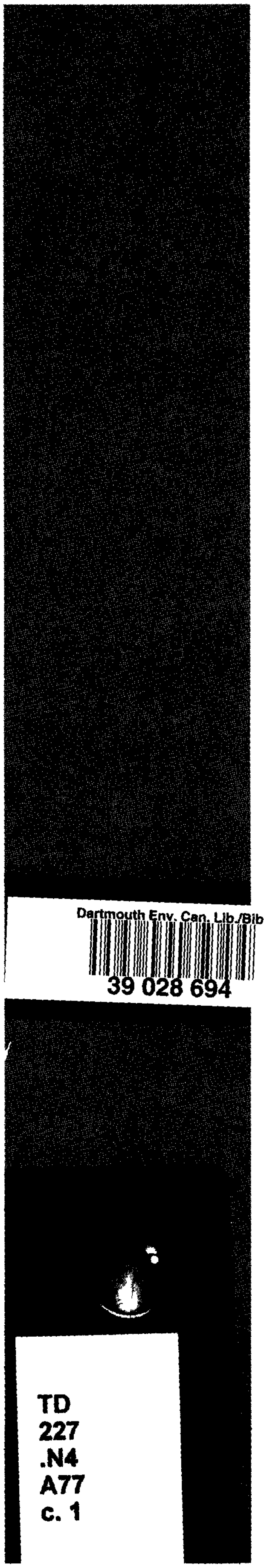

Assessment of Non-Point Source Pollution Models for their Utility in New Brunswick

Final Report

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Atlantic Region

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New Nouveau Brunswick
ENVIRONMENT
ENVIRONNEMENT

FINAL REPORT

ASSESSMENT OF NON-POINT SOURCE POLLUTION MODELS FOR THEIR UTILITY IN NEW BRUNSWICK

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EXECUTIVE SUMMARY

Agriculture and forestry activities are important contributors to the lowering of surface and ground water quality. The growing demand for food and fibre, water, and energy, requires that we better understand the transport of sediment and chemicals, and implement more effective watershed management to maintain acceptable water quality. A need to identify watershed management plans has been identified under the New Brunswick Water Economy Agreement and the Atlantic Coastal Action Program.

A variety of non-point source (NPS) pollution models have been developed in the USA and Canada to estimate the effects of various land management practices on water quality. Of current concern is the issue of which of the presently-available models to use in New Brunswick and how good and applicable is the data against which they are tested.

At best, a model is a simplification of the real world. The best we can hope for is an unbiased estimate, which of course depends on the applicability of the model in the location and circumstances under which it is being used. Important considerations are simplicity of use, accuracy, consistency and sensitivity of model parameters.

To choose an appropriate model from existing ones, the goal for which the model is to be used and the resources available to meet those goals must be clearly understood and explicitly defined. Models range in complexity from detailed research tools to relatively simple planning tools. Discussions with federal and provincial government representatives revealed that the model applications envisioned for N.B. broadly embody means of providing a basis for supporting decisions. Models would act as tools for planning, research and persuasion, as well as a means of establishing best management practices.

This report provides the results of a review of seven NPS models to determine their applicability for N.B. based on existing literature, requirements for and availability of data, and the end use envisioned. The following models were reviewed:

MUSLE (Modified Universal Soil Loss Equation) - developed to provide an estimate of soil loss from a single storm event utilizing the USLE data base;

GAMES (Guelph model for evaluating effects of Agricultural Management systems on

Erosion and Sedimentation) - developed to facilitate direct use of the USLE on an integrated spatial basis to provide seasonal estimates of individual field soil loss and stream sedimentation;

AGNPS (Agricultural Non-Point Source pollution model) - developed to estimate soil loss from fields, and, point and non-point source pollution arising from a single extreme event storm;

CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) - were developed to assess the long term effects of best management practices on single fields taking rotations into account;

SWRRB (Simulator for Water Resources in Rural Basins) - developed to provide a prediction of sediment, nutrients and pesticides from ungauged rural catchments;

ANSWERS (Areal Non-point Source Watershed Environment Response Simulation) - developed for detailed evaluation of the effects of differing management practices on resulting location and amount of soil loss, deposition and stream sediment.

The models were classified according to whether they were intended primarily to address on-farm or off-farm concerns, and whether they could serve best as research or planning tools.

Each of the models contain some desirable aspects, but all lack in one or more components. Each has a particular strength for a specific application, but none can be regarded as a 'global' model. The selection of a specific model therefore depends on the problem and the resources available for its application.

For on-farm assessment of best management practices in a specific field, either CREAMS (surface effects) or GLEAMS (for additional subsurface chemical effects) should be used. If off-farm chemical effects from point and non-point sources from a specific event are important then only AGNPS is applicable. SWRRB provides a relatively quick estimate of integrated daily runoff, and soil, nutrient and pesticide loss from up to 10 differing sub-basins. MUSLE provides a rapid estimate of soil loss from a field for a specific storm event, assuming runoff is known or estimated by some other method. GAMES provides a seasonal estimate of soil loss on specific fields, taking spatial effects into account and has the advantage of direct use of the well-tested and well-known USLE. ANSWERS facilitates detailed investigation of the response of a catchment to a given rainfall event. None of the models directly addresses forestry concerns.

New Brunswick is one of the provinces most seriously affected by water induced soil erosion in Canada (Coote et al. 1986). Intensive potato production on steep, highly erodible soils in the northwest "Potato Belt" is the primary source of sediment and associated pollutants in the province. Over half of the potential agricultural land in this region, has a slope of 5 percent or greater (Stewart 1976, in Coote et al. 1986). Sheet and rill erosion under conventional potato production has been estimated to be approximately 20 t/ha/yr. The use of chemical fertilizers and pesticides is generally deemed to be essential for economic crop production. Chow et al. have suggested that, due to deteriorating soil quality, the application of these inputs is increasing in this geographic region (Herb Rees, personal communication). Erosion concerns are considerably less in other cultivated areas of the province due to a more diversified, livestock-based agriculture.

An important aspect, which it is not possible to address at this stage, is the applicability (accuracy) of each of the models under New Brunswick conditions. The question of applicability can only be assessed through testing against recorded data. The following sources of potentially useful data have been identified:

-One intensively monitored watershed exists in New Brunswick as a result of the Black Brook Experimental Watershed project located north of Grand Falls. However, the installation is recent and only a year of data is presently available for model validation.

-A series of runoff and erosion monitoring plots, also located in the Grand Falls area, have been in operation for approximately ten years.

-Environment Canada has been collecting suspended sediment data on the Kennebecasis River since 1966.

-Soil Conservation Service (SCS) curve number data and other parametric data required for use with the USLE and other US government funded models such as CREAMS/GLEAMS are available for the State of Maine and could be assessed for their applicability to New Brunswick conditions.

Two options are presented for proceeding with the process of model selection/validation. The first entails the establishment of monitoring stations in two additional, representative watershed ecosystems. To compliment the existing monitoring program in the Black Brook watershed, these would likely include a site in the livestock-intensive southeast region of the province, and a forested watershed. The second option entails testing the SWRRB, CREAM/GLEAMS, AGNPS and ANSWERS models with currently available data.

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1.0 INTRODUCTION

Agriculture and forestry activities are important contributors to the lowering of surface and ground water quality. The growing demand for food and fibre, water, and energy, requires that we better understand the transport of sediment and chemicals, and implement more effective watershed management to maintain acceptable water quality. This study reviews a number of non-point source (NPS) pollution models which have been developed to estimate the effects of various land management practices.

Measurement and modelling are complimentary fundamental activities for design and optimum utilization of resources. However, as noted by Wagenet (1988), in the area of hydrology, laboratory and field-oriented experimenters of the past generation are increasingly reaching retirement age and, with the explosion in microcomputer technology, are replaced by young computer-oriented scientists and engineers. The pendulum has therefore swung from emphasis on measurement towards the field of mathematical (computer) modelling of complex systems in which assumptions are perforce made for unknown component processes and field measurements are often questionable. This in itself is an ultimately-beneficial phase in the evolution of environmental science and engineering, since global modelling forces multidisciplinary interaction, delineates the gaps in scientific knowledge and ultimately leads to an overall improved understanding of environmental concerns. However, of crucial current concern is the issue of which of the currently-available models to use and how good and applicable is the data against which they were tested.

In viewing the measurement/modelling process we recognize that for many processes it clearly is not realistic to create each scenario of interest in order to determine the outcome. For systems, which comprise many interrelated processes having multiple inputs and outputs, even measurement in itself becomes a major undertaking. For systems, such as a watershed, in which the driving force is natural climatic events, the creation of specific inputs and measurement of the responses of interest is not even feasible. We therefore resort to measurement of stimuli and responses and apply the information in predictive models. The model may comprise a single equation, a set of equations describing a specific process (such as the nitrogen cycle), or a set of processes, such as the water, soil and chemical balances in a watershed.

Whether the pollutants originate from pervious or impervious lands, from agricultural or urban areas, or from natural or modified lands, the major transport mode of runoff and its associated sediment load is operative. Ghadiri and Rose (1992) have suggested that the modelling of NPS pollution arising from overland flow has a structure analogous to a three-layered pyramid. The base of the pyramid is the hydrologic behavior of the watershed. Without the accurate representation of runoff, modelling NPS pollutants in overland flow is impossible. The second layer represents the process of sediment loss, providing the major transport mechanism for all absorbed pollutants.

