# Review of Nutrient Loading and Soil Erosion Models and Validation of the Nutrient Loading Model (NLM) for Phosphorus

**For**

## Manitoba Livestock Manure Management Initiative
## and
## Agriculture Research and Development Initiative

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**Report and validation by**

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**NLM model developed jointly by**

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# EXECUTIVE SUMMARY

With the increase in the livestock industry in Manitoba, there is more manure that must be managed in an environmentally acceptable manner. Nutrient content of the manure and its addition to land is one of the aspects that needs to be managed. For nitrogen (N), the issue is more or less resolved by ensuring the N addition matches the crop requirements, so that on average there is little or no residual environmentally important (soluble) N. For phosphorus (P), the issue is not as simple because crops cannot in a single season remove all the environmentally important P. The reason is that the P sorbs strongly to soil particles, and the environmental importance comes to a large extent from erosion. The Nutrient Loading Model (NLM) was designed to be a tool that a regulator could use to set P loading limits (P fertilization or manure-loading limits) based on the effect of P on stream water quality. Phase 1 of the project (1999-2000) developed the model. Phase 2, described here, considered improvements to the model, benchmarked the model against other models available for this purpose, and validated the model.

The benchmarking process involved comparison of the capabilities of 7 models to that of the NLM. These models varied from complex research-level models with far too many parameters for practical application, to simple look-up tables in use now for regulatory purpose. In general, these other models were not readily useable with available data and did not have attributes that were important to add to the NLM.

The validation of the NLM was the major undertaking. It was not possible to conduct experiments or measurements within this project, so the emphasis was to identify existing data and programs in Manitoba that met the requirements. There are quite a few programs in Manitoba related to stream quality. The drawback is that they are conducted by a number of agencies with differing mandates and differing abilities to consistently measure the important parameters. Four case studies were selected. These included reaches of the Whitemouth River, Joubert Creek, the Seine River and the west watershed of the South Tobacco Creek. The river reaches were about 10-km long, so there were many crops and landscape features included. The reaches were chosen to be predominantly through crop land, but there were inevitably other sources of P to the river, such as leaching from overhanging vegetation. In all cases, drawing the required information from the available data required assumptions and some interpolation. Also, no calibration for each river reach was carried out, this created an unbiased test. For better results, the NLM could be calibrated before application and there is data to do this for the Whitemouth River, Joubert Creek as well as the South Tobacco Creek watersheds. Given these uncertainties, the results of the NLM for the rainfall events considered agreed reasonably well with the validation data (see table below).

**Comparison of observed loss of P from all sources in specific reaches of a river with those estimated with the model from runoff of fields in wheat, canola and alfalfa.**

| Outcome | Observed | Model (Wheat) | Model (Canola) | Model (Alfalfa) |
|---|---|---|---|---|
| **Whitemouth River** | | | | |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 254 | 180 | 260 | 17 |
| **Joubert Creek** | | | | |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 100 to 440 | 180 | 260 | 17 |
| **Seine River** | | | | |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 590 | 350 | 500 | 32 |
| **South Tobacco watershed** | | | | |
| Particulate P loss (kg per event) | 0.377 | 0.362 | - | - |

There are many ways the NLM could be implemented in a management, guidelines or regulatory role. It was envisioned to be a tool for a regulator, where an upper-limit application rate of P to soils is determined based on the concentration of P in the receiving water. This application probably needs to be quite generic with respect to watershed characteristics. For example, it would not be fair to impose guidelines on a farmer in the lower regions of the watershed that are different from those for a farmer in the upper regions. Several alternative application modes are suggested, one of which is the concept of a water parcel. This water parcel is the water contributed by a unit of land to the total drainage effluent of a watershed, and it contains the P eroded (or leached) from that unit of land. This concept is for an annual average water and P loss, on the assumption that the appropriate integration time is a year. The P in this parcel of water may be subject to some fluvial processes such as sedimentation, but ultimately it is this P concentration that may, for example, impact the North Basin of Lake Winnipeg. It is proposed that the NLM is ready now for such an application.

# INTRODUCTION

ECOMatters has undertaken the development of a rudimentary landscape model to reflect farm settings in Manitoba, with the ability to predict environmental consequences of fertilizer P and manure applications (ECOMatters 2001). The final report of Phase 1 described the development of the ECOMatters Nutrient Loading Model (NLM). The NLM is in a Microsoft EXCEL computer platform using Visual Basic macros. The model describes the erosion and leaching of phosphorus (P) and nitrate from topsoil of a landscape surface into a nearby water body, including P and nitrate loss from surface soil fertilizer and manure application through root uptake and crop removal. Two environmental compartments, (topsoil and subsurface) are connected to a third water body compartment, and nutrients leached and eroded from the first compartments are discharged into the water body in two scenarios:

- a single-event scenario from a single rainfall or snowmelt event, and
- a yearly average scenario.

This Phase 1 work was jointly funded by the Manitoba Livestock Manure Management Initiative, the Agricultural Research Development Initiative and ECOMatters Inc. (ECOMatters 2000).

The performance of the NLM was sufficiently promising in both its concept and development that a second project (Phase 2) was launched in 2001-2002 to review the model's capability, compare details of the NLM model with other models already developed (e.g., AGNPS – Agricultural Non-Point Source pollution model, WEPP – Water Erosion Prediction model, etc.), identify potential shortcomings in the NLM and decide on the path forward. The path forward was either: 1) to adopt a "better" publically available model (if one was deemed suitable for the objective of describing P loading), or 2) fine-tune the NLM with improvements deemed useful from other models. Whichever path forward was chosen, the remaining project task was to validate[1] the chosen model for Manitoba climate and soil conditions.

The report objectives are to document the steps taken to develop and validate the NLM, or an alternative, for use in Manitoba. The report contains the following major subject areas:

- ✓ Review of models that predict soil erosion and agricultural P loss to streams,
- ✓ Recommendations for future soil model development (NLM or other),
- ✓ Sensitivity analysis of the chosen model,
- ✓ Data acquisition for model validation,

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[1] 'Validate' has a specific meaning in the context of model development, and entails the comparison of model estimates with independent observational data.

- ✓ Model validation, and
- ✓ Recommendations for future work and applications.

These subjects are presented in full below. In order to make the main body of the report more readable, a significant amount of the detailed information is presented in the Appendices.

## MODEL REVIEW

This first task of model review, although briefly carried out in 1999, was to entail a more detailed review of models in use currently, such as the Phosphorus Suitability Index, PSI, model now being used in the State of Maryland for agricultural P regulation. Maryland was the first state in the U.S.A. to regulate P and this regulation was introduced in 2001. Further details of several models that have the same purpose as the NLM are described below. The objective of this description is to point out how the models are useful in the context of regulating P (and possibly N) and how they are superior or inferior to the NLM for this purpose. Since the NLM model is generally more transparent and user-friendly than many of the others, it is possible that the best outcome is to add "useful" functions found in the other models to the NLM and to continue its development.

For each model, the most complete up-to-date information was acquired and the documentation reviewed for comparative features with the NLM, with careful attention to whether it would better fulfill the objectives set out for the NLM in 1999. The detailed review of each model is presented in Appendix A and a summary of all the models with respect to the NLM is given below.

### Model Review Summary

We focused on the major models used and being developed in North America. The models reviewed in detail were:

- ➢ PSI
- ➢ Opus
- ➢ EPIC
- ➢ SWAT
- ➢ EROSION_2D
- ➢ AGNPS
- ➢ TOOLKIT
- ➢ WEPP

The **Phosphorus Site Index (PSI)** model is a much simpler model; it predicts the susceptibility for erosion but does not quantify either erosional soil losses or P losses. The PSI doesn't compare with the NLM which estimates actual P losses for specific soils, crop systems and landscape positions.

**Opus** includes a higher level of sophistication in some aspects than the NLM, such as the simulation of plant growth and temperature effects for plant production and snowmelt. More sophisticated models offer a closer approximation to the real world; however, they introduce the need for more parameter values and this introduces further uncertainties. It is not evident that Opus offers a better alternative to assisting the land management of manure than does the NLM. Some aspects of Opus could be used to improve the NLM, primarily: the conceptual view of the system and possibly the use of the weather generator to produce future annual trends based on historic weather data.

The **EPIC** model has useful aspects for the NLM, in particular, it may be useful to more fully describe the P cycle, differentiating between all forms of P.

In comparison to our NLM model, **SWAT** would only be comparable to the long-term P loading losses as no event calculations are made in SWAT. The emphasis on the development of SWAT is for the simulation of larger watersheds with multiple basins and reservoirs. The in-stream nutrient water quality equations in SWAT are taken from QUAL2E – The Enhanced Stream Water Quality Model (Brown and Barnwell 1987). SWAT offers no new concepts to the models that are of most importance to nutrient loading modelling.

**EROSION_2D** offers no P cycling or loading to the water body. It deals only with erosion and sediment transport on the basis of single erosion events, not the long-term annual average. The NLM, as it is, is more useful than EROSION_2D. Correspondence from Jim Kinney in Wisconsin indicates the Natural Resource Conservation Service will adopt the SWAT model and supporting routines for use as their TOOLKIT.

**AGNPS** has two aspects that could serve as improvements to the NLM, the GEM weather generator routine (similar to that of Opus) and additional output related to sediment delivery by specifying the particle-size classes output to the stream through the HUSLE model.

Bhuyan et al. 2002 has compared the three models **WEPP**, EPIC and ANSWERS on the basis of individual event, total yearly and mean event-based soil loss predictions and all models were within range of the observed values. The overall results showed that WEPP predictions were the best. Although a lot of effort has gone into developing WEPP as a superior tool for calculating soil erosion effects, it does not deal with water quality degradation due to the addition of agronomic P, either as a manure or a chemical fertilizer. Nor does it calculate the stream water quality for a flowing or stagnant water body as does the NLM. The WEPP model does not appear to have any aspects that could be directly utilized to improve the NLM.

No models really do what the NLM does, nor are they as transparent as the NLM. An additional and distinct advantage of the NLM model is that it can be modified in Manitoba to reflect Manitoba conditions and meet regulatory needs in Manitoba. Many of the other models are ‘canned’, preventing adaptation to specific applications.

## PREVIOUS RECOMMENDATIONS FOR MODEL DEVELOPMENT AND IMPROVEMENT

The path forward was either: 1) to adopt a "better" publically available model (if one was deemed suitable for the objective of describing P loading), or 2) fine-tune the NLM with improvements deemed useful from other models. It was decided that further development of the NLM was the preferred route. The other models have several limitations with respect to complexity and data requirements.

Comment by independent researchers during Phase 1, and the detailed review of other nutrient loading and erosion models, raised some issues that should be addressed in Phase 2. The NLM was thought to benefit from the addition of all or some of these improvements. In some cases, the NLM included the process or function described; however, it fulfilled this through a different method. In other cases, the feature was incorporated.

We made changes to the original model to improve it and these are briefly discussed in Appendix B. The most notable of these was the mating of the EXCEL model to CrystalBall to achieve a probabilistic approach and the ability to have correlations between variables that influence each other, such as relating high stream flow with high rainfall.

## SENSITIVITY ANALYSIS

In order to better evaluate which variables and parameter values were the most important to the predictive capability of the NLM, it was appropriate to carry out a sensitivity analysis[2]. This will direct effort more efficiently in further development of the model as well as guide research on those parameter values that need to be carefully assigned for the model to be useful. It is also a useful tool in calibration[3] of the model, if that is desired, for key Manitoba river systems.

There are a large number of input parameters to the model. To conduct a sensitivity analysis, it was decided to utilize a Monte Carlo simulation[4] software package "Crystal Ball" to perform stochastic multivariate simulations of event scenarios. The Crystal Ball (CB) software essentially takes control of the EXCEL spreadsheet model and allows various assumptions to be made about the potential variation in each input parameter. The results are a series of forecast (output) parameter values. One of the strengths of the

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[2] 'Sensitivity analysis' in the context of model development entails a systematic investigation of the variation in predicted outcomes in response to specific variations in input parameter values.

[3] 'Calibration' in the context of model development implies the adjustment of input and other model parameters so that the predicted outcomes more closely match a specific modeling case. For the NLM, one might calibrate the model for a watershed in order to predict more accurately future events.

[4] 'Monte Carlo simulation' is a method of model application where multiple input parameter parameters are varied randomly, within their probability density distributions, in a large number of simulations so that their correlation to the predicted outcomes can be evaluated over multiple cases.

Monte Carlo approach and the CB software is the ability to conduct sensitivity analyses to rank the effect of variations of input variables on the output.

The input parameters for the NLM are presented in Table 1 along with the default input values defined in the model. The available data for Manitoba rivers were analyzed to determine bounding ranges for each of the model input parameters. This ensured that the model was tested over an appropriate range of river and drainage way conditions. Ranges were derived for the parameters in blue in Table 1, while the other input parameters were held constant at the default value for the sensitivity analysis. Each input variable was assigned a normal or lognormal distribution, depending on its anticipated characteristics, and a mean and standard deviation. If considered necessary, the probability distribution function for a parameter was truncated to the observed range. The input assumptions, ranges, mean, standard deviations and probability distribution functions as used by the CB version of the NLM are documented in Appendix C.

Output (forecast) values chosen for the sensitivity analysis were:

**Single Event Scenario:**

| | |
|---|---|
| Soil Eroded | - amount of soil eroded during the storm (t ha$^{-1}$) |
| P Loss | - loss of P as erosive flushing rate at storm end (kg P h$^{-1}$) |
| Stream P | - stream concentration for flushing event, fast water (mg P L$^{-1}$) |
| Water Contamination | - water body P concentration, slow water (mg P L$^{-1}$) |
| Amount Eroded | - amount of soil eroded (t ha$^{-1}$) |
| Final Soil Concentration | - final soil concentration in (kg m$^{-3}$) |

**Yearly Average Scenario:**

| | |
|---|---|
| Soil Eroded | - total amount of soil eroded in one year (t ha$^{-1}$) |
| Release Max to Water | - maximum yearly release rate to water body (kg P a$^{-1}$) |
| Topsoil Concentration | - final soil concentration (mg kg$^{-1}$) |

The CB program was then run with 2000 simulations or cases, which was a sufficient number to obtain statistically stable results. On completion of a 2000-simulation run, the CB software produced a series of sensitivity plots for each output parameter. The overall sensitivity of the forecast to each assumption is a combination of the model sensitivity of the forecast to the assumption and the assumption's uncertainty. The forecast sensitivity output charts are also presented in Appendix C. These charts can be used to determine which assumptions are:

- influencing forecasts the most – allowing identification of the parameters that need the highest level of confidence, and
- influencing forecasts the least – allowing identification of parameters whose variability could potentially be ignored and a constant used instead.

These results should facilitate calibration of the model, if necessary, as the effect of a parameter assumption is known.

## Sensitivity Analysis Results

The complete output of the CB input parameter sensitivity analyses is presented in Appendix C. These data are summarized in Table 2, where the most sensitive parameters are ranked on the rank correlation coefficients and normalized to 100% for a specific output value. The sensitivity can be either positive (increase in input value increases output value) or negative (increase in input value decreases output value). Input parameters whose sensitivity contribution was <0.1% are not presented in Table 2. Parameters contributing >10% are bolded and shaded and parameters contributing from 1% to 10% are lightly shaded. The input parameters that produce the highest sensitivity in the output values are Slope %, Crop Management Factor, Rain Intensity, Extraction Efficiency of $NaHCO_3$ as % and Soil Test P concentration.

No specific model improvements can be made to alter the importance of these parameters. It is clear that these parameter values need to be measured and specified for the field and series of fields along a waterway for good model prediction. With this in mind, we proceeded to test the model on selected waterways in Manitoba relevant to the needs of MLMMI and ARDI.

## Table 1: Input parameters and their variability as employed in the sensitivity analysis

| Input Parameters | Default | Range | Mean | Std. Dev. | Dist.* |
|---|---|---|---|---|---|
| **Single Event Scenario** | | | | | |
| rainfall intensity (mm/hr) | 6 | 1 – 25 | 12 | 4 | N |
| duration of storm (hours) | 3 | 1 – 21 | 10 | 3 | N |
| max 30 minute rainfall rate (mm/hr) | 4.5 | | | | |
| length of the slope (m) | 100 | 1500 – 1850 | 1675 | 60 | N |
| percent slope (%) | 1.6 | 0.1 – 10.0 | 2.0 | 1.5 | LN |
| erodibility factor K (t•h•(MJ)$^{-1}$•mm$^{-1}$) | 0.021 | 0.01 – 0.05 | 0.03 | 0.01 | N |
| cropping management factor P | 1 | 0.01 – 0.4 | 0.2 | 0.1 | N |
| erosion control practice factor | 1 | | | | |
| soil test P level (kg/ha in $NaHCO_3$ input as $P_2O_5$) | 15 | 25 – 175 | 100 | 25 | N |
| extraction efficiency of $NaHCO_3$ (%) | 1.2 | 0.2 – 10 | 5 | 1.6 | N |
| yearly deposition per unit area (kg $P_2O_5$/ha) | 35 | 20 – 50 | 35 | 5 | N |
| distribution coefficient of contaminant[5]; Kd (L/kg) | 6500 | 16,000-75,000 | 38,000 | 11,000 | LN |
| volumetric stream flow rate (m$^3$/s) | 0.1 | 0.1 – 100 | 55 | 15 | N |
| thickness of deposition mixing layer (m) | 0.2 | | | | |
| volume of the water body (m$^3$) | 100 | | | | |
| width of the field (m) | 100 | 150 – 1500 | 800 | 210 | N |
| bulk density of the soil (kg m-$^3$) | 1500 | 1200 – 1600 | 1400 | 65 | N |
| porosity of the soil (volume per volume) | 0.48 | 0.4 – 0.6 | 0.5 | 0.04 | N |
| moisture fraction of topsoil before the storm (volume/volume) | 0.18 | 0.15 – 0.4 | 0.27 | 0.04 | N |
| saturated hydraulic conductivity of soil (cm/s) | 0.01 | 1E-05 – 0.1 | 0.01 | 0.01 | LN |
| **Yearly Event Scenario** | | | | | |
| yearly rainfall erosivity index for the field (MJ•mm•ha$^{-1}$•h$^{-1}$) | 832 | 604 – 2000 | 1000 | 300 | N |
| fraction of the year over which rainfall occurs | 0.5 | 0.3 – 0.7 | 0.5 | 0.06 | N |
| total yearly amount of rainfall infiltrating soil (m) | 0.526 | 0.2 – 0.9 | 0.53 | 0.1 | N |
| yearly average moisture fraction of topsoil | 0.22 | 0.1 – 0.4 | 0.22 | 0.04 | N |
| crop harvested yield (kg ha$^{-1}$) | 2000 | 1632 – 6352 | 4000 | 800 | N |
| P concentration in harvested crop (% P not $P_2O_5$) | 0.6 | 0.1 – 2 | 1 | 0.3 | N |
| depth topsoil accessible to roots for crop loss (m) | 0.5 | 0.2 – 0.5 | 0.35 | 0.05 | N |
| average density of suspended particles in water body (kg m$^{-3}$) | 2650 | | | | |
| geometric mean suspended particle diameter (m) | 6.20E-05 | | | | |
| concentration of suspended particles (kg m$^{-3}$) | 1.50E-01 | | | | |
| average depth of the water body (m) | 0.5 | | | | |

* Dist. refers to N – normal or LN – lognormal probability density distribution.

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[5] 'Contaminant' is used as a general term in the NLM, because the NLM can deal with materials other than P. In this report, contaminant refers only to P.

**Table 2: CB Sensitivity analysis (rank %) of input variables on the single event and yearly average output variables**

| **Input Variable** | **Single Event** | | | | | | **Yearly Average** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Soil Eroded** | **P Loss** | **Stream P** | **Water Contam** | **Amount Eroded** | **Final Soil P** | **Soil Eroded** | **Release Max Water** | **Topsoil Conc** |
| **Slope %** | **47** | **41** | **40** | **39** | **39** | | **57** | **42** | |
| **Crop Mgmt Factor** | **23** | **21** | **20** | **20** | **20** | | **30** | **23** | |
| **Rain intensity** | **18** | **13** | **13** | **14** | **14** | | | | |
| Extract Eff. | | 8 | 8 | 8 | 8 | **60** | | 9 | **60** |
| Soil Test P | | 5 | 5 | 5 | 5 | **39** | | 7 | **39** |
| Storm Duration | 8 | | | 5 | 5 | | | 0.3 | |
| Field Width | | 6 | 6 | 5 | 5 | | | 7 | |
| Erodability Factor K | 4 | 3 | 4 | 3 | 3 | | 6 | 4 | |
| Rain Erosivity | | | | | | | 6 | 4 | |
| Stream Flow Rate | | | 5 | | | 0.3 | | | 0.3 |
| Rain Yearly Frac. | | | | | | | | 1 | |
| P Crop % | 0.3 | | 0.2 | | | | 0.2 | | |
| Soil Porosity | 0.2 | | | | | | | | |
| Bulk Soil Density | | | | | | | | | 0.6 |
| Crop Yield | | | | | | 0.2 | | | 0.2 |
| P Kd | | | | | | | 0.5 | 0.2 | |
| Saturated Conductivity | | | | | | | | 0.2 | |
| Slope Length | | | | | | | | 0.2 | |

# MODEL VALIDATION

The next step in model evaluation is the test of the model predictions versus observed data. Test scenarios were identified for the NLM: these scenarios had to fulfill specific criteria to be appropriate for model validation purposes. Some of these criteria, not in any particular order, are:

1. Is the watershed primarily agricultural with no major point source (sewage from small town or large commercial/industrial facility) nearby?
2. Does the stream water-quality data show elevated P loading?
3. Are the stream characteristics known – is it nearly stagnant or moving, are depth, width, flow-rate, dissolved- and particulate-P and suspended solids concentrations known?
4. Is ancillary data available, such as crop type and yields, fertilizer or manure application rates?
5. Is there good quality meteorological data such as locally measured daily rainfall and/or rainfall intensity?
6. Is there good soil texture and field size data?
7. Is there data available for various types of single events within the same watershed?

There are various aspects of the model that can be chosen for validation. In the first phase of this project, we emphasized long-term sustainability and the buildup of soil P with time from various application rates under varying conditions of crop, soil and P application. There are very few or no sites where long-term validation is possible. In this phase, we concentrate on the stream water quality and the loss of soil and P from agricultural land to the nearby water body by erosive events.

Finding and acquiring good quality data is the most significant task in the validation of a model, and this required substantial effort. First, a reconnaissance of several ongoing projects was made to see if any of these projects were able to provide historic or current data. The result of this effort is presented fully in Appendix D.

