were modeled for the simulation in the forested portion of LRB. The minimum threshold of one percent was used for land use coverage and soil class within each land use category. This yielded 21 unique land use and soil combinations. Appendix G summarizes these land use and soil combinations.

7.4 Comparison of Simulated and Measured Output

The SWAT simulations for monthly stream discharge and sediment yield are based on the BBB SWAT calibration, as detailed in Table 6.2. Measured and simulated values are listed in Table 7.4. For example, the total stream discharge for the 15-month period from October 2000 to December 2001 was 711mm. This was 113 mm greater than the simulated stream discharge of 598 mm. In general, monthly stream discharge values were underestimated for 11 of the 15 months. Although stream discharge was generally underestimated, the simulated monthly trend closely resembled the measured data except for January and February of 2001, and the peak

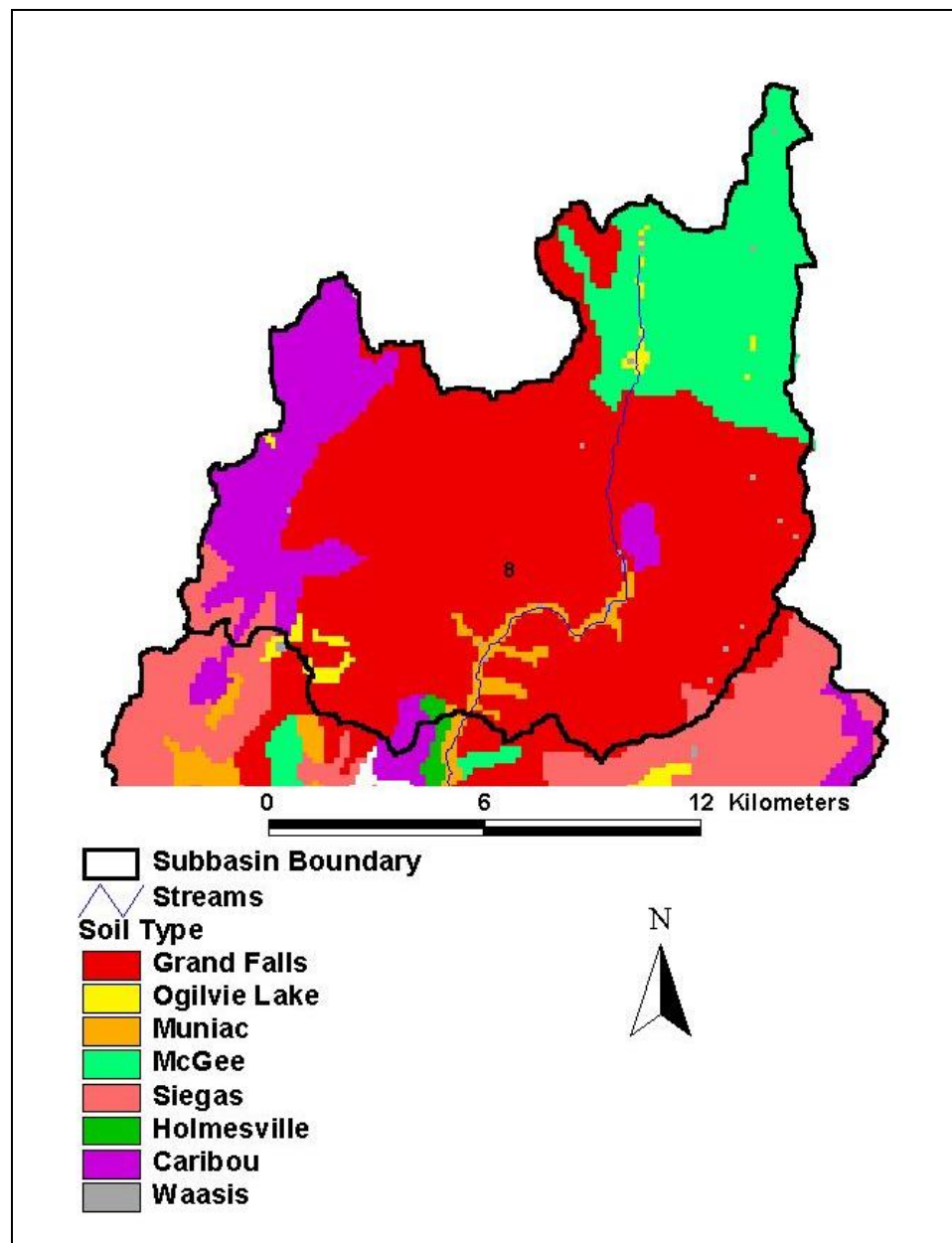


Figure 7.2. Canadian soil types and distribution within forested portion of Little River Basin.

Table 7.3. Soil type distribution and U.S. equivalents.

Soil Series	Canadian Soil Sub Group	US Equivalent	SWAT Code (S5ID)	Area (ha)	% of Watershed
Caribou	Podzolic Gray Luvisol	Caribou	ME0041	2448.58	1.72
Grand Falls	Orthic Humo-ferric Podzol	Machias	ME0033	11752.06	0.05
Holmesville	Orthic Humo-ferric Podzol	Plaisted	ME0007	9.88	63.98
McGee	Orthic Humo-ferric Podzol	Thorndike	ME0022	3370.56	1.67
Muniac	Orthic Humo-ferric Podzol	Stetson	ME0021	306.30	18.35
Ogilvie Lake	Gleyed Orthic Humo-ferric Podzol	Monarda	ME0011	166.97	0.91
Siegas	Gleyed Podzolic Gray Luvisol	Daigle	ME0031	315.15	13.33

Table 7.4. Summary of measured and simulated data in forested portion of Little River Basin (17,982 ha).

Year	Month	Measured		Simulated	
		Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)	Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)
2000	10	20.08	0.001	31.44	0.002
	11	33.26	0.003	46.55	0.002
	12	76.05	0.010	54.03	0.000
2001	1	57.87	0.018	9.48	0.000
	2	48.00	0.003	2.96	0.000
	3	50.37	0.005	1.38	0.000
	4	85.87	0.010	224.83	0.001
	5	112.31	0.012	51.40	0.011
	6	48.27	0.006	44.98	0.009
	7	48.16	0.147	39.90	0.008
	8	22.98	0.003	24.68	0.002
	9	21.58	0.002	20.44	0.007
	10	23.25	0.005	14.88	0.001
	11	26.32	0.003	18.11	0.002
	12	36.33	0.004	9.67	0.000
Total		710.70	0.232	597.74	0.045

that occurred in April 2001. Figure 7.3 illustrates the monthly trend of stream runoff.

Sediment yields were also underestimated by SWAT. Total simulated sediment inputs were 0.045 t ha^{-1} compared to the measured 0.23 t ha^{-1} (Table 8.5). Sediment yield peaked in July 2001 with 0.15 t ha^{-1} . This accounted for 63% of the measured total input. This outlier could potentially be from: local washout; a natural or anthropogenic disturbance in the stream; sampling and analysis error. All other measured monthly values were equal to or below 0.018 t ha^{-1} . Monthly measured peak values did not correlate with the SWAT simulations (Figure 7.4).

7.5 Sensitivity Analysis of Different Land Uses

Sensitivity analyses were performed to determine the effect of three different forest covers within the forested portion of the LRB: softwood (SW), hardwood (HW), and mixed wood (MW). All model runs were the same as the default run (simulation settings and calibration adjustments), except that a particular land use was set to be exclusive.

Each run with SW, HW or MW yielded lower water yields than the measured values. The HW and MW simulations were identical and had the most realistic prediction of stream discharge. The predicted discharge was 688 mm compared to the measured value of 711 mm. Predicted stream discharge for SW was 506 mm. This value is substantially lower than the measured value and 89 mm lower than the original simulation. The largest differences occurred between September and December of 2001 (Table 7.5).

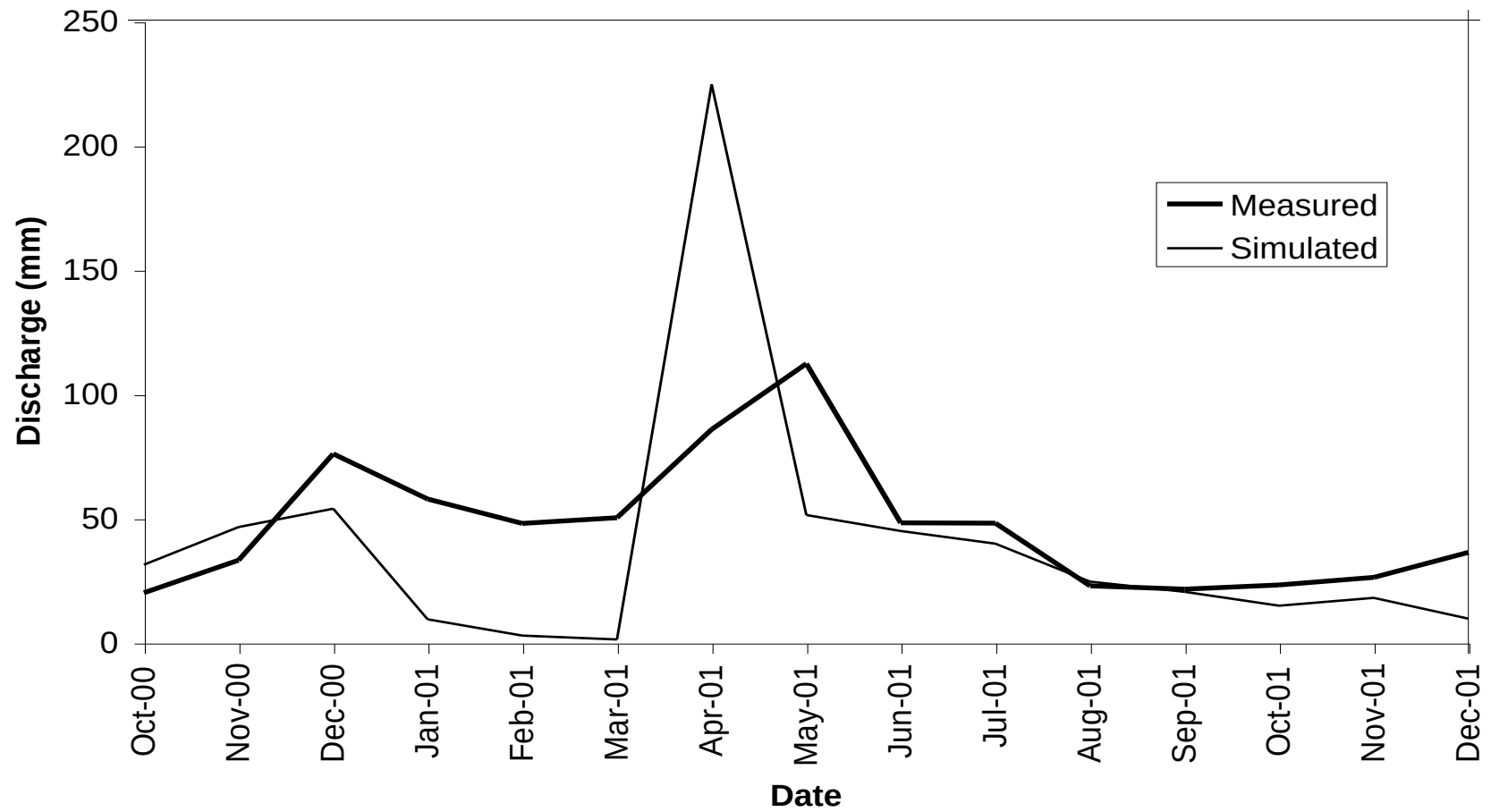


Figure 7.3. Comparison of monthly measured and simulated stream discharge in a forested subbasin of the Little River Basin.

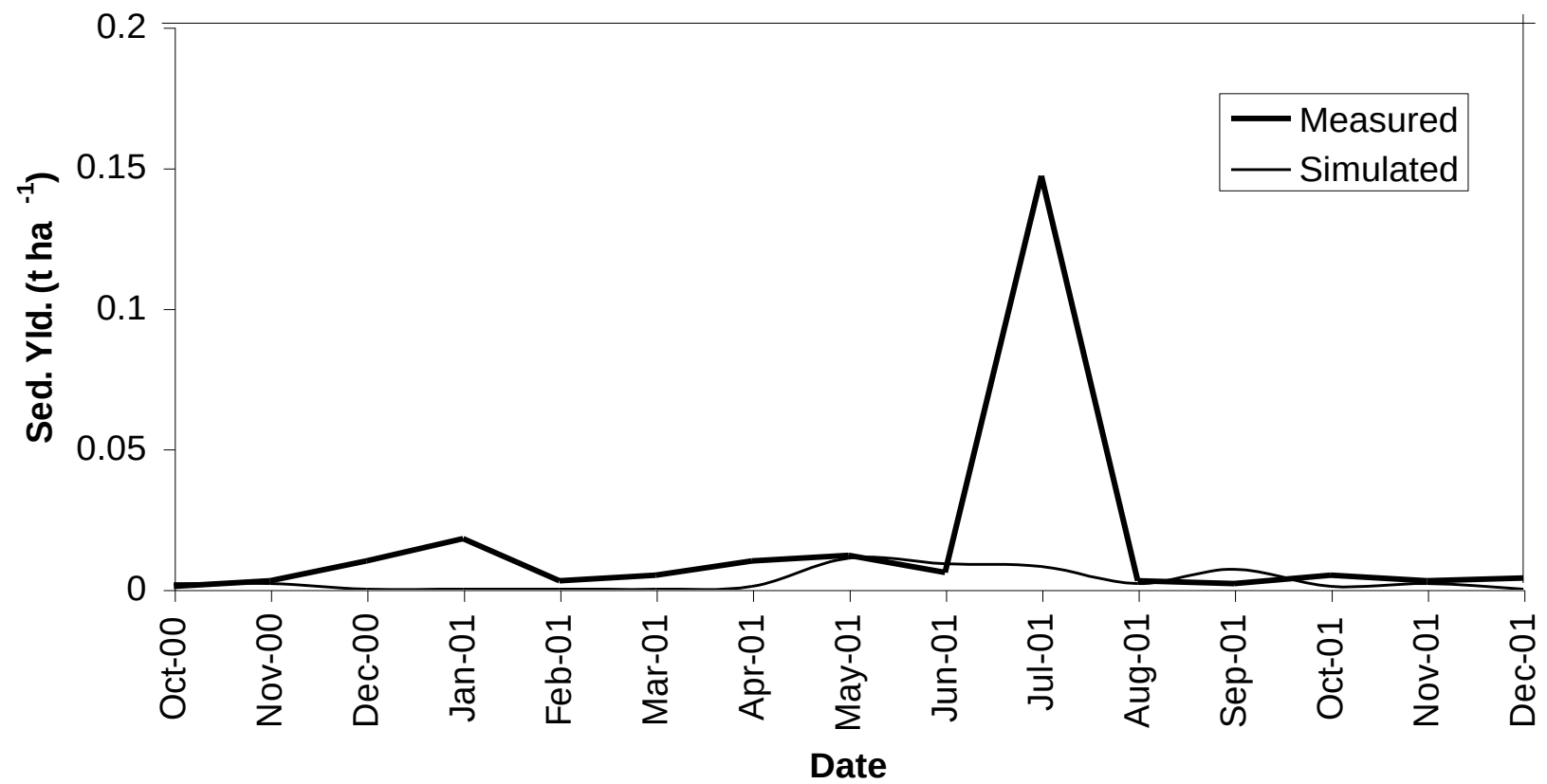


Figure 7.4. Comparison of monthly measured and simulated sediment yield in forested subbasin of the Little River Basin (180 km²).