The top layer of the pyramid is the interaction of the various pollutants with sediment loss and runoff that results in the overall transport and delivery of NPS pollutants to streams and other water bodies.

The measurements we take and the model we use are interrelated and are determined by the objective of the undertaking. At best a model is a simplification of the real world. As indicated by Woolhiser and Brakensiek (1982), important considerations are simplicity of use, accuracy, consistency and sensitivity of model parameters. But how simple? And does complexity necessarily imply accuracy?

Although we would like to think that a NPS model can give absolute answers, the best we can hope for is an unbiased estimate, which of course depends on the applicability of the model in the location and circumstances under which it is being used. As indicated by Barfield et al (1989), hydrological models are most applicable in predicting relative differences in management practices.

To choose an appropriate model from existing ones, the goal for which the model is to be used and the resources available to meet those goals must be clearly understood and explicitly defined. Models range in complexity from detailed research tools to relatively simple planning tools.

Global NPS models vary in their consideration of spatial variation, the time step, whether parameters are physically measurable or abstract, whether meteorological input data is recorded or generated, and the level to which interrill and rill erosion, nutrient cycling, pesticide fate, winter effects, crop growth, interflow and groundwater are modelled. Many models are dynamic in the sense of continuing development through refinement, the addition of components and testing under a range of diverse conditions.

No single NPS model provides global solutions. In terms of spatial variation, the models reported on in this review comprise field-scale (MUSLE, CREAMS and GLEAMS), quasi-spatial, selectably-stochastic (SWRRB) and distributed parameter (AGNPS, GAMES and ANSWERS). In terms of time steps one is seasonal (GAMES), some utilize daily time steps (CREAMS, GLEAMS and SWRRB), MUSLE and AGNPS utilize an event time step and ANSWERS has a user-selectable time step of 1 to 60 seconds. All model runoff and soil loss in varying degrees of detail. For surface effects on a watershed scale, phosphorous is modelled by AGNPS and revised versions of SWRRB (SWRRBWQ) and GAMES (GAMES-P). Nitrogen is modelled by AGNPS and SWRRBWQ, pesticides are modelled by SWRRBWQ, and chemical oxygen demand (COD) is modelled by AGNPS. CREAMS models surface effects for N, P and pesticides while GLEAMS additionally models subsurface effects.

A study, such as herein, is becoming commonplace as administrators through researchers struggle for tools to understand and provide guidelines for sustainability of bioresources and the maintenance of the environment. Of particular note are recommendations by von Euw et al (1992) for conducting a comparative assessment of non-point source models, and a study in Mississippi (Bingner et al 1989; Bingner 1990; Bingner et al 1992) in which four of the models in this study (CREAMS, SWRRB, ANSWERS and AGNPS) were tested against recorded data.

2.0 BACKGROUND TO REVIEWED MODELS

Of the models considered all except GLEAMS, which is a direct modification of CREAMS, had somewhat independent origins. ANSWERS was developed from an original runoff model by Huggins and Monke (1966). MUSLE (Williams 1975) and GAMES (Vers. 1.0 was authored by D.J. Clark in 1981, according to Cook et al 1985) are adaptations of the USLE (Wischmeier and Smith 1965).

As a result of The Clean Waters Act of 1972 in the USA, the Environmental Protection Agency (EPA) requested the Department of Agriculture (USDA) to develop means to predict and regulate non-point source pollutants from farmlands, including evaluation of the effects of various Best Management Practices (BMPs). CREAMS then developed from a USDA-SEA-ARS team effort initiated in 1978 (Knisel and Nicks 1980). The

CREAMS team disbanded following release of the model and support was passed to the Southeast Watershed Laboratory, Tifton, Georgia. GLEAMS was developed by personnel at this facility and arose as a modification of CREAMS to better address questions of pesticide leachate (Knisel 1989).

The SWRRB model was developed by Williams et al (1985) and presented in a detailed user's manual by Arnold et al (1990). SWRRB uses the CREAMS daily rainfall hydrology model in developing a model applicable to up to ten subbasins.
N, P and pesticide components were later added to the subsequent release, SWRRBWQ, in 1991.
The AGNPS model has a simplified spatial structure of the ANSWERS model and includes CREAMS concepts. The model was developed by the Agricultural Research Service (ARS) of the USDA with support from USDA-SCS, EPA and the Minnesota Pollution Control Agency (Young et al 1987).

The models of the 1960's and early 1970's tended to be individualistic efforts arising mainly from universities in the U.S.A. However, the national focus placed on the environment in the 1970's under the concepts of 'sustainability' and 'clean waters' led to the assembling of teams of Federal personnel to produce improved predictive technology. This led, in particular, to the EPIC and CREAMS models.
The emphasis had now shifted towards team effort as models escalated in complexity in this multidisciplinary area. University research reverted to focusing on component processes. Similarity in current models arises because of perceived needs and because of commonality of personnel involved in the modelling process. In particular J.R. Williams has been involved in the development of the SWRRB, EPIC and CREAMS models, and has recently taken over from Walt Knisel as the coordinator of the CREAMS and GLEAMS models. George R. Foster has been involved in the soil erosion components of all of the major models either directly or indirectly.

3.0 DESCRIPTION OF MODELS

MUSLE

The USLE (Universal Soil Loss Equation) is:

$$A = RKLSCP \qquad (1)$$

where, A = avg. annual soil loss ($Mg.ha^{-1}$); R = rainfall erosivity ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$); K = soil erodibility ($Mg.h.MJ^{-1}.mm^{-1}$); LS = length and degree of slope index; C = cropping management factor; and P = contouring factor. Rainfall erosivity, as the driving effect, is calculated as the product of the maximum rainfall intensity over a 30 minute period for a storm multiplied by the storm raindrop kinetic energy. This is summed for all storms (generally those of over 13 mm in rainfall) over a number of years to obtain an average annual R for prediction.

The USLE is an 'average annual equation' and, as often stated by Wischmeier, is not directly usable for individual storm events. Over time the USLE takes into account variations in initial soil moisture, rill as against interrill erosional processes, variations in crop cover, etc. However, in order to verify the applicability of the USLE by evaluating soil erodibilities for a specific location and crop, etc., long term (10 years) monitoring should be carried out under natural conditions. The equation is a poor predictor for individual storm events.

MUSLE (Modified Universal Soil Loss Equation) is a model presented by Williams (1975), as a single storm equation. As implied, it is a modification of the USLE, and thereby utilizes the vast amount of background data and experience associated with the USLE. MUSLE is:

$$D = 9.05\ (V.q)0.56\ KLSCP \qquad (2)$$

where, D = soil loss (Mg); V = volume of runoff (m^3); q = peak runoff rate ($m^3.s^{-1}$); and K,LS,C and P are as in the USLE. In particular, it may be noted that while the USLE predicts average annual soil loss in mass per unit area, MUSLE predicts storm soil loss in mass units. It is principally used as a design tool for soil conservation measures on disturbed lands and construction sites.

MUSLE replaces rainfall, as the sole causative effect of soil loss in the USLE, with a result of rainfall, viz., the volume and peak rate of runoff. This philosophy is used in varying forms in CREAMS, GLEAMS, SWRRB and AGNPS.

GAMES

GAMES (Guelph model for evaluating effects of Agricultural Management systems on Erosion and Sedimentation) is a distributed parameter model which uses fields as cells. Each cell (field) is assumed uniform in soil type, slope and cropping practice but may be of any shape and size. The model applies the USLE directly to each cell (field) in the watershed on a one-time seasonal or annual basis generating the gross erosion rate from the cell and routing the sediment to a stream cell using the concept of a cell delivery ratio. Neither erosion nor deposition is permitted in stream cells. A sequential array is set up in which a cell (field or stream) drains into a single downslope cell. Field cells may be designated as 'terminal' denoting that drainage does not leave the cell as in the case of potholes.

The model requires an 'analytical' run for calibration. A measured or best estimate of sediment load at the catchment outlet is required for the season or year modelled in order to fix the two cell delivery ratio parameters which is accomplished by an optimization (minimum error) technique. These two parameter values (A and B in the model) then apply to every field cell. 'Predictive' runs then can be made for any combination of cropping practices using the two parameters generated in the 'analytical' run to generate each cell's delivery ratio. However, in absolute terms the output values are, of course, dependent on the analytical run.

The manual (Cook et al 1985) includes extensive information on USLE parameter values and recommends variation in 'K' (soil erodibility) values dependent on season for seasonal use. The 'R' (erosivity) values recommended are based on the Wischmeier 'EI' values and do not include the effects of snowmelt runoff although, if data are available, this can be included by adjustment of the input 'R' value.

The major assumption is the concept of field cell delivery ratios based on a 'hydrologic coefficient' which denotes a cell's ability to generate runoff during the period considered.

A separate program GAMESC allows the user to sort cells into a 5 by 5 matrix according to selectable levels of sediment contribution to outflow by soil gross erosion. Chemicals are not modelled.

GAMES-P is the result of adding a phosphorous component to the GAMES model. GAMES-P also requires calibration and therefore, requires field validation before it can be useful as a guide in practical management.

ANSWERS

ANSWERS (Areal Non-point Source Watershed Environment Response Simulation) is a distributed parameter model in which a watershed is conceived as a grid of square elements each of which has a specific slope, soil type and cropping practice. Channel drainage, if present, is provided for by a conceived overlying tree of channel elements. ANSWERS is an event model in which time steps are user-selectable from 1 to 60 seconds. The output time step is indirectly user-specified by selection of the number of lines of output. Output in tabular form is the watershed rainfall rate, runoff rate, sediment concentration and accumulated sediment at specified times. Mass sediment loss or gain for each element follows.