### Analysis of Manitoba Conservation stream water quality data

Analysis of data from Joubert Creek, the Rat River and the Whitemouth River showed some interesting trends in total and dissolved P in relation to other measured parameters. These trends were considered important to evaluate in Manitoba waterways before undertaking the model validation. Data obtained from Manitoba Conservation and Manitoba Agriculture were thoroughly analyzed, as well as the water gauging information for Manitoba rivers. It was a challenge to find river and stream flow data that corresponded with the water quality information.

Stream P can be in several forms, notably dissolved, particulate (associated with mineral particles such as clay in suspension), and organic (associated with organic colloids in suspension). The NLM models P movement to the stream in both dissolved and particulate forms, but inevitably there is a larger contribution from particulate P. A first question is what portion of P in the river is particulate.

A relatively limited subset of data for Joubert Creek allowed for the comparison of total dissolved P[6] with total P[7]. This showed a 1:1 linear relationship (Figure 1), suggesting that most of the total P was as dissolved P at the time of sampling. This might suggest that particle erosion had little to do with stream P concentration. However, at those time periods, total P concentrations were relatively low and total suspended solids were also low, or were not available (perhaps not detectable). Thus, the background, between-storm stream P may be dissolved, and storm event P may still be as particulate P. Other time periods for Joubert Creek had data for total P and total suspended solids (dissolved P was not reported), and for these there was some indication that higher values of total P were associated with higher values of total suspended solids (Figure 2). This suggests that during erosion events that generated higher loads of suspended solids, total P concentrations were also higher and this may mean that during erosion there was more particulate P present. A similar trend is shown by data from the Rat River (Figure 3). Since Joubert Creek area soils are silt loam (Emerson Soil Series) and Loamy sand (Pine Ridge), some subsurface transport of soluble P may be occurring. Probably more importantly, much of the Creek is overhung by vegetation, and throughfall (P and organic acids leached from leaves into the Creek by rainfall) and litter fall (vegetation falling directly into the Creek) may account for much of the P loading between rainfall events.

The only other data for both total P and dissolved P was for a few samples on the Whitemouth River in about 1992. The two measures of P were linearly related, but not 1:1. The dissolved P ranged from 35 to 81% of the total P. Again, when these data were available coincided with times of relatively low total suspended solids. The relationship of total P and total suspended solids (Figure 4) was similar to the Joubert Creek data.

For the Whitemouth River, there was also an opportunity to compare total P, ortho P[8] and total suspended solids. The ratio of ortho P to total P is an indication of the dissolved/total P ratio. Plotting the ortho P to total P ratio versus total suspended solids for the Whitemouth River (Figure 5) clearly shows that when there is more suspended solid, less of the total P is present as ortho P. This suggests that more of the total P is particulate, again evidence that during erosion events there is more particulate P in the river. Although this may seem obvious, it is an important point for the NLM because although it does compute the contribution of soluble P to the river, this is small compared to the erosion/runoff-related P.

Water quality data is also available for the Seine River and there is good quality streamflow data to combine with this. Rainfall data collected at St. Pierre-Jolys could

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[6] Dissolved P is operationally defined based on filtration, with P that passes a filter and is then converted to ortho P (the species analysed) by acid digestion is designated as dissolved P.

[7] Total P is operationally defined as that P measured on an unfiltered sample after an acid digestion of the sample to release particulate and colloidal P to the measurable species.

[8] Ortho P is the chemical species that is measured, and when reported for river water data it is the P measured directly on an unfiltered sample, there is no acid digestion step so the reported ortho P excludes some particulate and colloidal P that might be in the water sample.

suffice for the Rat and Seine Rivers as well as Joubert Creek. South Tobacco Creek streamflow data collected in 1994 to 1996 for one site and 1994 to 2001 for the second site by Manitoba Conservation will add to the data for South Tobacco Creek already located in public documents to allow model validation.

## Validation of the NLM Event Model

The compilation of data for events was reasonably straightforward. It was not straightforward for annual P loss. As will be described, there was on average no change or even a downstream decrease in total P between sites on the Whitemouth River. This implies no net continuous P contribution. The NLM estimated a very low annual P contribution for the Whitemouth River, but this case was not considered a useful validation. In Joubert Creek, the water flow was not recorded in winter, and late-season flow appeared to be well less than 10% of the spring flow. The P flux to the Joubert appeared to vary at least 250-fold from month to month in the ice-free season, and was confounded by an undefined source of P that was not related to erosion (we speculate it is from vegetation overhanging the Creek). As a result, the annual contribution of P to Joubert Creek was low and very uncertain. There was a similar problem with the Seine. As a result, there was no opportunity to validate the NLM for annual P loss. There is another argument which supports the event-based estimates as the most useful for P management, and this is discussed further below.

## Selected Validation Cases

### Whitemouth River

The Whitemouth River has been the subject of study by the Whitemouth-Reynolds Soil and Water Conservation Association with the assistance of Manitoba Agriculture and Food, PFRA and Manitoba Conservation since 2001. This current study allows ancillary data to be easily obtained. Further, good water-flow monitoring data are available from Manitoba Conservation as well as soil test P data, both surface and with depth, P concentrations in several different manure types, and crop and soil management information.

Water samples were collected 13 times from April to October in 2001 with two samples collected through the ice early in 2002. There were four collection locations along the Whitemouth River representing an overall 'snapshot' of the river.

Site 1: Whitemouth River at Seven Sisters
Site 2: Whitemouth River at Whitemouth
Site 3: Whitemouth River at PTH #506
Site 4: Whitemouth River near PTH #503 south of TransCanada Highway

Samples were analyzed for a number of water quality characteristics that represented general chemistry, nutrients, and bacteria. In general, the averaged results for 2001 showed no significant accumulative impacts of nutrients; however, the total P concentration in the river is at or above the P guideline of 0.05 mg P $L^{-1}$ (Manitoba Water Quality Standards, Objectives, and Guidelines, Draft 2000) (Figure 6). Commonly, rivers in agricultural areas exhibit an accumulation of materials (mostly nutrients) as flow begins in the upper portion of the watershed, and moves downstream through the lower reaches of the river. Concentrations of P and nitrogen (N) in the Whitemouth River remained relatively constant from the most upstream site (just south of TransCanada Hwy) to the most downstream site (at Seven Sisters). An additional site at Kellner Drain (#5), between stations #2 and #3 was added in 2002. This Figure shows no particularly strong point source within the watershed; however, station #3 (town of Whitemouth) does show elevated P concentrations with respect to station #2 (town of Elma). These two points offer a test case.

Nutrient concentrations tend to increase as the summer progresses and this trend is also evident in the Whitemouth River (Figure 7). This is fairly common in rivers as conditions of the open water season progress from the copious water during spring melt water through to the drier summer conditions.

Precipitation records have been kept at Seven Sisters by Leon Clegg, a Conservation Association volunteer, and these provide useful local data, especially for the extreme events of July 16 and July 27-28 in 2001 where over 78 mm of rain fell.

Similarly, the Whitemouth Reynolds Soil and Water Conservation Association have carried out manure and soil testing and recorded previous crop history on these soils. Brent Reid, the agriculture representative, confirmed crop yield data and has given guidance on major crop types and crop rotations in this area.

An input file was prepared summarizing all of the data in the correct units. This required some interpretation of the landscape. Determinations included: slope of the fields next to the river, and which fields probably contribute to soil loss and which fields may have been buffered by forest, shrub or a perennial crop. Also necessary was an interpretation of the field or frontage width and the slope or field length.

In order to understand the dimensions of the fields and how and if they were connected to the Whitemouth River, we acquired the aerial photos of the section of the river from south of Elma (Station #3) to Whitemouth (Station #2) downstream. The air photos were assembled into a photo mosaic and on-the-ground reconnaissance confirmed which fields were the most probable to contribute to soil erosion and which fields had sufficient buffer strips of vegetation or bush to consider them non-contributors. A sample of one air photo and how the area contributed to erosion to the river is shown as Figure 8. The reconnaissance also confirmed the crops frequently grown in the area; however, it was not possible to tell which crops had been grown in each cultivated field the previous year, the model validation year. Next, characterization of the fields and their widths next to the river edge and classification as to forest/shrub or agricultural provided a guideline to calculate the potential frontage length for erosion on both sides of the river. About 50% of the river length was attributed to cropped fields, the remainder was natural continuous vegetation. The details of this calculation are shown in Appendix E. These data were then used in calculating the contribution of P from the fields to the entire river segment. The actual model was run for 100-m frontage lengths[9], and because the results scale linearly with frontage length, the total P contribution along the frontage length for the entire river segment can be computed.

As noted above (Figure 6), the total P concentrations in the Whitemouth do not tend to increase downstream, and even in the Elma to Whitemouth stretch, there is an increase in total P only at certain times (Table 3). Presumably, the lower P concentration downstream is the result of processes such as sorption of P to bed-load sediment and dilution by an influx of water at lower concentration. There is no formal tributary in this stretch of the river, but there will be a contribution of water from groundwater seepage and gullies.

**Table 3. Total P (mg L$^{-1}$) in the Whitemouth River in 2001, the event used for validation testing was on July 16, 2001, and the stretch of river considered was from the towns of Elma (upstream) to Whitemouth (downstream).**

| Sampling date | Elma | Whitemouth | Difference | Ratio |
|---|---|---|---|---|
| Apr-24 | 0.034 | 0.038 | 0.004 | 1.12 |
| May-15 | 0.036 | 0.03 | -0.006 | 0.83 |
| Jun-05 | 0.043 | 0.036 | -0.007 | 0.84 |
| Jun-19 | 0.041 | 0.049 | 0.008 | 1.20 |
| Jul-04 | 0.048 | 0.048 | 0 | 1.00 |
| Jul-17 | 0.057 | 0.049 | -0.008 | 0.86 |
| Jul-31 | 0.056 | 0.062 | 0.006 | 1.11 |
| Aug-14 | 0.07 | 0.056 | -0.014 | 0.80 |
| Aug-28 | 0.062 | 0.049 | -0.013 | 0.79 |
| Sep-11 | 0.091 | 0.064 | -0.027 | 0.70 |
| Oct-19 | 0.064 | 0.051 | -0.013 | 0.80 |
| Jan-02 | 0.053 | 0.045 | -0.008 | 0.85 |
| Feb-02 | 0.057 | 0.061 | 0.004 | 1.07 |
| average | 0.055 | 0.049 | -0.0057 | 0.92 |

During spring runoff (April 24 sampling) and after the July 27-28 event (July 31 sampling), there was an increase in total P in this stretch of river, and so the July 27-28 event was used for validation.

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[9] Frontage length is used to describe the length (m) of the field/stream interface where erosion may cause soil P to enter the stream.

**Table 4. Interpolation of P flux in the Whitemouth River after the July 16 and July 27-28 events. Measured total P are bolded, the others were linearly interpolated with time. Although the two events were each about 78 mm rain, the river flows were not markedly affected until after the second event. The difference in P flux, averaged for July 27 and 28 to give 254 mg P $s^{-1}$, was used for validation comparison.**

| Date | River flow ($m^3$ $s^{-1}$) | Elma (upstream) total P (mg $L^{-1}$) | Flux of P (mg $s^{-1}$) | Whitemouth (down-stream) total P (mg $L^{-1}$) | Flux of P (mg $s^{-1}$) | Difference in P flux (mg $s^{-1}$) |
|---|---|---|---|---|---|---|
| July 15, 2001 | 26.7 | **0.048** | 1282 | **0.048** | 1282 | 0 |
| July 16, 2001 | 30.8 | 0.0525 | 1617 | 0.0485 | 1494 | -123 |
| July 17, 2001 | 39.3 | **0.057** | 2240 | **0.049** | 1926 | -314 |
| July 18, 2001 | 44.2 | 0.057 | 2519 | 0.05 | 2210 | -309 |
| July 19, 2001 | 47.5 | 0.057 | 2708 | 0.051 | 2423 | -285 |
| July 20, 2001 | 47.1 | 0.057 | 2685 | 0.052 | 2449 | -236 |
| July 21, 2001 | 44.8 | 0.057 | 2554 | 0.053 | 2374 | -179 |
| July 22, 2001 | 41.2 | 0.057 | 2348 | 0.054 | 2225 | -124 |
| July 23, 2001 | 37.4 | 0.057 | 2132 | 0.055 | 2057 | -75 |
| July 24, 2001 | 33.2 | 0.057 | 1892 | 0.056 | 1859 | -33 |
| July 25, 2001 | 29.0 | 0.056 | 1624 | 0.057 | 1653 | 29 |
| July 26, 2001 | 25.4 | 0.056 | 1422 | 0.058 | 1473 | 51 |
| July 27, 2001 | 34.4 | 0.056 | 1926 | 0.059 | 2030 | 103 |
| July 28, 2001 | 101 | 0.056 | 5656 | 0.06 | 6060 | 404 |
| July 29, 2001 | 104 | 0.056 | 5824 | 0.061 | 6344 | 520 |
| July 30, 2001 | 89.4 | 0.056 | 5006 | 0.062 | 5543 | 536 |
| July 31, 2001 | 80.4 | **0.056** | 4502 | **0.062** | 4985 | 482 |

The important model forecast parameters are the contribution rate of soil P to the river, and the increase in water P concentration between the upstream and downstream positions (Table 4). The model predicted an increase in P flux for this stretch of the Whitemouth for the July 27-28 event of 180 mg P $s^{-1}$ if the cropped fields were all cereals, ranging to 260 mg P $s^{-1}$ for all canola/flax. The observed value (Table 4, see caption) was 254 mg P $s^{-1}$. The corresponding difference in water total P concentration was estimated by the model to be 0.0026 mg P $L^{-1}$ for all wheat to 0.0038 mg P $L^{-1}$ for all canola, and the observed difference (averaging the differences on July 27 and 28) was 0.0035 mg P $L^{-1}$. This was considered reasonably good agreement, and relatively minor adjustment in any one of a number of the input parameters would achieve an apparently perfect fit of predicted with observed.

In addition, we tabulate (Table 5) other model outputs, such as the amount of soil eroded during the storm event in tonnes (1000-kg units), and soil P lost. This information is crop-specific and we show the estimates for wheat, canola and alfalfa below. Results for barley, oats, flax and grass were also computed but are not shown because they are generally intermediate to the values shown in Table 5.

We conclude the application of the model to the Whitemouth River for 2001 successfully estimates the soil P entering the stream as a result of a major storm event, one that resulted in flooding along this part of the river. The NLM gives extra information such as soil and soil P loss that could be of use to farmers and soil and crop management advisors.

**Table 5: Whitemouth River observed and predicted soil and P loss.**

| Outcome | Observed | Model (Wheat) | Model (Canola) | Model (Alfalfa) |
|---|---|---|---|---|
| Soil loss by erosion during the storm (t or 1000-kg) | | 13 | 19 | 1 |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 254 | 180 | 260 | 17 |
| Increment in stream water P concentration (mg $L^{-1}$) | 0.0035 | 0.0026 | 0.0038 | 0.0002 |
| Amount of P eroded up to the end of the storm (kg) | | 5.2 | 7.5 | 0.5 |

* field/stream frontage length taken from air photos as 13.92 km.

### Joubert Creek

Joubert Creek and the Rat and Marsh Rivers have been the subject of a soil and nutrient loading monitoring program for a few years. Manitoba Agriculture joined with the South East Soil Conservation Organization (SESCO) to direct this work and collect ancillary data, such as rainfall in St. Pierre-Jolys. Kira Rowat and her staff, Danielle Berard and Lynne Peloquin, at St. Pierre provided this data for 2001 and 2002. Stan Banasiak of Manitoba Agriculture was also very helpful in showing us the sampling locations on Joubert Creek and the Rat, Marsh and Whitemouth Rivers.

Similar to the approach for the Whitemouth River, we acquired the stream quality and flow data and analysed this data for an upstream and downstream location as well as a location that exhibited cropping alongside the river. Our final selection was for Joubert Creek and using Joubert #2 (at the point where Joubert Creek crosses Hwy 403 between Hwys 216 and 12) as the upstream location and Joubert #1 (at St Pierre-Jolys) as the downstream location. The rainfall event of June 16, 2001 was the event chosen to simulate. One shortcoming was that the Joubert #2 site was not part of the 2001 sampling campaign for P analysis. A review of the data for 2002 (Table 6) showed that the downstream site had on average a 2.1-fold higher total P concentration than the upstream site. This ratio was used to generate data against which to compare the model. All other required data were available and appropriate for the validation.

**Table 6: Comparison of total stream P (mg $L^{-1}$) for sampling positions on Joubert Creek (Joubert #1 and #2) for sampling done in 2002. The ratios of P concentrations between the sites was considered more consistent than the absolute differences, and so downstream was considered on average to have 2.1-fold higher P concentrations than upstream.**

| Date in 2002 | Upstream (Joubert 2) | Downstream (Joubert 1) | Difference | Ratio |
|---|---|---|---|---|
| May 16 | 0.046 | 0.116 | 0.070 | 2.52 |
| June 25 | 0.217 | 0.314 | 0.097 | 1.45 |
| July 10 | 0.099 | 0.265 | 0.166 | 2.68 |
| July 25 | 0.085 | 0.164 | 0.079 | 1.93 |
| Aug 07 | 0.103 | 0.162 | 0.059 | 1.57 |
| Aug 20 | 0.085 | 0.190 | 0.105 | 2.24 |
| average | 0.106 | 0.202 | 0.096 | **2.06** |

Air photos of the Joubert Creek area were used to derive an estimate of both the length of the Creek and the frontage length of Creek bounded by agricultural cropland between the two sampling sites. Some errors will be inherent in this measurement because of the tortuousness of the Creek and the difficulty in discerning the location of the Creek in some places on the air photos because of the amount of vegetation.

**Table 7. Interpolation of P flux in Joubert Creek around the 2001 June 16 event. Measured total P are bolded, the others were interpolated. Note there was a net flux of P to the Creek even before the event, suggesting a background, non-storm contribution of 278 mg P $s^{-1}$ and consistent with the observation of most P in this Creek between events is as dissolved P. Subtracting the background flux, the event increased the difference in P flux by 100 mg P $s^{-1}$ on the day of the event to 440 mg P $s^{-1}$ on the day of peak flow (June 22) after the event.**

| Date in 2001 | River flow ($m^3$ $s^{-1}$) | Estimated upstream (mg $L^{-1}$) | Flux of P (mg $s^{-1}$) | Downstream (mg $L^{-1}$) | Flux of P (mg $s^{-1}$) | Difference in P flux (mg $s^{-1}$) |
|---|---|---|---|---|---|---|
| June 12 | 3.46 | 0.08 | 262 | **0.159** | 550 | 288 |
| June 13 | 3.17 | 0.08 | 246 | 0.163 | 517 | 271 |
| June 14 | 3.17 | 0.08 | 252 | 0.167 | 530 | 278 |
| June 15 | 3.98 | 0.08 | 325 | 0.171 | 682 | 357 |
| June 16 | 4.12 | 0.08 | 344 | 0.175 | 722 | 378 |
| June 17 | 3.48 | 0.09 | 297 | 0.179 | 624 | 327 |
| June 18 | 3.31 | 0.09 | 289 | 0.183 | 607 | 318 |
| June 19 | 4.04 | 0.09 | 361 | 0.188 | 758 | 397 |

| Date in 2001 | River flow ($m^3 s^{-1}$) | Estimated upstream ($mg L^{-1}$) | Flux of P ($mg s^{-1}$) | Downstream ($mg L^{-1}$) | Flux of P ($mg s^{-1}$) | Difference in P flux ($mg s^{-1}$) |
|---|---|---|---|---|---|---|
| June 20 | 5.04 | 0.09 | 460 | 0.192 | 966 | 506 |
| June 21 | 6.61 | 0.09 | 616 | 0.196 | 1294 | 678 |
| June 22 | 6.89 | 0.10 | 656 | 0.200 | 1377 | 721 |
| June 23 | 6.2 | 0.10 | 602 | 0.204 | 1264 | 662 |
| June 24 | 4.7 | 0.10 | 465 | 0.208 | 977 | 512 |
| June 25 | 3.56 | 0.10 | 359 | 0.212 | 755 | 395 |
| June 26 | 2.68 | 0.10 | 271 | **0.212** | 568 | 298 |

The model predicted an increase in P flux for this stretch of Joubert Creek for the June 16 event of 180 mg P $s^{-1}$ if the cropped fields were all cereals, ranging to 260 mg P $s^{-1}$ for all canola/flax. The observed value (Table 7) was from 100 mg P $s^{-1}$ on the day of the event (378 less the background of 278) to 440 mg P $s^{-1}$ (721 less 278) at the time of peak flow after the event (June 22). The corresponding difference in water total P concentration was estimated by the model to be 0.026 mg P $L^{-1}$ for all wheat to 0.038 mg P $L^{-1}$ for all canola/flax, and the observed difference (after subtracting background as above) was 0.006 mg P $L^{-1}$ on June 16 up to 0.019 mg P $L^{-1}$ on June 22. The model predictions were considered in reasonably good agreement for P flux and somewhat of an underestimate for stream P concentration. For the Whitemouth River, the estimated versus modelled values for flux and stream P concentrations differed to a similar extent, whereas for Joubert Creek the P flux data are in better agreement than are the stream P concentrations. This may reflect that Joubert Creek has 16-fold lower flow than the Whitemouth River, perhaps there is more sedimentation in the Joubert following an event than is accounted for in the NLM. As previously, relatively minor adjustment in any one of a number of the input parameters would achieve an apparently perfect fit of predicted with observed for Joubert Creek.

We tabulate the stream water P concentration comparison for the event as well as other information of interest that the model yields. Again, this information is crop-specific and we show the estimates for wheat, canola and alfalfa (Table 8). We conclude the model predicted reasonably well for this event for Joubert Creek, considering we did not have all of the required data. Measurements of rainfall intensity data for that storm – the most important parameter value to have as accurate as possible – may also have improved the estimates.

**Table 8: Joubert Creek observed and predicted soil and P loss.**

| Outcome | Observed | Model (Wheat) | Model (Canola) | Model (Alfalfa) |
|---|---|---|---|---|
| Soil loss by erosion during the storm (t or 1000-kg) | | 12 | 18 | 1.1 |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 100 to 440 | 180 | 260 | 17 |
| Increment in stream water P concentration with June 16 flow rate (mg $L^{-1}$) | 0.006 | 0.0433 | 0.0626 | 0.0040 |
| Increment in stream water P concentration with June 22 flow rate (mg $L^{-1}$) | 0.019 | 0.0259 | 0.0375 | 0.0024 |
| Amount of P eroded up to the end of the storm (kg) | | 5.2 | 7.4 | 0.5 |

* field/stream frontage length taken from air photos as 12.94 km.

### Seine River

The details of the approach for the Seine River are the same as for the previous model tests. Even less data were available for stream flow and water quality in the Seine, since no specific sampling campaign has been carried out. However, some crop and soil management information as well as recent soil test data were available for the area adjacent to the Seine River. Another feature of the Seine is that this Rural Municipality may house one of the largest animal populations of any in Manitoba.