Table 7.5. Sensitivity analysis of SWAT output to different forest covers.

Year	Month	Measured		Simulated-Calibrated		Simulated-SW		Simulated-HW		Simulated-MW	
		Stream Discharge (mm)	Sediment Loadings (t/ha)	Stream Discharge (mm)	Sediment Loadings (t/ha)	Stream Discharge (mm)	Sediment Loadings (t/ha)	Stream Discharge (mm)	Sediment Loadings (t/ha)	Stream Discharge (mm)	Sediment Loadings (t/ha)
2000	10	20.08	0.001	31.44	0.002	30.31	0.000	30.40	0.000	30.40	0.000
	11	33.26	0.003	46.55	0.002	50.10	0.002	49.35	0.002	49.35	0.002
	12	76.05	0.010	54.03	0.000	85.88	0.010	84.13	0.011	84.13	0.011
2001	1	57.87	0.018	9.48	0.000	8.62	0.000	8.48	0.000	8.48	0.000
	2	48.00	0.003	2.96	0.000	3.09	0.000	3.04	0.000	3.04	0.000
	3	50.37	0.005	1.38	0.000	52.20	0.000	52.17	0.000	52.17	0.000
	4	85.87	0.010	224.83	0.001	108.03	0.007	110.70	0.009	110.70	0.009
	5	112.31	0.012	51.40	0.011	39.48	0.001	46.72	0.002	46.72	0.002
	6	48.27	0.006	44.98	0.009	45.37	0.001	53.41	0.001	53.41	0.001
	7	48.16	0.147	39.90	0.008	31.32	0.000	55.39	0.000	55.39	0.000
	8	22.98	0.003	24.68	0.002	16.17	0.000	46.67	0.001	46.67	0.001
	9	21.58	0.002	20.44	0.007	5.88	0.000	35.74	0.002	35.74	0.002
	10	23.25	0.005	14.88	0.001	4.97	0.000	40.19	0.000	40.19	0.000
	11	26.32	0.003	18.11	0.002	5.08	0.000	38.17	0.000	38.17	0.000
	12	36.33	0.004	9.67	0.000	19.51	0.004	33.02	0.006	33.02	0.006
Total		710.7	0.231	597.74	0.045	505.99	0.025	687.59	0.034	687.59	0.034

Based on the discharge data, it could be concluded that the output from the default simulation is heavily influenced from the presence of softwood around the stream network. Approximately 48% of land cover in the subbasin is coniferous.

Predicted sediment loadings from SW, HW, and MW were all lower than the default simulation. The HW and MW predictions were the same (0.034 kg ha^{-1}) and SW was 0.025 kg ha^{-1} . These values are approximately 10 times lower than the measured value.

7.6 Concluding Remarks

Overall, it appears that the SWAT simulations underestimates measured stream discharge rates and sediment yields. The likely reason for low stream discharge simulations could be that the effective watershed surface available for evapotranspiration is overestimated, i.e., the assumed leaf area for the forest may be too large. In general, one should consider that the forest of the area is not fully stocked, and there are many open areas within the forest, such as clearcuts, roads, and other hard surfaces that would reduce the overall leaf area of the basin. This, in turn, would reduce the overall water loss through interception and through transpiration.

The likely reason that SWAT generates low stream sediment loads is that point and line sources for sediment generation within the LRB basins, subbasins and HRUs are not considered. For example, stream channel erosion alone could outweigh the areal erosion contributions from the forest by a factor of 10, as demonstrated by Pomeroy (2003).

CHAPTER 8

THE LITTLE RIVER BASIN: SWAT SIMULATED N AND P LEACHING LOSSES

8.1 Introduction

This Chapter summarizes methods and results regarding SWAT simulations for nitrate and soluble P loads in the main stem of the Little River, i.e., downstream from the upland agriculture-forestry operations within LRB. These simulations are also compared with measured sediment and stream discharge for the same period (Chow, 2002).

8.2 Methods

The DEM of the LRB was created from the same map tiles used in the preceding Chapter for watershed and stream definition. The DEM is based on a 50-metre grid, obtained by using the IDW interpolation method. The stream network uses a stream definition threshold area of 300 hectares (1200 cells). The weather data of Chapter 4 serve as weather input. The calibration adjustments already listed in Table 6.2 serve as parameter input.

The soil information collected from the BBB and the Canadian Soil Classification System for LRB yielded 15 Canadian soil series, which are summarized in Table 9.1. There were three pairs of Canadian soils that had a common U.S. equivalent. They were the Thibault/Caribou, McGee/Glassville, and Holmesville/Victoria soil series. Each of these soil pairings was modeled as one soil.

Table 8.1. Soil type distribution and U.S. equivalents for Little River Basin (35,653 ha).

Soil Series	Canadian Soil Sub Group	US Equivalent	SWAT Code (S5ID)	% of Watershed
Caribou	Podzolic Gray Luvisol	Caribou	ME0041	9.8
Carlingford	Gleyed Gray Luvisol	Conant	ME0042	11.6
Glassville	Orthic Ferro-humic Podzol	Thorndike	ME0022	3.0
Grand Falls	Orthic Humo-ferric Podzol	Machias	ME0033	1.0
Holmesville	Orthic Humo-ferric Podzol	Plaisted	ME0007	29.2
Interval	Orthic Regosol	Fryeburg	ME0080	0.01
McGee	Orthic Humo-ferric Podzol	Thorndike	ME0022	6.8
Muniac	Orthic Humo-ferric Podzol	Stetson	ME0021	5.2
Ogilvie Lake	Gleyed Orthic Humo-ferric Podzol	Monarda	ME0011	0.9
Siegas	Gleyed Podzolic Gray Luvisol	Daigle	ME0031	20.6
St. Quentin	Terric Mesisol	Wonsqueak	ME0121	0.1
Thibault	Orthic Humo-ferric Podzol	Caribou	ME0041	1.9
Undine	Orthic Dystric Brunisol	Mapleton	ME0025	0.9
Victoria	Orthic Humo-ferric Podzol	Plaisted	ME0007	8.9
Waasis	Gleyed Orthic Regosol	Lovewell	ME0081	0.3

Pairings were made based on similarity in erodibility factors, drainage regime, and parent geological material.

Land use data for the entire LRB were generated by way of Image Classification, as described in Section 7.3. All of BBB within LRB was treated as potato land. Approximately 96 % of the land in LRB is within subbasins 7 and 8. The remaining land is BBB with its 6 subbasins. The coniferous forest occupies 41 percent of the land area. Approximately 5 percent of the land classified in the forested portion of LRB (subbasin 8) was classified as agricultural land. This land is most likely forest plantation. All agricultural land outside of subbasin 8 was assigned to potato cropping. A distinction was made between Forest-Evergreen and Forest-Plantation designations, but the same parameters were applied to both. The physical characteristics of the 8 subbasins are summarized in Table 8.2. Land use information is summarized in Table 8.3. The length of the simulated stream network from the headwaters to the gauging station (Weir 12) is 34.6 km.

Multiple HRUs were created using the minimum threshold of one percent for land use coverage and soil class in a particular land designation. There were 122 HRUs created for the eight subbasins. Nine HRUs occurred in subbasin 5 while 29 HRUs occurred in subbasin 7.

Table 8.2. Physical characteristics of subbasins and stream attributes of the entire Little River Basin (357 km²).

Subbasin Number	Subbasin Area (ha)	Fraction of Total Area	HRU Total	Main Channel Width (m)	Avg Slope of Channel (m)	Main Channel Length (km)	Channel Width:Depth Ratio
1	184	0.005	10	5.9	0.010	1.2	16.5
2	219	0.006	17	4.1	0.011	2.4	14.6
3	143	0.004	11	3.3	0.010	1.1	13.5
4	322	0.009	13	2.6	0.006	0.3	12.5
5	103	0.003	9	2.9	0.013	1.0	13.0
6	290	0.008	12	2.4	0.040	0.1	12.3
7	16,412	0.460	29	43.8	0.003	16.5	32.1
8	17,982	0.504	21	29.1	0.003	18.1	28.0

Table 8.3. Summary of crop types modelled in Little River Basin (357 km) and percent coverage.

Land Use	SWAT Code	% of Watershed
Range-Brush	RNGB	22.6
Forest-Deciduous	FRSD	21.4
Forest-Evergreen	FRSE	38.4
Forest-Plantation	FRSE	2.5
Potato	POTA	15.1

8.3 Comparison of Simulated and Measured Output

Parameters in the basin input file (*.bsn) were changed to reflect the calibration adjustments determined in Table 6.2. Total measured stream discharge for the 15 months of simulation was 695 mm (Table 8.4). Simulated stream discharge was 651 mm, which is 43 mm less than the total of measured data. The months of

January through March have much lower values of discharge compared to measured data. Measured data for the 3 months accounts for 26% of the total discharge compared to 2% for the simulated data. However, the model predicts almost double the discharge in April compared to the measured data. Figure 8.1 shows that the general trend of simulated discharge closely followed the measured values, from June through December, but there were considerable differences between the months of January and April. Calibrations were determined by averaging 3 years of simulated data.

Total simulated sediment loadings were 7.4 t ha^{-1} compared to 0.48 t ha^{-1} for measured data (Table 8.4). Monthly comparison is illustrated in Figure 8.2. Values for May and June are high ($\sim 2 \text{ t ha}^{-1}$ each month) compared to the other values. All agricultural land was classified as potatoes and it is well understood that increased erosion is associated with row crops and particularly potato farming. Having higher resolution land use data would most likely decrease sediment yields to more closely reflect measured values.

8.4 Comparison of Agriculture-Forestry Basins

When generalizing the partitioning of LRB into mixed forestry-agriculture (subbasins 1 through 7) or forestry (subbasin 8) land cover, both occupy approximately the same amount of area. In 2001, the total discharge was 109 million cubic metres, while total sediment was 3939 tonnes for the forested portion. Measured discharge at the outlet, which includes the forested portion, of LRB was 198 million cubic metres and total sediment was 13,800 tonnes (Chow, 2002). The

forested portion accounts for 54 % of stream discharge and only 29 % of total sediments for approximately the same spatial extent. Also, based on the 2001 data (Table 2.2), each hectare of agricultural land (BBB) will produce approximately 10x more sediment compared to the forested basin. Agricultural land inputs approximately are 2.23 t ha^{-1} compared to 0.218 t ha^{-1} of forested land.

8.5 Conclusion

Modeled stream discharge was underestimated compared to measured data, but more closely reflected actual discharge when using calibration adjustments. It appears that more attention is required for understanding how SWAT simulates snowmelt. Monthly discharge values follow the same trend and within the same magnitude except for the winter and early spring months. Comparisons were made with 15 months of data and calibration adjustments are based on a three-year average.

Sediment yield was overestimated, but it is expected considering all agricultural land was deemed potatoes. Even though modeled sediment inputs were exaggerated, there is utility in having an understanding of potential extremes of soil erosion from different land uses.

Table 8.4. Summary of measured and simulated data for Little River Basin (357 km²).

Year	Month	Measured		Simulated	
		Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)	Stream Discharge (mm)	Sediment Loadings (t ha ⁻¹)
2000	10	17.28	0.004	29.65	0.430
	11	31.16	0.050	44.98	0.526
	12	91.32	0.042	65.87	0.028
2001	1	58.32	0.002	9.17	0.000
	2	59.05	0.002	2.66	0.000
	3	63.37	0.002	1.42	0.000
	4	68.83	0.162	132.26	0.000
	5	112.59	0.014	157.78	1.968
	6	40.75	0.005	54.49	1.948
	7	43.92	0.154	46.49	0.638
	8	17.53	0.021	19.86	0.290
	9	16.94	0.005	26.13	0.722
	10	21.54	0.008	12.25	0.242
	11	19.09	0.005	20.55	0.228
	12	33.11	0.009	27.82	0.372
Total		694.8	0.483	651.37	7.392

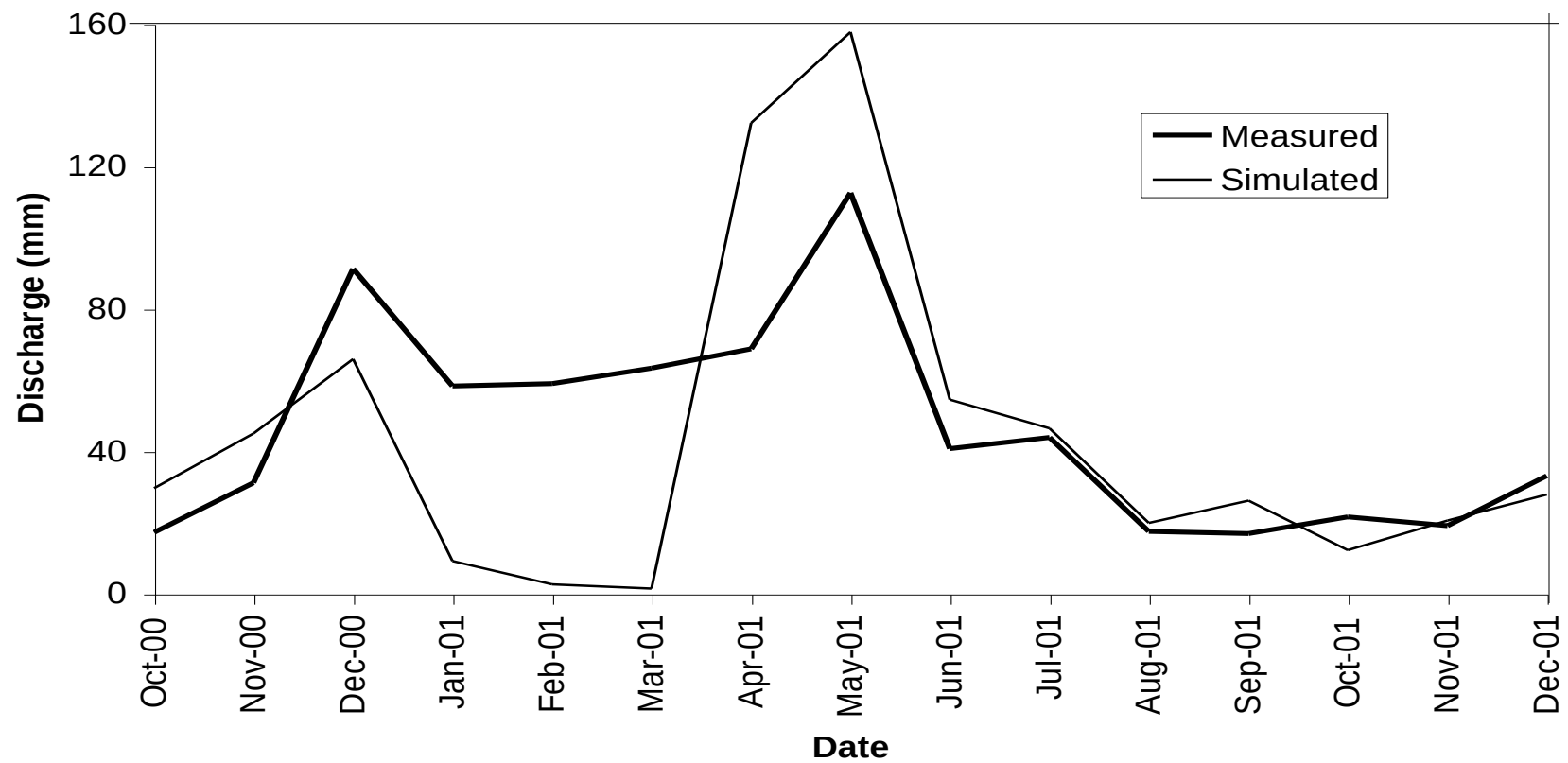


Figure 8.1. Comparison of monthly measured and simulated stream discharge (Q) for Little River Basin.