Two versions of ANSWERS are currently available, the 'public' model (ANSWERS) which is little changed since 1977, and a version which additionally gives the particle size distribution for the mass soil loss (ANS77PS). Chemicals are not modelled, although the particle size distribution routines provide a basis for adding nitrogen and phosphorus routines. A developmental version (not yet released) has added components for modelling plant nutrient transport. Work on the model is continuing for a variety of applications. Of particular relevance to this study is the COSSEM (Cool Season Soil Erosion Model) (Burney and Edwards 1992) for year-round cool temperate climate use. This model is still in the developmental stage. Whereas ANSWERS is a summer model, COSSEM is a late winter/spring model.

ANSWERS is best characterized as a research model most applicable to answering 'what-if' type questions. The model uniquely includes the dynamic effects of time variation in rainfall from up to 5 raingauges and resulting runoff and soil loss under unrestricted variation in soil, slope and cropping practices. As such it is demanding in computer time. A second demand in application is the generation of the data base, which is particularly time-consuming because of the model detail. For each element in a modelled watershed, the soil type, direction and degree of slope, whether or not it contains a channel element, the slope of the channel element and whether or not the field is tile drained all must be specified. In ANSWERS the cropping practice for the element also must be specified which means extensive modification for changes in cropping practices. In COSSEM the field must be specified which means that a set of elements can readily be changed as a single specification.

CREAMS

CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems) is a field-scale model defined by Knisel and Nicks (1980) as having a single land use, relatively homogeneous soils, spatially uniform rainfall and a single management practice including terracing. At the time a watershed-scale version was conceived as a later logical extension, and has been indirectly accomplished by modification of the SWRRB model (described later) and by incorporating some CREAMS concepts in other models such as AGNPS (also described later).

CREAMS comprises three separate programs linked through pass files. These programs in turn deal with hydrology, erosion and chemicals (nutrients and pesticides) from a field. The hydrology program generates a pass file which, together with a user-generated erosion file, is read by the erosion program. The same structure exists for the chemicals program. All three programs also separately generate their own output file specifying information at a level (storm, monthly or annual) selected by the user.

The hydrology program has two options, option 1 is the use of daily rainfall and option 2 is the use of breakpoint or hourly rainfall. If option 1 is selected the SCS curve number technique, with adjustment for soil moisture, is used to generate the volume and peak rate of runoff for days on which rainfall occurs. If option 2 is selected then physical modelling based on the Green and Ampt infiltration equation and kinematic routing, is adopted to generate each day's volume and peak rate of runoff and rainfall erosivity (Wischmeier EI) value. If hourly rainfall data is used, assumptions are made to correct for peak intensity deficiencies. For both options a daily time step is used for evapotranspiration (as separate soil evaporation and plant transpiration) and moisture budgeting. However, for option 1, the root zone is divided into 7 layers with moisture budgeting in each layer. For option 2, the root zone is divided into 2 layers, a shallow

surface layer (used in the infiltration model) and the remaining rooting depth. Snow accumulation and melt are handled by simple temperature models.
Of particular note in the hydrology model is that some aspects are modelled in detail (in particular infiltration and runoff from breakpoint rainfall) whereas others (hourly rainfall and snowmelt) are simplistic.

The erosion program is extremely detailed and as noted by Ferreira and Smith (1988) provides an example of component imbalance in modelling. As they point out, the erosion program sorts sediment into particle sizes (a necessity for the later nutrient/pesticide program) along a varied-slope plane of differing allowable cropping practices and soils based on rainfall erosivity, and runoff volume and peak estimates which, for option 1 in the hydrology program, are obtained from a lumped, time-independent SCS curve number which provides the same values whether the rain falls in 1 hour or 24 hours.

The erosion program allows for combinations of channels and ponds, as for a terraced field comprising terrace banks and a waterway, or PTO terraces. The basic component is a defined overland surface, which may run down the whole field, be a typical section between terrace banks, or be the side of a potato hill. The slope of this surface is defined by three planes of user-defined degree and position. Also down this profile both soil erodibility and cropping-management are user defined spatially, and in the latter case, also temporally. Both interrill and rill erosion are modelled using quasi-process equations based on the USLE 'K'. Erosion is calculated as functions of runoff peak rate and volume (the concept used in MUSLE), although interrill erosion is also a function of rainfall erosivity. Outflow sediment, from the end of the overland strip, waterway or pond is segregated into 5 classes (3 particle sizes and two aggregate sizes).

The chemicals program is an amalgamation of nutrient and pesticide modelling. Both components require a pass file from the erosion program and an input file, but cannot be run concurrently. Additionally, both components assume an active top layer of 1 cm depth which interacts with runoff and the remaining root zone depth acts as a homogeneous reservoir.

The nutrient component models phosphorous and nitrogen. For phosphorous only field applications are considered with losses through adsorption to sediment and in solution in runoff. For nitrogen, sources considered are rainfall, fertilizer and mineralization with losses in sediment, and in solution in runoff and leachate below the root zone.

The pesticide component separately considers foliar and soil application of chemicals. For foliar application the fraction on leaves is subject to decay and washoff into the 'active' surface layer of 1 cm depth where it is available for loss on sediment or in solution to runoff, or percolation into the remaining root zone depth. Leachate below the root zone does not appear to be considered. Pesticides incorporated into the root zone are also considered. Any major tillage operation, such as ploughing, creates a discontinuity in the chemicals program and necessitates restarting the entire simulation under these new conditions.

GLEAMS

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) represents a modification of CREAMS to specifically address questions of chemicals in the soil and groundwater. Since an accepted base for surface pollutants already existed in CREAMS, it was decided to build on this base. However, since the proposed modifications were substantial, and the emphasis was to shift to subsurface pollution, it was decided to create a new model named GLEAMS. It was also decided to concentrate firstly on modifying the pesticide routine (since pesticides in groundwater was an immediate problem area). The nutrient routine (which still considers only nitrogen and phosphorous) was then substantially expanded and is documented in Knisel et al (1993b).

GLEAMS is a single program, and therefore loses some of the flexibility of CREAMS. However, since the hydrology and erosion programs of CREAMS were little changed when incorporated in GLEAMS, stand alone questions requiring only runs of these components may still be achieved by using the applicable program in CREAMS. A major basic change in GLEAMS (as against CREAMS) is the way in which the soil profile, is depicted. CREAMS modelled the root zone as an 'active' surface layer of 1 cm depth, and a single remaining layer. In GLEAMS the soil profile is divided into generic horizons (for which physical and chemical properties are separately specified) and computational layers within horizons, one of which is the surface 1 cm deep 'active' layer used in CREAMS.

Changes in the hydrology section include deletion of option 2 (breakpoint rainfall and infiltration modelling in CREAMS) and the only option in GLEAMS therefore is daily rainfall and use of the SCS curve number technique. Daily temperatures optionally may be input to better simulate winter conditions, and especially periods of thaw, in particular, and snowmelt and irrigation modelling have been improved. Routines specific to forest hydrology have been added.

The erosion component of GLEAMS is only slightly different from that in CREAMS. Changes include fixing of some parameters for which defaults were conventionally used and simplification of the overland flow profile specification. As indicated previously, the main difference between CREAMS and GLEAMS is in the chemical (pesticide/nutrient) models. Both of these have been substantially revised.

The pesticide component simulates interactions among pesticide properties, climate, soil properties and management, and their effects on pesticide losses in runoff, attached to sediment and in percolation below the root zone. Multiple applications of up to ten different pesticides and metabolites may be simulated.
The nutrient component (Knisel et al 1993b) models the complete phosphorous and nitrogen cycles with distribution of these elements between soil layers and losses by volatilization, runoff, attached to sediment and by percolation below the root zone. The model also considers animal manure applications and nitrogen fixation by legumes.

File development programs to enable interactive building of the hydrology, erosion, pesticide and nutrient files are a part of the GLEAMS Vers. 2.0 package.

SWRRB

SWRRB (Simulator for Water Resources in Rural Basins) has a stated purpose of predicting the effect of management decisions on water and sediment yield from ungauged rural basins. The model is comprehensive in that it covers up to ten subbasins (each of which may have its own precipitation and/or temperature records). Aspects dealt with include surface runoff, lateral and return flow, evaporation and transpiration, snowmelt, frozen soil, crop growth and pond and reservoir storage. A watershed may comprise of a single basin or up to ten subbasins, which may be any mixture of congruency and nesting. However, the number of subbasins can be increased by increasing dimension statements in the supplied Fortran source code. Each basin must have a channel section into which surface and subsurface flow is discharged. Examples given are for watersheds of 18 and 233 km^2 and the model evaluations listed are for ten watersheds ranging from 17 to 538 km^2 in locations from Texas to Vermont.

The model therefore would appear to be most applicable to medium to large watersheds.

Weather data required is daily precipitation (with division between snow and rain at 0 C), temperature and solar radiation. Precipitation and temperature may be input or generated from stochastic parameters while radiation can only be generated.