The rainfall event in this case was a 25-mm event on May 31st, 2001, chosen in part because no river flow data is collected after the end of May each year. It is also useful as a smaller event to test the model compared to the large events considered for the Whitemouth and Joubert cases. The upstream location was near LaBroquerie where the Seine crosses Hwy 403 and the downstream location was at Ste Anne's where the Seine crosses Hwy 12. There were no stream quality data available for 2001 for the Seine River; however, there were stream flow data. This isn't exactly satisfactory, but this may be typical for the application of the NLM in Manitoba. In Table 9, the available total P concentrations for the two sites are shown, and the difference and ratio computed. Note that the total P concentrations reported for 2000 are similar to those reported in 1996, providing some support to the use of the ratios in this table to other time periods. It was assumed that the downstream total P concentrations were 1.68-fold higher than upstream.

**Table 9. Comparison of total stream P (mg L$^{-1}$) for sampling positions on the Seine River at LaBroquerie (upstream) and Ste.Anne (downstream). The ratios of P concentrations between the sites was considered more consistent than the absolute differences, and so downstream was considered on average to have 1.68-fold higher P concentrations than upstream.**

| Date | Upstream (LaBroquerie) | Downstream (Ste.Anne) | Difference | Ratio |
|---|---|---|---|---|
| Jan 22 1996 | 0.023 | 0.05 | 0.027 | 2.17 |
| Feb 20 1996 | 0.023 | 0.055 | 0.032 | 2.39 |
| Apr 16 1996 | 0.732 | 0.744 | 0.012 | 1.02 |
| Apr 23 1996 | 0.200 | 0.426 | 0.226 | 2.13 |
| Apr 30 1996 | 0.169 | 0.515 | 0.346 | 3.05 |
| May 07 1996 | 0.122 | 0.135 | 0.013 | 1.11 |
| May 14 1996 | 0.076 | 0.107 | 0.031 | 1.41 |
| May 21 1996 | 0.105 | 0.161 | 0.056 | 1.53 |
| May 28 1996 | 0.111 | 0.126 | 0.015 | 1.14 |
| Jun 04 1996 | 0.134 | 0.162 | 0.028 | 1.21 |
| Jun 12 1996 | 0.055 | 0.073 | 0.018 | 1.33 |
| Nov 09 2000 | 0.147 | | | |
| Nov 14 2000 | 0.157 | | | |
| Nov 21 2000 | 0.086 | | | |
| average | 0.153 | 0.232 | 0.073 | 1.68 |

Using the air photos of the River, an estimate was made of both its length between LaBroquerie and Ste.Anne and the frontage length of fields along both banks. Some errors will be inherent in this measurement because of the tortuousness of the River and the difficulty in discerning its location in some places on the air photos because of the amount of vegetation.

With an upstream total P concentration of 0.086 mg L$^{-1}$, the average flow rate of 10 m$^{3}$ s$^{-1}$, and the expected increase in total P at the downstream location, the P flux to the Seine was estimated to be 590 mg P s$^{-1}$. The increment in total P concentration was 0.058 mg P L$^{-1}$. The model estimate was 350 mg P s$^{-1}$ if the fields were all wheat, up to 500 mg P s$^{-1}$ for all canola/flax. The increment in total P concentration was estimated by the model to be 0.035 mg P L$^{-1}$ if the fields were all wheat, up to 0.050 mg P L$^{-1}$ for all canola/flax. Given the uncertainties in the observed values, this is reasonable agreement.

We tabulate the stream water P concentration comparison for the event as well as other information of interest that the model yields. Again, this information is crop-specific and we show the estimates for wheat, canola and alfalfa (Table 10).

**Table 10: Seine River observed and predicted soil and P loss.**

| Outcome | Observed | Model (Wheat) | Model (Canola) | Model (Alfalfa) |
|---|---|---|---|---|
| Soil loss by erosion during the storm (t or 1000-kg) |  | 25 | 37 | 2 |
| Rate of loss of P during the storm (mg P $s^{-1}$) | 590 | 350 | 500 | 32 |
| Increment in stream water P concentration (mg $L^{-1}$) | 0.058 | 0.035 | 0.050 | 0.0032 |
| Amount of P eroded up to the end of the storm (kg) |  | 10 | 14 | 0.9 |

* field/stream frontage length taken from air photos as 35.4 km.

### South Tobacco Creek

South Tobacco Creek, located in south western Manitoba, has numerous feeder streams and two major headwater branches. It also represents some of the more steeply sloping (>10%) landscapes of the southwest along the Manitoba Escarpment. The South Tobacco Creek watershed near Miami has been well-gauged and a considerable amount of information has been generated from this watershed (Green and Turner 2000; Yarotski and Miller 2000). The watershed has been divided into two nearly-equal halves, referred to as the Twin watersheds, and different soil and crop management techniques have been employed on each half to study the effects of management practices. The west half is under conventional tillage practices and the east half is under zero-till management (Figure 9). Another project was also carried out in 1999 on manure, referred to as the Manured Watershed in this study unit (Green and Turner 1999).

This validation case is quite different from the others. It is a very small, well-defined watershed and the P loss is recorded at a weir in the field as opposed to a position in a flowing river. This has the advantage that the specific field and slope conditions have been measured and can be input to the model. It is more important that the NLM be able to predict P load as delivered to or in a river, none-the-less the Twin watersheds are more like the settings in which the Universal Soil Loss Equation used in the NLM was developed.

We chose to simulate the event of May 22, 1999 when 36 mm of rain occurred. Field width, length and slope were determined from Yarotski and Miller (2000, their Figure 2-1). The outcome of interest is the total P lost during the event. Both total P and dissolved P were analysed, so in Table 11 we report total P and particulate P (total P minus dissolved P). Note that the ratio of particulate to dissolved P was different for the two watersheds. In the west watershed under conventional tillage, 86% of the P lost was particulate. In the east watershed under zero-till, only 40% of the P was particulate. This makes sense, in May the conventional till would be nearly bare soil where particles would erode. In contrast, the zero-till would have vegetation litter on the surface from which soluble or organic-colloidal P may leach. NLM does not specifically deal with leaching of P from litter. It is interesting that the total P loss was similar between the two watersheds, despite the difference in tillage practice that was intended, among other things, to reduce P loss.

**Table 11. Twin watersheds of the South Tobacco Creek study area observed and predicted P loss for the rainfall event of May 22, 1999.**

| Outcome | West watershed, conventional till | East watershed, zero till | Model |
|---|---|---|---|
| total P loss (kg per event) | 0.436 | 0.406 | |
| particulate P loss (kg per event) | 0.377 | 0.164 | 0.362 |

The model results for total P loss were quite similar to the observed total P loss, and close to the particulate P loss from the conventional till watershed. This was considered a satisfactory outcome for the validation.

## CONCLUSIONS FROM THE NLM VALIDATION

There are quite a few agencies and programs related to P loss from agricultural lands and P in streams and rivers in Manitoba. However, many of these are rather sporadic in space and time, so there are few continuous records, few complete records (complete in the sense of inputs for the NLM), and few for relevant agricultural practices. It was a major undertaking to locate and compile the available data, and there remained gaps. From another perspective, there will always be gaps in an application of the NLM, so it was appropriate to encounter them during the validation phase.

The ability of the NLM to predict P loss following specific events was compared to observations for four watersheds. The results were reasonably good, certainly they were within the range where minor adjustment or calibration of a few key input variables would result in apparently perfect predictions.

The NLM has significant potential for soil and crop management to avoid excess pollution of streams with P. Its predictive power for storm events is quite good. There is also the potential that the model could be calibrated for specific watersheds and used to better manage soil erosion, nutrient loss and consequent stream water quality degradation.

# RECOMMENDATIONS FOR FUTURE WORK WITH OR APPLICATION OF THE NLM

## Stage of Development

The NLM is appropriate for use on a broader scale. It does need some expert skills to obtain input data. It would be an excellent tool for educational purposes, because it can show the effect of size of field, slope, crop type or soil conditions. We believe anyone with some knowledge of agronomy and some basic spreadsheet skills could input the correct values, and properly utilize the NLM at its present development stage. Further visually pleasing interface aspects could be added.

## More Detailed River Model

It was evident in the validation process that the behaviour of P in flowing river systems is complex. There is 'nutrient spirally', where nutrient is absorbed by mobile entities such as phytoplankton, carried downstream, and then deposited to sediment, mineralized and then again remobilized. There are contributions of soluble P from vegetation and from exchange with bed-load sediments. There are point sources. There is dilution and dispersion. All of these can be effectively modelled, using either available software such as CORMIX, or with models developed specifically for Manitoba.

## Possible Methods of Application of the NLM

The NLM was developed to serve as a tool for setting P application limits for agricultural land for the protection of surface waters. It was envisioned that the NLM might support regulatory guidelines that would be applied on a field-by-field basis. This still leaves a great many possibilities. We describe below two possible scenarios.

### Adjacent Lands Scenario

This scenario would involve a regulatory guideline that is specific to agricultural fields adjacent to a surface water body. It would require the definition of surface water body, and this might be any body of water that has free surface water throughout the year, so that it is habitat for aquatic organisms. Adjacent could be defined as the field being within 30 m of the water body or 30 m of a gully or ditch leading directly to a water body.

### All Crop Lands Scenario

This scenario would involve a regulatory guideline that is for all agricultural fields, regardless of proximity to surface-water bodies. This is perhaps more fair among farmers, and also recognizes that all surface drainage eventually reaches a permanent water body, so that most fields contribute to surface waters.

### Water Parcel Concept

In the Adjacent Lands Scenario, and especially in the All Crop Lands Scenario, there is difficulty in defining in a generic way the volume of water into which the runoff P would be diluted. This is possible for a specific site, as done in the validation, but is problematic in a more generic use such as for regulatory guidelines. The volume (or rate of flow) of the receiving water will vary, and it would seem unfair to propose different guidelines on different farmers based on their location on the water course and the contributions of upstream sources. Additionally, it is not clear if it is eutrophication in a ditch, a major river or the upper basin of Lake Manitoba that should be the endpoint to be protected.

An alternative is to consider each field a source of both P and water. Indeed, the water body receives water from all fields in the watershed, some rapidly by surface runoff and some slowly by subsurface drainage. In general, only the water that is evapotranspired from the field does not ultimately reach the stream. We propose that the volume of water not evapotranspired is the appropriate dilution volume for the P lost from the field. This makes the resulting guideline independent of field position in the watershed, and should give accurate water P concentrations on the basis of a whole-watershed annual average.

We call this concept the ‘water parcel’ concept because it implies the P from a specific field is diluted by the water from that field (on an annual average), and this parcel of water should be judged for ecological impact independent of the watershed hydrology. It can be envisioned that the parcel of water moves downstream, towards Hudson’s Bay, and has the same potential to cause eutrophification at any point in its progress. This is an important step toward development of a generically applicable guideline.

The calculation of the volume (or rate of flow) of water from a field is not in the NLM model. It is available from stream flow data in Manitoba. As described, the volume of water is the fraction of total annual precipitation that does not evapotranspire. In general, this will be about 0.1 to 0.3 $m^3$ $m^{-2}$ in Manitoba, less than half of the annual precipitation. The total annual water flow for a watershed ($m^3$) divided by the area of the watershed ($m^2$) is the required number. It may vary somewhat with soil type and with land use, but probably not more than about threefold. Thus there is probably a relatively generic value that could be applied to cropland. It is proposed this be an empirical input parameter to the guideline development process.

To implement the water parcel concept, the NLM would be used to estimate the P flux from the field, and this would be divided by the water contribution from the field. The resulting concentration would be compared to a surface water quality objective, and the crop management plan rated accordingly. This could be devolved to the level of a look-up, or could be more interactive in the form of a web-enabled model.

Although this concept addresses a regulatory need, there are conceptual difficulties with it because it is well-known that the timing of P release from a unit of land will differ from the timing of water release. In the near term and close to the field, the relative timing is critical and the water concentration that can lead to eutrophication is closely dependent on the water available to dilute the P as it leaves the field. Further in time and further from the field, there is an integration of P and water releases with time so that, for example, in the North Basin of Lake Winnipeg, the water parcel concept more closely resembles reality.

### Mass balance concept

Another concept, that follows the adjacent lands approach, is to base limits of P application to cropland on a watershed mass balance. If the water P concentration limit is established, and the annual flow rate of a watershed is known, then the product of the two is the allowable export of P from the watershed. This can then be attributed back to the various sources in the watershed in some analytical manner. For example, some portion might be attributed to point sources such as water treatment plants, another portion to natural sources such as headwater wetlands and stream-bank vegetation, and the remainder apportioned among the fields used for crop land. The NLM would be useful for this apportionment, and a detailed river model would be useful for the point and natural sources.

**Figure 1: Joubert Creek data of total P versus total dissolved P.**

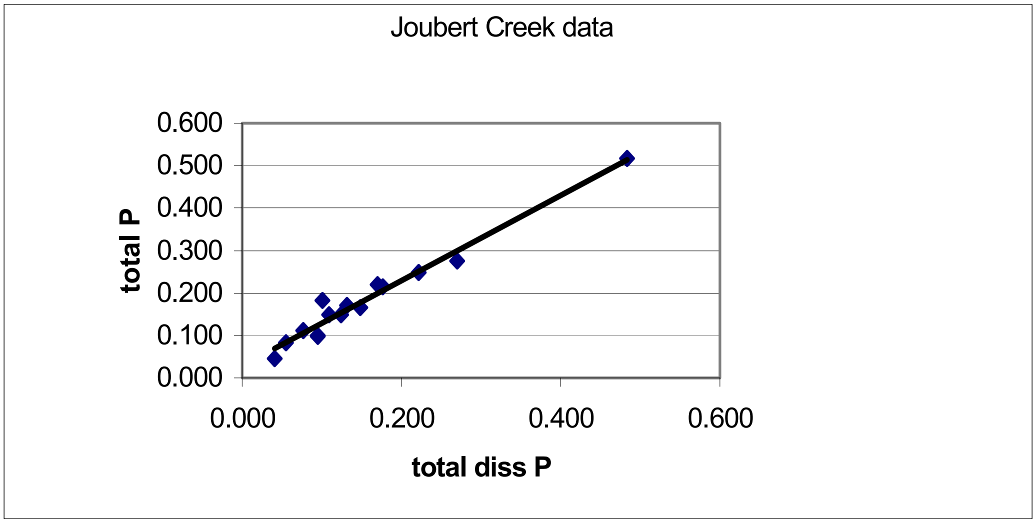


**Figure 2: Joubert Creek data of total suspended solids versus total P.**

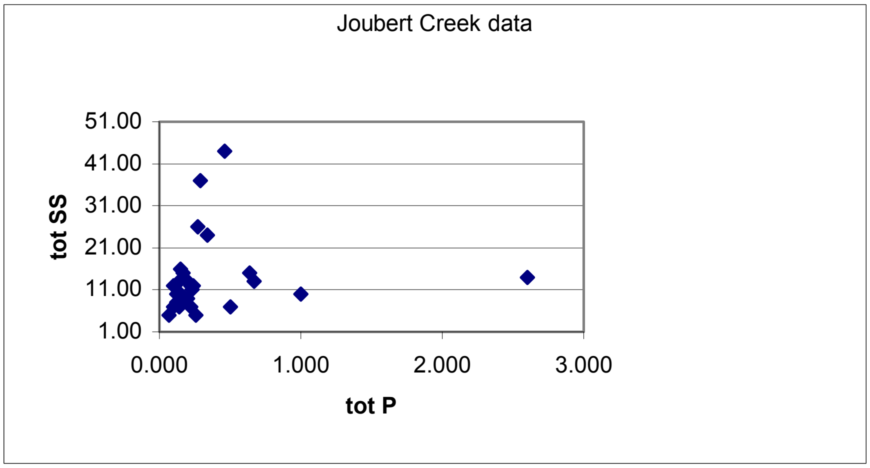


**Figure 3: Rat River data of total suspended solids versus total P.**

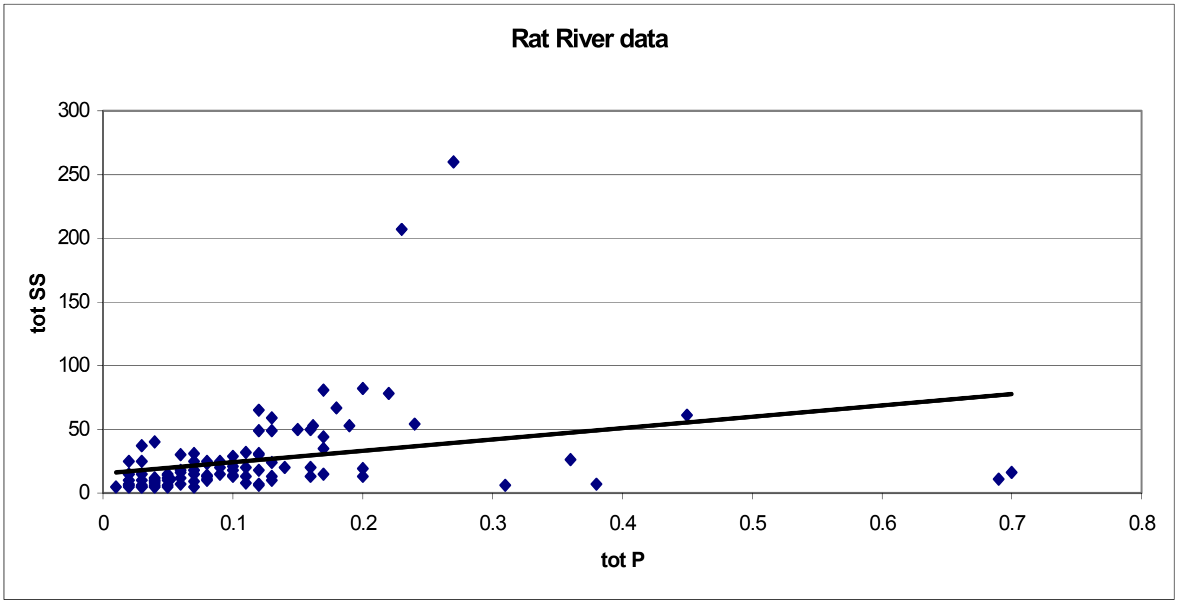


**Figure 4: Whitemouth River data for total P versus suspended solids**

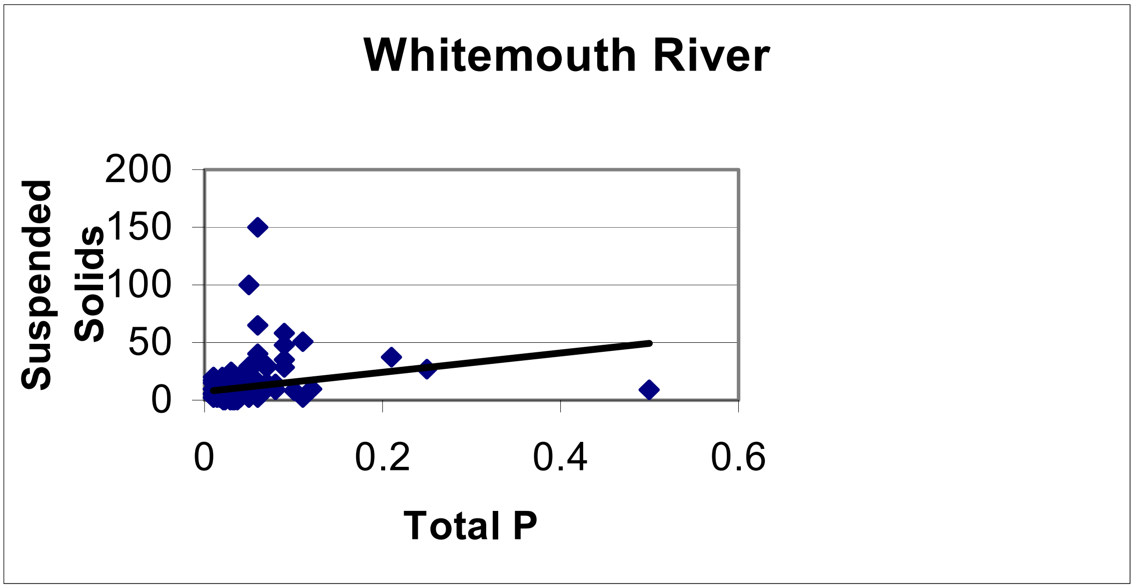


**Figure 5: Whitemouth data for ortho to total P ratio versus suspended solids**

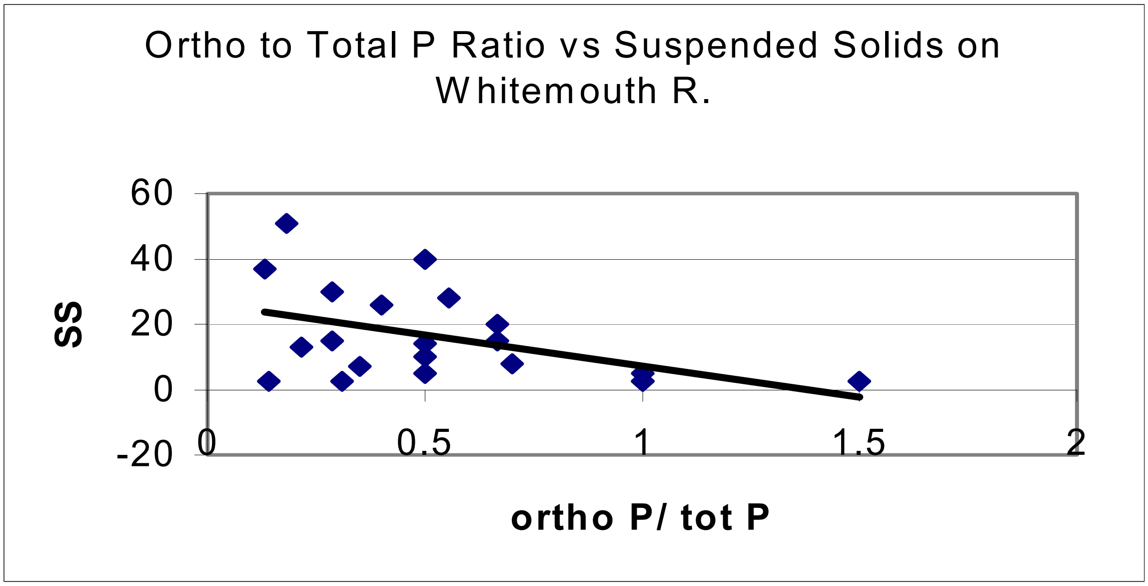


Figure 6: Total Phosphorus averaged with time at four locations on the Whitemouth River in 2001.