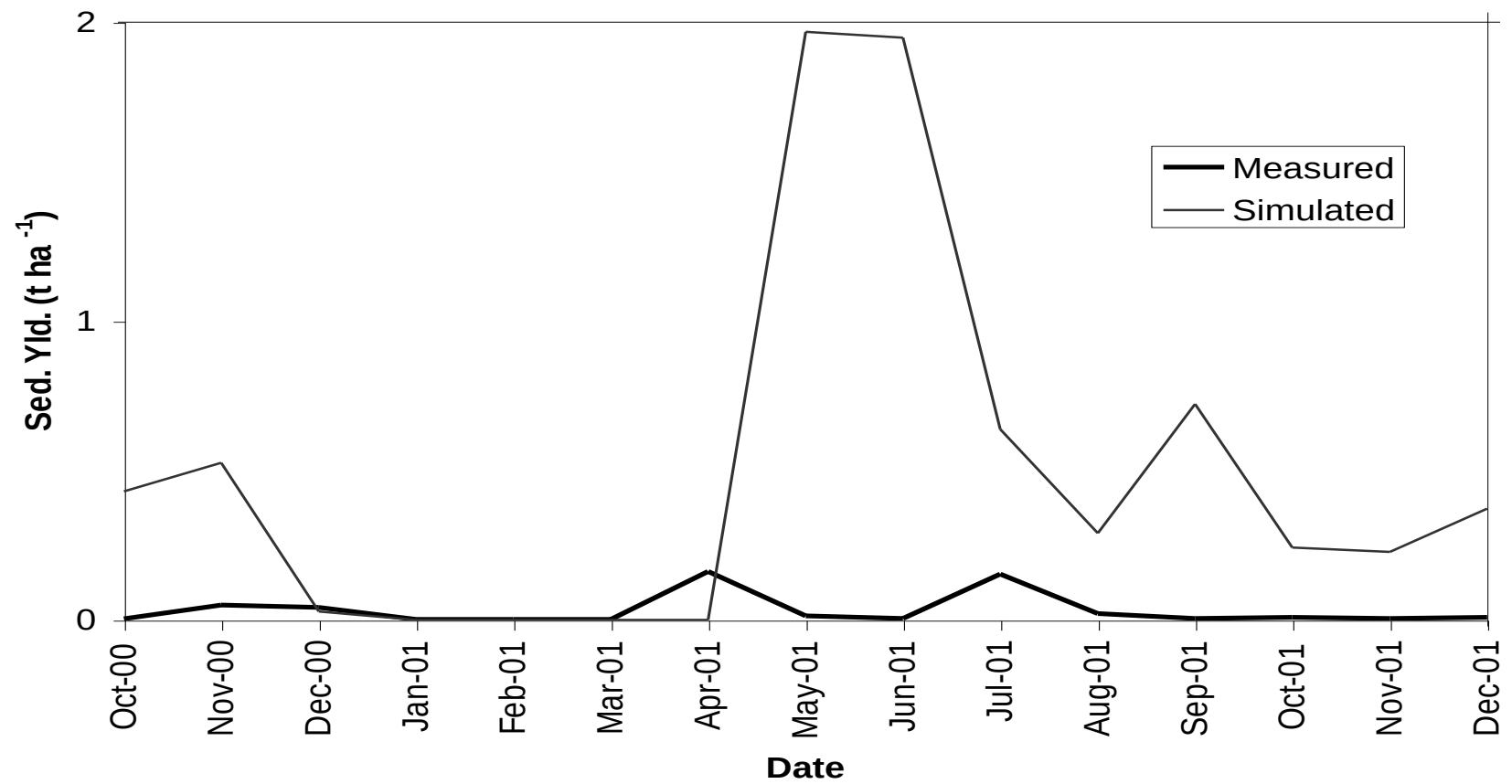


Figure 8.2. Comparison of monthly measured and simulated sediment yield for Little River Basi

CHAPTER 9

SUMMARY AND SUGGESTIONS

Comparisons were made between field observations and SWAT simulated values for stream discharge, and basin-wide sediment and nutrient (N.P) losses for three situations: the Black Brook Basin (mainly agriculture), the forested portion of the Little River Basin, and the entire basin of the Little River basin, which includes the Black Brook Basin. In this, the field observations derived from the Black Brook Basin were used to evaluate SWAT output as obtained by accepting its original parameter values (default values), and subsequently adjusting these values as needed. Revision of the default settings were required because of differences in climate, overall hydrogeology, and land-use between Texas, USA (source of the default values) and the general study area of this Thesis. In this, the application of SWAT to enable a systematic comparison of calculated and observed hydrological responses between forested basins and agricultural basins is essentially new.

New SWAT knowledge derived from this Thesis

- a) Default settings in the basin input file that control snowmelt processes do not reflect local phenomena such as areal coverage, amount of snow, or rates of snowmelt. Modeling snowmelt is important in this region because the majority of annual discharge, sediment-, and nutrient-loadings occur in April and May.

- b) Modeled output using default settings typically underestimates stream discharge, regardless of the evapotranspiration method that is selected. Also, the model is not accurately representing monthly peaks that occur in April and May. Calibrating the rate and temperature at which snowmelt occurs produces results that more closely resemble the measured values.
- c) Modeled sediment inputs are similar to measured values for two of the three years compared when using default settings. Calibrated stream discharge produced sediment values similar to measured values without changing parameters that specifically influence sediment output.
- d) The model underestimates annual simulated nitrate and phosphate loadings. Monthly values are also not accurately represented. There was also a peak lag in the monthly-simulated data for nitrate. The nitrogen percolation coefficient (NPERCO) in the basin input file is the most appropriate parameter to adjust for calibration purposes. Although the three-year average was comparable to the measured average, yearly predictions were not accurately predicted.
- e) The phosphorous sorption coefficient (PSP) and phosphorous soil-partitioning coefficient (PHOSKD) were used for calibrating SWAT generated outputs water soluble P.
- f) SWAT output is sensitive to the number hydrological response units and soil drainage regimes. Using a soil coverage that identified two soils produced higher stream discharge, sediment, and nutrient values compared to the detailed soil theme that identified 7 soils.

- g) Total stream discharge was underestimated for the 15-month comparison even though the Black Brook SWAT calibration settings were applied, but the simulated occurrences of monthly peaks were in agreement with the observations. The model also underestimated sediment yields.
- h) If the basin had a uniform softwood cover, then SWAT predicts a further decrease in stream discharge and sediment loss.
- i) Overall, SWAT predicts that forested basins produce approximately 46 % less stream discharge and 71 % less sediments and basin primarily used for potato cropping.

Technical suggestions to facilitate SWAT modelling

- a) It is very important to specify the type of projection that is used for watershed mapping within SWAT. For example, decimal degree or geographic projection requires the user to manually enter the latitude in the subbasin input file (*.sub). Failing to do this results in failed simulation runs and the potential for automatic exiting of the program.
- b) There appears to be no substantial gain from using the IDW, TIN, or Spline-Tensions methods of interpolation to reduce the impacts of ridging. The 50x50m resolution appears to be the optimal grid cell size to reduce the effects of ridging.

Suggestions for future research

- a) All types of land uses should be incorporated in future SWAT simulations.
For example, including the Saint-Andre Parish as a 2 km² urban land use should increase the accuracy of the SWAT simulations for the Black Brook Basin.
- b) Crop types and annual crop rotations are important SWAT elements for determining stream discharge, sediment yields and nutrient losses as these vary by hydrological response unit each year. This should be considered in future SWAT applications to the Black brook Basin.
- c) Future studies should also examine the role of the spatial configuration of the various soil types within the basin of interest, through sensitivity analysis.
- d) Also, future studies should add contributions from point and line sources for sediment and nutrients within each basin

REFERENCES

- Allen, R.G., Jensen, M.E., Wright, J.L., and Burman, R.D.** 1989. Operational estimates of evapotranspiration. *Agron. J.* **81**. 650-662.
- Allen, R.G.** 1986. A Penman for all seasons. *J. Irrig. And Drain Engng., ASCE.* **112**. 348-368.
- ArcView Help**, ArcViewTM GIS 3.2a software, Environmental Systems Research Institute Inc.
- Arnold, J.G., Srinivasan, R., Muttiah, R.S., and Williams, J.R.** 1998. Large area hydrologic modeling and assessment part 1: model development. *J. American Water Resources Association.* **34**. 73-89.
- Arnold, J.G., Williams, J.R., and Maidment, D.R.,** 1995. Continuous-time water and sediment routing model for large basins. *J. of Hydraulic Engineering.* **121**. 171-183.
- Arnold, J.G., Williams, J.R., Nicks, A.D., and Sammons, N.B.,** 1990. SWRRB: A basin scale simulation model for soil and water resources management. Texas A&M University Press, College Station.
- Brown, D. and Bara, T.** 1994. A Recognition and Reduction of Systematic Error in Elevation and Derivative Surfaces from 71/2-Minute DEMs, *Photogrammetric Engineering and Remote Sensing.* **60**. 189-194.
- Burrough, P.,** 1986. Principles of Geographic Information Systems for Land Resources Assessment, Oxford University Press, New York, NY. 194 pp.
- Cao, Y.Z., Coote, D.R., Rees, H.W., Wang, C., and Chow, T.L.,** 1994. Effects of intensive potato production on soil quality and yield at a benchmark site in New Brunswick. *Soil and Tillage Research.* **29**. 23-34.
- Chow, T.L.,** 2001. Unpublished data. Personal communication. Agriculture and Agri-food Canada, Fredericton, NB, Canada.
- Chow, T.L.,** 2002. Unpublished data. Personal communication. Agriculture and Agri-food Canada, Fredericton, NB, Canada.
- Chow, T.L., Rees, H.W., and Daigle, J.L.,** 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: A field evaluation, *J. Soil and Water Conservation.* **54**. 577-583.

- Chow, T.L., Rees, H.W., Ghanem, I., and Daigle, J.L.,** 1995. Effects of intensive potato production on surface water quality in the Black Brook Watershed, St Andre Parish, New Brunswick. 48th CWRA Annual Conference.
- Chow, T.L., Rees, H.W., Ghanem, I.,** 1991. Surface water monitoring in the Black Brook Watershed, Saint-Andre Parish, Madawaska County, New Brunswick. Canada/New Brunswick Agreement on Soil Conservation 89/92. 9 pp.
- Chow, T.L., Daigle, J.L., Ghanem, I., and Cormier, H.,** 1990. Effects of potato cropping practices on water runoff and soil erosion. Can J. Soil Sci. **70**. 137-148.
- Chow, V.T., Maidment, D.R., and Mays, L.W.,** 1988. Applied hydrology. McGraw-Hill, Inc., New York, NY.
- Coleman D.J.,** 2001. Personal Communication. Chairman, Dept. Geodesy and Geomatics Engineering, University of New Brunswick, July.
- Coote, D.R., Dumanski, J., and Ramsey, J.F.,** 1981. An assessment of the degradation of agricultural lands in Canada. Land Resource Research Institute Contribution No. 118, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Crain, D.,** 2001. Unpublished data. Personal communication. New Brunswick Department of Natural Resources, Fredericton, NB, Canada.
- Diluzio, M., Srinivasan, R., and Arnold, J.,** 2001. ArcView Interface for SWAT2000 – User’s Guide. Blackland Research Center, Texas Agricultural Experiment Station, Temple, Texas.
- Eidt, D.C.,** 1982. Silt can be forever. Forest Times. **4**.
- ESRI, 1996.** ArcViewTM Spatial Analyst, Environmental Systems Research Institute Inc. <http://www.esri.com/index.html>
- Fredriksen, R.L., Moore, D.G., and Norris, L.H.,** 1975. Impact of timber harvest, fertilization and herbicide treatment on stream water chemistry in the Douglas fir region. Pp.283-313. In. B. Bernier and C.H. Winget (eds) Forest Soils and Forest Land management. Proc. Fourth N.A. Forest Soils Conference., Les Presses de Universite Laval, Quebec.
- Fox, M.G., and Coote, D.R.,** 1986. A preliminary economic assessment of agricultural land degradation in Atlantic and Central Canada and Southern British Columbia, No. 85-70. LRRI, Agriculture Canada, Ottawa, Ontario. 166 pp.

Garbrecht, J., and Martz, L.W., 1999. Digital Elevation Model Issues in Water Resource Modeling, 19th Annual ESRI International User Conference in San Diego, California.

<http://www.esri.com/library/userconf/proc99/proceed/papers/pap866/p866.htm>

Hargreaves, G.L., Hargreaves, G.H., and Riley, J.P., 1985. Agricultural benefits for Senegal River Basin. *J. Irrig. And Drainage Engng.* **111**. 113-124.

International Joint Commission, 1983. Report of Great lakes water quality. Windsor, Ontario. 97 pp.

Internet, 2003. <http://203.147.186.54/wwwimages/Isco/6712%20sampler.jpg>

Introduction to Geomatica, PCI Geomatics Inc., Copyright 1996.

Jacobs, P., 1996. Application of the Soil and Water Assessment Tool (SWAT) model to estimate non-point source pollution in three New Brunswick watersheds. *Submitted to: Environmental Conservation Branch, Environment Canada, Moncton, NB.* No. 1463. 48 pp.

Knisel, W.G., 1980. CREAMS, a field scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Rept. No. 26.

Kraus, H.H., 1974. Effect of forest management practices on stream water chemistry and nutrient load in hilly terrain of central New Brunswick. Progress Report, April 1974, University of New Brunswick, Faculty of Forestry, Fredericton, NB.

Langmaid, K.K., MacMillan, J.K., and Losier, J.G., 1976. Soils of Northern Victoria County, New Brunswick. Research Branch, Canada Dept. of Agriculture and New Brunswick Dept. of Agriculture.

Langmaid, K.K., MacMillan, J.K., and Losier, J.G., 1980. Soils of Madawaska County, New Brunswick. Research Branch, Canada Dept. of Agriculture and New Brunswick Dept. of Agriculture.

Learning PCI OrthoEngine, PCI Geomatics Inc., Copyright 1996.

Lee, J., 1996. Digital Elevation Models: Issues of Data Accuracy and Applications, 1996 ESRI International User Conference, May 20-24.

<http://www.esri.com/library/userconf/proc96/TO150/PAP145/P145.HTM>

Lee, J., Snyder, P., and Fisher, P., 1992. Modeling the Effect of Data Errors on Feature Extraction From Digital Elevation Models. *Photogrammetric Engineering and Remote Sensing.* **58**. 1461-1467.

Leonard, R.A., Knisel, W.G., and Still, D.A., 1987. GLEAMS: Groundwater loading effects on agricultural management systems. *Trans. ASAE.* **30.** 1403-1428.

Matalas, N.C., 1967. Mathematical assessment of synthetic hydrology. *Water Resources Res.* **3.** 937-945.

Mellerowicz, K.T., Rees, H.W., Chow, T.L., and Ghanem, I., 1993. Soils of the Black Brook Watershed, St. Andre Parish, Madawaska County, New Brunswick. New Brunswick Dept of Agriculture and Agriculture Canada, Fredericton, N.B., Canada.

Mitasova H., and Mitas, L., 1993. Interpolation by regularized Spline with Tension: I. Theory and Implementation, *Mathematical Geology*, Vol: 25, No.6, pp. 641-655.
Moore, I.D., Gessler, P.E., Nielsen, G.A., and Peterson, G.A., 1993. Soil Attribute Prediction Using Terrain Analysis, *Soil Sci. Soc. Am. J.* **57.** 443-452.