Each subbasin is modelled as a plane having uniform slope, soil and vegetation with runoff volume estimated using the SCS curve number technique as in the CREAMS (Option 1) and GLEAMS models. Runoff peak is estimated using a modified Rational Formula method. These two values are then used in MUSLE to generate soil loss. This quantity of soil is then separated into five particle/aggregate sizes using the same model component developed for the CREAMS model and is then distributed between ponds/reservoirs and the subbasin channel. Since a daily time step is used, flood routing is not warranted, and total watershed runoff is simply the sum of the subbasin's surface runoff plus lagged subsurface flow for a particular day. Subsurface flow comprises lateral flow (interflow) and groundwater flow. However, sediment is routed through ponds/reservoirs and through the stream channels. The model permits both deposition and erosion in channels.

The soil profile, for each soil (with data obtainable directly from the Soils-5 data base for USA soils supplied with the package) can be divided into up to 10 layers. Only the top layer is restricted to 1 cm in depth, as in GLEAMS. A moisture balance is performed in the soil profile, with separate estimate of soil evaporation and plant transpiration and of percolation below the root zone. Crop growth is modelled using abridged EPIC routines with phenological development modified by heat units and moisture stress. Irrigation, based on moisture stress, may be modelled.

Winter conditions are modelled by routines to estimate soil temperature by layer and the simple snow accumulation and melt routines used in CREAMS. Although the model may be used for many years of simulation, particularly through use of the weather generators, no provision appears to exist for changing the cropping practice specified for a particular subbasin, which means that rotations are only permissible by reruns of the model.

Chemical transport components were added to the original version of the model in 1991 to create SWRRBWQ (Simulator for Water Resources in Rural Basins - Water Quality). SWRRBWQ models nitrogen, phosphorus and pesticide transport from the subbasins to the basin outlet.

AGNPS

The AGNPS (Agricultural Non-Point Source) model is a single-event pollution model (Young et al 1987, 1991) which views a catchment as comprising square cells which are uniform in soil, vegetation and management practices. Each cell is assumed to contain a channel into which all surface runoff flows. Outflow from a cell is in one of the eight cardinal directions wholly to the channel in the congruent cell. However, a unique feature is that any cell can be subdivided into four square cells and this may be repeated to the next lower level. This allows for both generalization and selective detail.

The AGNPS model uses the CREAMS (Option 1) hydrology routines (SCS curve number technique) to estimate daily runoff volume and peak discharge from each cell. The 24 hour, 25 year storm is the recommended rainfall to be used with the model used for comparing conservation practices. Sediment mass from each cell is calculated by direct application of the USLE using the rainfall EI value, with the addition of a multiplicative factor to adjust for slope shape. Sediment is divided into five classes as in CREAMS and is routed through the catchment including routing through designated PTO terrace ponds.

AGNPS models N, P and COD from non-point and point sources in the surface runoff. N and P are modelled as both attached to sediment and in soluble form.
For non-point source pollution (N and P) the CREAMS model assumption of a thin 'active' surface layer (in this case 0.5 inch) is utilized, with fertilizer in this layer vulnerable to runoff. Point source pollutants may emanate from small industry or feedlots (for which considerable detail is given). Gully erosion may also be added as a point sediment source within any cell. Subsurface percolation and return flow are not considered.

Output includes volume and peak runoff, sediment division into five classes, and N, P and COD for the catchment as a whole. Considerable detail on the functioning of any cell may also be selected.

A graphing utility (GRAFIX) is additionally available for graphical GIS type display.

4.0 COMPARISON OF MODELS

Selection of a specific model or models, as indicated in the introduction, depends on trade-offs among a large number of factors. Not least of these factors is a predetermining one, and that is, knowledge of the functioning and applicability of the various models from which the choice is made. Some of the major factors that require consideration, and the way in which each model relates, are as below.

Purpose

The models assessed were developed for specific purposes. MUSLE was developed to provide an estimate of soil loss from a single storm event utilizing the USLE data base. GAMES was developed to facilitate direct use of the USLE on an integrated spatial basis to provide seasonal estimates of individual field soil loss and stream sedimentation. AGNPS was developed to estimate soil loss from fields, and, point and non-point source pollution arising from a single extreme event storm. CREAMS and GLEAMS were developed to assess the long term effects of best management practices on single fields taking rotations into account. SWRRB was developed to provide a prediction of sediment, nutrients and pesticides lost from ungauged rural catchments. ANSWERS was developed for detailed evaluation of the effects of differing management practices on resulting location and amount of soil loss and soil deposition.

On-farm versus Off-farm

On-farm application of a model relates to the soil loss (and loss of nutrients and pesticides) only as far as a specific field is concerned. The concern of the model is therefore restricted and related to 'agricultural sustainability' and 'economy of production'.

Off-farm relates to the effects of sediment in roadside ditches, culverts and streams and to chemicals in watercourses and in groundwater. Modelling of transport, deposition, and possibly streambank erosion for surface waters and groundwater movement are of primary concern. However, such models require input of an 'on-farm' nature, while 'on-farm' models are self-sustaining. Therefore 'off-farm' models are combination models in practice.

The MUSLE, CREAMS and GLEAMS models are specifically 'on-farm' models in that they produce output at the edge of a field and, for the latter, additionally at the bottom of the root zone. SWRRB is more of an 'off-farm' type model in terms of lumping of 'on-farm' practices into 'sub-catchment' sources, which gives 'single-use' sub-basins of uniform slope each with a channel outlet. AGNPS, GAMES and ANSWERS, by virtue of spatial considerations, address both on-farm and off-farm surface concerns. AGNPS models channel processes in considerable detail, ANSWERS routs runoff and sediment through the watershed and GAMES uses a summation process for a series of distinctly contributing field areas.

Prediction versus Research

If prediction is defined as applicability and ease of use for long term modelling on ungauged watersheds over a wide range of conditions, then this may be considered to be the ultimate aim of all of the models considered. Research, on the other hand, relates to simulation of detail for assessment of specific effects.

A test of predictability is the statistical comparison of simulated and recorded parameters of concern whereas research relates to the ability of the model to replicate detail. In prediction, peak runoff for a given recurrence interval, or number of days in which a particular chemical exceeds a given standard, are of primary concern. In research the concern is to understand the interrelationship of component processes.

The trade-off comes in terms of practicality and the general requirement that a model be rapidly and easily used on a microcomputer. The greater the detail and the longer the period simulated, the longer the model execution time. Again the greater the spatial detail or permissible variation in time effects (rotations, chemical applications, cultivations, etc.) the more complex the required data input file. Achievement in meeting the aim of rapid and easy use ranges widely. MUSLE provides a rapid and easily used prediction of soil loss for a single storm event on a field. Of the comprehensive models, SWRRB appears to be structurally most suited to prediction, followed by CREAMS and GLEAMS (which are restricted by being field models).

SWRRB is intended for use on ungauged watersheds and has the build-in capacity to generate rainfall data using a statistical package. Furthermore, data requirements are not excessive and an interactive option exists for creating SWRRB input data. For these reasons, field staff are more likely to use this type of model when compared with the data-intensive element format of AGNPS and ANSWERS. SWRRB also seems to have worked well in a variety of basins.

Each of the distributed parameter models (AGNPS, GAMES and ANSWERS) has the disadvantage that the element data file is time consuming to generate. GAMES is relatively easy to use but requires calibration for a specific catchment. AGNPS and ANSWERS are single event models, and are therefore heavily dependent on the initial conditions assumed.

None of the models can be considered 'user friendly'; however, some provision exists (mainly in SWRRB, CREAMS and GLEAMS) for file building, access of data sources and use of default values.

Table 4-1 presents a simplified categorization of the models reviewed according to their capabilities for research or predictive/planning usage.

Table 4-1. Classification of Models by Scale for Research and Planning Purposes.

	Predictive/planning	Research
On-Farm	MUSLE GLEAMS	CREAMS
Off-farm	SWRRB GAMES AGNPS	ANSWERS
Combination models	AGNPS GAMES	ANSWERS

Complexity of Watershed

CREAMS, GLEAMS, MUSLE and SWRRB require varying levels of uniformity and are not directly applicable to multiuse watersheds. However, with judicious use of weighted averages for specific situations, SWRRB may be used. In particular, much of New Brunswick is forested with patches of agricultural use, and for such catchments SWRRB may be applicable.

GAMES is unrestricted by complexity, both in level and spatial variation due to its consideration of fields. AGNPS and ANSWERS both allow for unrestricted variation, but division of a watershed into square elements does limit definition unless a very small grid size is used. AGNPS, however, has an additional limitation in that each element must outlet into a channel and therefore grid size has a practical lower bound.

Data Requirements

In Appendix A, Table A-1 provides a summary of the parameter requirements for the four watershed scale models. The input parameter requirements of CREAMS and GLEAMS are too numerous for inclusion in this tabular format. Parameters used in the CREAMS model are provided in Appendix B.

MUSLE uses the well-documented USLE data base for which considerable experience exists in New Brunswick.

SWRRB utilizes a USA soil data base and, at least for areas of New Brunswick close to Maine, the correspondence between Maine and New Brunswick soils is well known. Given this data base, SWRRB should be reasonably easy to use. CREAMS and GLEAMS require large data bases for which some defaults could be used.

ANSWERS data base is very time consuming, but not difficult to generate in terms of element descriptions. Modelling parameters, however, require calibration for individual events.

As for ANSWERS, input file generation for the other two distributed parameter models (GAMES and AGNPS) file generation requires considerable time. This is not a major problem in a research sense, since once generated the file is then available for a specific catchment. However, for a once only prediction use this is a considerable drawback.

Chemicals

The original versions of AGNPS, CREAMS and GLEAMS all model chemical movement, while GAMES, SWRRB, MUSLE and ANSWERS do not model chemicals.