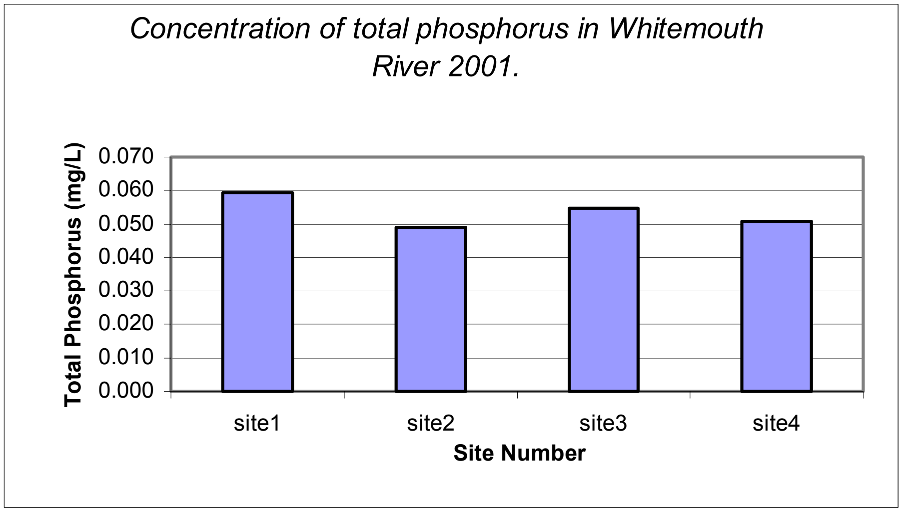


Figure 7: Total Phosphorus with time at the four stations on the Whitemouth River in 2001.

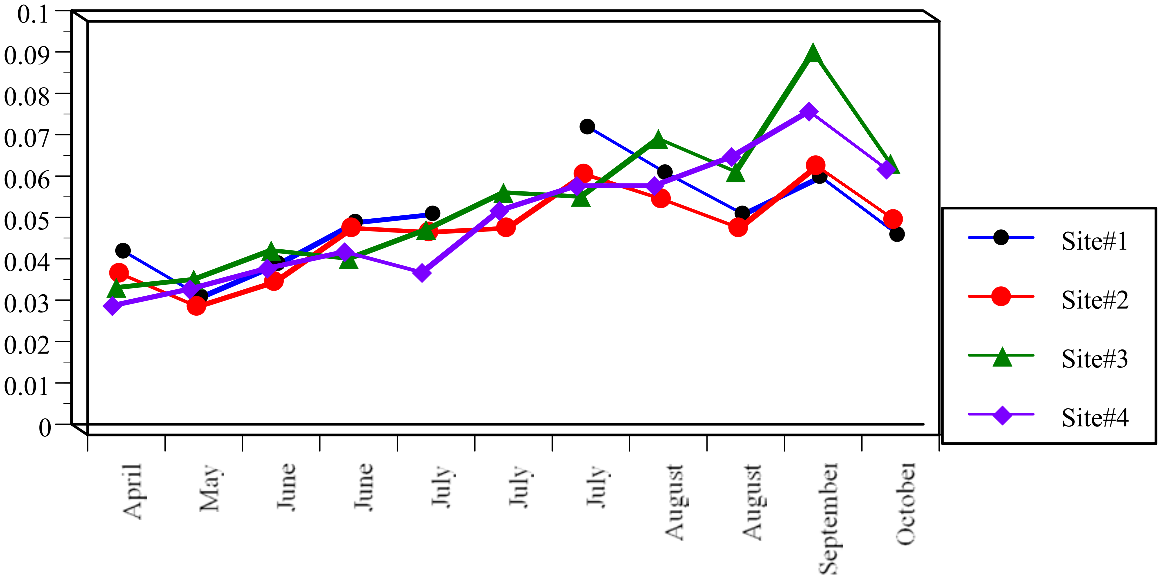


**Figure 8: Air photo of a section of the Whitemouth River between Elma and Whitemouth, MB, delineating fields that are potential contributors to stream P and areas where the stream is protected by shoreline and river bank vegetation.**

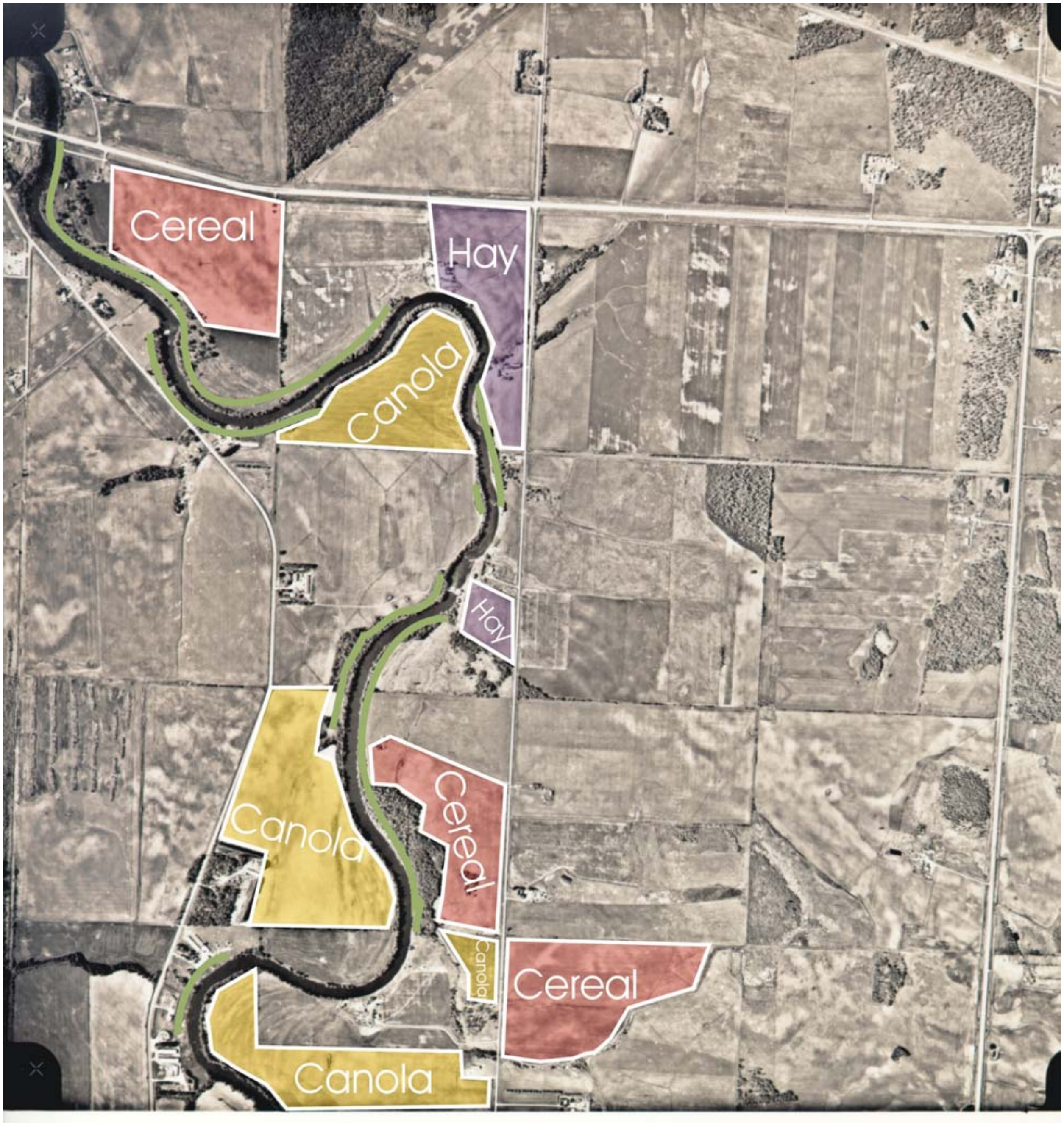
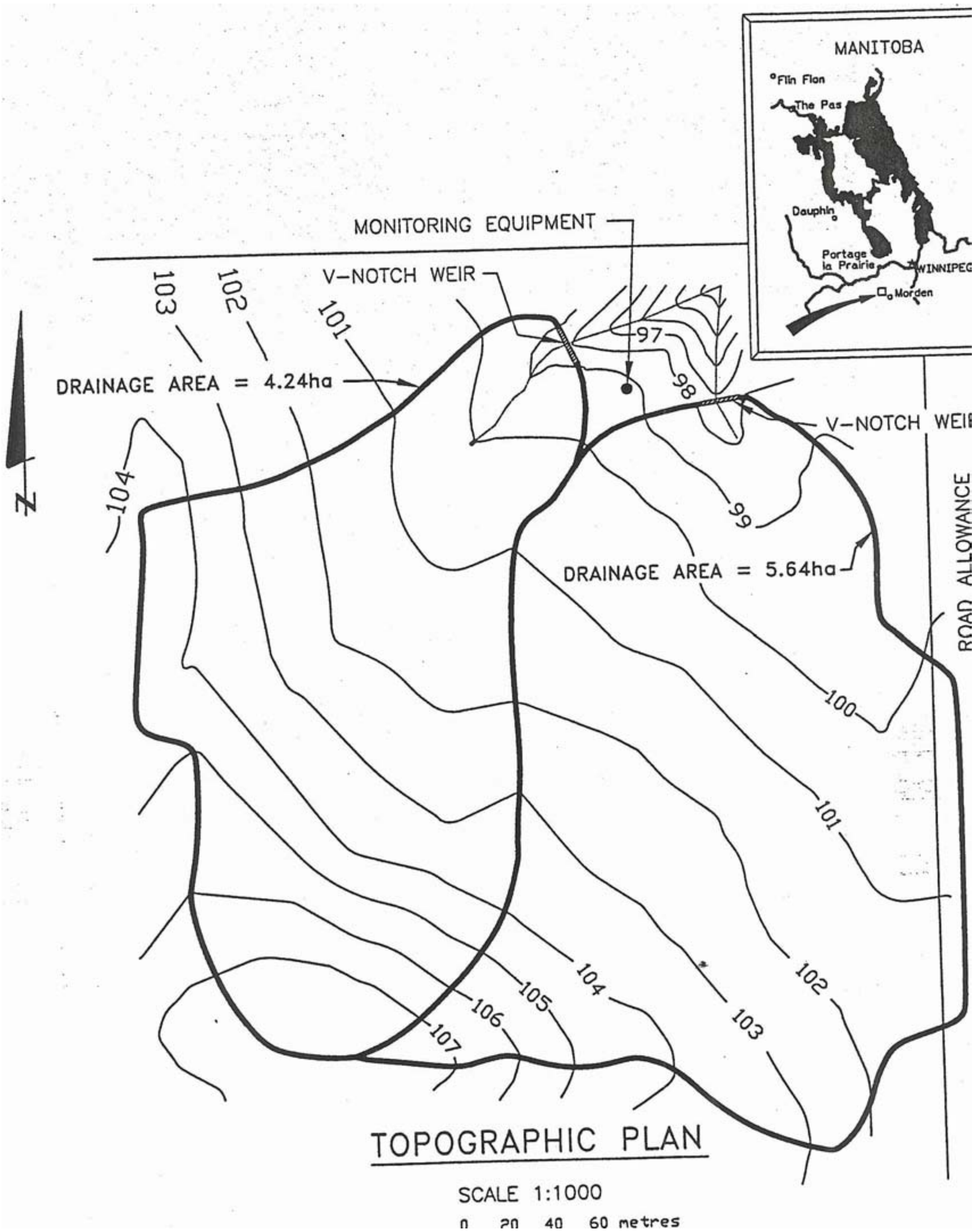


**Figure 9: South Tobacco Creek's Twin Watershed Monitoring Site and Topographic Plan (from Yarotski and Miller, 2000).**



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# APPENDIX A: Model Review Details

## Opus

### Opus, An Integrated Simulation Model for Transport of Nonpoint-Source Pollutants at the Field Scale - United States Department of Agriculture, Agricultural Research Service, July 1992. Contact: Roger E. Smith, U.S. Department of Agriculture, Agricultural Research Service, Water Management Research Unit, Fort Collins, CO.

Opus computes the transport of material in soil and surface water. The model is a simulation tool for studying the potential pollution from various agricultural management practices. It simulates water movement resulting from rainfall and other weather inputs and water movement affected by soil, crop, topography and many types of management actions as well as water use influencing the surface concentration. Opus includes models for the growth of plants; development of cover; water use; uptake of nutrients; cycling of nitrogen, phosphorus and carbon; transport of absorbed pesticides and nutrients; interaction of surface water and soil water; runoff and erosion (Smith 1992). Opus allows the user to choose between a) detailed simulation involving data on the time-intensity pattern of rainfall or b) a more lumped approach using either recorded daily rainfall or stochastically generated rainfall.

The Opus model borrows from other models developed in the US under agriculture funding. Models such as EPIC – Erosion-Productivity Impact Calculator, the Century – grassland and agroecosystem dynamics soil-nutrient model, CREAMS - Chemicals, Runoff and Erosion from Agricultural Management Systems and KINEROS, a surface infiltration, erosion and runoff model. Opus has several useful features that differ from other models and the NLM, in particular.

One of the useful and unique features of Opus is the inclusion of a weather generating routine, WGEN, that preserves relationships between solar radiation and temperature, but generates daily data from monthly means. This allows the modeller to fill data gaps, i.e. when daily data are not available, and also allows long term simulations to run into the future on generated data from historical trends. Daily rainfall occurrences are modeled as a Markov chain process, simulating the binary sequence of wet days and dry days. For example, if yesterday was a wet day, it increases the probability of today being a dry day. Data to use this WGEN routine have been tabulated for many locations in the U.S. Similar techniques are used to generate daily temperature and radiation from monthly data.

Another feature of Opus is the reasonably rigorous soil water balance method which includes the extraction of water by plant roots, the capillary rise of water from a water table and the ability to model drainage tile moisture flows. Opus also simulates changes in soil moisture in 3 (litter, surface soil and subsoil) to 20 soil layers.

Opus also simulates mean daily temperature used to predict both plant growth and microbial processes, such as those instrumental in the nitrogen cycle. Although water transport is included in the present NLM, the treatment is less mechanistic. Heat transport is not calculated in the present NLM, thus, it is limited in how it handles N.

Opus and the present NLM both use an equilibrium adsorption approach to dealing with solutes, N and P. Opus has an additional feature to include a relationship to organic soil carbon content for pesticides. Opus also includes a kinetic adsorption approach.

Opus, much like the current NLM, offers the user two methods of estimating surface water flow and erosion transport. Opus uses the methods of the EPIC model (Williams et al. 1984) to simulate runoff from daily rainfall data. Opus differs from the current NLM, it uses the Curve Number (CN) runoff estimation technique, whereas the current NLM doesn't predict water runoff, it only deals with the particles moving as a result of erosion. When storm intensity or pluviograph data are available a different approach is used. An infiltration rate is used to calculate the soil depth to which infiltration reached and surface ponding is accommodated.

Opus treats sediment or particle production similarly to the NLM, except that it uses the MUSLE rather than the USLE or RUSLE (Smith 1992). Erosion of particles accommodates five different particle-size classes similar to the methods used in CREAMS (Foster et al. 1980a).

Opus treats both water flows and sediment contribution to a pond; the current NLM model simulates dissolved and solid material coming to either a stagnant water body, like a pond or a faster-moving river.

Opus mechanistically melts the snow cover based on the soil thermal heat flux, the current NLM makes larger assumptions about the contribution of snowmelt to water and water-mediated transport.

Opus follows the Century model (Parton et al. 1987, 1988b) for the simulation of soil nutrients. Opus simulates the soil organic matter and ties it to the decomposition and release and cycling of nutrients. The organic matter is divided into three pools: an active Soil Organic Matter, SOM, a slow SOM and a passive SOM. The active SOM has a short turnover time (1 to 5 years) and consists of live microbial matter and partially humified SOM. The slow SOM fraction contains C, N and P that is physically protected or more biologically resistant to decomposition and has an intermediate turnover time (20 to 40 years). The passive SOM is chemically resistant and may also be physically protected. This has the longest turnover time (200 to 1500 years). Plant residue degradation is split into rates for metabolic and structural components. Plant chemicals can be leached from the canopy depending on crop cover, leached from plant residues on the soil surface, leached through the soil layer or removed by the movement of particulate. The Opus model and the NLM model treat the simulation of P similarly. The NLM does not explicitly model the relationship of P to C and its degradation, however, it does include an export and an import term to cycle P through the plant system (only a portion of the P in the crop is lost).

Opus contains a plant growth model that responds to soil moisture conditions and temperature and the current NLM only uses the crop yield as a loss term for P. Opus also contains a soil management option that allows for tillage, addition of fertilizer or animal wastes, pesticide application, irrigation and chemigation. Tillage only ever allows the mixing of the surface 20 cm of soil and a mixing efficiency parameter determines the completeness of the tillage process. The interesting feature about tillage is that it returns the soil bulk density to a prechosen minimum value. The current NLM does not change the density of the soil with time.

A validation case was summarized in the Opus documentation and the performance of Opus on this good, but not complete, dataset gives an inconclusive message as to the usefulness of Opus. It is not inconsistent with any validation of a large complex model where all parameter values are not measured and all processes are not well understood.

In summary, Opus includes a higher level of sophistication in some aspects, such as the simulation of plant growth and temperature effects for plant production and snowmelt. More sophisticated models offer a closer approximation to the real world, however, they introduce the need for more parameter values and this introduces further uncertainties. It is not evident that Opus offers a better alternative to assisting the land management of manure than does the NLM. Some aspects of Opus could be used to improve the NLM, primarily: the conceptual view of the system and possibly the use of the weather generator to produce future annual trends based on historic weather data.

## EPIC

### EPIC – A model for assessing the effects of erosion on soil productivity. J.R. Williams, P.T. Dyke and C.A. Jones. IN: Analysis of Ecological Systems: State of the Art in Ecological Modeling, 3rd International Conference on State of the Art in Ecological Modelling. Laueroth, Skogerboe and Flug (Eds.), pp 553-572.

EPIC – Erosion Productivity Impact Calculator is composed of physically based components for simulating erosion, plant growth and economic components for assessing the cost of erosion and determining optimal management strategies over hundreds of years (Williams et al., 1987). The EPIC model was developed in the 1980s and was originally coded in Fortran.

The model consists of modules for hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage and economics. Its simulation timeframes are: daily time step and for long-term simulations (1 to 4000 years). The hydrology model simulates surface runoff volume and peak discharge rate given daily rainfall amounts. Other hydrology components include evapotranspiration, percolation, lateral subsurface flow, drainage, irrigation and snowmelt. EPIC can simulate both water and wind erosion, water erosion is simulated using the USLE. EPIC considers both N and P loss. Phosphorus processes simulated include runoff of soluble P, sediment transport of mineral and organic P, immobilization, mineralization, sorption-desorption, crop uptake and fertilizer. A general plant growth model simulates above-ground biomass, yield and roots for corn, grain, sorghum, wheat, barley, oats, peanuts, sunflowers, soybeans, alfalfa, cotton and grasses. The plant growth model simulates energy interception; energy conversion to roots, above-ground biomass, and grain and fiber production; and water and nutrient uptake. Plant growth is constrained by water, nutrient and air temperature stresses. Soil temperature is simulated to serve the nutrient cycling and root components of EPIC.

The simulation of surface runoff is similar between EPIC and CREAMS except EPIC accommodates variable soil layers and CREAMS does not. EPIC includes both rainfall and runoff variables in the calculation. In addition, EPIC includes provision for estimating runoff from frozen soil. EPIC uses the same snowmelt module as does CREAMS.

The EPIC model treats P similarly to N and accommodates the nutrient cycling of P through sediment load, mineralization from the fresh organic P pool, and immobilization of P contained in the crop residue. It specifically cycles P between the three pools: labile, active mineral and stable mineral. The crop uptake of P is similar to that of N where the crop P use is estimated with a supply and demand approach. EPIC, like Opus uses a mixing efficiency term for tillage. The EPIC model allows three means of harvest: a traditional harvest that removes seed, fiber, etc., hay harvest (95% of above-ground biomass), and no harvest.

The EPIC model had been tested on several sites (17 in the Continental US and 13 in Hawaii) as of the early 1980's and has been used extensively since then. The EPIC model has useful aspects for the NLM, in particular, it may be useful to more fully describe the P cycle.

## SWAT

### SWAT – Soil and Water Assessment Tool (http://www.brc.tamus.edu/swat/)

SWAT predicts the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungauged river basins. SWAT is a well supported model developed by the USDA Agriculture Research Service. It consists of several hydrologic GIS-based models and other database access tools integrated to form a basin-scale hydrologic model. SWAT was developed from SWRRB, Simulator for Water Resources in Rural Basins (Williams et al. 1985; Arnold et al. 1990); CREAMS (Knisel, 1980); GLEAMS – Groundwater Loading Effects of Agricultural Management Systems (Leonard et al. 1987) and EPIC. SWAT has been validated at several spatial scales from 18 to 9000 km$^2$ (Arnold et al. 1993; Srinivasan and Arnold 1994). The SWAT model is meant to be calibrated with stream gauge data, sediment and nutrient grab samples for numerous sites throughout the watershed of interest. Of interest, SWAT is not designed to simulate detailed, single-event flood routing, but designed as a continuous time model to estimate long-term watershed management outcomes.

In comparison to our NLM model, SWAT would only be comparable to the long-term P loading losses as no event calculations are made in SWAT. The emphasis on the development of SWAT is for the simulation of larger watersheds with multiple basins and reservoirs. Its in-stream nutrient water quality equations are taken from QUAL2E – The Enhanced Stream Water Quality Model (Brown and Barnwell 1987).

In summary, it appears that SWAT offers no new concepts to the models that are of most importance to nutrient loading modelling.

### EROSION_2D

**EROSION_2D – Model for Erosion on Slopes. Schmidt, J. 1991. Entwicklung und Anwendung eines physikalisch begruendeten Simulationsmodells fuer die Erosion geneigter, landwirtschaftlicher Nutzflaechen. Forschungsbericht, BMBF, Referat 522, pp.70.**

EROSION_2D is a physically based computer model for simulating sediment transport on slopes. The model is based on the moment fluxes exerted by the falling droplets and by the slope. The input parameters are the altitude co-ordinates of the initial slope profile, the surface and soil properties and the vegetation cover of the slope.

In summary, EROSION_2D offers no P cycling or loading to the water body. It deals only with erosion and sediment transport on the basis of single erosion events, not the long-term annual average. The NLM, as it is, is more useful than EROSION_2D.

### TOOLKIT

**TOOLKIT – the USDA - Natural Resources Conservation Service is developing this tool.**

Correspondence from Jim Kinney in Wisconsin makes it sound like the NRCS will adopt the SWAT model and supporting routines for use as their TOOLKIT.