Monteith, J.L., 1965. Evapotranspiration and the environment. pp. 205-234. *In* The state and movement of water in living organisms, XIXth Symposium. Soc. For Exp. Biol., Swansea, Cambridge University Press.

Moore, I.D., Grayson, R.B., and Ladson, A.R., 1991. Digital Terrain Modelling: A Review of Hydrological, Geomorphological, and Biological Applications. *Hydrological Processes.* **5.** 3-30.

Moore, I.D., Mackay, S.M., Willbrink, P.J., Burch, G.J., and O'Loughlin, E.M., 1986. Hydrologic Characteristics and Modeling of a Small Forested Catchment in Southeastern New South Wales. Pre-Logging Condition, *J. of Hydrology.* **83.** 307-355.

NBGIC, 1995. A User Guide to the digital terrain model database, New Brunswick Geographic Information Corporation (currently Service New Brunswick), Fredericton, NB.

NBGIC, 1996. User's Guide to the digital enhanced topographic base (ETB Data Base) of New Brunswick. New Brunswick Geographic Information Corporation, Fredericton, New Brunswick.

Neitsch, S.L., Arnold, J.G., and Williams, J.R., 2000. Soil and Water Assessment Tool – User's Manual.
<http://www.brc.tamus.edu/swat/swat2000.html>

Nicks, A.D., 1974. Stochastic generation of the occurrence, pattern, and location of maximum amount of daily rainfall. pp. 154-171. *In* Proc. Symp. Statistical Hydrology, Aug.-Sept. 1971, Tuscon, AZ. U.S. Dept. of Agriculture, Misc. Publ. No. 1275.

- Peglar, K and Coleman, D.J., and Castonguay, R.,** 1999. TIN Random Densification: A Process to Minimize the Ridging Phenomenon in DTMs. 19th Annual ESRI International User Conference in San Diego, California.
<http://www.esri.com/library/userconf/proc99/navigate/proceed.htm>
- Pomeroy, J.H.,** 2003. Stream turbidity signatures within the Hayward Brook watershed study. Thesis (M.Sc.F.) -- University of New Brunswick, Dept. of Forestry and Environmental Management. 151 pp.
- Priestly, C.H.B. and Taylor, R.J.,** 1972. On the assessment of surface heat flux and evaporation using large scale parameters. *Mon. Weather. Rev.* **100**. 81-92.
- Rees, H.W.,** 2002. Personal Database. Research Branch, Agriculture and Agri-food Canada, Fredericton, NB, Canada.
- Rice, R.M., Tilley, F.B., and Datzman, P.A.,** 1979. A watershed's response to logging and roads: South Fork Creek, California, 1967-1976, Pacific Southwest For. And Range Exp. Stn., US For. Serv. Res. Pap. PSW-146. Berkeley, CA. 12 pp.
- Richards, W.,** 2002. Unpublished data. Personal communication. New Brunswick Weather Services Office, Fredericton, NB, Canada.
- Rosenberg, N.J., Epstein, D.L., Wang, D., Vail, L., Srinivasan, R., and Arnold, J.G.,** 1999. Possible impacts of global warming on the hydrology of the Ogallala aquifer region. *J. of Climate.* **42**. 677-692.
- Saini, G.R. and Grant, W.J.,** 1980. Long-term effects of intensive cultivation on soil quality in the potato growing areas of New Brunswick (Canada) and Maine (USA). *Can J. Soil Sci.* **60**. 421-428.
- Saleh, A., Arnold, J.G., Gassman, P.W., Hauck, L.W., Rosenthal, W.D., Williams, J.R., and McFarland, A.S.,** 2000. Application of SWAT for the upper north Bosque watershed. *Transactions of the ASAE.* **43**. 1077-1087.
- Sharpley, A.N. and Williams, J.R.,** eds. 1990. EPIC-Erosion Productivity Impact Calculator, 1. model documentation U.S. Dept. of Agriculture, Agricultural Research Service, Tech. Bull. 1768.
<http://www.brc.tamus.edu/epic/appendixes/wxgen.html>
- Srinivasan, R., Arnold, J.G., Ramanarayanan, T.S., and Bednarz, S.T.,** 2000. Modeling Wister Lake watershed with the soil and water assessment tool (SWAT). *J. American Water Resources Association* (in review).
- Stephens, P.R., Daigle, J.L., and Chilar, J.,** 1982. Use of sequential aerial photographs to detect and monitor soil management changes affecting cropland erosion. *J. Soil Water Conservation.* **37**. 101-105.

Sullivan, K., 1985. Long-term patterns of water quality in a managed watershed in Oregon:1. suspended sediment. *Water Res. Bull.* **21**. 977-987.

Tim, U.S. and Jolly, R., 1994. Evaluating agricultural nonpoint-source pollution using integrated Geographic Information System and Hydrology/Water Quality Model. *J. Environ. Qual.* **23**. 35-35.

U.S. Army, 1988. GRASS Reference Manual. USA CERL, Champaign, Illinois.
Wang, C. Rees, H.W., and Daigle, J.L., 1984. Classification of podzolic soils as affected by cultivation. *Can. J. Soil Science.* **64**. 229-239.

Wechsler Perlitsh, S., 1999. A Methodology for Digital Elevation Model (SEM) Uncertainty Evaluation: The Effect DEM Uncertainty on Topographic Parameters, 19th Annual ESRI International User Conference in San Diego, California.
<http://www.esri.com/library/userconf/proc99/navigate/proceed.htm>

White, J.B., and Krause, H.H., 1993. The impact of forest management practices on water quality and the establishment and management of protective buffer zones: A review of literature. Dept. of Forest Resources, University of New Brunswick, Fredericton, New Brunswick. 46 pp.

Williams, J.R., 1975. Sediment-yield prediction with universal equation using runoff factor. In Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment yield workshop, USDA Sedimentation Lab., Oxford, MS, November 28-30, 1972. ARS-S-40. 244-252.

Williams, J.R., 1995. Chapter 25. The EPIC Model. In Computer Models of Watershed Hydrology. Water Resources Publications. Highlands Ranch, CO. 909-1000

Williams, J.R., Berndt, H.D., 1977. Sediment Yield prediction based on watershed hydrology. *Trans. ASAE.* **20**. 1100-1104.

Williams, J.R., Nicks, A.D., and Arnold, J.G., 1985. Simulator for water resources in rural basins. *J. of Hydraulic Engineering.* **111**. 970-986.

Williams, J.R. and Hann, R.W., 1973. HYMO: Problem oriented computer language for hydrologic modeling. USDA ARS-S-9. 76 pp.

Williams, J.R., Jones, C.A., Dyke, P.T., 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Trans. ASAE.* **27**. 129-144.

Wischmeier, W.H. and Smith, D.D., 1978. Predicting rainfall erosion losses: a guide to conservation planning. Agriculture Handbook 282. USDA-ARS.

Yang, Y., 1997. Evaluating agricultural non-point source pollution using the Soil and Water Assessment Tool (SWAT). Thesis (M.Sc.E.) -- University of New Brunswick, Dept. of Civil Engineering, 1997. 191 pp.

Young, R.A, Onstad, C.A., Bosch, D.D., and Anderson, W.P., 1987. AGNPS, Agricultural nonpoint-source pollution model; A large watershed analysis tool. U.S. Dept. of Agri. Res. Serv., Conserv. Res. Report 35. Washington, D.C. 77 pp.

APPENDIX A

DEM INTERPOLATION AND GRID CELL COMPARISON

Introduction

Generating a digital elevation model (DEM) that correctly simulates topography, watershed boundaries, and flow accumulation patterns within the watershed area of interest serves as the initial step in creating a SWAT model of that watershed area. The goal is to ensure that the DEM is as accurate as possible such that the estimated watershed boundaries reflect the actual boundaries, and that the simulated flow pattern leads to the already mapped stream and water bodies.

In general, a DEM can be defined as “any digital representation of the continuous variation of relief over space” (Burrough, 1986). In practice, DEMs are represent the area of interest by way of an semi-regular x-y-z grid, where x and y represent location (latitude and longitude), and z represents elevation. In the province of New Brunswick, these points were collected manually with a stereo-plotter using 1:35,000 aerial photography, and selecting points every 70 m or closer where topographical gradients increase. The resulting digital terrain model (DTM) database files are based on the ATS77 Datum Double Stereographic projection, with a resolution of 1.0 m horizontal, 0.1m vertical, at a 1:10000 scale (NBGIC, 1996). These files were subject to extensive data quality checks to remove error associated, but the accuracy of the vertical dimension remains ± 2.5 m at best (Coleman, 2001). Part of the remaining inaccuracies are due to a combination of systematic and random errors (Wechsler Perlitsh, 1999, Peglar et al., 1999, Lee, 1996, Brown and Bara,

1994, Lee et al., 1992, and Moore et al., 1991). Systematic errors result from the methods used to collect the data. A lag error is caused from shuttlecock or boustrophedonic (left to right, right to left) sampling, and the tendency of the photogrammetric operator to misjudge height values when scanning upslope or downslope. Random errors are due to inaccurate surveying, machine miscalibrations, or improper recording of elevation data (Wechsler Perlitsh, 1999, Peglar et al., 1999).

A special and fairly glaring error feature is the regular occurrences of conical or pointed blips that – together - form erroneous ridge patterns as already noted by Peglar et al. (1999): “The systematic creation of evenly spaced triangles of similar dimensions produces a linear pattern...ridging.” Generally, ridges may occur parallel along specific directions, and this occurrence is more predominant in areas with little relief (Peglar et al, 1999). These features are “virtual”, and are created during the geospatial interpolation phase of the irregular grid (see below). Figure A.1 illustrates the phenomenon of ridging in the central portion of the Black Brook basin. Typically, the magnitude of the ridges is less than 10 metres (NBGIC, 1995).

The ridging effect interferes, unfortunately, with any attempt to accurately calculate any hydrological surface features that would be affected by incorrect assessment of slope and aspect. Calculated surface features that would directly or indirectly be affected by the presence of ridges refer to (e.g.) the delineation of the watershed boundaries, the delineation of the flow accumulation, and the assessment of local shading, albedo, and intercepted radiation (Moore et al., 1991; Lee, 1996; Garbrecht and Martz, 1999; Wechsler Perlitsh, 1999; and Pegler et al., 1999).

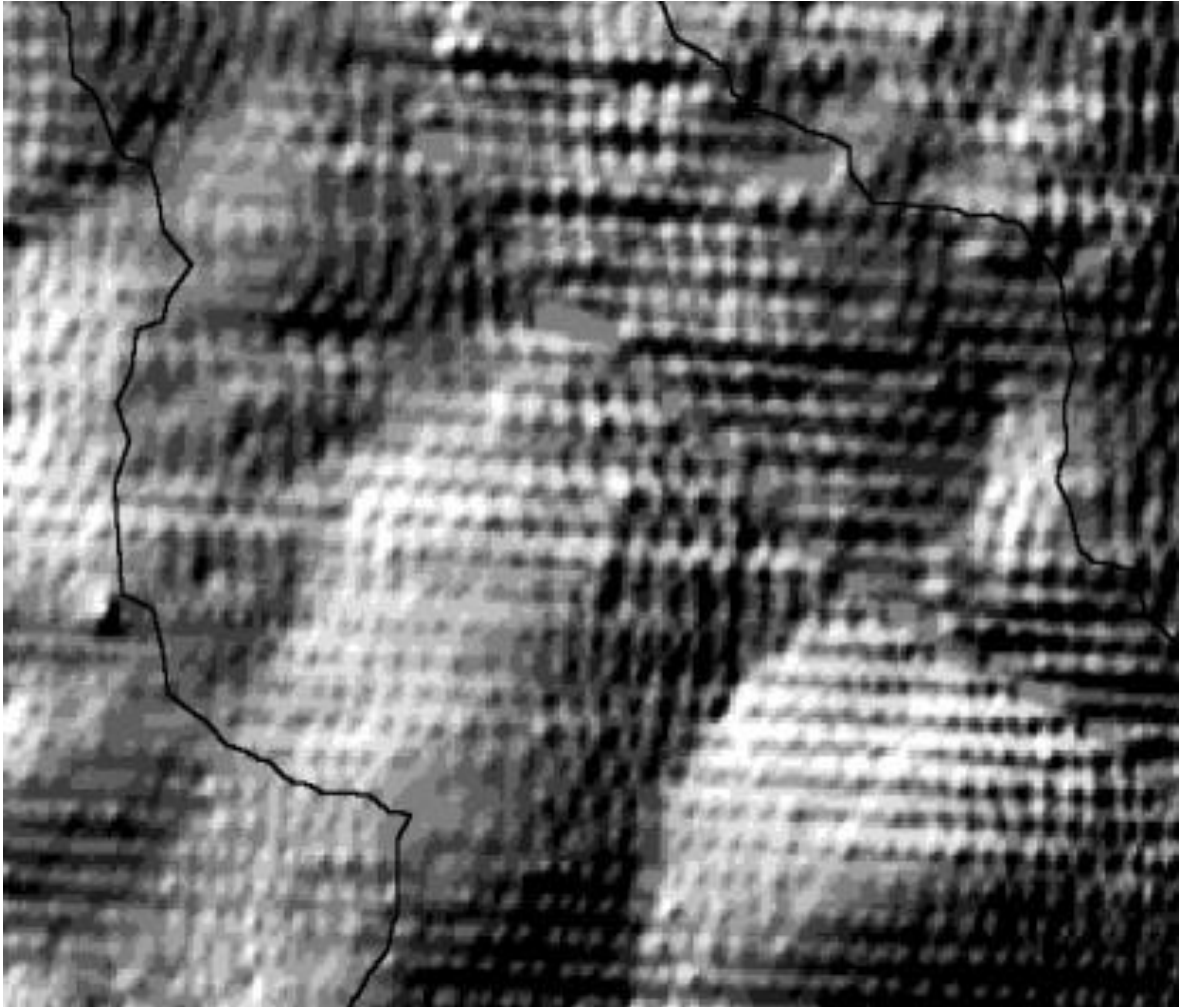


Figure A.1. Phenomenon of ridging in BBB at a scale of 1:15371.

Geospatial Interpolation Methods for Digital Elevation Grids

Three geospatial interpolation methods were used to analyze the ridging patterns for the Black Brook Basin, and to determine ways and means by which to reduce if not eliminate this pattern. The methods were:

- The Inverse Distance Weighted Method (IDW)
- The Triangulated Irregular Network Method (TIN)
- The Spline-Tension Method

The IDW method is based on the supposition that all points around a given point influence its value. The influence on a given point will decrease as the distance between the two points increases (Perlitsch-Wechsler, 1999; ESRI, 1996). The number of points that can be used can be modified, as well as the influence of the surrounding points.

The TIN method creates a series of juxtaposed triangles that do not overlap which have height values at each point of the triangle. Points between the triangles are interpolated and the surface is created (Moore et al., 1991 and ArcViewTM Help).

The spline method creates a smooth surface by creating a minimum-curvature plane that is based on the points of the irregular grid. The degree to which the plane adheres to the points depends on the tension setting (ESRI, 1996; Mitasova and Mitas, 1993). Spline-Tension was used instead of the regular option because preliminary interpolations yielded surfaces that were excessively smoothed and therefore uncharacteristic of the topographic attributes.

Using each of these interpolation method, four DEMs were created with the following grid cell size: 10x10m, 30x30m, 50x50m, and 70x70m. The resulting DEMs were viewed by computing Hillshade in ArcViewTM. It was found that the 70x70m grid had no ridging.

To make a quantitative assessment of the differences associated with decreasing grid cell sizes, nine new grids were created by subtracting the 10x10m, 30x30m, and 50x50m resolutions from the 70x70m grid. The cell size of the new grid is, in turn, dependent on the grid that is being subtracted from the 70x70m grid,

regardless of the interpolator that is being used. For example, if the new grid was generated as a result of the subtraction of a 70x70m grid from a 50x50m grid, the cell size would be 50x50m.