AGNPS models N, P and COD in surface only flow, CREAMS models N, P and pesticides in surface flow, while GLEAMS models N, P and pesticides on the surface as well as in and from the root zone. A later version of GAMES (GAMESP) added a surface P components. SWRRBWQ has added components to model N, P and pesticides. ANSWERS Version 9301, which is in the testing and review stage of development, has also included a capacity to model and N and P surface transport.

Subsurface

GLEAMS has detailed modelling of water and chemicals (N, P and pesticides) within and from the bottom of the root zone. CREAMS, SWRRB (on a sub-basin scale), and ANSWERS (on an element scale) model water loss from the bottom of a subsurface zone. AGNPS, MUSLE and GAMES have no subsurface routines.

Forested Catchments

None of the models specifically addresses forestry concerns. GLEAMS is the only model which has a specific forestry component. However, forested areas are assigned SCS curve numbers and in practice forested areas are generally modelled as a variation of cropped lands.

Winter Effects

In the literature, the significance of snowmelt to the erosion process is not well documented. Where winter effects are included in the models they tend for the most part to be treated in a simple manner. SWRRB includes estimation of soil freezing (and therefore decrease in soil infiltration and transmission by layer) as well as snow accumulation and melt based on a single daily temperature value. CREAMS and GLEAMS do not include soil freezing but model snow as in SWRRB. GAMES does not directly consider winter effects, but indirectly recommends differing soil erodibility values based on season. MUSLE similarly could be considered to have a seasonally varied soil erodibility value. ANSWERS has no winter routines, although snow accumulation and melt routines based on air temperature are included in COSSEM. The developmental WEPP model (not discussed in this study) does have a very detailed winter effect capacity.

5.0 LINKAGES WITH GEOGRAPHIC INFORMATION SYSTEMS (GIS) AND GROUNDWATER MODELS

5.1 GIS and NPS Pollution Models

Most GIS use one of two fundamental map representation techniques: vector and raster.

1) **vector based** - With vector representation, the boundaries or the course of the features are defined by a series of points that, when joined with straight lines, form a graphic representation of the feature - for example, the outline of a field. Points are encoded with X and Y coordinates. Attributes of the features are stored in a conventional database file.

2) **raster based** - With raster systems the graphic representation of the features and the attributes they possess are merged into unified data files. The study area is subdivided into a fine mesh of grid cells in which is recorded the condition or attribute of the earth's surface at that point.

Each of these data management formats lend themselves well to the spatial information requirements of distributed parameter, watershed scale, NPS models. Most GIS systems have a capability to convert data from one format to another. Nevertheless, it is logical that the data files of the grid based models such as ANSWERS and AGNPS are inherently transferable to a raster based GIS while the data files of the polygon based models of GAMES and SWRRB are most readily transferable to a vector based GIS.

ANSWERS, SWRRB and AGNPS have been linked to GIS to facilitate management and graphic presentation of input and output files (personal communications). GAMES is presently being linked to a GIS (Dickenson, T., personal communications).

5.2 Groundwater models and NPS models

Numerous NPS models exist for assessing the potential for groundwater contamination. For example, many models have been developed for assessing the potential for pesticides to leach to the groundwater regime, such as LP/LI (Laskowski et al. 1982), DRASTIC (Aller et al. 1985), GUS (Gustafson 1989) and CDFA (Wilkerson and Kim 1986). Other NPS models exist for assessing groundwater contamination from nitrates. Ghadiri and Rose (1992) identify two subsurface models, PRZM (Carsel et al., 1985) and SESOIL (Bonazountas and Wagner, 1984) that would appear to be linked to surface hydrology. "PZRM is a compartmental model, with a chemical submodel including plant uptake of solute, transport by surface runoff and erosion, solute decay, retardation, and transformation, as well as transport by dispersion." "SESOIL is a compartmental model aimed at predicting solute distribution in both the soil profile and watershed on a seasonal basis." However, although these models do include a surface runoff and erosion component, they do so to determine only the amount of water that should be removed from that available for infiltration. Furthermore, these models are classified as point source models (Crowe, personal communication).

Very little work appears to have been done on linking NPS models to groundwater models. Essentially all of the current models that do contain such a linkage, focus on one of these components with the other component being handled with a relatively simple model. The main reason for the general lack of a comprehensive linkage is the considerable difference in the time scale for simulating overland flow and subsurface flow, and associated solute transport (Crowe, Ibid).

6.0 LITERATURE REVIEW

The following brief literature review is derived from a search of the AGRICOLA Index for publications on the studied models with particular relevance to conditions in New Brunswick or of an evaluating or comparative nature. Additionally, an extensive review of NPS models conducted by Ghadiri and Rose (1992) entitled Modeling Chemical Transport in Soils: natural and applied contaminants was also consulted.

GAMES

Ghadiri and Rose (1992) assessed that the GAMES model requires a relatively limited amount of readily available data and in this respect has advantages over other distributed parameter models.

In the opinion of Ghadiri and Rose, the model's approach provides a logical tool for watershed soil erosion and sediment control planning.

With regard to sediment delivery Dickenson et al. (1986) found that the variability in the delivery ratio is pronounced in steep slope/low roughness zones. This would have particular relevance on bare potato areas in the pre-planting spring season in northwestern New Brunswick, implying that particular attention be given to the accurate determination of this parameter.

ANSWERS

Ghadiri and Rose (1992) concluded that the primary strength of the model arises from the use of a distributed method of analysis, which can account for a real distribution of many relevant factors. Its weaknesses were deemed to be (1) its need for a large computer to simulate large watersheds, (2) the complexity of the data file necessary to describe the watershed, and (3) the assumptions that zero sediment transport by subsurface flow, negligible channel erosion, and similar energy requirement of original and previously detached sediment.

CREAMS

Ghadiri and Rose (1992) concluded that CREAMS "is comprehensive, powerful and well documented... and is essentially suitable for making relative comparisons of pollutant loads from alternative management practices." They found the major drawbacks to be its complexity, intensive data requirements and its reliance on modified USLE relationships and parameters. This degree of empiricism, they concluded, makes it useful for planning purposes and immediate application to field conditions, but limits its use for research in the physical processes causing erosion.

Knisel et al. (1985) found the comparison between observed and simulated runoff without calibration to be generally good except in areas where snowmelt is a significant part of annual runoff.

Rudra et al. (1985) applied CREAMS to the semi-humid and winter freezing environments in southern Ontario under a variety of plant cover and soil conditions and found that the overall performance of the model was unsatisfactory.

GLEAMS

Knisel et al. (1991) found that calibration of the GLEAMS model was not required where snowmelt and frozen ground are not factors. No studies have been published to suggest that calibration is required for these conditions but the model's authors suggest that it would be required.

SWRRB

SWRRB was classified by Ghadiri and Rose (1992) in a limited class of models which account for the agronomic productivity impacts of soil erosion.

General

Bingner et al. (1992) evaluated the runoff and erosion predicting capability of several erosion models (CREAMS, SWRRB, EPIC, ANSWERS, and AGNPS) on an upland watershed (3-8% slope), a flatland watershed (0.2%) and a terraced watershed under a range of rainfall events. ANSWERS and AGNPS, event based models, were modified to run continuously for a given year. The study found that only CREAMS and SWRRB were successful in predicting annual average runoff and sediment yield within 20% of measured amounts from the upland watershed. Only SWRRB and AGNPS were successful to within 20% in prediction for the flatland watershed. None of the models predicted within 20% of the measured amounts from the terraced watershed. The 20% criteria is considered, by experience, to indicate a very accurate model. In all cases, errors were greatest for the larger storms.

7.0 RELEVANT CONDITIONS IN NEW BRUNSWICK

New Brunswick is one of the provinces most seriously affected by water induced soil erosion in Canada (Coote et al. 1986). Intensive potato production on steep, highly erodible soils in the northwest "Potato Belt" is the primary source of sediment and associated pollutants in the province. Over half of the potential agricultural land in this region, including the counties of Carleton, Madawaska and Victoria, has a slope of 5 percent or greater (Stewart 1976, in Coote et al. 1986). Sheet and rill erosion under conventional potato production has been estimated to be approximately 20 t/ha/yr. Furthermore, the use of chemical fertilizers and pesticides is generally deemed to be essential for economic crop production. Due to deteriorating soil quality, Chow et al. have suggested that the application of these inputs is increasing in this geographic region.

Erosion concerns are considerably less in other cultivated areas of the province due to a more diversified, livestock-based agriculture. In these areas the greatest source of potential pollutants to surface and groundwater resources is manure storage and application. Other characteristics of agroecosystems in New Brunswick which are relevant to the consideration of appropriate NPS models include the intermix of agriculture with the predominantly forested landscape of the province, a generally rolling topography, the frequent presence of a less permeable hardpan layer in the soil profile, relatively small field size, and steep slopes modified by terracing.

7.1 Availability of Data

The question of applicability (accuracy) of a given model to New Brunswick conditions can only be assessed through testing against recorded data. The following sources of potentially data have been identified:

-One intensively monitored watershed exists in New Brunswick as a result of the Black Brook Experimental Watershed project located north of Grand Falls in Madawaska County. Although the data being collected from this site is considered to be reasonably comprehensive, the installation is recent and only a year of data is presently available for model validation.

-A series of runoff and erosion monitoring plots, also located in the Grand Falls area, have been in operation for approximately ten years.

-Outside of the above mentioned projects, meteorological data are available through Environment Canada's observing network.