### AGNPS

**AGNPS - Agricultural Non-Point Source pollutant loading model is under further development by the National Sedimentation Laboratory of the USDA, ARS (www.sedlab.olemiss.edu/agnps).**

The latest development that has relevance to manure management and the NLM is a model called AnnAGNPS (version 2.0). AnnAGNPS continues to use RUSLE for its soil erosion portion, similar to the NLM. HUSLE is also used; it determines the delivery ratio for the sheet & rill erosion for each cell to its receiving reach. The delivery ratio for the individual particle–size classes is proportioned according to their respective fall velocities. AnnAGNPS simulates a single-event or a continuous simulation over longer times, much like the NLM. Several reference databases are used to input the data required to run AnnAGNPS and these are:

- Animal waste characteristics
- Crop characteristics
- Equipment/Operations
- Non-crop land use characteristics
- Nutrient source characteristics
- Pesticide characteristics
- Runoff cover conditions
- Runoff Curve Number data
- USLE LS factors

A synthetic weather generator (Generator of weather Elements for Multiple applications – GEM) can be used to generate the precipitation and min/max air temperatures required for AnnAGNPS. Some historic data is also required (relative humidity, percent sky cover & wind speed) to fulfill the AGNPS weather data requirements. We mentionned this as an improvement for the NLM earlier, the full climate routine to take historical data and convert to an AnnAGNPS ready format is complete, however the historical data must be in a specific format and there is no software to convert this from existing files at this time.

The chemical routine calculates the daily mass balance of N, P and organic carbon, C, for each landscape cell. Major components considered are uptake of N and P by plants, applications of fertilizers, residue decomposition and downward movement of N and P. The output from each cell includes sediment bound N, soluble N in runoff, sediment bound P, soluble P in runoff and sediment bound organic carbon. Nitrogen and P are partitioned into organic and mineral phases and a separate mass balance computed for each. The N and C cycles are simplifications that track only the major processes. Plant uptake of N and P is modelled through a simple crop growth stage index. Chemical reach routings assume instant partitioning between the adsorbed and solute states after mixing upstream and also downstream to reflect the respective losses of adsorbed chemicals due to deposition of the fine sediment.

In summary, AGNPS has two aspects that could serve as improvement to the NLM, the GEM weather generator routine (similar to that of Opus') and additional output related to sediment delivery by specifying the particle-size classes output to the stream through HUSLE.

Bhuyan et al. 2002 has compared the three models WEPP, EPIC and ANSWERS on the basis of individual event, total yearly and mean event-based soil loss predictions and all models were within range of the observed values. The overall results showed that WEPP predictions were the best.

## WEPP

**WEPP – Water Erosion Predictor Project. Foster, G.R. and L.J. Lane. 1987. User requirements: USDA-Water Erosion Predictor project (WEPP). NSERL Report No. 1, USDA-ARS National Soil Erosion Research laboratory, W. Lafayette, IN., 43 pp.**

WEPP is based on the fundamentals of stochjastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics and erosion mechanics. The hillslope or landscape profile application of the model improves upon other erosion model technology by including capabilities for estimating spatial and temporal distributions of soil loss (net soil loss for an entire hillslope or for each point on a slope profile on a dailt, monthly or average annual basis). Specific processes that are included that are usueful in the Manitoba context are snow melt and frozen soil effects on infiltration and erodibility.

An entire downloadable version can be found on the internet (http://topsoil.nserl.purdue.edu/nserlweb/weppmain/), complete with default files containing values for specific soils, climate data for selected specific states and a complete selection of crop and soil management possibilities as well as tile drainage.

Although WEPP performed really well compared to other soil erosion predictors, it does not predict soil P loss and does not predict the impact of agronomic practices, including soil and crop management options on water quality. It simply delivers a load of sediment to the stream under a variety of conditions. Our NLM has two addition features, it delivers both the eroded soil and calculates the addition of soil P to the stream and then it carries out a flushing calculation to show the short- and long-term effects of this additional soil P to the stream's water quality over time for both a storm event and average annual erosion.

Letcher et al. (2002) recently reviewed four nutrient loading models (CMSS, MOSS, IHACRES and AQUALM) for use in Australian catchments and concludes that each of these models has their strengths and weaknesses and the appropriate model for an application will depend critically on the objectives of the modeling or estimation exercise". They conclude that data limitations are the greatest impediment to good estimations of nutrient loading and model application. The suggestion for best results is to calibrate the model on one or two years of watershed data before trying to validate it.

# APPENDIX B: Model Modifications and Improvements

1. Account for the depletion of soil P after erosion takes place,
   This is explicitly handled in the year soil model, where there are specific first-order loss rates computed for erosion, lateral subsurface flow and crop removal. All of these first-order loss rates are applied to the total amount of P in the soil, and for a specified time period the total amount of P in the soil is diminished accordingly.

2. Add in the ability to have a buffer zone next to the waterway, a no-P-addition strip from the edge of the field to the surface water,
   This is achievable with the present model in two ways. One is by modification of the ULSE input parameter P (not to be confused with phosphorus) value. This is an empirical adjustment for erosion management practices (P is for 'practices'). The other approach is to use one sheet of the spreadsheet as the upland soil and a second sheet as the lowland buffer strip. These modifications were not directly pursued, but the issue was dealt with in the validation process. The decision about using a constant slope length of 30 m precludes development of buffer strip models. The argument is that at this stage we do not explicitly model P loss from further than 30 m upslope, and so it is assumed there is no loss of P when there is a buffer strip.

3. Relate stream flow rate to rainfall and infiltration,
   It would be appropriate to correlate these in a stochastic approach. This was not developed as an explicit function, because it would introduce the need to model and parameterize a full watershed.

4. Compute soluble, bioavailable or filterable water P concentration, since only some of the P reaching the stream is of concern,
   The stream quality data we use in Manitoba (collected by Manitoba Conservation) is usually total P (analysis method converts all organic and inorganic P to $PO_3$). In some cases (some waterways and some years), we have total dissolved P, which is filtered (analysis is the same, the sample is filtered first through 0.45 $\mu$). In some cases, we also have ortho P (usually unfiltered, no digestion). Recently, guidelines were set for Manitoba rivers and streams – concentrations of total phosphorus should not exceed 0.05 mg P $L^{-1}$ (Manitoba Water Quality Standards, Objectives and Guidelines, Draft 2000). Because this is the most likely form of P to be described in guidelines, we do not speciate P in the river.

5. Explicitly model the addition of manure,
   No model reviewed to date actually explicitly models the addition of manure and its subsequent erosion. However, because we are looking at the long-term picture, the manure is already expected to be degraded, so we don't presently differentiate manure P and soil P.

To differentiate the types of P would better address the fact that soluble P might be leaving the watershed as "leached P" to the subsurface aquifer or more porous soil layers. We can manipulate Kd to model this.

A manure degradation rate, and possibly a mineralization rate could be included as well as subsequent manurings. The P types to be included would be:

- insoluble organically bound P,
- organic soluble P – leachable subject to runoff (present NLM model handles this well), and
- inorganic P – leachable but with a much higher Kd, dominated by particle movement

This is possible once literature data is available to partition the P into these fractions and also prescribes appropriate leach rates, primarily for soluble organic P.

6. <u>Add the ability of the soil particles to desorb P according to Sharpley,</u>
   In the soil, the solution P is assumed to be at equilibrium with the P adsorbed to the soil matrix. This is an assumption of the soil Kd model for sorption and the model allows the P in solution to be replenished by desorption from the soil solids as it is lost from solution. In the stream, a shift in pH or P concentration could cause desorption. This process could be accommodated by setting a lower Kd in the stream.

7. <u>Build in a probabilistic approach and the ability to have correlations, such as relating high stream flow with high rainfall,</u>
   The stochastic version (CrystalBall version) developed allows these correlations to be included.

8. <u>Ability to stochastically generate long-term daily weather inputs from monthly or annual means,</u>
   We really don't need this at this stage, it is only required if you were modelling a series of events. The water system integrates over a number of years, so we don't have to model, for example, a worst year followed by two good years. We can pick a 30-yr average, or increase or decrease the present conditions some proportion, e.g., 10-20%. We can put in a pattern over time, but don't need to stochastically generate the weather data. This was the modification/improvement suggested following the review of other models and available from Opus or AnnAGNPS.

# APPENDIX C: Ancillary Sensitivity Analysis Data and Plots

### Slope %

It is evident from the sensitivity charts here and in the text Table 2, that the slope of the field is a predominant influencing factor on most output values. This parameter is closely correlated to the field length, which was not taken into account in the sensitivity analysis. A more detailed analysis of the influence of the slope % and field width parameters was undertaken and is presented in a following section.

### Crop Management Factor

This factor is the mean annual cropping practice factor describing the effect of soil and crop management on the loss of soil by erosion. This factor represents the ratio of soil loss for cropped land under specific cropping or cover conditions to the corresponding soil loss from continuously tilled or fallow land for the same soil, slope and rainfall intensity. This factor ranged from 0.01 to 0.4 and has a significant effect on the Single Event Scenario output for Soil Eroded, P Loss, Stream P, Water Contaminant, Amount Eroded, and yearly average scenario outputs Soil Eroded and Release Max to Water.

This parameter appears to be relatively well defined for various crops relevant to Manitoba. The sensitivity of the model to this parameter suggests that models for individual fields must be run separately. This has been considered in our whole river segment validation cases.

### Rainfall Intensity

This parameter is the single event rainfall intensity and has a significant effect on the outputs for Soil Eroded, P Loss, Stream P, Water Contaminant and Amount Eroded. Sensitivity to this parameter suggests that specific event models will need to have reliable data for rainfall intensity in the field region as this is likely region specific.

### Extraction Efficiency

This parameter is the $NaHCO_3$ extraction efficiency in %. This variable was investigated over the range 0.2 to 10%. At present, this parameter is not rigorously defined and a default value of 1.2% is assumed in the model. The Yearly Average output values Final Soil P and Topsoil P concentration are very strongly affected while the Single event output values P Loss, Stream P, Water Contamination and Amount Eroded and the Yearly Average output value Release Maximum to Water are less strongly affected. The strong dependence on this parameter warrants investigation into a better-defined extraction efficiency value to reduce the uncertainty in the parameter range.

### Soil Test P

This parameter is the initial topsoil concentration of P before any erosional events take place for both the single event and yearly average scenarios. The Yearly Average output values Final Soil P and Topsoil P concentration are strongly affected while the Single event output values P Loss, Stream P, Water Contamination and Amount Eroded and the Yearly Average output value

Release Maximum to Water are less strongly affected. This input value will depend on individual data available for a field scenario and must be well characterized to reduce uncertainty and to provide an appropriate input to the model.

### Storm Duration

This parameter describes the storm (rainfall) duration and can affect both the single event and yearly average scenario outputs. The single event output values Soil Eroded, Water Contamination and Amount Eroded are most strongly affected. The effect on the yearly average outputs is minimal. Sensitivity to this parameter suggests that specific event models will need to have reliable data for rainfall intensity and storm duration in the field region as these events are region specific.

### Field Width

This parameter affects both single event and yearly average scenarios. The most strongly affected output values are the single event P Loss, Stream P, Water Contamination, and Amount Eroded and the Yearly Average output value Maximum yearly release rate of P to water. It might be anticipated that this value would scale directly to output parameters and a more detailed analysis of the affect of this parameter on output values was analysed separately and is presented in a following section.

### Soil Erodibility Factor K

This factor is the inherent susceptibility of soil to detachment and transportation by water and is related to the soil texture, percent organic matter, soil structure and permeability. The values were varied over the range 0.01 to 0.05 as detailed in the project's Phase 1 final report (ECOMatters 2000). The single event scenario output values Soil Eroded, P Loss, Stream P, Water Contamination, and Amount Eroded and the yearly average scenario values Soil Eroded and Maximum yearly release rate of P to water were weakly affected by variations in this parameter. The weak sensitivity to this parameter suggests that it may be possible to treat this parameter as a stochastic variable; however, appropriate field characterization data would reduce the uncertainty related to variations in this parameter.

### Rain Erosivity

This factor is the number of erosion index units in a particular rainfall event or year and is a measure of the erosive force of a specific rain storm. This parameter was varied over the range 604 to 2000 to cover the range of Manitoba data described in the previous ECOMatters final report. Specific regional data can be obtained from published data (Eilers et al. 1989) and this may be the most appropriate approach to reduce uncertainty related to variations in this parameter.

### Volumetric Stream Flow Rate

This parameter is the rate at which clean water flushes contaminated water from the portion of the stream or water body receiving the nutrient. The single event output Stream P concentration is weakly affected by variations in this parameter over the range 0.1 to 100. This value will be stream, time and event specific and regional specific data should be used to reduce uncertainty related to variations in this parameter.

## Yearly Rainfall Fraction

This parameter affects only the yearly average scenario and describes the fraction of the year over which rainfall and snowmelt occurs. The model is relatively insensitive to this parameter, which was varied over a range of 0.3 to 0.7. Regional specific data should be used to reduce uncertainty related to variations in this parameter.

## Remaining Parameters

The remaining input parameters P Crop %, Soil Porosity, Bulk Soil Density, Crop Yield, P Kd, Saturated Conductivity and Slope Length had the least sensitivity on the output values.

**P Crop**% - P concentration in the harvested crop. Varied over the range 0.1 to 2%. The relative insensitivity to this parameter suggests that it may be possible to treat it stochastically or as a representative average for specific crops if field specific data is not available.

**Soil Porosity** – volume of voids or pore space within a unit volume of soil affecting both single event and yearly average scenarios. Varied over the range 0.4 to 0.6. These values are well defined for a variety of soils but it may be possible to treat it stochastically or as a representative average for specific crops if field specific data is not available.

**Bulk Soil Density** – mass per unit volume of soil affecting both scenarios. Varied over the range 1200 to 1600 kg soil $m^{-3}$. Soil density varies depending on soil texture and organic matter. Default values exist for specific soil types if field specific data are not available. Organic soils should be treated separately due to the low bulk density of 150 kg soil $m^{-3}$.

**Crop Yield** - Crop harvested yield in kg/ha. Varied over the range 1632-6352 (kg $ha^{-1}$). The relative insensitivity to this parameter suggests that it may be possible to treat it stochastically or as a representative average for regional crops if field specific data is not available.

**P $K_d$** – Distribution coefficient of nutrient (ratio of soil P to pore water P). This parameter depends heavily on soil type and will affect both scenarios. The relative insensitivity to this parameter suggests that it could be treated as an average value or deterministically with soil type. This parameter is more important in the stagnant water body case.

**Saturated Hydraulic Conductivity** – the rate at which water flows through the soil at saturation when the interconnectivity of the pores is complete. Varied over the range 1.0E-05 to 1.0 (cm $s^{-1}$). The relative insensitivity to this parameter suggests that major errors will not be introduced in the model if parameter value selection is incorrect. As this parameter varies between soil textures and even within soil textures, it may be difficult to quantify but the value chosen may have little significance.

**Slope Length** – This parameter combines the actual slope length and slope steepness. Due to the high correlation with slope % a separate analysis of the effect of this parameter is presented in a following section.

## Detailed analysis of sensitivity to Slope Length and Slope %

As previously mentioned, the slope of the field is a predominant influencing factor on most output values. This parameter is closely correlated to the field (slope) length and a more detailed analysis was undertaken to understand the correlation between slope% and field length and its influence on output parameters.

For this analysis, the EXCEL NLM model was used directly with all parameters held at default values. The length of the field was varied from 50 m to 1000 m and a height above the water discharge area was held constant at 1 m. This allowed a calculation of the slope % for each field length. Using each field length and slope % pair, the representative forecast single event values **Stream P** and **P Loss** were determined and plotted as a function of slope length (Figure 1). A power function was used to fit the data.

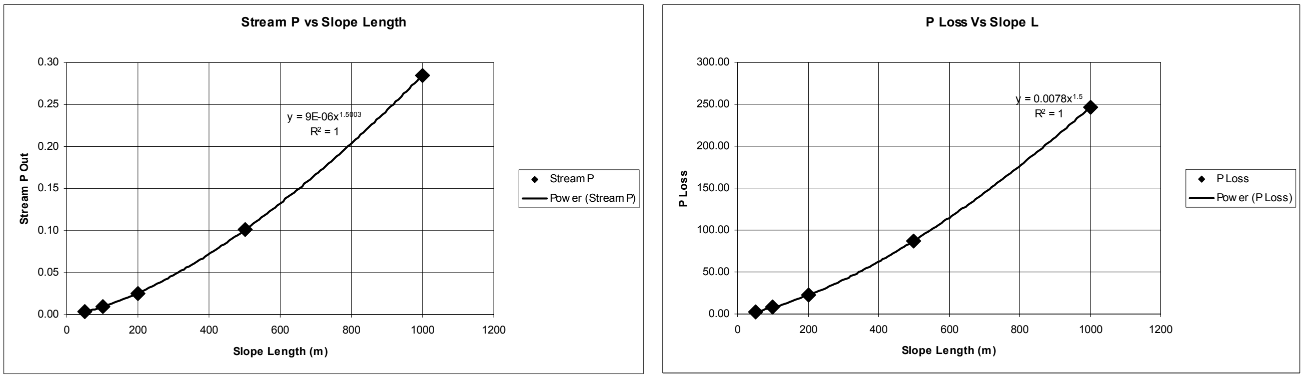


**Figure C1. Variation of the Stream P and P Loss as a function of slope length for a field height of 1 m calculated using the EXCEL NLM model. Slope% was calculated over the field length**

These data appear to imply that as field length increases (and corresponding slope% decreases) the total P loss as a result of erosive flushing and the stream P concentration increase as a power function. Apparently slope length is more important in the model than slope percent. These results seem counterintuitive if one extrapolates to extreme slope lengths. These results suggest that the model objectives for these parameters be reviewed and that the relationship between field length and slope% could be built into the model.

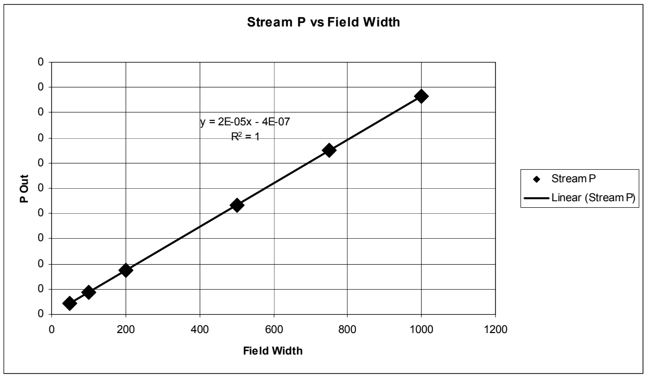


**Figure C2. Variation of Stream P with Field Width as calculated using the EXCEL NLM model.**

A second related parameter is the width of the field exposed to the discharge stream. The EXCEL NLM model was used to calculate **Stream P** as a function of **Field Width** while holding all other parameters constant. The results, shown in Figure C2, imply that the P discharged to the stream is linearly dependent upon the Field Width. This would suggest that Field Width may not be required as an independent variable in the model and could be arbitrarily set to unit width. This could have the advantage that when modeling cumulative releases from a variety of fields to a stream, a weighted release could be applied to each field dependent upon its individual release and effective field width.

## Forecast Statistics

The forecast statistics and percentiles for the chosen output values are presented in the next section.

### Input parameter assumptions used in the CB sensitivity analysis

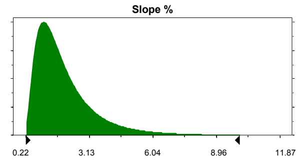
The data presented in here are the variable input parameters used in the CB sensitivity analysis. Parameter ranges were derived from an analysis of the Joubert Creek and the Seine and Whitemouth river data and represent bounding ranges for the actual river data or anticipated ranges for each parameter if no range could be derived from the river data. Means and Standard Deviations were assigned to a chosen probability distribution for the input data to correspond to the defined ranges and do not represent a true mean or standard deviation uncertainty in the variable.