The measure of success for the most appropriate interpolation method and grid cell size will was determined in three ways:

- Visual inspection of the nine DEMs using the Hillshade theme.
- Calculating the standard deviations for the entire DEM as a quantitative measure of the ridging effect.
- Generating two lateral 2.5 to 3 km elevation profiles along the new grids, with one profile positioned west-to-east, and the other south-to-north.

Each profile was analyzed by two methods: Within the first method, each each grid was converted to a three-dimensional ArcView™ shape file (*.shp). The resulting visualization interpolated between the points of the grid, and a vertical assessment profile was then be generated across the grid along any particular direction. With the second method, every pixel within the grid visualization resulting from the point-to-point interpolations was used for the statistical evaluation of the interpolated digital grid.

Results

Using the Hillshade theme showed that the extent of ridging was most prominent at the 10-m x 10-m resolution for all three-interpolation methods (Figure A.2). It is especially prominent across the entire basin using the IDW method, but is only prominent in areas of little topographic relief using the TIN and Spline methods.

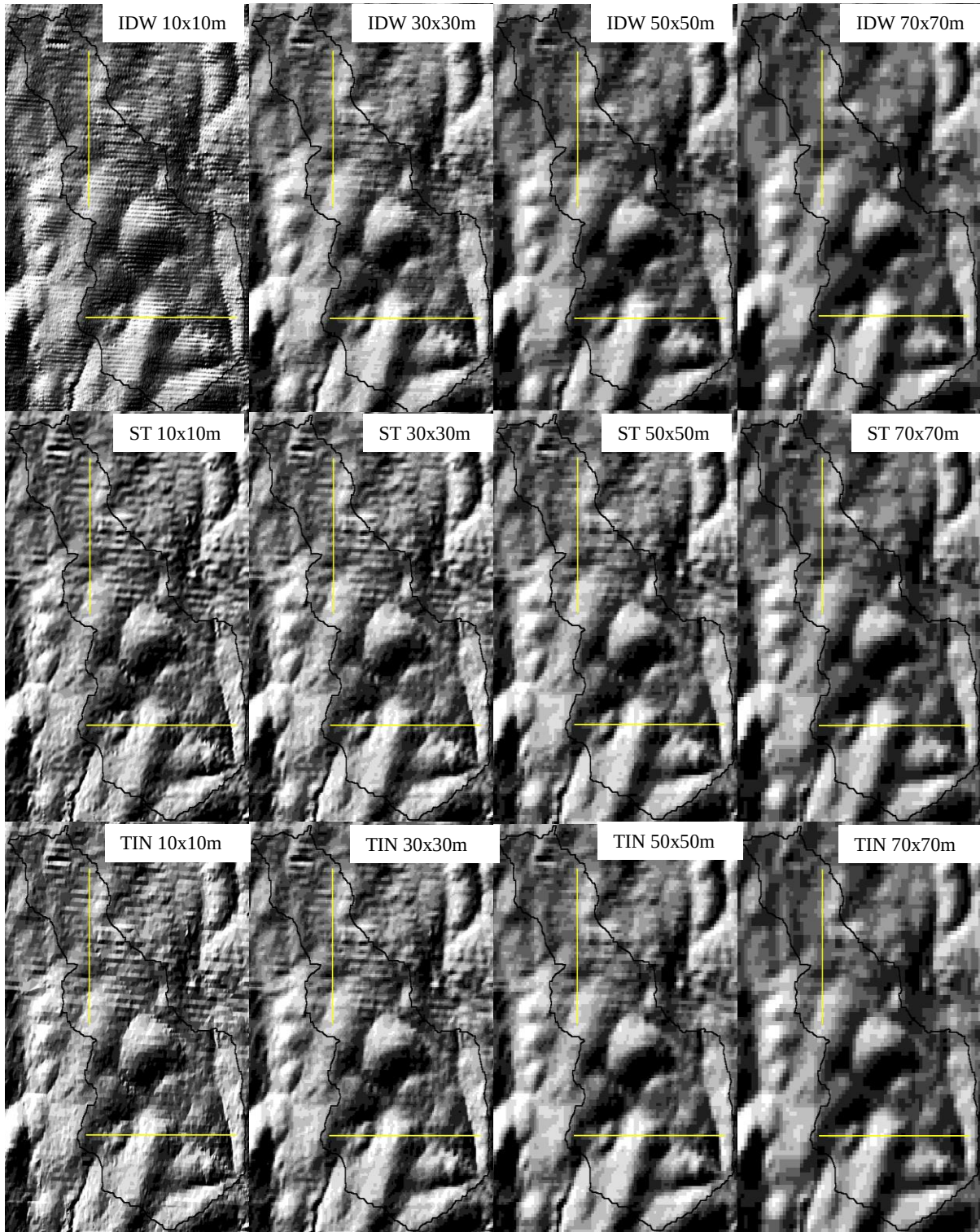


Figure A.2. Impact of interpolation methods (IDW-Inverse Distance Weighted, ST-Spline-Tension, and TIN-Triangulated Irregular Network) grid sizes. South-north and west-east transects are also shown (yellow)

The 30-metre resolution still exhibits ridging in the northern portion of the basin where topographic relief is low, but this ridging appears to be less exaggerated with the IDW method than what was obtained with the other two methods. Ridging is faintly recognizable at the 50-metre resolution with all three methods, while it is quite clear that ridging is not part of the 70-m grid. Based on visual observations, partial conclusion could be made that the IDW method with a 50-m resolution is the optimum combination.

The various grid profiles that are generated for the same grid cell size are essentially the same regardless of geospatial interpolation method, as shown in Figures A.3 through A.8. The general trend of crests and troughs occurs in the same places throughout the profile, but there are differences in the range of relief between the grids. For the south-to-north profiles, maximum relief ridging occurs at the 10-metre resolution, decreases at the 30-metre resolution, and slightly increases again at the 50-metre resolution for all three interpolation techniques. For the west-to-east profiles, this trend also exists except for the spline-tension at the 30-metre to 50-metre resolution. Also, the range in relief is greater when the profiles are arranged in this orientation. This is most likely due from the boustrophedonic sampling method.

There is a negligible change in the standard deviation as the resolution of the grid decreases (see Table A.1): the standard deviation values for each interpolation method are essentially the same for the 10-, 30-, and 50-m grid cell size. The TIN and IDW methods produce lower standard deviations than the spline-tension method. The interpolator and grid cell size with the lowest standard deviation ($\Phi=1.19$) was the IDW method with a 50-m grid cell size.

Tables A.2 and A.3 summarize the results from analyzing the pixel values of the DEM along both profile directions. The results are similar to those obtained from the 3-D shape file. Again, there appear to be fewer variations when the profiles are oriented south-to-north than west-to-east. For every interpolation method, the 30-metre grid has a higher variation in elevation values than the other two grid cell sizes. For comparison, the difference between the 70x70 m resolution and a 69x69 m resolution was calculated and the standard deviation remained at 1.12 m.

???????This implies that the most likely cause of deviation from the mean is not from the change in resolution itself, but it could be from the overlapping of the grids.???????Huh???

Concluding Remark

In general, the IDW and TIN methods of interpolation produce the least variation in elevation values, but this does not help in determining the optimal resolution because the standard deviation of the six grid cell sizes are all within 0.03 of each other. The interpolator and grid cell size that appears to have the least standard deviation was the IDW method with a 50-m grid cell size.

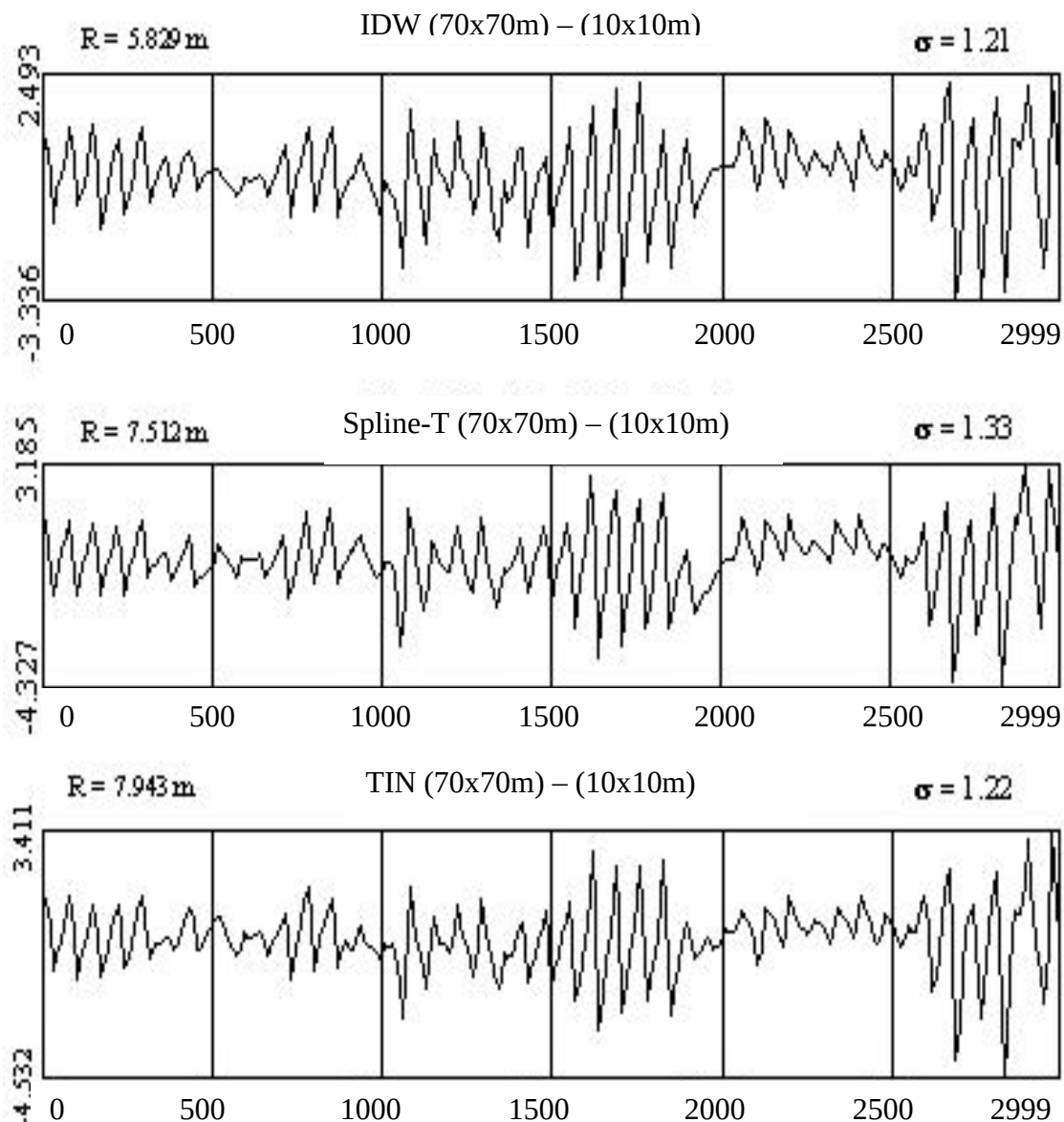


Figure A.3. Comparison of north to south profiles using 10x10m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), Φ - Standard deviation.

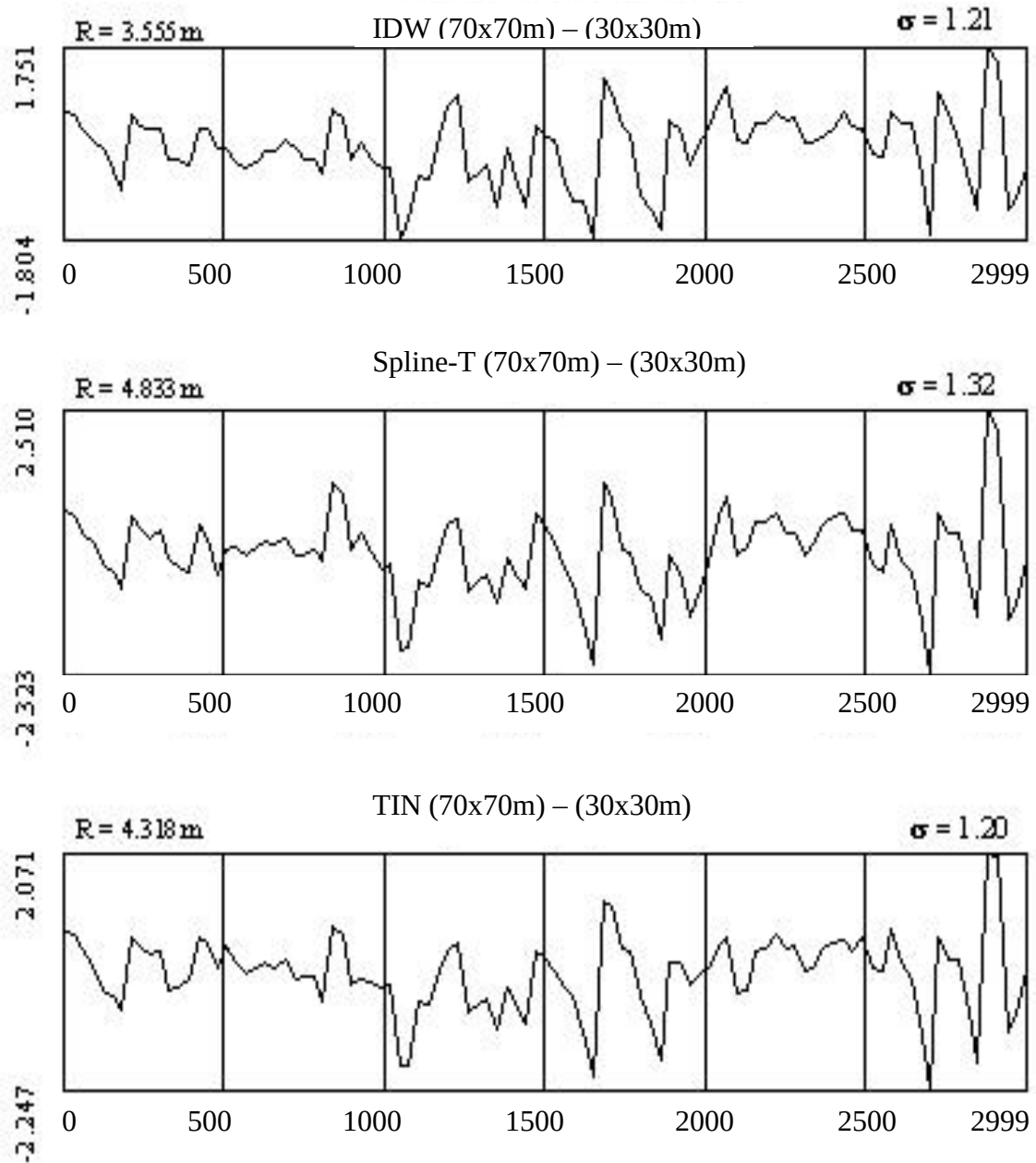


Figure A.4. Comparison of north to south profiles using 30x30m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), Φ - Standard deviation.