-Environment Canada has been collecting suspended sediment data on the Kennebecasis River in southeastern New Brunswick since 1966.

-Soil Conservation Service curve (SCS) number data and other parametric data required for use with the USLE and other US government funded models such as CREAMS/GLEAMS are available for the State of Maine and could be assessed for their applicability to New Brunswick conditions.

8.0 DISCUSSION AND RECOMMENDATIONS

8.1 Discussion

Each of the models contain some desirable aspects, but all lack in one or more components. Each has a particular strength for a specific application, but none can be regarded as a 'global' model. The selection of a specific model therefore depends on the problem and the resources available for its application.

An important aspect, which it is not possible to address, is the applicability (accuracy) of each of the models under New Brunswick conditions. It therefore has been assumed throughout this report that each model is capable of giving unbiased estimates. However, this is not an unreasonable assumption, assuming that the specific model is properly calibrated.

If the requirement is for on-farm assessment of best management practices in a specific field then either CREAMS (surface effects) or GLEAMS (for additional subsurface chemical effects) should be used. If off-farm chemical effects from point and non-point sources from a specific event are important then only AGNPS is applicable. SWRRB provides a relatively quick estimate of integrated daily runoff, nutrients, soil loss and pesticides and soil loss from up to 10 differing sub-basins. MUSLE provides a rapid estimate of soil loss from field for a specific storm event, assuming runoff is known or estimated by some other method. GAMES provides a seasonal estimate of soil loss on specific fields, taking spatial effects into account and has the advantage of direct use of the well-tested and well-known USLE. ANSWERS facilitates detailed investigation of the response of a catchment to a given rainfall event. None of the models directly addresses forestry concerns.

Each model therefore potentially has certain advantages and certain disadvantages. The question of applicability to New Brunswick conditions, however, can only be assessed through testing against recorded data. To this end, additional monitoring facilities should be set up to cover other ecological conditions and regions in New Brunswick. In particular, forested catchments should be monitored.

8.2 Options

Monitoring and modelling of watersheds is both difficult and expensive. On the monitoring side a large number of variables need to be recorded with the most relevant data occurring during the most adverse conditions of storms, spring snowmelt, etc. On the modelling side no single model is universal in the sense of covering the range of rapid and simple prediction through to detailed research. Current data which can be used to evaluate models in New Brunswick is sparse. Possible options are:

Option 1. Set up additional watershed monitoring sites covering two or three specific ecosystems of applicability in New Brunswick. Concurrent with the setting up of these new sites, an hydrologist/computer programmer type engineer should be hired to oversee installation and later maintenance, and to model all the catchments using existing models.

Since the location and nature of, say, three sites, would have to be decided, and can 8have a major affect on costs, cost data is presented below as a more easily-definable new and independent single site, followed later by a speculative estimate for two new sites in addition to the existing site at the Black Brook Watershed.

(i) Estimated Costs for a Single New Monitoring Site

Approximate costs for a new and independent single watershed monitoring station with year-round monitoring are:

a) Capital (in one time $)

Flume (construction and installation)	15,000
Instrumentation hut	2,500
Datalogger, 2 DSPs, field unit, reader and eraser	7,000
486 Microcomputer plus software	6,000
Well to groundwater table with level recorder and sampling	7,500
Flume stage recorder	1,500
Flume sediment sampler	5,000
2 Rain/snowgauges	3,000

Miscellaneous sensors (air and soil temperature, soil moisture, radiation)	2,000
Miscellaneous supplies	3,000
Set-up labour (2 person-months)	5,000
Data formatting software (2 person-months)	5,000
Sediment analysis equipment (vacuum pump, glassware, oven, balance)	7,000
TOTAL	69,500

b) Operating (in $ per year)

Labour to service (1 person-day/week)	6,000
Travel to site (est. 100 km/week)	1,600
Electricity for heating	500
Repairs and replacement	2,500
Downloading, formatting and storage of data (0.5 person-day/week)	3,000
Sample analysis for sediment (0.5 person-day/week)	3,000
Laboratory supplies for sediment	400
Office miscellaneous	1,000
Chemical analyses (external lab)	5,000
TOTAL per year	$23,000

Obviously the above total costs can vary considerably, depending on whether the project is in-house or is contracted out; distance from the office/laboratory to the site; the number of watershed monitoring stations set up in a given location; whether an AES weather station is located sufficiently close by; what level of software exits for data formatting; and, the degree of detail of the monitoring program, including number and type of chemical analyses and sampling.

(ii) Estimated Costs for Three Sites

Based on the above costs for a single monitored catchment, the estimated cost for the recommended two new sites, assuming servicing from one location (for three sites including the Black Brook Watershed), two monitoring stations at each site and a complement of one professional and one technician (again excluding the cost of office and laboratory space) is estimated as:

a) Capital (one time only)	187,000
b) Operating	
(i) Technician full time	30,000
(ii) Professional full time	45,000
(iii) Part-time, casual and professional	15,000
(iv) Travel (assuming 1000km/wk, and project vehicle)	8,000
(v) Office and lab. supplies	17,000
(vi) Chemical analyses	30,000
TOTAL per year	$145,000

If the work is to include modification to existing models, it is recommended that this be done through specific contracts with universities in the region.

Option 2. Evaluate selected models using available data (historical as well as current) with no new monitoring sites and no modification of the models. Costs are estimated below assuming contracting out; testing of all selected models investigated in this report; and access of all relevant available data by the contractor.

Labour, professional (50 days @ $ 500/day)	25,000
Labour, assistant, professional (0.5 man-year)	17,500
Travel, site visitations	6,000

Office supplies	1,500
Report preparation	500
Miscellaneous (@ 10% of above total	5,000
TOTAL	$ 55,500

General Comments

Obviously a number of scenarios exist other than Options 1 and 2 which were selected as reasonable extremes. In view of the dominance of forested catchments in New Brunswick, and the lack of data from such catchments, it is recommended that at least one well-instrumented forested catchment monitoring site be set up, and that additional models specific to forest hydrology be evaluated.

8.3 Recommendations

It is recommended that:

1. Option 2, as discussed above (testing of SWRRB, CREAM/GLEAMS, AGNPS and ANSWERS models with currently available data) be exercised immediately. Should this course of action be followed, it is recommended that the professional assistant be hired on short term contract to work with the contractor and thereby gain experience with each model, and with data availability and relevance in New Brunswick. This would provide the option of trained continuity to some aspect of Option 1, if this course of action is later followed.

2. The CREAMS (daily rainfall option) model be validated using the soil erosion plot data from the Grand Falls area. This could lead to acceptance of GLEAMS as a field erosion (including effects of BMPs) and, surface as well as sub-root zone chemicals model, if CREAMS hydrology and erosion components prove acceptable.

3. SWRRB be validated against recorded catchment data for as wide a range of catchments as possible in New Brunswick for potential use as a predictor model for runoff and soil, nutrient and pesticide loss on ungauged catchments.

4. ANSWERS be used as a basis for research purposes on the Black Brook catchments (and any other monitored catchments which may be set up) with provision to modify the model as deemed beneficial. Such modifications could add aspects of the winter components in SWRRB, stream processes in AGNPS, and chemical processes in GLEAMS for spatial linkage to groundwater models. However, although this is a desirable course of action, it is strongly emphasized that this would be a long-term and difficult undertaking requiring considerable highly qualified labour. Such additions would also considerably slow down model execution time.

5. At least one model devoted specifically to non-point source forest hydrology be acquired and evaluated.

6. GAMES be tested using Black Brook data.

7. Field rainfall simulator tests be conducted on the dominant soils, and particularly on soils for which no close counterpart exists in Maine.

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APPENDIX A

Model parameters for SWRRB, ANSWERS, AGNPS and GAMES.

SWRRB ANSWERS AGNPS GAMES

	SWRRB	ANSWERS	AGNPS	GAMES
GENERAL				
TITLE	YES	YES		
SEASON				SEASON
NUMBER OF CELLS				NCL
TOTAL WATERSHED SEDIMENT LOADING				REFERO
CLIBRATED A				XA
WATERSHED AREA	DA			RWAREA
YEARS OF SIMULATION	NBYR			
BIGINNING YEAR	IYR			
LATITUDE OF WATERSHED	YLT			
RANDOM NUMBER GENERATOR CODE	IGN			
CALCULATION CODE				CODE
PRINT CODE	IPD			
K SELECTION CODE				K
C SELCTION CODE				IC
0			YES	IDRAIN
ASPECT			YES	
************************************				
RAINFALL DATA				
RAINFALL INPUT CODE	NSIM			
RAINFALL CORRECTION FACTOR	RF			
SEASONAL RAINFALL EROSION INDEX				SRAIN
NO. GAUGES USED		YES		
STROM IDENTIFIER		YES		
TIME/INTENSITY EVENT		YES		
DAILY RAINFALL	OPTIONAL			
*********************************				
SOIL INFORMATION				
NUMBER SOIL TYPES	NSO			
SOIL SERIES TYPE	MS			
NUMBER SOIL LAYERS	NS1			
BULK DENSITY	BD			
AVAILABLE WATER CAPACITY	AWC			
CLAY CONTENT	CLA			
% PASSING #200 SIEVE	SIL			
SAND CONTENT	SAN			