**Assumption: Slope %** **Event - Cell: D13**

Lognormal distribution with parameters:

| | |
|---|---|
| Mean | 2.00 |
| Standard Dev. | 1.50 |

Selected range is from 0.10 to 10.00

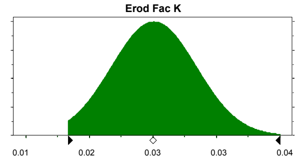


**Assumption: Erod Fac K** **Event - Cell: D14**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.03 |
| Standard Dev. | 0.01 |

Selected range is from 0.01 to 0.05

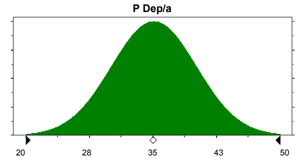


**Assumption: P Dep/a** **Event - Cell: D24**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 35 |
| Standard Dev. | 5 |

Selected range is from 20 to 50

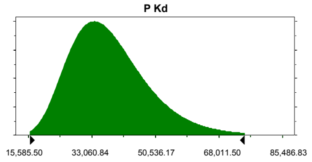


**Assumption: P Kd** **Event - Cell: D25**

Lognormal distribution with parameters:

| | |
|---|---|
| Mean | 38,000.00 |
| Standard Dev. | 11,000.00 |

Selected range is from 16,000.00 to 75,000.00

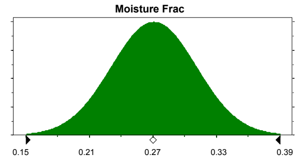


**Assumption: Moisture Frac** **Event - Cell: D38**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.27 |
| Standard Dev. | 0.04 |

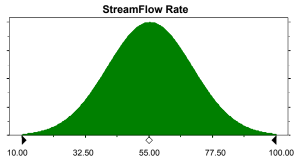
Selected range is from 0.15 to 0.40



**Assumption: StreamFlow Rate** **Event - Cell: D29**

Normal distribution with parameters:
Mean 55.00
Standard Dev. 15.00

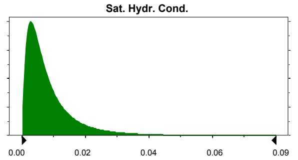
Selected range is from 0.10 to 100.00



**Assumption: Sat. Hydr. Cond.** **Event - Cell: D39**

Lognormal distribution with parameters:
Mean 0.01
Standard Dev. 0.01

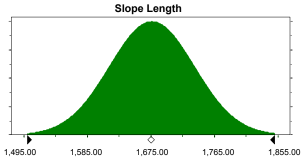
Selected range is from 0.00 to 0.10



**Assumption: Slope Length** **Event - Cell: D12**

Normal distribution with parameters:
Mean 1,675.00
Standard Dev. 60.00

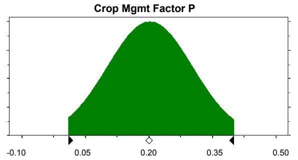
Selected range is from 1,500.00 to 1,850.00



**Assumption: Crop Mgmt Factor P** **Event - Cell: D15**

Normal distribution with parameters:
Mean 0.20
Standard Dev. 0.10

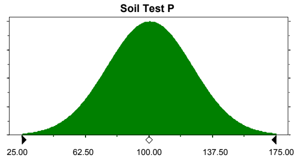
Selected range is from 0.01 to 0.40



**Assumption: Soil Test P** **Event - Cell: D21**

Normal distribution with parameters:
Mean 100.00
Standard Dev. 25.00

Selected range is from 25.00 to 175.00

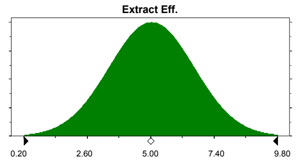


**Assumption: Extract Eff.** **Event - Cell: D22**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 5.00 |
| Standard Dev. | 1.60 |

Selected range is from 0.20 to 10.00

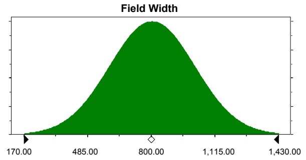


**Assumption: Field Width** **Event - Cell: D32**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 800.00 |
| Standard Dev. | 210.00 |

Selected range is from 150.00 to 1,500.00

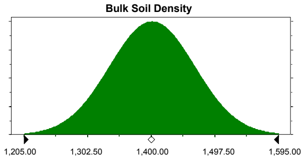


**Assumption: Bulk Soil Density** **Event - Cell: D36**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 1,400.00 |
| Standard Dev. | 65.00 |

Selected range is from 1,200.00 to 1,600.00

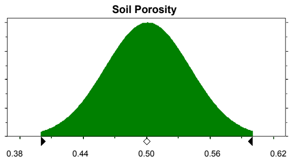


**Assumption: Soil Porosity** **Event - Cell: D37**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.50 |
| Standard Dev. | 0.04 |

Selected range is from 0.40 to 0.60

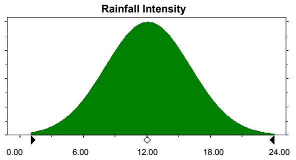


**Assumption: Rainfall Intensity** **Event - Cell: D6**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 12.00 |
| Standard Dev. | 4.00 |

Selected range is from 1.00 to 25.00

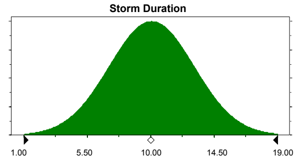


**Assumption: Storm Duration** **Event - Cell: D7**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 10.00 |
| Standard Dev. | 3.00 |

Selected range is from 1.00 to 21.00

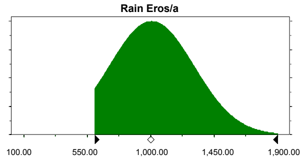


**Assumption: Rain Eros/a** **Yearly - Cell: D6**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 1,000.00 |
| Standard Dev. | 300.00 |

Selected range is from 604.00 to 2,000.00

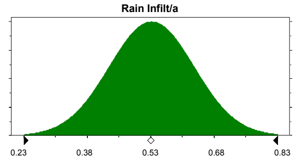


**Assumption: Rain Infilt/a** **Yearly - Cell: D8**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.53 |
| Standard Dev. | 0.10 |

Selected range is from 0.20 to 0.90

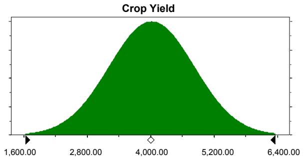


**Assumption: Crop Yield** **Yearly - Cell: D13**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 4,000.00 |
| Standard Dev. | 800.00 |

Selected range is from 1,632.00 to 6,352.00

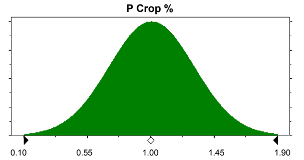


**Assumption: P Crop %** **Yearly - Cell: D14**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 1.00 |
| Standard Dev. | 0.30 |

Selected range is from 0.10 to 2.00

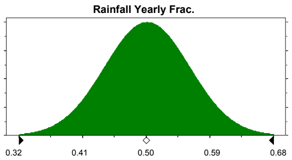


**Assumption: Rainfall Yearly Frac.** **Yearly - Cell: D7**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.50 |
| Standard Dev. | 0.06 |

Selected range is from 0.30 to 0.70

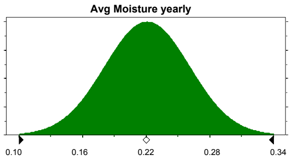


**Assumption: Avg Moisture yearly** **Yearly - Cell: D9**

Normal distribution with parameters:

| | |
|---|---|
| Mean | 0.22 |
| Standard Dev. | 0.04 |

Selected range is from 0.10 to 0.40

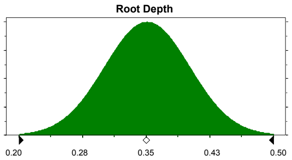


**Assumption: Root Depth** **Yearly - Cell: D16**

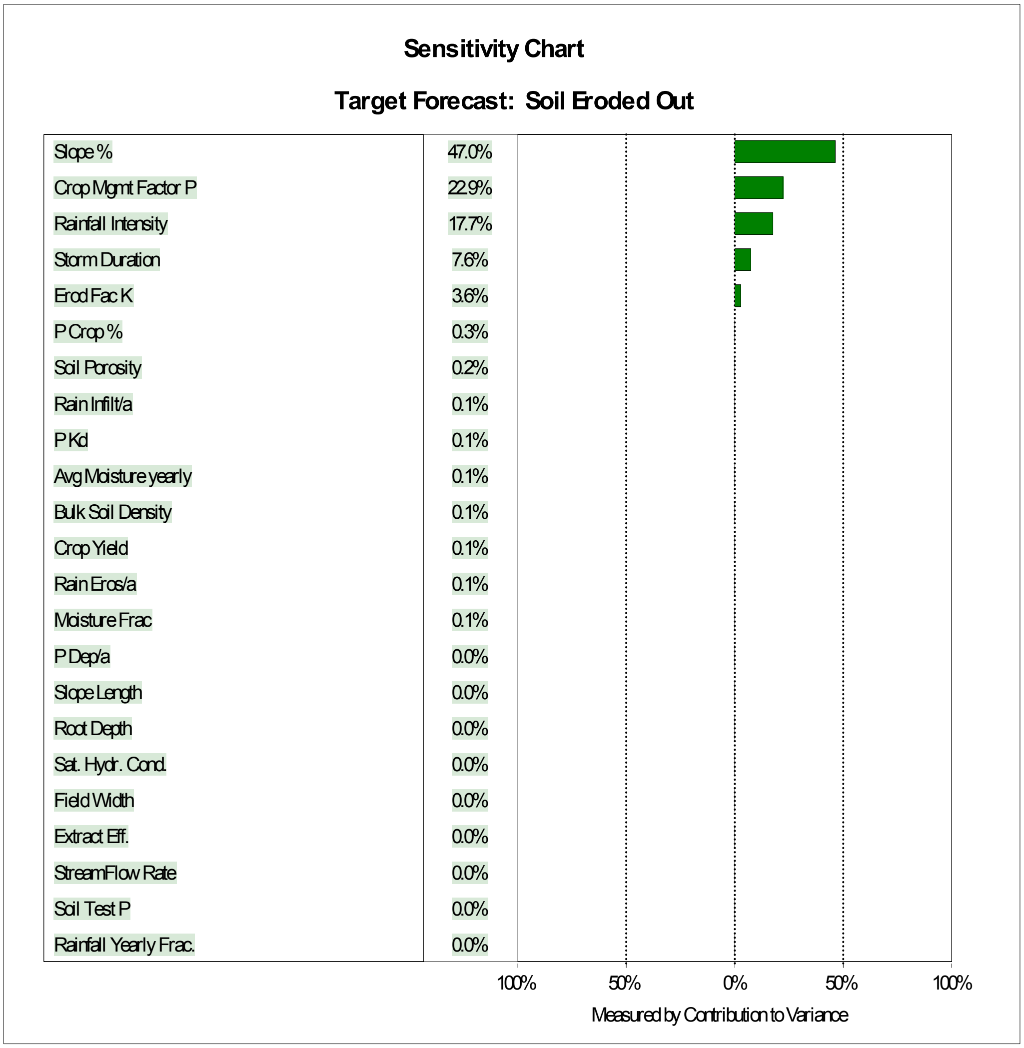
Normal distribution with parameters:

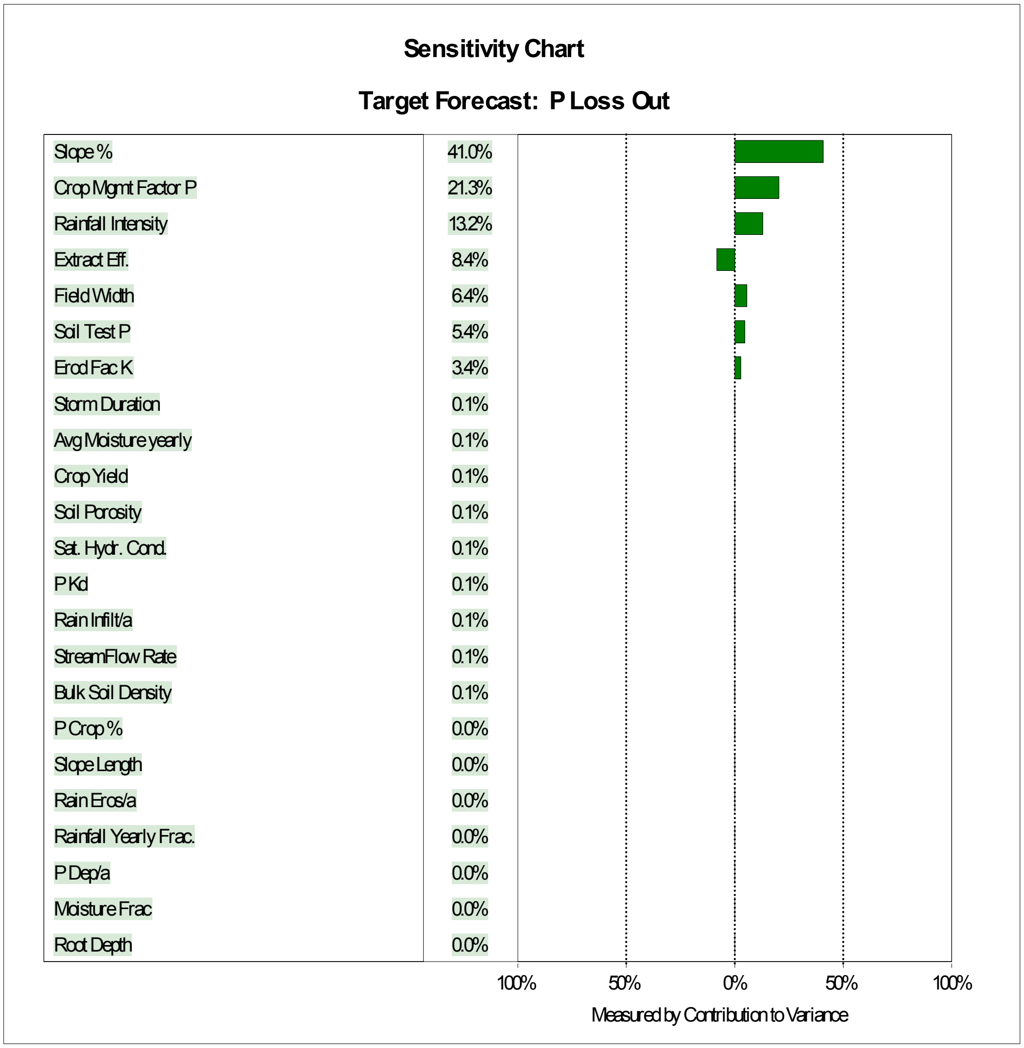
| | |
|---|---|
| Mean | 0.35 |
| Standard Dev. | 0.05 |

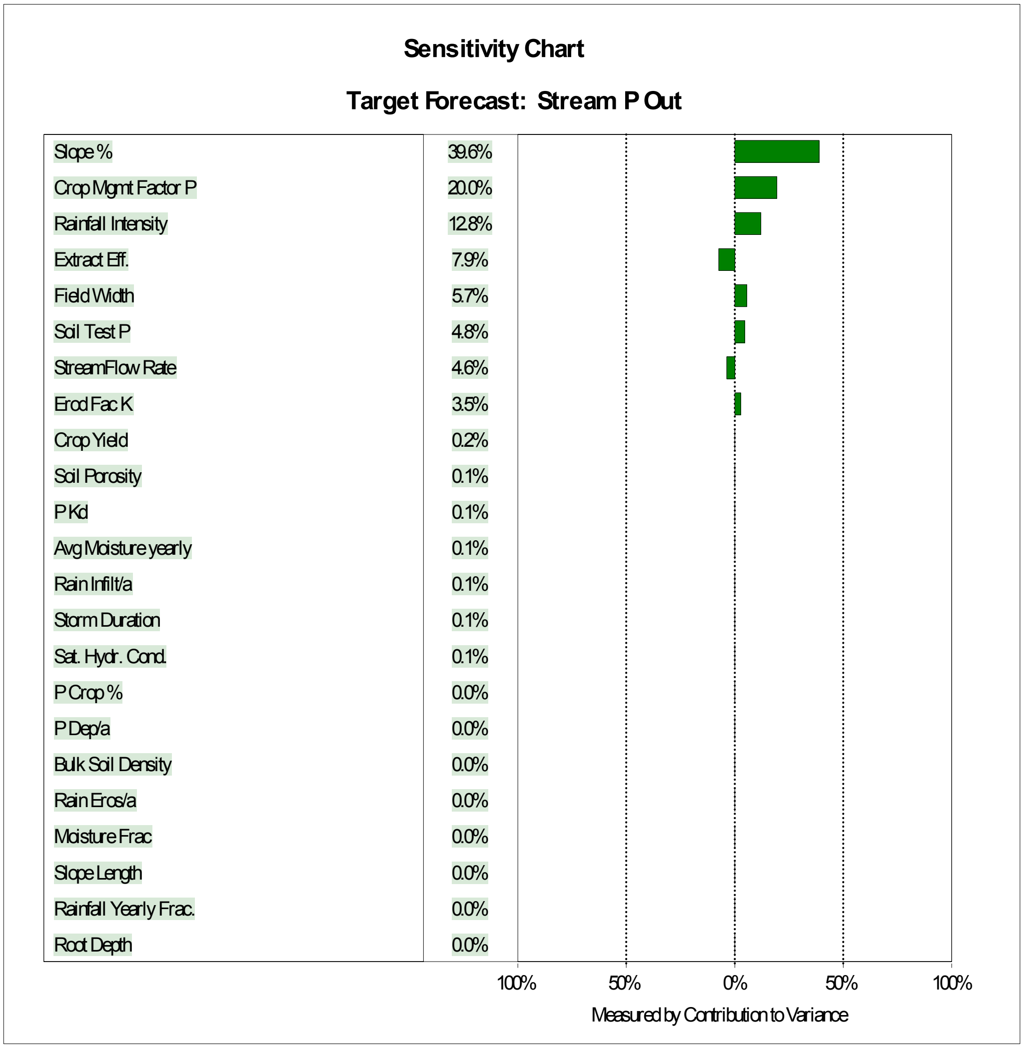
Selected range is from 0.20 to 0.50

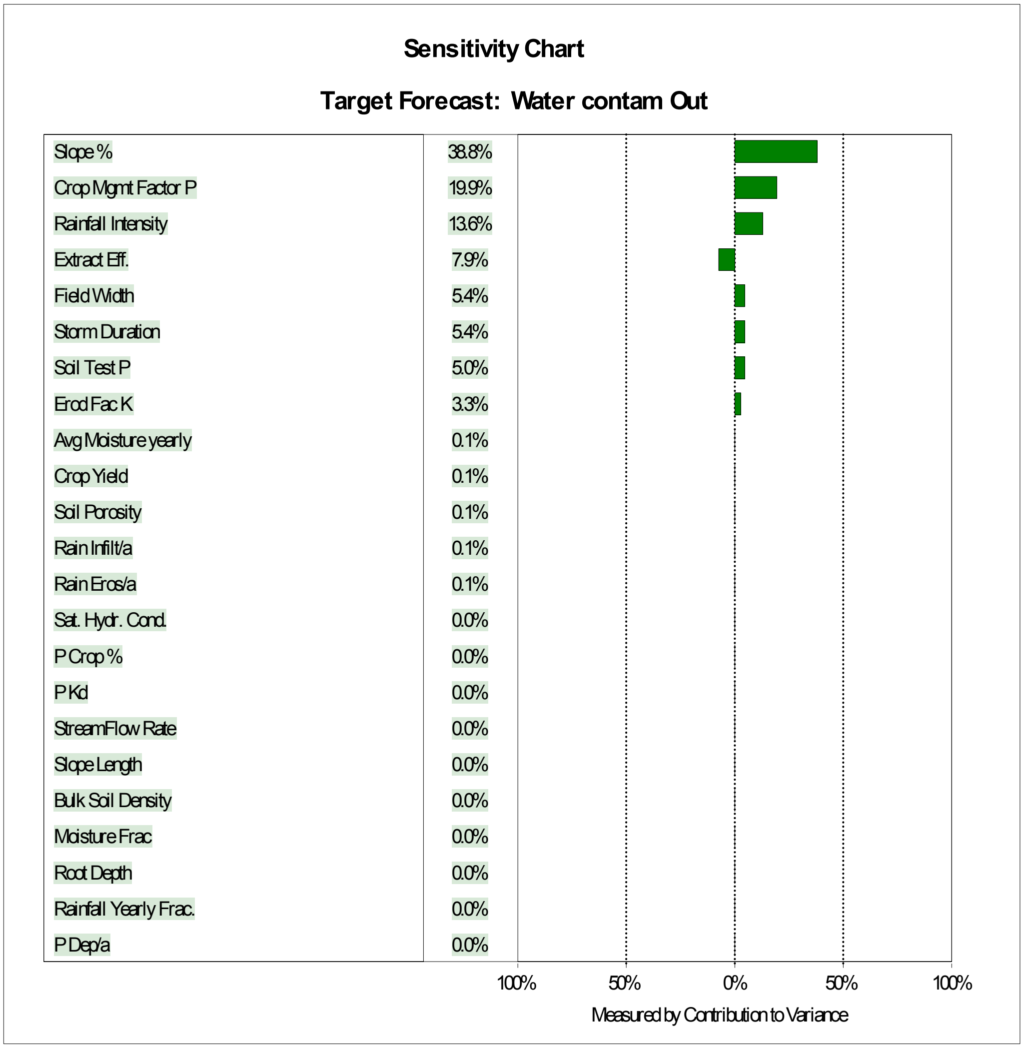


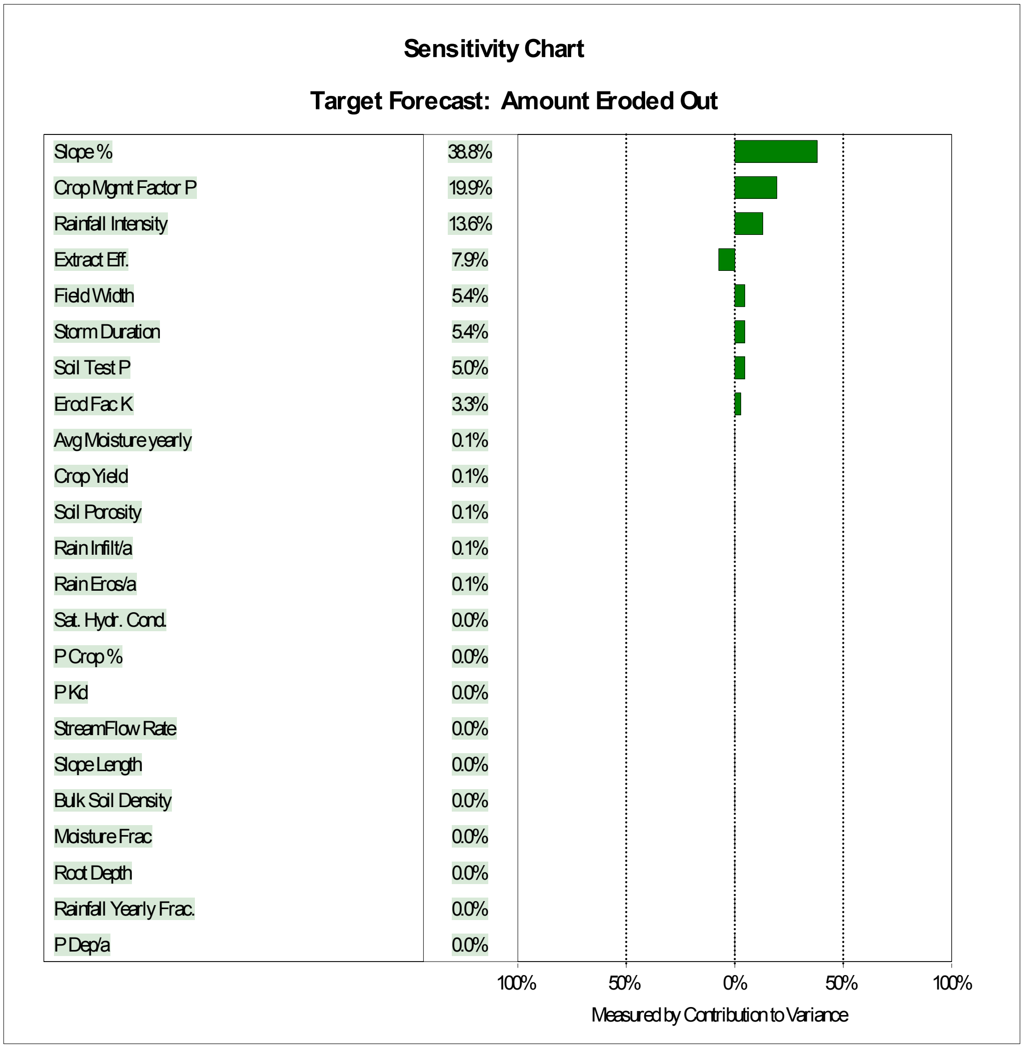
The data presented here are the input parameter sensitivity charts as produced by the CB software following the completion of 2000 simulation runs using the input data presented above. The data are summarized in Table 2 in the text.