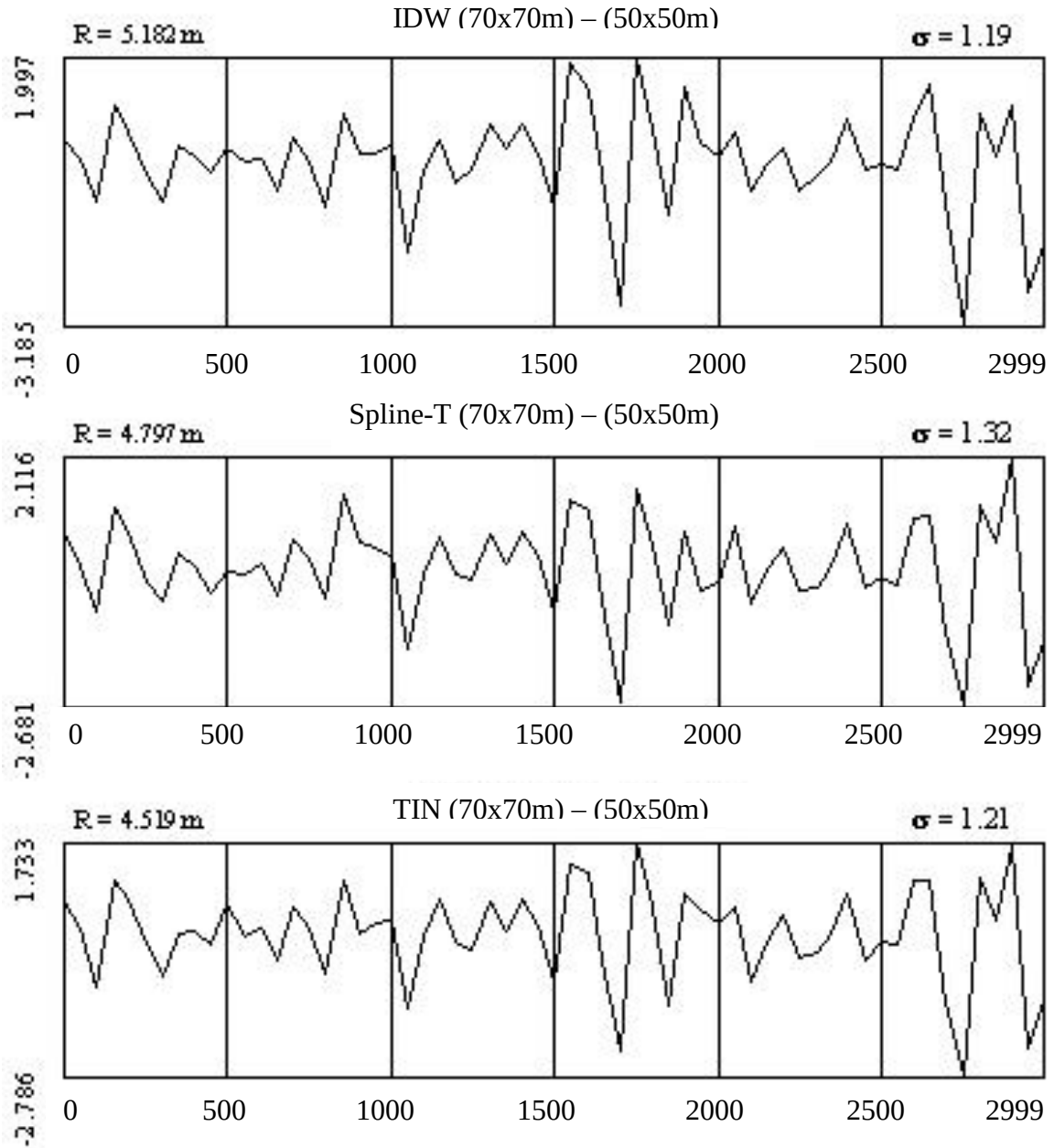


Figure A.5. Comparison of north to south profiles using 50x50m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), Φ - Standard deviation.

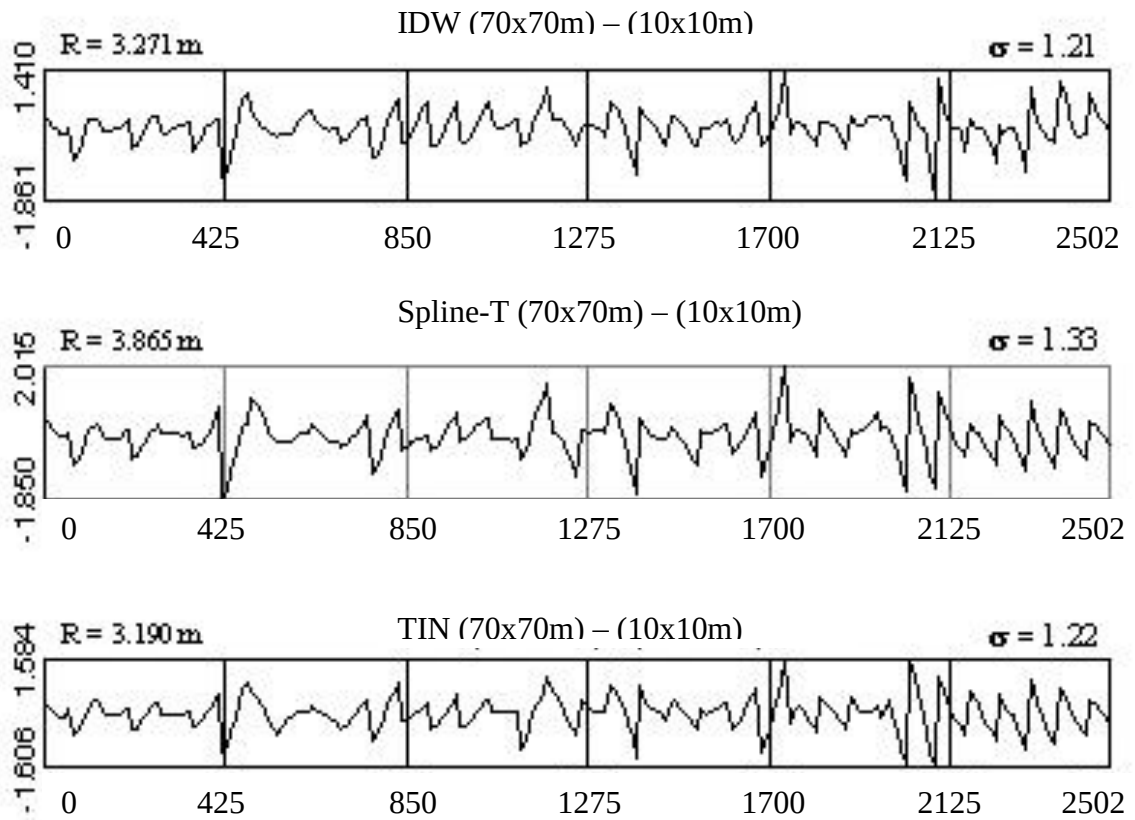


Figure A.6. Comparison of west to east profiles using 10x10m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), Φ - Standard deviation.

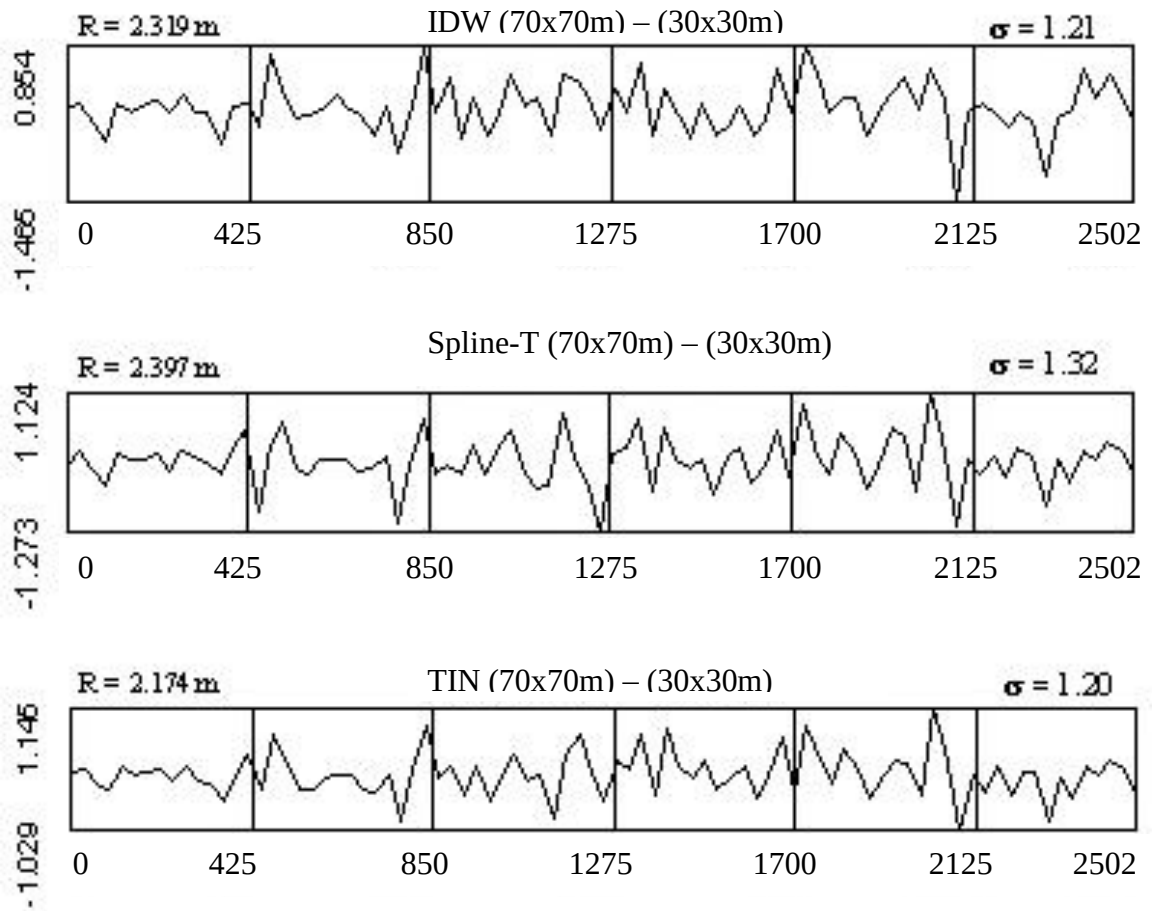


Figure A.7. Comparison of west to east profiles using 30x30m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), Φ - Standard deviation.

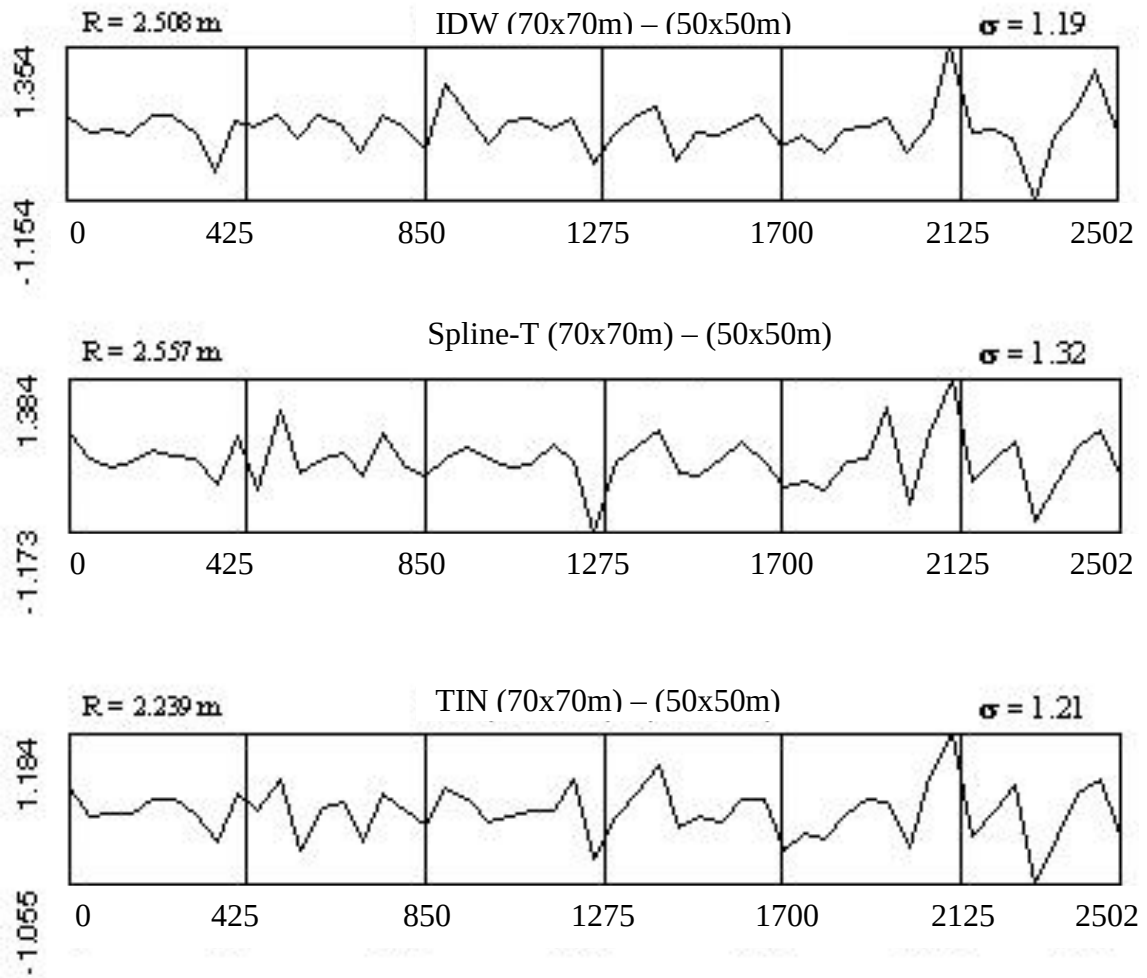


Figure A.8. Comparison of west to east profiles using 50x50m and 70x70m resolution. Vertical exaggeration - 75x, X-axis – Distance (metres), Y-axis – Difference in elevation between two grids (metres), R – Maximum relief between two grids (metres), σ - Standard deviation.

Table A.1. Comparison of interpolation and grid cell sizes using profiles from 3-D shape file.

	Grid	Profile Direction	Min (m)	Max (m)	Range (m)	Std Dev.*
TIN	70-10	South-North	-1.606	1.584	3.190	1.22
		West-to-East	-4.532	3.411	7.943	
	70-30	South-North	-1.029	1.145	2.174	1.20
		West-to-East	-2.247	2.071	4.318	
	70-50	South-North	-1.055	1.184	2.239	1.21
		West-to-East	-2.786	1.733	4.519	
Spline-T	70-10	South-North	-1.850	2.015	3.865	1.33
		West-to-East	-4.327	3.185	7.512	
	70-30	South-North	-1.273	1.124	2.397	1.32
		West-to-East	-2.323	2.510	4.833	
	70-50	South-North	-1.173	1.384	2.557	1.32
		West-to-East	-2.681	2.116	4.797	
IDW	70-10	South-North	-1.861	1.410	3.271	1.21
		West-to-East	-3.336	2.493	5.829	
	70-30	South-North	-1.465	0.854	2.319	1.21
		West-to-East	-1.804	1.751	3.555	
	70-50	South-North	-1.154	1.354	2.508	1.19
		West-to-East	-3.185	1.997	5.182	
* Standard deviation values are for entire grid						

Table A.2. Summary of results from south-north profiles.