SWRRB ANSWERS AGNPS GAMES

	SWRRB	ANSWERS	AGNPS	GAMES
SATURATED CONDUCTIVITY	SC			
WILTING CONTENT MOISTURE CONTENT	WP			
TOTAL POROSITY	POR	TP		
FIELD CAPACITY		FP		
INITIAL FIELD CAPACITY	FFC			
STEADY STATE INFILTRATION RATE		FC		
DIFFERENCE BETWEEN SS ANS MAX INFILTRATION		A		
EXPONENT IN INFILTRATION EQUATION		P		
INFILTRATION CONTROL ZONE DEPTH		DF		
ANTECEDENT SOIL MOISTURE		ASM		
USLE "K"		K		
SCS SOIL CLASSIFICATION				ISOIL
SOIL TEXTURE			YES	
SOIL ALBEDO	SALB			
LAND USE AND SURFACE CONDITION INFORMATION				
LAND USE MANAGEMENT		CROP		
POTENTIAL INTERCEPTION VOUME		PIT		
% OF SURFACE COVERED BY LAND USE		PER		
ROUGHNESS COEFFICIENT		RC		
MAX ROUGHNESS HEIGHT		HU		
MANNING'S N VALUE	CHN		MANNINGS'S ROUGHNESS COEFFICIENT	RN(I)
CHANNEL "N"	CHNN			
RELATIVE EROSIVENESS		C		
LAND SLOPE			YES	
SLOPE SHAPE FACTOR			YES	
FIELD SLOPE LENGHT			YES	
SCS CROPPING FACTOR				ICROP
CURVE NUMBER	CN2		YES	
USLE EROSION CONTROL PRACTICE	EP			
************************				
CHANNEL DESCRIPTIONS				
WIDTH	CHW1	WIDTH		
ROUGHNESS COEFF.		ROUGHNESS COEFF		
LENGHT OF FLOW PATH	CHL			XLEN
SLOPE OF FLOW PATH	CHS		YES	SLO

SWRRB ANSWERS AGNPS GAMES

	SWRRB	ANSWERS	AGNPS	GAMES.
CHANNEL SIDESLOPE			YES	
HYDRAULIC CONDUCTIVITY OF MAIN CHANNEL	CHK1			
HYDRAULIC CONDUCTIVITY	CHK			
HYDRAULIC CONDUCTIVITY	CHK2			
RETURN FLOW TRAVEL TIME	RT			
SEDIMENT CONCENTRATION IN RETURN	CSS			
BASEFLOW FACTOR	BFF			
BASIN LAG TIME	BRT			
AVERAGE CHANNEL DEPTH	CHD			
AVARAGE CHANNEL WIDTH	CHW2			
CHANNEL SLOW	CHSS			
******************************				
INDIVIDUAL ELEMNET INFORMATION				
SUBBASIN AREA FRACTION	FLU			
OUTLET ELEMENT		YES		
NUMBER OF CELL (I)			YES	NUM
ROW NUMBER		YES		
COLUMN NUMBER		YES		
AREA OF CELL				AREA
SLOPE STEEPNESS		YES		
DIRECTION OF STEEPEST SLOPE		YES		
CHANNEL SIZE CATEGORY		YES		
SOIL ERODIBILITY FACTOR			YES	RK(I)
CROPPING FACTOR			YES	RC(I)
PRACTICE FACTOR			YES	
USLE SOIL FACTOR	CHXK			
USLE CROP MANAGEMENT FACTOR	CHC			
SURFACE CONDITION CONSTANT			YES	
BMP ID NUMBER		YES		
FIRST BMP DESCRIPTOR		YES		
SECOND BMP DESCRIPTOR		YES		
MEAN ELEVATION OF ELEMENT		YES		
X CENTROID	XIJ			
Y CENTROID	YIJ			
FERTILIZATION LEVEL			YES	
FERTILIZER AVAILABILITY FACTOR			YES	

	SWRRB	ANSWERS	AGNPS	GAMES
POINT SOURCE IDENIFICATION			YES	
GULLY SOURCE LEVEL			YES	
CHEMICAL OXYGEN DEMAND			YES	
IMPOUNDMENT FACTOR			YES	
**********************************				
WEATHER INFORMATION				
TEMPERATURE INPUT CODE	MSIM			
MINIMUM TEMPERATURE	OBMN			
MAXIMUM TEMPERATURE	OBMX			
COEFF. VARIATION FOR TEMERATURE	CVT			
10-YEAR 0.5 HR RIANFALL	TP5			
10-YEAR 6H RAINFALL	TP6			
NO. YEARS FOR MAX.MON. 0.5H RAIN	TP24			
MON. MAX. 0.5H RAINFALL	WI			
PROBABILITY OF WET AFTER DRY DAY	PRW1			
PROBABILITY OF WET AFTER WET	PRW2			
AVERAGE MONTHLY SOLAR RADIATION	OBSL			
WATER CONTENT OF SNOW AT START	SNO			
**********************************				
POND DATA				
FRACTION OF BASIN FLOWING INTO POND	FP			
POND AREA	SAX			
FILL VOLUME	VMX			
INITIAL POND VOLUME	VM			
INITIAL SEDIMENT	CS			
NORMAL SEDIMENT	CFP			
POND HYDRAULIC CONDUCTIVITY	HC			
RESERVOIR DATA				
INITIAL SEDIMENT	CSR			
NORMAL SEDIMENT	CFR			
RESERVOIR HYDRAULIC CONDUCTIVITY	HCR			
*****************************				
CROP DATA				
PLANTING.DATA	IPL			
HARVEST DATE	IHV			
TILAGE PRACTICE	ITIL			
C FACTOR FOR EROSION	CVA			

	SWRRB	ANSWERS	AGNPS	GAMES
MAX. LEAF AREA INDEX	BLAI			
******************************				
IRRIGATION DATA				
IRRIGATION CODE	IRR			
WATER STRESS LEVEL TO START IRRIGATION	WSF			
IRRIGATION RUNOFF RATIO	EFI			

APPENDIX B

Model parameters for CREAMS.

Hydrology model parameters

Parameter	Model option	Reference/definition	Source of estimate	Quality
DACRE	Both	Field area in acres.	Measurable	Good.
RC	Both	Saturated hydraulic conductivity, in/hr (K_s in equation I-9).	Estimate from SCS soil class; or measure, infiltrometer or in lab.	Poor to good; sensitive.
FUL	Both	Portion of plant-available water storage filled at field capacity.	Estimate or from reference.	Well defined quantity.
BST	Both	Portion of plant-available water storage filled when simulation begins.	Field measure or estimate.	Not sensitive.
CONA	Both	Soil evaporation parameter, a_s (eq. I-43).	Estimate from handbook.	Fair.
POROS	Both	ϕ, soil porosity (eq. I-8).	Estimate or measure.	Not sensitive.
BR15	Both	Immobile soil water content.	Estimate or measure, or from (1).	Not sensitive.
TEMP()	Both	Average monthly temperature (read values) °F.	Climatological data	Good, but only average.
RADI()	Both	Average monthly net radiation (read 12 values) langleys/day.	Climatological data	Good, but only average.
GR	Both	Winter cover factor (1 for crops, 0.5 for grass.)	Crop information	Rough.
X(I)	Both	Leaf area index, day I [must specify X(1) and X(366)].	Crop information handbook (table II-8).	Good.
SIA	1	Initial abstraction coefficient CN method (eq. I-2).	Use 0.2s in absence of measured value (5).	Fair.
CHS	1	Channel slope (CS in eq. I-7).	Field measurement	Good.
CN2	1	SCS curve number for AMC condition II.	Handbook; soils data.	Fair.
WLW	1	Watershed length/width ratio.	Watershed map	Good.
UL(1-7)	1	Plant-available water storage in 7 soil layers, in inches.	Difference between total soil porosity and 15 bar water content.	Fair to good.
DS	2	Depth of surface soil layer.	User estimate	Varies; subjective.
DP	2	Depth of root soil zone	Knowledge of soil; rooting depth.	Fair.
GA	2	G in equation I-16. Effective capillary tension.	Soil data; infiltrometer tests.	Fair to good.
RMN	2	Manning roughness for field surface (C_c in eq. I-30).	Handbooks; field observation.	Good; subjective.
SLOPE	2	Average field slope (S_c in eq. I-36).	Maps; field survey.	Good.
XLP	2	Length of flow plane (L in eq. I-36). ;	Maps; field survey.	Good.

Erosion model parameters, definitions, and sources and quality of estimates

Parameter	Definition	Source of estimate	Quality of Estimate
ν	Kinematic viscosity	Handbook	Excellent. However, only parameter expressing temperature effect. Quality for expressing that effect unknown.
n_{bov}	Manning's n for overland flow over bare smooth soil (fine seedbed).	Model manual	Good but subjective.
n_{bch}	Manning's n for channel flow over bare, smooth soil (fine seedbed).	Model manual	Good but subjective.
ρ_{soil}	Weight density of soil mass.	Soil survey and experience.	Good.
K_{rch}	Soil erodibility factor for channel erosion.	Model manual	Poor. May require calibration.
C_{yal}	Constant in Yalin sediment transport equation.	Model manual	Good. Supposedly fixed, but may require calibration.
Sand, silt, clay.	Primary particle distribution of original soil mass.	Soil survey, soil tests experience.	Very good.
Particle characteristics.	Particle size class and density of particle.	Model manual and soil survey information or calculated from model equations using primary clay, silt and sand.	Good for most midwestern silt loam soils; unknown for most other soils.
λ_{ov}	Overland flow slope length.	Maps, soil survey, field observation.	Good, but problem of choosing representative length.
$\bar{S}$	Average overland flow slope steepness.	Maps, soil survey, field observation.	Good, but problem of choosing representative length.
S_b	Slope at beginning of overland flow profile.	Maps, soil survey field observation.	Good, but problem of choosing representative steepness.
S_m	Slope at middle of overland flow profile.	Maps, soil survey, field observation.	Good, but problem of choosing representative steepness.
S_e	Slope at end of overland flow profile.	Maps, soil survey, field observation.	Good, but problem of choosing representative steepness.
x_3, y_3 x_4, y_4	Coordinates of mid-uniform slope section.	Maps, soil survey, field observation.	Good, but problem of choosing representative section.
A_{ov}	Overland flow area	Map	Very good.
K	Soil erodibility factor (rill-interrill erosion).	Model manual; also USLE Handbook.	Good, based on extensive plot data.
C	Cover-management factor (rill-interrill erosion).	Model manual; also USLE Handbook.	Good, based on extensive plot data.
P	Contouring factor (rill-interrill erosion).	Model manual; also USLE Handbook.	Poor; value poorly defined for individual storms.
n_{cov}	Manning's n for overland flow over a covered soil surface.	Model manual	Good, but subjective.