Sensitivity Chart
Target Forecast: Soil Eroded Out
Slope % 47.0%
Crop Mgmt Factor P 22.9%
Rainfall Intensity 17.7%
Storm Duration 7.6%
Erod Fac K 3.6%
P Crop % 0.3%
Soil Porosity 0.2%
Rain Infilt/a 0.1%
P Kd 0.1%
Avg Moisture yearly 0.1%
Bulk Soil Density 0.1%
Crop Yield 0.1%
Rain Eros/a 0.1%
Moisture Frac 0.1%
P Dep/a 0.0%
Slope Length 0.0%
Root Depth 0.0%
Sat. Hydr. Cond. 0.0%
Field Width 0.0%
Extract Eff. 0.0%
StreamFlow Rate 0.0%
Soil Test P 0.0%
Rainfall Yearly Frac. 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance

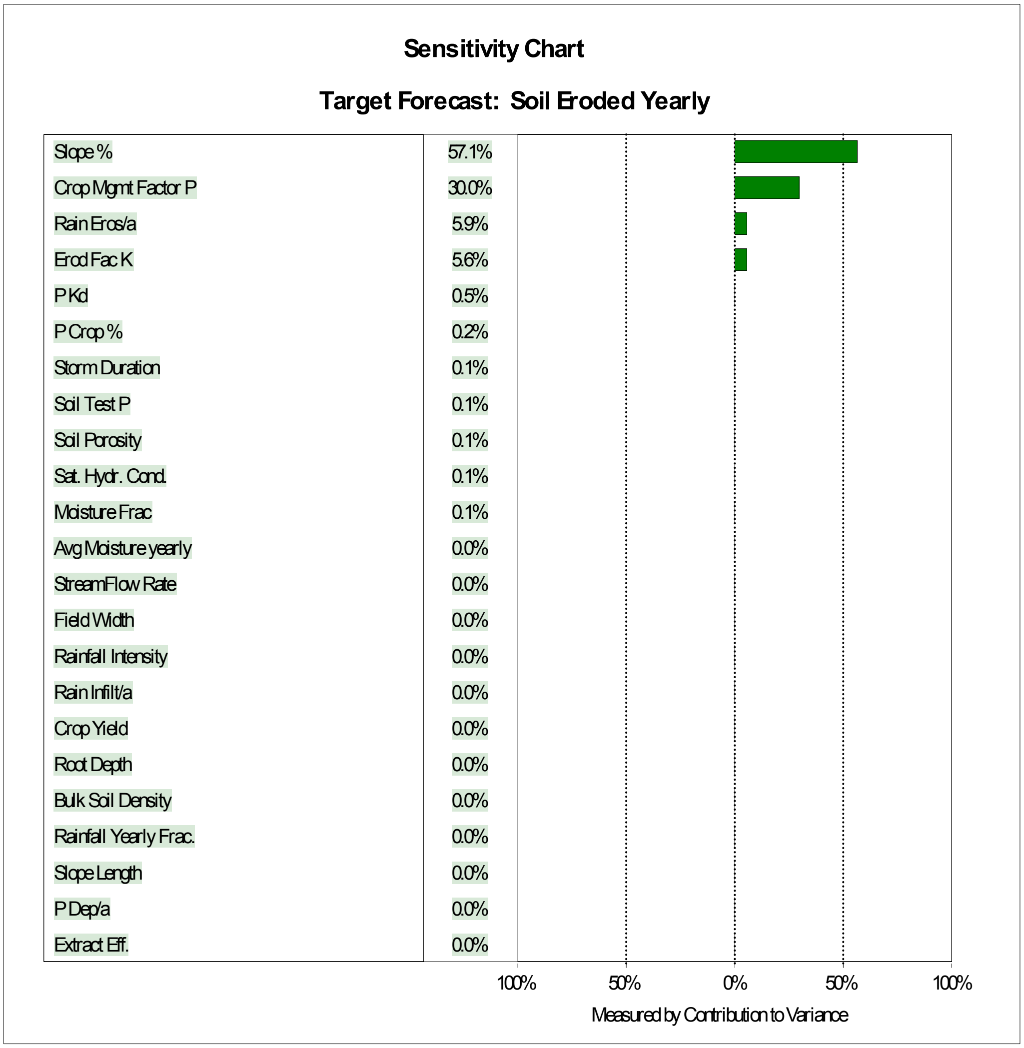

Sensitivity Chart
Target Forecast: P Loss Out
Slope % 41.0%
Crop Mgmt Factor P 21.3%
Rainfall Intensity 13.2%
Extract Eff. 8.4%
Field Width 6.4%
Soil Test P 5.4%
Erod Fac K 3.4%
Storm Duration 0.1%
Avg Moisture yearly 0.1%
Crop Yield 0.1%
Soil Porosity 0.1%
Sat. Hydr. Cond. 0.1%
P Kd 0.1%
Rain Infilt/a 0.1%
StreamFlow Rate 0.1%
Bulk Soil Density 0.1%
P Crop % 0.0%
Slope Length 0.0%
Rain Eros/a 0.0%
Rainfall Yearly Frac. 0.0%
P Dep/a 0.0%
Moisture Frac 0.0%
Root Depth 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance

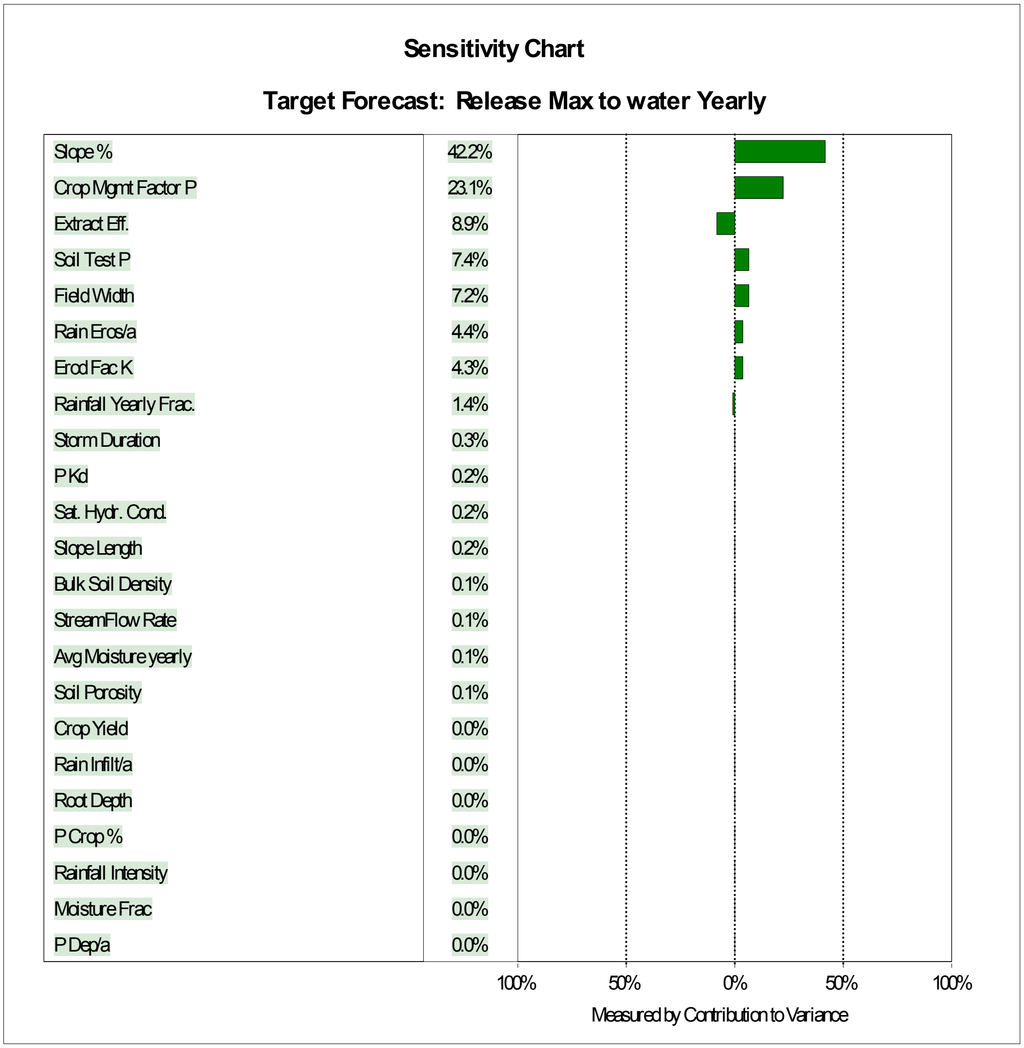

Sensitivity Chart
Target Forecast: Stream P Out
Slope %
39.6%
Crop Mgmt Factor P
20.0%
Rainfall Intensity
12.8%
Extract Eff.
7.9%
Field Width
5.7%
Soil Test P
4.8%
StreamFlow Rate
4.6%
Erod Fac K
3.5%
Crop Yield
0.2%
Soil Porosity
0.1%
P Kd
0.1%
Avg Moisture yearly
0.1%
Rain Infilt/a
0.1%
Storm Duration
0.1%
Sat. Hydr. Cond.
0.1%
P Crop %
0.0%
P Dep/a
0.0%
Bulk Soil Density
0.0%
Rain Eros/a
0.0%
Moisture Frac
0.0%
Slope Length
0.0%
Rainfall Yearly Frac.
0.0%
Root Depth
0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance

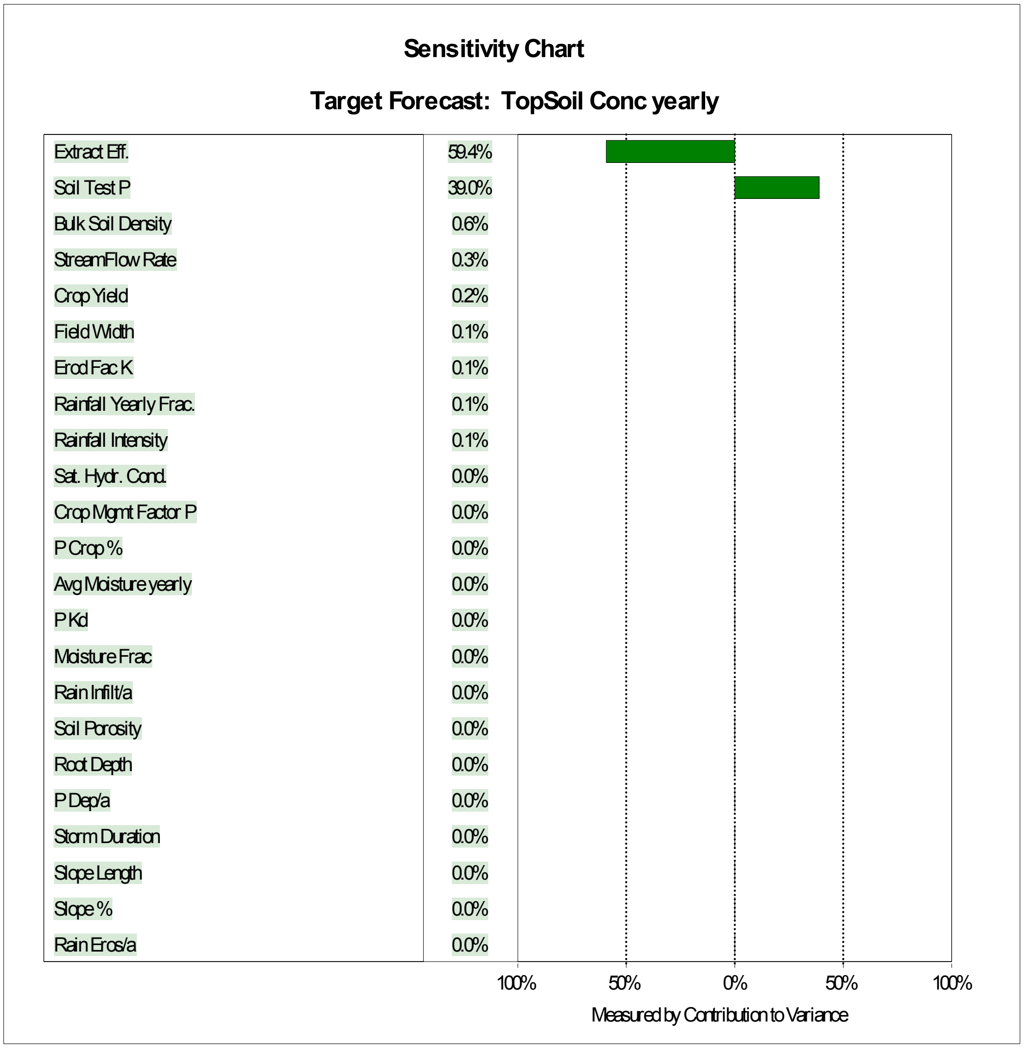

Sensitivity Chart
Target Forecast: Water contam Out
Slope % 38.8%
Crop Mgmt Factor P 19.9%
Rainfall Intensity 13.6%
Extract Eff. 7.9%
Field Width 5.4%
Storm Duration 5.4%
Soil Test P 5.0%
Erod Fac K 3.3%
Avg Moisture yearly 0.1%
Crop Yield 0.1%
Soil Porosity 0.1%
Rain Infilt/a 0.1%
Rain Eros/a 0.1%
Sat. Hydr. Cond. 0.0%
P Crop % 0.0%
P Kd 0.0%
StreamFlow Rate 0.0%
Slope Length 0.0%
Bulk Soil Density 0.0%
Moisture Frac 0.0%
Root Depth 0.0%
Rainfall Yearly Frac. 0.0%
P Dep/a 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance


Sensitivity Chart
Target Forecast: Amount Eroded Out
Slope % 38.8%
Crop Mgmt Factor P 19.9%
Rainfall Intensity 13.6%
Extract Eff. 7.9%
Field Width 5.4%
Storm Duration 5.4%
Soil Test P 5.0%
Erod Fac K 3.3%
Avg Moisture yearly 0.1%
Crop Yield 0.1%
Soil Porosity 0.1%
Rain Infilt/a 0.1%
Rain Eros/a 0.1%
Sat. Hydr. Cond. 0.0%
P Crop % 0.0%
P Kd 0.0%
StreamFlow Rate 0.0%
Slope Length 0.0%
Bulk Soil Density 0.0%
Moisture Frac 0.0%
Root Depth 0.0%
Rainfall Yearly Frac. 0.0%
P Dep/a 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance


Sensitivity Chart
Target Forecast: Final Soil Conc P
Extract Eff. 59.8%
Soil Test P 39.2%
StreamFlow Rate 0.3%
Crop Yield 0.2%
Field Width 0.1%
Erod Fac K 0.1%
Rainfall Yearly Frac. 0.1%
Bulk Soil Density 0.1%
Crop Mgmt Factor P 0.0%
Rainfall Intensity 0.0%
P Crop % 0.0%
Sat. Hydr. Cond. 0.0%
P Kd 0.0%
Moisture Frac 0.0%
Avg Moisture yearly 0.0%
Root Depth 0.0%
P Dep/a 0.0%
Rain Infilt/a 0.0%
Soil Porosity 0.0%
Storm Duration 0.0%
Slope % 0.0%
Slope Length 0.0%
Rain Eros/a 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance


Sensitivity Chart
Target Forecast: Soil Eroded Yearly
Slope % 57.1%
Crop Mgmt Factor P 30.0%
Rain Eros/a 5.9%
Erod Fac K 5.6%
P Kd 0.5%
P Crop % 0.2%
Storm Duration 0.1%
Soil Test P 0.1%
Soil Porosity 0.1%
Sat. Hydr. Cond. 0.1%
Moisture Frac 0.1%
Avg Moisture yearly 0.0%
StreamFlow Rate 0.0%
Field Width 0.0%
Rainfall Intensity 0.0%
Rain Infilt/a 0.0%
Crop Yield 0.0%
Root Depth 0.0%
Bulk Soil Density 0.0%
Rainfall Yearly Frac. 0.0%
Slope Length 0.0%
P Dep/a 0.0%
Extract Eff. 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance


Sensitivity Chart
Target Forecast: Release Max to water Yearly
Slope % 42.2%
Crop Mgmt Factor P 23.1%
Extract Eff. 8.9%
Soil Test P 7.4%
Field Width 7.2%
Rain Eros/a 4.4%
Erod Fac K 4.3%
Rainfall Yearly Frac. 1.4%
Storm Duration 0.3%
P Kd 0.2%
Sat. Hydr. Cond. 0.2%
Slope Length 0.2%
Bulk Soil Density 0.1%
StreamFlow Rate 0.1%
Avg Moisture yearly 0.1%
Soil Porosity 0.1%
Crop Yield 0.0%
Rain Infilt/a 0.0%
Root Depth 0.0%
P Crop % 0.0%
Rainfall Intensity 0.0%
Moisture Frac 0.0%
P Dep/a 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance


Sensitivity Chart
Target Forecast: TopSoil Conc yearly
Extract Eff. 59.4%
Soil Test P 39.0%
Bulk Soil Density 0.6%
StreamFlow Rate 0.3%
Crop Yield 0.2%
Field Width 0.1%
Erod Fac K 0.1%
Rainfall Yearly Frac. 0.1%
Rainfall Intensity 0.1%
Sat. Hydr. Cond. 0.0%
Crop Mgmt Factor P 0.0%
P Crop % 0.0%
Avg Moisture yearly 0.0%
P Kd 0.0%
Moisture Frac 0.0%
Rain Infilt/a 0.0%
Soil Porosity 0.0%
Root Depth 0.0%
P Dep/a 0.0%
Storm Duration 0.0%
Slope Length 0.0%
Slope % 0.0%
Rain Eros/a 0.0%
100%
50%
0%
50%
100%
Measured by Contribution to Variance

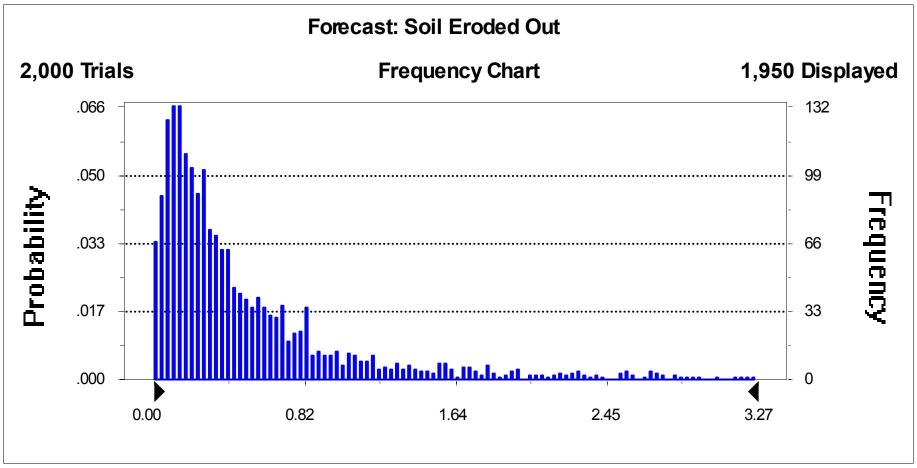
# Forecast Statistics

**Forecast: Soil Eroded Out** **Event - Cell: H52**

**Summary:**
Display Range is from 0.00 to 3.27
Entire Range is from 0.00 to 14.19
After 2,000 Trials, the Std. Error of the Mean is 0.02

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 0.62 |
| Median | 0.32 |
| Mode | --- |
| Standard Deviation | 1.03 |
| Variance | 1.07 |
| Skewness | 6.21 |
| Kurtosis | 60.27 |
| Coeff. of Variability | 1.67 |
| Range Minimum | 0.00 |
| Range Maximum | 14.19 |
| Range Width | 14.18 |
| Mean Std. Error | 0.02 |

| Percentile | Value |
|---|---|
| 0% | 0.00 |
| 10% | 0.08 |
| 20% | 0.13 |
| 30% | 0.18 |
| 40% | 0.25 |
| 50% | 0.32 |
| 60% | 0.42 |
| 70% | 0.58 |
| 80% | 0.80 |
| 90% | 1.32 |
| 100% | 14.19 |

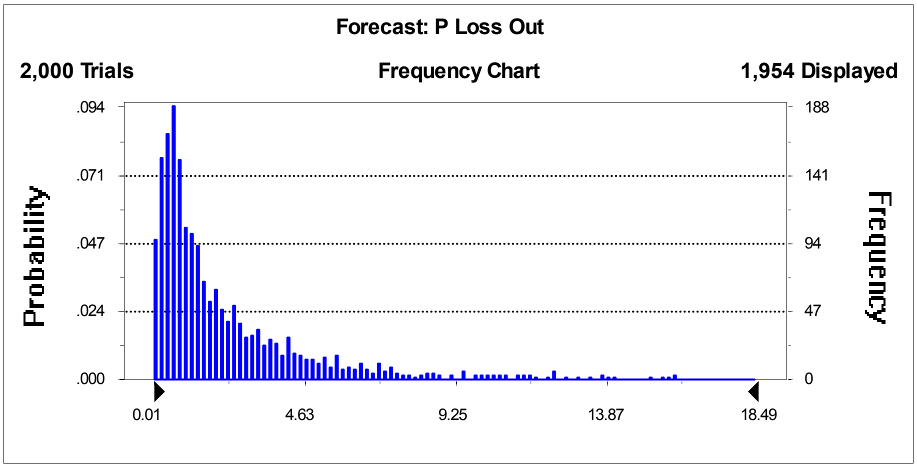


**Forecast: P Loss Out** **Event - Cell: H53**

**Summary:**
Display Range is from 0.01 to 18.49
Entire Range is from 0.01 to 93.89
After 2,000 Trials, the Std. Error of the Mean is 0.13

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 3.10 |
| Median | 1.38 |
| Mode | --- |
| Standard Deviation | 5.95 |
| Variance | 35.41 |
| Skewness | 7.06 |
| Kurtosis | 76.65 |
| Coeff. of Variability | 1.92 |
| Range Minimum | 0.01 |
| Range Maximum | 93.89 |
| Range Width | 93.88 |
| Mean Std. Error | 0.13 |

| Percentile | Value |
|---|---|
| 0% | 0.01 |
| 10% | 0.32 |
| 20% | 0.54 |
| 30% | 0.75 |
| 40% | 1.00 |
| 50% | 1.38 |
| 60% | 1.92 |
| 70% | 2.67 |
| 80% | 3.99 |
| 90% | 6.66 |
| 100% | 93.89 |



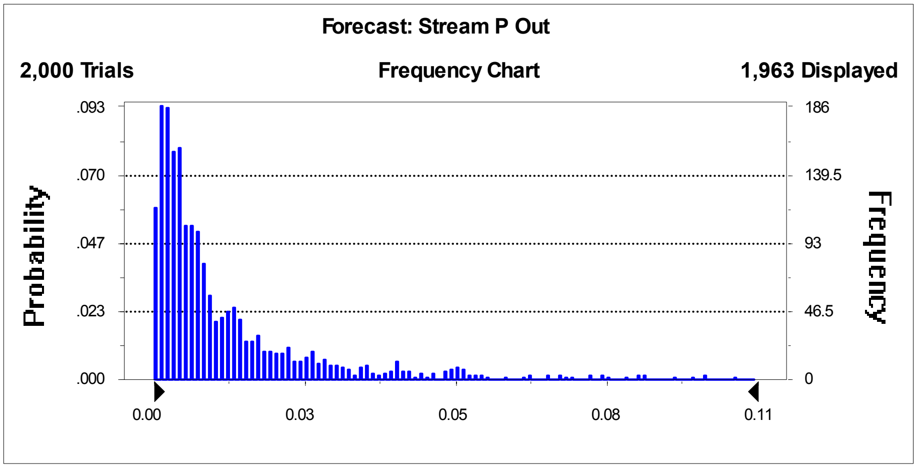
**Forecast: Stream P Out** **Event - Cell: H56**