	Grid	Min (m)	Max (m)	Range (m)	Mean (m)	Std. Dev	Sum
TIN	70-10	-1.6458	1.5780	3.2238	-0.0048	0.4871	-2.4073
	70-30	-1.0114	1.6605	2.6719	0.0844	0.5129	14.1750
	70-50	-1.0832	1.1340	2.2172	0.0195	0.3920	1.9541
S-T	70-10	-2.1481	2.0296	4.1776	-0.0007	0.5621	-0.3693
	70-30	-1.6862	1.7230	3.4092	0.0484	0.6025	8.1345
	70-50	-1.2360	1.3558	2.5918	0.0301	0.4487	3.0056
IDW	70-10	-1.9230	1.3878	3.3108	-0.0198	0.4512	-9.8799
	70-30	-1.6547	1.6857	3.3404	0.0132	0.5420	2.2109
	70-50	-1.1825	1.3155	2.4980	0.0148	0.3833	1.4847

Table A.3. Summary of results from west-to-east profiles.

	Grid	Min (m)	Max (m)	Range (m)	Mean (m)	Std. Dev	Sum
TIN	70-10	-4.9971	3.7887	8.7858	-0.0934	1.2508	-28.1253
	70-30	-4.1552	3.7887	7.99440	-0.1415	1.2927	-14.2907
	70-50	-2.8921	2.0810	4.9731	-0.0704	1.0590	-4.2934
S-T	70-10	-4.9767	3.8768	8.8535	-0.0829	1.2875	-24.9384
	70-30	-4.4158	3.9342	8.3501	-0.1323	1.3331	-13.3633
	70-50	-3.1180	2.3218	5.4398	-0.0348	1.1073	-2.1204
IDW	70-10	-4.3187	3.0109	7.3296	-0.1385	1.1817	-41.6944
	70-30	-3.3318	2.7977	6.1295	-0.1400	1.2035	-14.1372
	70-50	-3.5143	2.3847	5.8990	-0.0319	1.1355	-1.9440

APPENDIX B

WEATHER FREQUENCIES USED FOR GENERATING CLIMATE DATA

Month	1	2	3	4	5	6	7	8	9	10	11	12
Avg max temp (°C)	-7.01	-5.04	-0.68	7.49	16.08	21.49	24.40	23.04	17.92	11.11	3.23	-4.43
Avg min temp (°C)	-17.39	-16.18	-9.57	-2.11	4.25	9.56	12.46	11.02	6.30	1.28	-4.36	-13.48
Std dev for avg max temp (°C)	6.64	5.89	5.17	5.12	5.94	5.11	4.00	4.15	4.86	5.42	5.24	6.28
Std dev for avg min temp (°C)	7.66	7.40	6.84	4.14	4.08	3.93	3.37	3.76	4.66	4.36	5.30	7.52
Avg precipitation (mm H ₂ O)	57.30	53.90	63.40	64.80	75.70	87.50	102.70	97.30	83.70	78.90	88.60	75.90
Std dev for precipitation (mm H ₂ O/day)	5.30	5.60	6.10	6.30	7.40	8.10	9.90	10.20	9.90	9.90	8.10	7.10
Skew coefficient for daily precipitation	1.38	1.00	0.98	1.50	1.57	1.26	1.25	2.34	2.42	3.28	1.33	1.94
Probability of wet day following dry day	0.40	0.37	0.33	0.34	0.33	0.38	0.40	0.35	0.37	0.32	0.40	0.39
Probability of wet day following wet day	0.52	0.51	0.51	0.54	0.54	0.52	0.48	0.50	0.46	0.49	0.54	0.54
Avg number of precipitation days	14.09	12.48	12.48	12.75	12.95	13.26	13.48	12.76	12.20	11.95	13.95	14.22
Max 0.5 hour rainfall (mm)	8.10	4.30	4.60	6.90	12.20	14.70	23.10	29.50	12.40	8.40	6.90	5.30
Avg solar radiation (MJ/m ² /day)	5.66	9.68	15.21	16.80	20.07	19.94	21.49	18.94	14.25	9.13	4.82	4.61
Avgdew point temp (°C)	-13.89	-15.00	-9.44	-2.22	3.33	10.00	13.33	12.22	8.33	2.22	-2.78	-11.11
Avg wind speed (m/s)	5.48	5.41	5.74	5.36	5.20	4.78	4.51	4.35	4.71	4.95	5.05	5.21

APPENDIX C

METHOD FOR CONVERTING THEMES TO A COMMON MAP PROJECTION

Version 300

Charset "WindowsLatin1"

Delimiter ", "

CoordSys Earth Projection 20, 33, "m", -66.5, 46.5, 0.999912, 300000, 800000

Bounds (-99700000, -99200000) (100300000, 100800000)

NOTE. Use above projection and copy/paste to the *.MIF file after it has been converted from *.shp to *.MIF and before it is opened in MapInfo (open in Wordpad first). This allows MapInfo to "know" initial projection. It can then be "save copy as" to implement new projection and then can be exported and converted back to a *.shp file.

For SHP2MIF:

1. Navigate to folder where SHP2MIF.exe is in DOS environment
2. Start program
3. Type file path i.e. SHP2MIF a:\test
** This will give the MIF file the same name and location (default).
** SHP2MIF a:\test c:\newmap This will give the new MIF file the name "new map" and place it on the new drive (c:\)
4. Open the .mif file (WordPad) and add the projection (at top)
5. Open in MapInfo, import the table (Table/Import) and change to new projection (File/Save copy as)
6. Export the table (Table/Export) and it is now ready to be changed back to *.shp file for ArcView.

For MIFSHAPE Utility:

1. Open MIFSHAPE utility
2. Follow instructions.
** Example of converting MIF to SHP, where output is polygon:
** poly a:\soilmap a:\soilmap
3. Shape (*.shp) files can then be opened in ArcView

Hints:

1. Dont have directories that use numbers as their name or more than 8 letters.
2. If you have problems converting MIF file back to .shp file because of problems with the program completing the DBase file, you may want to query the table in MapInfo and select one (more if necessary) column(s) that is(are) complete and can later be linked in ArcView.

MAPINFO-creating points

When a table is opened in MAPINFO and the "Create Points" under the Table menu is to be used, the following has to be done before the points can be created and then they can be converted to the desired projection: Get X coordinates from Y, Get Y coordinates from X, Multiply X by -1, Multiply Y by 1

APPENDIX D

SUMMARY OF HRU CLASSIFICATION FOR EACH SUBBASIN IN BLACK BROOK BASIN

		Area [ha]	%Watershed Area	%Subbasin Area
SUBBASIN # 1		209.50	16.68	
LANDUSE:				
	Grain Sorghum-->GRSG	69.72	5.55	33.28
	Pasture-->PAST	2.39	0.19	1.14
	Field Peas-->FPEA	5.13	0.41	2.45
	Forest-Evergreen-->FRSE	10.25	0.82	4.89
	Potato-->POTA	117.91	9.39	56.28
	Forest-Mixed-->FRST	4.10	0.33	1.96
SOIL:				
	me0031	1.03	0.08	0.49
	me0033	28.02	2.23	13.38
	me0007	163.02	12.98	77.81
	me0025	17.43	1.39	8.32
HRUs:				
1	Grain Sorghum-->GRSG/me0031	1.03	0.08	0.49
2	Grain Sorghum-->GRSG/me0025	11.96	0.95	5.71
3	Grain Sorghum-->GRSG/me0007	36.57	2.91	17.46
4	Grain Sorghum-->GRSG/me0033	20.16	1.61	9.62
5	Pasture-->PAST/me0007	2.39	0.19	1.14
6	Field Peas-->FPEA/me0025	0.68	0.05	0.33
7	Field Peas-->FPEA/me0007	4.44	0.35	2.12
8	Forest-Evergreen-->FRSE/me0007	7.86	0.63	3.75
9	Forest-Evergreen-->FRSE/me0033	2.39	0.19	1.14
10	Potato-->POTA/me0025	3.76	0.3	1.79
11	Potato-->POTA/me0007	111.41	8.87	53.18
12	Potato-->POTA/me0033	2.73	0.22	1.31
13	Forest-Mixed-->FRST/me0025	1.03	0.08	0.49
14	Forest-Mixed-->FRST/me0007	0.34	0.03	0.16
15	Forest-Mixed-->FRST/me0033	2.73	0.22	1.31
		Area [ha]	%Watershed Area	%Subbasin Area
SUBBASIN # 2		206.75	16.46	
LANDUSE:				
	Pasture-->PAST	17.99	1.43	8.7
	Range-Grasses-->RNGE	4.00	0.32	1.93
	Field Peas-->FPEA	5.71	0.45	2.76
	Forest-Deciduous-->FRSD	16.85	1.34	8.15
	Forest-Evergreen-->FRSE	11.42	0.91	5.52
	Potato-->POTA	90.81	7.23	43.92
	Forest-Mixed-->FRST	59.97	4.77	29.01
SOIL:				
	me0031	34.55	2.75	16.71
	me0033	8.57	0.68	4.14
	me0007	145.35	11.57	70.3
	me0025	18.28	1.46	8.84
HRUs:				
16	Pasture-->PAST/me0031	3.71	0.3	1.8
17	Pasture-->PAST/me0025	2.57	0.2	1.24
18	Pasture-->PAST/me0007	11.71	0.93	5.66
19	Range-Grasses-->RNGE/me0031	0.29	0.02	0.14
20	Range-Grasses-->RNGE/me0007	3.71	0.3	1.8
21	Field Peas-->FPEA/me0007	5.71	0.45	2.76
22	Forest-Deciduous-->FRSD/me0031	10.28	0.82	4.97
23	Forest-Deciduous-->FRSD/me0007	6.57	0.52	3.18
24	Forest-Evergreen-->FRSE/me0031	1.71	0.14	0.83
25	Forest-Evergreen-->FRSE/me0025	0.29	0.02	0.14
26	Forest-Evergreen-->FRSE/me0007	9.42	0.75	4.56
27	Potato-->POTA/me0031	8.85	0.7	4.28
28	Potato-->POTA/me0025	13.71	1.09	6.63
29	Potato-->POTA/me0007	65.97	5.25	31.91
30	Potato-->POTA/me0033	2.28	0.18	1.1
31	Forest-Mixed-->FRST/me0031	9.71	0.77	4.7
32	Forest-Mixed-->FRST/me0025	1.71	0.14	0.83

33	Forest-Mixed-->FRST/me0007	42.26	3.36	20.44
34	Forest-Mixed-->FRST/me0033	6.28	0.5	3.04
		Area [ha]	%Watershed Area	%Subbasin Area
SUBBASIN # 3		139.00	11.07	
LANDUSE:				
	Grain Sorghum-->GRSG	10.30	0.82	7.41
	Pasture-->PAST	26.03	2.07	18.72
	Range-Grasses-->RNGE	24.88	1.98	17.9
	Forest-Evergreen-->FRSE	6.86	0.55	4.94
	Potato-->POTA	70.93	5.65	51.03
SOIL:				
	me0031	55.20	4.39	39.71
	me0007	24.31	1.94	17.49
	me0021	3.15	0.25	2.26
	me0025	56.34	4.49	40.53
HRUs:				
35	Grain Sorghum-->GRSG/me0031	8.01	0.64	5.76
36	Grain Sorghum-->GRSG/me0025	2.29	0.18	1.65
37	Pasture-->PAST/me0031	8.29	0.66	5.97
38	Pasture-->PAST/me0021	1.72	0.14	1.23
39	Pasture-->PAST/me0025	8.87	0.71	6.38
40	Pasture-->PAST/me0007	7.15	0.57	5.14
41	Range-Grasses-->RNGE/me0031	22.31	1.78	16.05
42	Range-Grasses-->RNGE/me0025	2.57	0.2	1.85
43	Forest-Evergreen-->FRSE/me0031	6.86	0.55	4.94
44	Potato-->POTA/me0031	9.72	0.77	7
45	Potato-->POTA/me0021	1.43	0.11	1.03
46	Potato-->POTA/me0025	42.62	3.39	30.66
47	Potato-->POTA/me0007	17.16	1.37	12.35
		Area [ha]	%Watershed Area	%Subbasin Area
SUBBASIN # 4		277.50	22.09	
LANDUSE:				
	Grain Sorghum-->GRSG	28.00	2.23	10.09
	Range-Brush-->RNGB	70.14	5.58	25.27
	Pasture-->PAST	14.14	1.13	5.09
	Range-Grasses-->RNGE	8.04	0.64	2.9
	Forest-Deciduous-->FRSD	16.36	1.3	5.89
	Forest-Evergreen-->FRSE	21.62	1.72	7.79
	Potato-->POTA	61.27	4.88	22.08
	Forest-Mixed-->FRST	57.94	4.61	20.88
SOIL:				
	me0031	215.68	17.17	77.72
	me0007	20.79	1.66	7.49
	me0021	1.39	0.11	0.5
	me0121	27.17	2.16	9.79
	me0025	12.48	0.99	4.5
HRUs:				
48	Grain Sorghum-->GRSG/me0031	28.00	2.23	10.09
49	Range-Brush-->RNGB/me0031	53.78	4.28	19.38
50	Range-Brush-->RNGB/me0025	1.11	0.09	0.4
51	Range-Brush-->RNGB/me0121	13.03	1.04	4.7
52	Range-Brush-->RNGB/me0007	2.22	0.18	0.8
53	Pasture-->PAST/me0031	13.86	1.1	5
54	Pasture-->PAST/me0007	0.28	0.02	0.1
55	Range-Grasses-->RNGE/me0031	6.38	0.51	2.3
56	Range-Grasses-->RNGE/me0025	0.55	0.04	0.2
57	Range-Grasses-->RNGE/me0007	1.11	0.09	0.4
58	Forest-Deciduous-->FRSD/me0031	9.70	0.77	3.5
59	Forest-Deciduous-->FRSD/me0007	6.65	0.53	2.4
60	Forest-Evergreen-->FRSE/me0031	11.64	0.93	4.2
61	Forest-Evergreen-->FRSE/me0121	9.98	0.79	3.6
62	Potato-->POTA/me0031	41.31	3.29	14.89
63	Potato-->POTA/me0021	1.39	0.11	0.5
64	Potato-->POTA/me0025	10.81	0.86	3.9