Erosion model parameters, definitions, and sources and quality of estimates--continued

Parameter	Definition	Source of estimate	Quality of Estimate
Shape	Channel shape	Experience and field observation.	Good, but subjective.
λ_{ch}	Channel length	Map, field observation.	Good, but can be quite subjective.
A_{chup}	Drainage area draining into upper end of channel.	Map	Very good.
A_{chlo}	Area drained by channel	Map	Very good.
Outlet control.	Outlet control parameters including channel width, sideslope, longitudinal slope, Manning's n, rating curve.	Experience, field observation, model manual.	Poor and highly subjective.
Slope	Slope along channel	Map, field observation.	Very good.
n_{ch}	Manning's n for channel with cover.	Model manual, handbooks provided; n_{bch} selected from same handbook.	Good, but subjective.
τ_{cr}	Critical shear stress which erosion begins in channel.	Model manual, experience.	Poor, values not known for many agricultural soils and management effects not known.
τ_{cov}	Critical shear stress for cover breakup.	Model manual, experience.	Fair for nonincorporated residue, poor for incorporated.
d_{ne}	Depth to nonerodible layer in channel.	Model manual, experience, field observation.	Fair, but subjective.
d_{side}	Depth to nonerodible layer at side of channel.	Model manual, experience, field observation.	Poor and highly subjective.
w_{ch}	Channel width	Model manual, field observation photo.	Fair.
Z	Channel sideslope	Model manual, field observation map.	Fair to good.
F_s, B	Coefficients for pond surface area vs depth intake rate.	Field survey model manual, map	Excellent with field survey, good with other means of estimating.
i	Intake rate	Soil survey, experience.	Good.
d_{or}	Diameter of orifice in outlet pipe.	Design notes, field observation experience.	Excellent or good if based on experience.
A_{pd}	Drainage area above pond.	Map	Excellent.

Nutrient model parameters

Parameter	Definition	Source of estimate	Quality of estimate	
SOILN	Soil nitrogen	Soil survey data; lab analysis; literature.	± 40% ± 20% ± 100%	Good for sampled soil series.
SOILP	Soil phosphorus	Soil survey data; lab analysis; literature.	± 40% ± 20% ± 100%	Dependent upon sampling scheme for unsurveyed soils.
EXKN	Extraction coefficient for nitrogen.	Analysis of runoff data; literature.	± 100% ± 300%	Do.
EXKP	Extraction coefficient for phosphorus.	Analysis of runoff data; literature.	± 100% ± 300%	Do.
AN	Enrichment coefficient for nitrogen.	Analysis of erosion data; literature.	± 30% ± 300%	Do.
BN	Enrichment exponent for nitrogen.	Analysis of erosion data; literature.	± 30% ± 300%	Do.
AP	Enrichment coefficient for phosphorus.	Analysis of erosion data; literature.	± 30% ± 300%	Do.
BP	Enrichment exponent for phosphorus.	Analysis of erosion data; literature.	± 30% ± 300%	Do.
FC	Field capacity	Soil survey data; lab studies.	± 30% ± 15%	Excellent for point samples; fair to poor for variability in space.
POR	Porosity	Soil survey data; lab studies.	± 30% ± 15%	Do.
POTM	Potential mineralization for nitrogen.	Lab analysis; literature.	± 20% ± 100%	Do.
RCN	Concentration of nitrogen in rainfall.	Lab analysis; literature.	± 10% ± 100%	Do.
RZMAX	Maximum depth of root zone.	Field study; soil survey.	± 20% ± 100%	Good for cultivated crops; poor for weeds, rangelands.
DOM	Date of miduptake	Local information; general information.	± 15% ± 30%	Generally not available on a local basis.
SD	Standard deviation of uptake.	Local information; general information.	± 15% ± 30%	Do.
PU	Potential nitrogen uptake.	Local information; general information.	± 15% ± 30%	Do.
YP	Yield potential	Local information; general information.	± 15% ± 30%	Occasionally available locally.
C_1; C_2; C_3; C_4	Plant nitrogen uptake coefficients.	Manual		Good for crops measured.

Inputs and parameters for pesticide submodel

Parameter	Definition	Source of estimate	Quality of estimate[1]
R,[2] ARATE[3]	Pesticide application rate.	Recommendations on label, farm records, table II-40.	Good, but may vary depending on application equipment and operator care.
ID, DEPINC.	Depth of pesticide incorporation.	Application recommendation, experience.	Good, but may vary depending on soil conditions.
EF, EFFINC.	Efficiency factor for incorporation.	Measurement, experience.	Fair to good, depending on soil conditions.
FF, FOLFRC.	Fraction on foliage	Model manual, experience, observations.	Fair to good, depending on source of estimate.
SF, SOLFRC.	Fraction on soil	Model manual, experience, observations.	Fair to good, depending on source of estimate.
FOLRES	Initial foliar residue	Experience, measurement.	Unknown, depends on source of estimate.
SOLRES	Initial soil residue	Measurement, inferred from past management and pesticide persistence.	Good if measured; poor if inferred.
WSHFRC	Fraction of foliar pesticide washed off.	Model manual, literature.	Good for limited number of pesticides; fair to unknown for others.
THRWSH	Rainfall threshold for washoff.	Judgment based on canopy.	Probably fair, subjective.
H2OSOL	Pesticide solubility in water.	Handbooks, table II-40, and table II-41.	Good to excellent for most pesticides.
$C_{1/2}$, HAFLIF.	Foliar pesticide half-life.	Model manual, literature, measurement.	Fair to Good for limited pesticides, but is site- and condition-specific.
k_s, DECAY.	Dissipation rate from soil surface.	Model manual, literature, measurement.	Fair to good, but site- and condition-specific, estimates from bulk soil. Measurements often underestimate.
B, EXTRCT.	Extraction ratio, ratio of soil:water in mixing zone.	Model manual	Fair based on model performance, but subjective.
K_d, KD.	Distribution coefficient.	Model manual, literature, measurement.	Fair to good, but laboratory value may poorly describe field behavior.

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[1] Excellent - known to be within few percent; Good - errors of 50% possible; Fair - error by factor of 2 possible; Poor - error by factor in excess of 2 possible.

[2] Notation used in documentation.

[3] Notation used in computer program.

Inputs and parameters for pesticide submodel

Parameter	Definition	Source of estimate	Quality of estimate[1]
R,[2] ARATE[3]	Pesticide application rate.	Recommendations on label, farm records, table II-40.	Good, but may vary depending on application equipment and operator care.
ID, DEPINC.	Depth of pesticide incorporation.	Application recommendation, experience.	Good, but may vary depending on soil conditions.
EF, EFFINC.	Efficiency factor for incorporation.	Measurement, experience.	Fair to good, depending on soil conditions.
FF, FOLFRC.	Fraction on foliage	Model manual, experience, observations.	Fair to good, depending on source of estimate.
SF, SOLFRC.	Fraction on soil	Model manual, experience, observations.	Fair to good, depending on source of estimate.
FOLRES	Initial foliar residue	Experience, measurement.	Unknown, depends on source of estimate.
SOLRES	Initial soil residue	Measurement, inferred from past management and pesticide persistence.	Good if measured; poor if inferred.
WSHFRC	Fraction of foliar pesticide washed off.	Model manual, literature.	Good for limited number of pesticides; fair to unknown for others.
THRWSH	Rainfall threshold for washoff.	Judgment based on canopy.	Probably fair, subjective.
H2OSOL	Pesticide solubility in water.	Handbooks, table II-40, and table II-41.	Good to excellent for most pesticides.
$C_{1/2}$, HAFLIF.	Foliar pesticide half-life.	Model manual, literature, measurement.	Fair to Good for limited pesticides, but is site- and condition-specific.
k_s, DECAY.	Dissipation rate from soil surface.	Model manual, literature, measurement.	Fair to good, but site- and condition-specific, estimates from bulk soil. Measurements often underestimate.
B, EXTRCT.	Extraction ratio, ratio of soil:water in mixing zone.	Model manual	Fair based on model performance, but subjective.
K_d, KD.	Distribution coefficient.	Model manual, literature, measurement.	Fair to good, but laboratory value may poorly describe field behavior.

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[1] Excellent - known to be within few percent; Good - errors of 50% possible; Fair - error by factor of 2 possible; Poor - error by factor in excess of 2 possible.

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