65	Potato-->POTA/me0007	7.76	0.62	2.8
66	Forest-Mixed-->FRST/me0031	51.01	4.06	18.38
67	Forest-Mixed-->FRST/me0121	4.16	0.33	1.5
68	Forest-Mixed-->FRST/me0007	2.77	0.22	1
SUBBASIN # 5		Area [ha]	%Watershed Area	%Subbasin Area
LANDUSE:		44.50	3.54	
	Grain Sorghum-->GRSG	3.79	0.3	8.53
	Pasture-->PAST	10.69	0.85	24.03
	Field Peas-->FPEA	4.48	0.36	10.08
	Forest-Evergreen-->FRSE	3.10	0.25	6.98
	Potato-->POTA	12.07	0.96	27.13
	Forest-Mixed-->FRST	10.35	0.82	23.26
SOIL:				
	me0031	44.50	3.54	100
HRUs:				
69	Grain Sorghum-->GRSG/me0031	3.79	0.3	8.53
70	Pasture-->PAST/me0031	10.69	0.85	24.03
71	Field Peas-->FPEA/me0031	4.48	0.36	10.08
72	Forest-Evergreen-->FRSE/me0031	3.10	0.25	6.98
73	Potato-->POTA/me0031	12.07	0.96	27.13
74	Forest-Mixed-->FRST/me0031	10.35	0.82	23.26
SUBBASIN # 6		Area [ha]	%Watershed Area	%Subbasin Area
LANDUSE:		83.75	6.67	
	Grain Sorghum-->GRSG	34.59	2.75	41.3
	Potato-->POTA	49.16	3.91	58.7
SOIL:				
	me0031	3.64	0.29	4.35
	me0007	80.11	6.38	95.65
HRUs:				
75	Grain Sorghum-->GRSG/me0031	0.91	0.07	1.09
76	Grain Sorghum-->GRSG/me0007	33.68	2.68	40.22
77	Potato-->POTA/me0031	2.73	0.22	3.26
78	Potato-->POTA/me0007	46.43	3.7	55.43
SUBBASIN # 7		Area [ha]	%Watershed Area	%Subbasin Area
LANDUSE:		295.00	23.49	
	Grain Sorghum-->GRSG	84.73	6.75	28.72
	Pasture-->PAST	4.53	0.36	1.54
	Red Clover-->CLVR	4.88	0.39	1.65
	Potato-->POTA	167.03	13.3	56.62
	Forest-Mixed-->FRST	30.69	2.44	10.4
	Winter Wheat-->WWHT	3.14	0.25	1.06
SOIL:				
	me0031	40.45	3.22	13.71
	me0033	10.81	0.86	3.66
	me0007	181.67	14.46	61.58
	me0080	2.44	0.19	0.83
	me0025	59.63	4.75	20.21
HRUs:				
79	Grain Sorghum-->GRSG/me0031	14.65	1.17	4.96
80	Grain Sorghum-->GRSG/me0025	18.83	1.5	6.38
81	Grain Sorghum-->GRSG/me0007	49.17	3.91	16.67
82	Grain Sorghum-->GRSG/me0033	2.09	0.17	0.71
83	Pasture-->PAST/me0007	4.53	0.36	1.54
84	Red Clover-->CLVR/me0031	2.09	0.17	0.71
85	Red Clover-->CLVR/me0007	2.79	0.22	0.95
86	Potato-->POTA/me0031	8.37	0.67	2.84
87	Potato-->POTA/me0025	40.80	3.25	13.83
88	Potato-->POTA/me0007	110.89	8.83	37.59
89	Potato-->POTA/me0033	6.97	0.56	2.36
90	Forest-Mixed-->FRST/me0031	15.34	1.22	5.2
91	Forest-Mixed-->FRST/me0007	12.90	1.03	4.37

92	Forest-Mixed-->FRST/me0080	2.44	0.19	0.83
93	Winter Wheat-->WWHT/me0007	1.39	0.11	0.47
94	Winter Wheat-->WWHT/me0033	1.74	0.14	0.59

APPENDIX E

SUMMARY OF HRU CLASSIFICATION USING LOWER RESOLUTION SOIL MAPS

SUBBASIN #	1	Area [ha]	%Watershed Area	%Subbasin Area
LANDUSE:		209.5	16.68	
		Grain Sorghum-->GRSG	67.5166	5.38
		Pasture-->PAST	2.3167	0.18
		Field Peas-->FPEA	4.9645	0.4
		Forest-Evergreen-->FRSE	10.9218	0.87
		Potato-->POTA	114.8444	9.14
		Forest-Mixed-->FRST	8.936	0.71
SOIL:				
		me0042	209.5	16.68
HRUs:				
		1 Grain Sorghum-->GRSG/me0042	67.5166	5.38
		2 Pasture-->PAST/me0042	2.3167	0.18
		3 Field Peas-->FPEA/me0042	4.9645	0.4
		4 Forest-Evergreen-->FRSE/me0042	10.9218	0.87
		5 Potato-->POTA/me0042	114.8444	9.14
		6 Forest-Mixed-->FRST/me0042	8.936	0.71
SUBBASIN #	2	206.75	16.46	
LANDUSE:				
		Pasture-->PAST	17.8918	1.42
		Range-Grasses-->RNGE	3.976	0.32
		Field Peas-->FPEA	5.6799	0.45
		Forest-Deciduous-->FRSD	17.0398	1.36
		Forest-Evergreen-->FRSE	11.3599	0.9
		Potato-->POTA	90.8791	7.24
		Forest-Mixed-->FRST	59.9234	4.77
SOIL:				
		me0042	206.75	16.46
HRUs:				
		7 Pasture-->PAST/me0042	17.8918	1.42
		8 Range-Grasses-->RNGE/me0042	3.976	0.32
		9 Field Peas-->FPEA/me0042	5.6799	0.45
		10 Forest-Deciduous-->FRSD/me0042	17.0398	1.36
		11 Forest-Evergreen-->FRSE/me0042	11.3599	0.9
		12 Potato-->POTA/me0042	90.8791	7.24
		13 Forest-Mixed-->FRST/me0042	59.9234	4.77
SUBBASIN #	3	139	11.07	
LANDUSE:				
		Grain Sorghum-->GRSG	10.2541	0.82
		Pasture-->PAST	25.9201	2.06
		Range-Grasses-->RNGE	25.3504	2.02
		Forest-Evergreen-->FRSE	6.8361	0.54
		Potato-->POTA	70.6393	5.62
SOIL:				
		me0031	66.3668	5.28
		me0042	72.6332	5.78
HRUs:				
		14 Grain Sorghum-->GRSG/me0031	10.2541	0.82
		15 Pasture-->PAST/me0042	14.2418	1.13
		16 Pasture-->PAST/me0031	11.6783	0.93
		17 Range-Grasses-->RNGE/me0042	18.7992	1.5
		18 Range-Grasses-->RNGE/me0031	6.5512	0.52
		19 Forest-Evergreen-->FRSE/me0042	3.7029	0.29
		20 Forest-Evergreen-->FRSE/me0031	3.1332	0.25
		21 Potato-->POTA/me0042	35.8893	2.86
		22 Potato-->POTA/me0031	34.75	2.77
SUBBASIN #	4	277.5	22.09	
LANDUSE:				
		Grain Sorghum-->GRSG	29.4401	2.34
		Range-Brush-->RNGB	69.7839	5.56
		Pasture-->PAST	14.1749	1.13
		Range-Grasses-->RNGE	7.9052	0.63
		Forest-Deciduous-->FRSD	16.083	1.28
		Forest-Evergreen-->FRSE	21.2623	1.69
		Potato-->POTA	61.3335	4.88
		Forest-Mixed-->FRST	57.5172	4.58
SOIL:				
		me0031	271.2304	21.59
		me0042	6.2696	0.5
HRUs:				
		23 Grain Sorghum-->GRSG/me0031	29.4401	2.34
		24 Range-Brush-->RNGB/me0042	1.6356	0.13
		25 Range-Brush-->RNGB/me0031	68.1483	5.43

	26 Pasture-->PAST/me0042	4.6341	0.37	1.67
	27 Pasture-->PAST/me0031	9.5408	0.76	3.44
	28 Range-Grasses-->RNGE/me0031	7.9052	0.63	2.85
	29 Forest-Deciduous-->FRSD/me0031	16.083	1.28	5.8
	30 Forest-Evergreen-->FRSE/me0031	21.2623	1.69	7.66
	31 Potato-->POTA/me0031	61.3335	4.88	22.1
	32 Forest-Mixed-->FRST/me0031	57.5172	4.58	20.73
SUBBASIN #		5	44.5	3.54
LANDUSE:				
	Grain Sorghum-->GRSG	3.6805	0.29	8.27
	Pasture-->PAST	10.7068	0.85	24.06
	Field Peas-->FPEA	4.3496	0.35	9.77
	Forest-Evergreen-->FRSE	3.0113	0.24	6.77
	Potato-->POTA	12.0451	0.96	27.07
	Forest-Mixed-->FRST	10.7068	0.85	24.06
SOIL:				
	me0031	44.5	3.54	100
HRUs:				
	33 Grain Sorghum-->GRSG/me0031	3.6805	0.29	8.27
	34 Pasture-->PAST/me0031	10.7068	0.85	24.06
	35 Field Peas-->FPEA/me0031	4.3496	0.35	9.77
	36 Forest-Evergreen-->FRSE/me0031	3.0113	0.24	6.77
	37 Potato-->POTA/me0031	12.0451	0.96	27.07
	38 Forest-Mixed-->FRST/me0031	10.7068	0.85	24.06
SUBBASIN #		6	83.75	6.67
LANDUSE:				
	Grain Sorghum-->GRSG	34.5924	2.75	41.3
	Potato-->POTA	49.1576	3.91	58.7
SOIL:				
	me0031	1.8207	0.14	2.17
	me0042	81.9293	6.52	97.83
HRUs:				
	39 Grain Sorghum-->GRSG/me0042	32.7717	2.61	39.13
	40 Grain Sorghum-->GRSG/me0031	1.8207	0.14	2.17
	41 Potato-->POTA/me0042	49.1576	3.91	58.7
SUBBASIN #		7	295	23.49
LANDUSE:				
	Grain Sorghum-->GRSG	88.37	7.04	29.96
	Pasture-->PAST	4.2236	0.34	1.43
	Red Clover-->CLVR	4.5485	0.36	1.54
	Potato-->POTA	164.3943	13.09	55.73
	Forest-Mixed-->FRST	30.2148	2.41	10.24
	Winter Wheat-->WWHT	3.2489	0.26	1.1
SOIL:				
	me0031	20.1432	1.6	6.83
	me0042	274.8568	21.88	93.17
HRUs:				
	42 Grain Sorghum-->GRSG/me0042	84.1465	6.7	28.52
	43 Grain Sorghum-->GRSG/me0031	4.2236	0.34	1.43
	44 Pasture-->PAST/me0042	4.2236	0.34	1.43
	45 Red Clover-->CLVR/me0042	4.5485	0.36	1.54
	46 Potato-->POTA/me0042	148.4747	11.82	50.33
	47 Potato-->POTA/me0031	15.9196	1.27	5.4
	48 Forest-Mixed-->FRST/me0042	30.2148	2.41	10.24
	49 Winter Wheat-->WWHT/me0042	3.2489	0.26	1.1

APPENDIX F

RESULTS OF IMAGE CLASSIFICATION USING PCI SOFTWARE

Time: 12:10 12-Nov-02
File: C:\Fanrui\91-93\all27.pix
Classification Algorithm: Maximum Likelihood
Classification Input Channels: 2,3,5
Classification Training Channel: 9
Classification Result Channel: 8

Name	Code	Pixels	Image	Thres	Bias
Brand Leaves	1	7165680	12.48	3.00	1.00
Needle Leaves	2	11357092	19.77	3.00	1.00
Clear cut	3	12567058	21.88	3.00	1.00
Agriculture	4	2578442	4.49	3.00	1.00
Water	5	564163	0.98	3.00	1.00
Class-06	6	23201621	40.40	3.00	1.00
NULL	0	0	0.00		
Total		57434056	100.00		

CONFUSION MATRIX

Areas		Percent Pixels Classified by Code					
Name	Code	Pixels	1	2	3	4	5
Brand Leaves	1	5643	98.23	0.57	1.21	0.00	0.00
Needle Leaves	2	8666	0.91	97.00	2.04	0.05	0.00
Clear cut	3	1943	1.75	1.18	96.35	0.72	0.00
Agriculture	4	4745	0.00	0.02	0.63	99.35	0.00
Water	5	3331	0.03	1.29	0.57	0.00	98.11
Class-06	6	18869	0.00	0.00	0.00	0.00	0.00

Average accuracy = 98.17
Overall accuracy = 98.78

KAPPA COEFFICIENT = 0.98341 Standard Deviation = 0.00072
Confidence Level :
99 +/- 0.00185
95 +/- 0.00141
90 +/- 0.00118

TOTALIZATION REPORT for Training Sites

SUBTOTALIZATION REPORT for Training Site: NULL

code: 0

Name	Code	Pixels	Train	Image
Brand Leaves	1	7160023	12.48	12.47
Needle Leaves	2	11348587	19.77	19.76
Clear cut	3	12564892	21.89	21.88
Agriculture	4	2573710	4.48	4.48
Water	5	560895	0.98	0.98
Class-06	6	23182752	40.39	40.36

Totals	57390859	100.00	25.14
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SUBTOTALIZATION REPORT for Training Site: Brand Leaves code: 1

Name	Code	Pixels	Train	Image
Brand Leaves	1	5543	98.23	0.01
Needle Leaves	2	32	0.57	0.00
Clear cut	3	68	1.21	0.00
Totals		5643	100.00	0.01

SUBTOTALIZATION REPORT for Training Site: Needle Leaves code: 2

Name	Code	Pixels	Train	Image
Brand Leaves	1	79	0.91	0.00
Needle Leaves	2	8406	97.00	0.01
Clear cut	3	177	2.04	0.00
Agriculture	4	4	0.05	0.00
Totals		8666	100.00	0.02

SUBTOTALIZATION REPORT for Training Site: Clear cut code: 3

Name	Code	Pixels	Train	Image
Brand Leaves	1	34	1.75	0.00
Needle Leaves	2	23	1.18	0.00
Clear cut	3	1872	96.35	0.00
Agriculture	4	14	0.72	0.00
Totals		1943	100.00	0.00

SUBTOTALIZATION REPORT for Training Site: Agriculture code: 4

Name	Code	Pixels	Train	Image
Needle Leaves	2	1	0.02	0.00
Clear cut	3	30	0.63	0.00
Agriculture	4	4714	99.35	0.01
Totals		4745	100.00	0.01

SUBTOTALIZATION REPORT for Training Site: Water code: 5

Name	Code	Pixels	Train	Image
Brand Leaves	1	1	0.03	0.00
Needle Leaves	2	43	1.29	0.00
Clear cut	3	19	0.57	0.00
Water	5	3268	98.11	0.01
Totals		3331	100.00	0.01

SUBTOTALIZATION REPORT for Training Site: Class-06 code: 6

Name	Code	Pixels	Train	Image
Class-06	6	18869	100.00	0.03
Totals		18869	100.00	0.03

APPENDIX G

SUMMARY OF HRU CLASSIFICATION IN FORESTED SUBBASIN OF LRB

	Area (ha)	Sub.Area (%)
SUBBASIN # 8	17981.80	
HRUs:		
1. Range-Brush-->RNGB/ME0021	118.59	0.66
2. Range-Brush-->RNGB/ME0041	209.06	1.2
3. Range-Brush-->RNGB/ME0007	1929.41	10.73
4. Range-Brush-->RNGB/ME0011	40.54	0.23
5. Range-Brush-->RNGB/ME0031	108.20	0.60
6. Range-Brush-->RNGB/ME0022	420.39	2.34
7. Forest-Deciduous-->FRSD/ME0041	469.26	2.61
8. Forest-Deciduous-->FRSD/ME0007	4064.77	22.13
9. Forest-Deciduous-->FRSD/ME0031	60.68	0.34
10. Forest-Deciduous-->FRSD/ME0022	1115.26	6.20
11. Forest-Evergreen-->FRSE/ME0021	143.17	0.80
12. Forest-Evergreen-->FRSE/ME0041	1542.12	8.58
13. Forest-Evergreen-->FRSE/ME0007	5235.34	29.11
14. Forest-Evergreen-->FRSE/ME0011	124.52	0.69
15. Forest-Evergreen-->FRSE/ME0022	1550.94	8.63
16. Forest-Plantation -->FRSE/ME0021	44.30	0.25
17. Forest-Plantation -->FRSE/ME0041	143.04	0.80
18. Forest-Plantation -->FRSE/ME0007	442.78	2.46
19. Forest-Plantation -->FRSE/ME0031	129.87	0.72
20. Forest-Plantation -->FRSE/ME0022	136.20	0.76
21. Forest-Plantation -->FRSE/ME0033	9.87	0.05

VITA

Candidate's Full Name:

Frederick Craig Fowler

Place and Data of Birth:

Saint John, New Brunswick

July 9, 1973

Present Address:

39 Clearview Avenue

Fredericton, NB, E3A 1J9

Schools Attended:

Fredericton High School, graduated 1991

NBCC-Miramichi, graduated 1997

Universities Attended:

University of Alberta

Bachelor of Science, Environmental and Conservation Sciences, graduated
2000

University of New Brunswick

Master of Science in Forestry and Environmental Management
(candidate)