**Summary:**

Display Range is from 0.00 to 0.11
Entire Range is from 0.00 to 0.55
After 2,000 Trials, the Std. Error of the Mean is 0.00

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 0.02 |
| Median | 0.01 |
| Mode | --- |
| Standard Deviation | 0.03 |
| Variance | 0.00 |
| Skewness | 7.23 |
| Kurtosis | 77.56 |
| Coeff. of Variability | 2.02 |
| Range Minimum | 0.00 |
| Range Maximum | 0.55 |
| Range Width | 0.55 |
| Mean Std. Error | 0.00 |

| Percentile | Value |
|---|---|
| 0% | 0.00 |
| 10% | 0.00 |
| 20% | 0.00 |
| 30% | 0.00 |
| 40% | 0.01 |
| 50% | 0.01 |
| 60% | 0.01 |
| 70% | 0.01 |
| 80% | 0.02 |
| 90% | 0.04 |
| 100% | 0.55 |

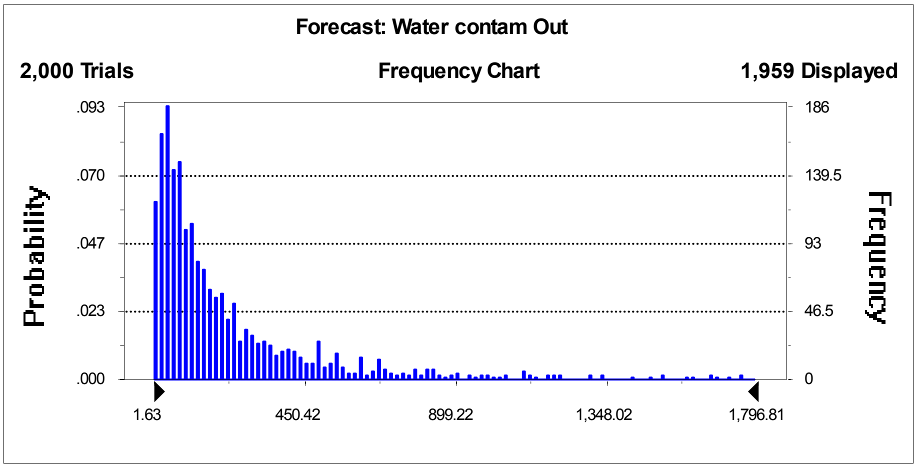


**Forecast: Water contam Out** **Event - Cell: H60**

**Summary:**
Display Range is from 1.63 to 1,796.81
Entire Range is from 1.63 to 13,304.19
After 2,000 Trials, the Std. Error of the Mean is 13.80

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 303.73 |
| Median | 131.64 |
| Mode | --- |
| Standard Deviation | 617.12 |
| Variance | 3.81E+05 |
| Skewness | 8.83 |
| Kurtosis | 132.74 |
| Coeff. of Variability | 2.03 |
| Range Minimum | 1.63 |
| Range Maximum | 13,304.19 |
| Range Width | 13,302.56 |
| Mean Std. Error | 13.80 |

| Percentile | Value |
|---|---|
| 0% | 1.63 |
| 10% | 29.36 |
| 20% | 47.70 |
| 30% | 70.41 |
| 40% | 95.83 |
| 50% | 131.64 |
| 60% | 183.57 |
| 70% | 252.06 |
| 80% | 393.50 |
| 90% | 670.18 |
| 100% | 13,304.19 |

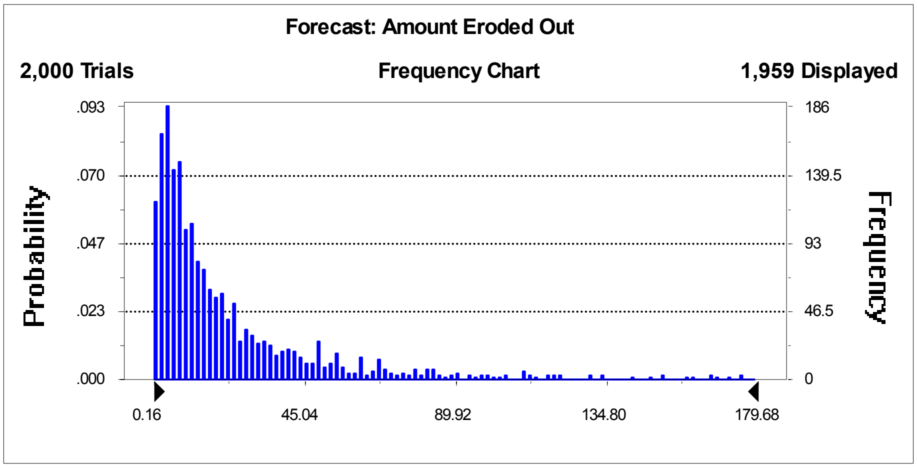


**Forecast: Amount Eroded Out** **Event - Cell: H69**

Summary:
Display Range is from 0.16 to 179.68
Entire Range is from 0.16 to 1,330.42
After 2,000 Trials, the Std. Error of the Mean is 1.38

| **Statistics:** | **Value** |
|---|---|
| Trials | 2000 |
| Mean | 30.37 |
| Median | 13.16 |
| Mode | --- |
| Standard Deviation | 61.71 |
| Variance | 3,808.31 |
| Skewness | 8.83 |
| Kurtosis | 132.74 |
| Coeff. of Variability | 2.03 |
| Range Minimum | 0.16 |
| Range Maximum | 1,330.42 |
| Range Width | 1,330.25 |
| Mean Std. Error | 1.38 |

| **Percentile** | **Value** |
|---|---|
| 0% | 0.16 |
| 10% | 2.94 |
| 20% | 4.77 |
| 30% | 7.04 |
| 40% | 9.58 |
| 50% | 13.16 |
| 60% | 18.36 |
| 70% | 25.21 |
| 80% | 39.35 |
| 90% | 67.02 |
| 100% | 1,330.42 |

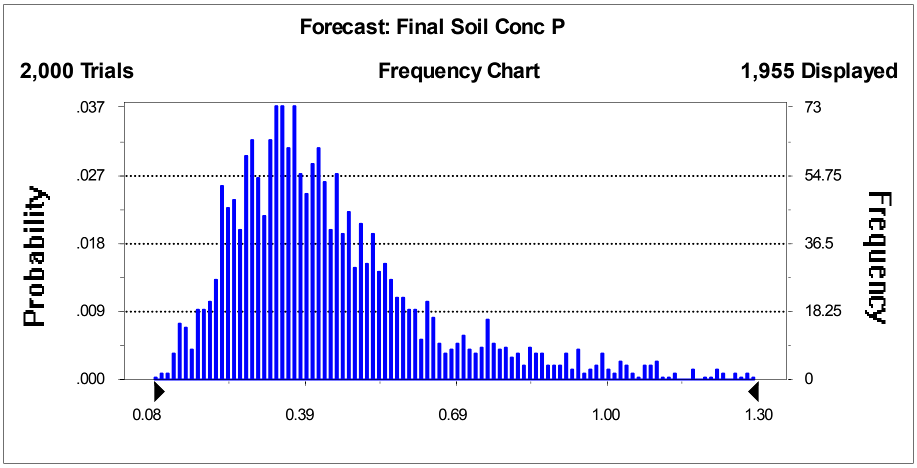


**Forecast: Final Soil Conc P** **Event - Cell: H73**

**Summary:**
Display Range is from 0.08 to 1.30
Entire Range is from 0.08 to 4.21
After 2,000 Trials, the Std. Error of the Mean is 0.01

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 0.47 |
| Median | 0.40 |
| Mode | --- |
| Standard Deviation | 0.31 |
| Variance | 0.10 |
| Skewness | 3.90 |
| Kurtosis | 28.89 |
| Coeff. of Variability | 0.66 |
| Range Minimum | 0.08 |
| Range Maximum | 4.21 |
| Range Width | 4.14 |
| Mean Std. Error | 0.01 |

| Percentile | Value |
|---|---|
| 0% | 0.08 |
| 10% | 0.23 |
| 20% | 0.28 |
| 30% | 0.32 |
| 40% | 0.36 |
| 50% | 0.40 |
| 60% | 0.45 |
| 70% | 0.50 |
| 80% | 0.58 |
| 90% | 0.77 |
| 100% | 4.21 |

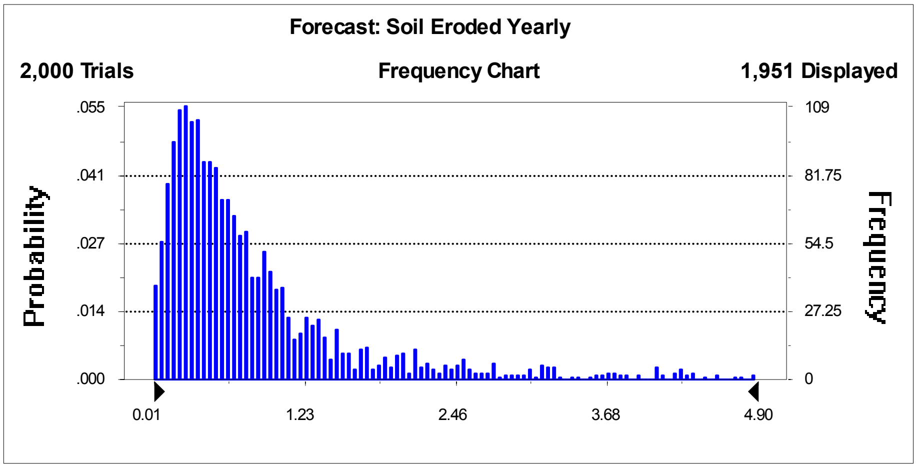


**Forecast: Soil Eroded** **Yearly - Cell: G30**

**Summary:**
Display Range is from 0.01 to 4.90
Entire Range is from 0.01 to 18.32
After 2,000 Trials, the Std. Error of the Mean is 0.03

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 1.01 |
| Median | 0.58 |
| Mode | --- |
| Standard Deviation | 1.53 |
| Variance | 2.35 |
| Skewness | 5.36 |
| Kurtosis | 43.32 |
| Coeff. of Variability | 1.52 |
| Range Minimum | 0.01 |
| Range Maximum | 18.32 |
| Range Width | 18.31 |
| Mean Std. Error | 0.03 |

| Percentile | Value |
|---|---|
| 0% | 0.01 |
| 10% | 0.17 |
| 20% | 0.27 |
| 30% | 0.36 |
| 40% | 0.46 |
| 50% | 0.58 |
| 60% | 0.73 |
| 70% | 0.93 |
| 80% | 1.26 |
| 90% | 2.10 |
| 100% | 18.32 |



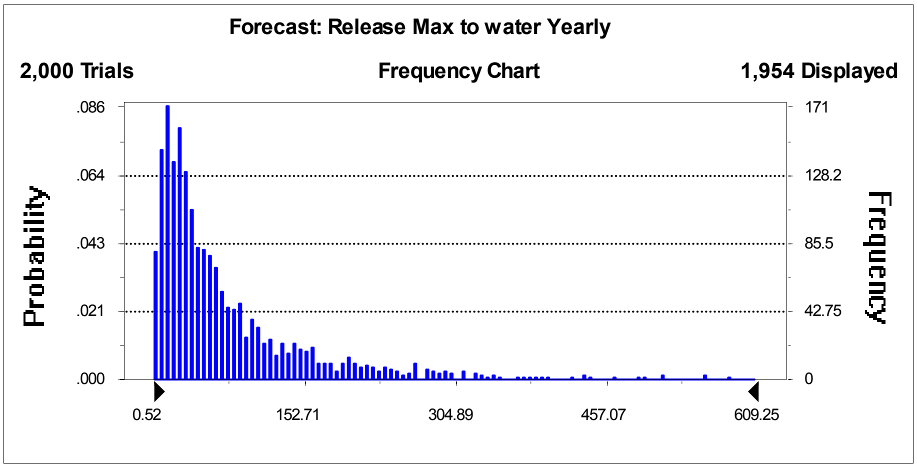
**Forecast: Release Max to water Yearly - Cell: G38**

**Summary:**

Display Range is from 0.52 to 609.25
Entire Range is from 0.52 to 3,356.32
After 2,000 Trials, the Std. Error of the Mean is 4.37

| Statistics: | Value |
|---|---|
| Trials | 2000 |
| Mean | 101.93 |
| Median | 47.82 |
| Mode | --- |
| Standard Deviation | 195.21 |
| Variance | 38,108.61 |
| Skewness | 7.50 |
| Kurtosis | 90.20 |
| Coeff. of Variability | 1.92 |
| Range Minimum | 0.52 |
| Range Maximum | 3,356.32 |
| Range Width | 3,355.80 |
| Mean Std. Error | 4.37 |

| Percentile | Value |
|---|---|
| 0% | 0.52 |
| 10% | 11.88 |
| 20% | 19.02 |
| 30% | 27.24 |
| 40% | 35.76 |
| 50% | 47.82 |
| 60% | 64.15 |
| 70% | 86.75 |
| 80% | 129.39 |
| 90% | 214.03 |
| 100% | 3,356.32 |

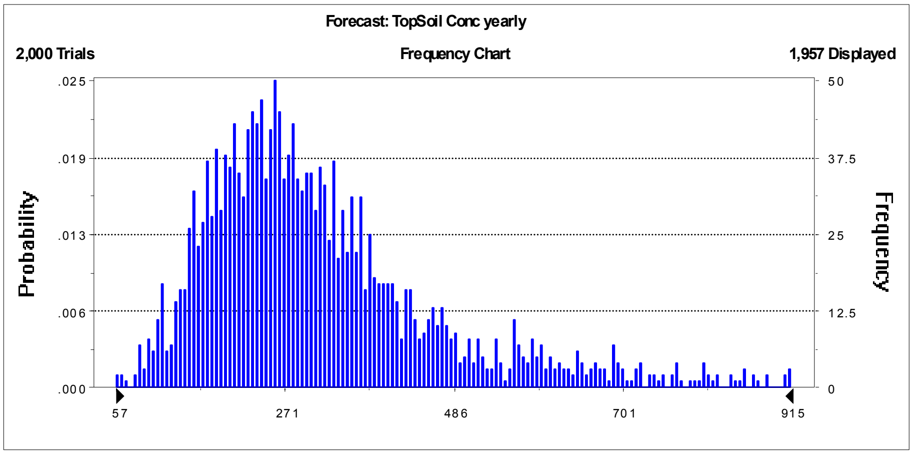


**Forecast: TopSoil Conc yearly** **Yearly - Cell: G42**

**Summary:**
Display Range is from 57 to 915
Entire Range is from 57 to 3182
After 2,000 Trials, the Std. Error of the Mean is 5

| **Statistics:** | **Value** |
|---|---|
| Trials | 2000 |
| Mean | 338 |
| Median | 285 |
| Mode | --- |
| Standard Deviation | 222 |
| Variance | 49318 |
| Skewness | 3.98 |
| Kurtosis | 30.83 |
| Coeff. of Variability | 0.66 |
| Range Minimum | 57 |
| Range Maximum | 3182 |
| Range Width | 3125 |
| Mean Std. Error | 4.97 |

| **Percentile** | **Value** |
|---|---|
| 0% | 57 |
| 10% | 166 |
| 20% | 201 |
| 30% | 231 |
| 40% | 257 |
| 50% | 285 |
| 60% | 319 |
| 70% | 359 |
| 80% | 419 |
| 90% | 563 |
| 100% | 3182 |



## APPENDIX D: Contacts Made to Ongoing Programs for Validation Data

Several researchers have been approached for data for validation of the NLM. Bob Betcher, Manitoba Conservation, was contacted to review and evaluate the data collected in their groundwater quality programs in the Interlake. Bob's study plots are not near waterways, however, one is close to a wetland area. This study does not appear useful to us, unless in future, a site was chosen closer to a stream or larger waterway.

Mr. Dwight Williamson, Manitoba Conservation, has shared data on surface water quality measurements taken at various locations throughout the province since the 1970's. This data on P in streams was used to pinpoint locations that may fulfill the scenario criteria listed above. We have compared animal population numbers and see that Southeastern Manitoba and the Interlake region have the highest populations. Using a map of the waterways in the province and locating streams that have few municipalities, the Rat River is an attractive possibility. One concern is the flatness of the terrain, however, many other desirable criteria are present.

We discussed the possibility of using data from the South Tobacco Creek Watershed with Mr. Bill Turner of the Deerwood Soil & Water Conservation Association. This is the best instrumented erosion facility in the province and possibly in western Canada. Bill has pointed out that Environment Canada does not have the resources to interpret and release the data. Ten years worth of water quality and meteorological data required to interpret the erosion data sit unavailable for use. Some of this data may be available through Manitoba Conservation. Wendy Ralley and David Green have access to some of the data that they collected themselves and would be willing to share this with us since it is already in interim reports.

Water quality studies are ongoing on several small waterways in SE Manitoba, where the animal populations are the highest or second highest after the Interlake Region.

Discussions with Andrew Dickson and John Ewanek of Manitoba Agriculture pointed us towards studies being carried out jointly between Manitoba Agriculture and Manitoba Conservation in the eastern and southeastern portion of the province. Manitoba Conservation data shows that the Marsh and Rat River and Joubert Creek have high levels of P. A study carried out in 2001 by Wendy Ralley (MB Con.) and Kira Rowat (MB Agr.) for the South East Soil Conservation Organization (SESCO) may contain useful data. Collaboration with SESCO this year (2002) to gather storm- or event-related information may be feasible. A meeting was held with SESCO and a collaborative approach discussed. We accompanied Stan Banasiak (Mb Agr.) on his river sampling tours of the Whitemouth, Joubert, Marsh and Rat Rivers on two occasions. The Whitemouth/Reynolds River is another possible watershed for data, Brent Reid is the contact for this study. Leon Clegg provided rainfall information.

Wendy Ralley sent us the latest report on long-term (30-year) trends in water quality in the province (Jones and Armstrong 2001). This report is helpful in directing the selection of a site for model validation. Other areas of interest were La Broquerie, however, here most of the manure goes on pasture rather than open cropland which tend to reduce erosion. However, the model could also simulate accounting for this. Hanover and de Salaberry areas may also be candidate areas for a model test, however, several large municipalities may direct P toward streams in that area.

The Killarney area might be another location for model testing, the landscape here is more rolling and the soils may be more susceptible to erosion. There is a large project on loading to the Assiniboine River from the Saskatchewan border to Brandon. This includes point and non-point sources and this is a livestock-related initiative (Mike Kagan is the contact).

We have discussed data possibilities and site selection for model testing with Curtis Cavers. His first thoughts were in the Red River Valley around Morris, Brunkild and Sperling as well as in southeastern Manitoba. He also pointed to the South Tobacco Creek work near Somerset and Miami. He also pointed to the Fannystelle, Starbuck Sanford area, also highlighting the LaSalle River. This was affected by flooding in 1997. This event may eliminate this area because of difficulties in delineating a large flooding event which tends to homogenize contamination. There are good farm co-operators in this area. Other possibilities are the Pembina and Cypress River areas. Manitoba Conservation water quality data shows some monitoring locations on the Pembina River and several on the Cypress River. The locations of these monitoring stations with respect to communities was reviewed.

A nutrient balance study (including the input and output of chemical fertilizers and manures, grains, meats, forages and dairy products) being carried out by DGH Engineering in four Manitoba Rural Municipalities may contain useful data once locations for model validation have been shortlisted. Doug Small was contacted to identify the four municipalities and discuss collaboration between this MLMMI-funded study and ours. Leo Nicolas provided us with data from the municipalities of Hanover and La Broquerie. This data was used along with information on the P levels in the Seine River.

Another piece of information to acquire, once the site(s) is located for validation, is water flow data and stream volume information (Rick Bowering, Surface Water Management Section). Bob Harrison (MB Con.) provided streamflow data for 2001 for all of the validation sites required and also provided some historic data for South Tobacco Creek. More supporting information that is required is soil type, manure loading, P soil concentration, etc.. This information was made available through SESCO and MB Agriculture.

# APPENDIX E: Calculation of the area possibly contributing P to the stream

**Whitemouth River Edge Characterization**
**Hwy 44 west of Whitemouth to Elma bridge**

| **Scale Factor** | 15840 One side | | | | |
|---|---|---|---|---|---|
| | **cm** | **km** | | **cm** | **km** |
| TOTAL | 85.8 | 13.59 | | | |
| **Forest east** | 2 | 0.32 | **Field Width east** | 3 | 0.48 |
| | 5 | 0.79 | | 7 | 1.11 |
| | 1 | 0.16 | | 1.2 | 0.19 |
| | 4.5 | 0.71 | | 4 | 0.63 |
| | 2.2 | 0.35 | | 4 | 0.63 |
| | 2 | 0.32 | | 2.2 | 0.35 |
| | 4 | 0.63 | | 3.8 | 0.60 |
| | 2 | 0.32 | | 2.5 | 0.40 |
| | 2.5 | 0.40 | | 6.2 | 0.98 |
| | 0.8 | 0.13 | | 3.5 | 0.55 |
| | 4 | 0.63 | Total | **37.4** | **5.92** |
| | 3 | 0.48 | Average | **3.74** | **0.59** |
| Total forest east | **33** | **5.23** | | | |
| **Agricultural east** | | **8.36** | | | |
| **Forest west** | 12 | 1.90 | **Field Width west** | 3 | 0.48 |
| | 2.2 | 0.35 | | 2.5 | 0.40 |
| | 3.5 | 0.55 | | 4 | 0.63 |
| | 4.5 | 0.71 | | 5.5 | 0.87 |
| | 14 | 2.22 | | 1.3 | 0.21 |
| | 2.4 | 0.38 | | 3 | 0.48 |
| | 3.2 | 0.51 | | 1.8 | 0.29 |
| | 2.2 | 0.35 | | 3.5 | 0.55 |
| | 3.7 | 0.59 | | 2.8 | 0.44 |
| | 1 | 0.16 | | 1 | 0.16 |
| | 1 | 0.16 | | 2.8 | 0.44 |
| | 1 | 0.16 | Total | **31.2** | **4.94** |
| Total forest west | **50.7** | 8.03 | Average | **2.84** | **0.45** |
| **Agricultural west** | | **5.56** | | | |
| | | | **Average field width (km)** | | **0.52** |

# Joubert Creek Characterization

## St-Pierre-Jolys, Hwy #59 to #403

**SCALE 15840**

| **Forest west** | | **Field Width west** | | **Forest east** | | **Field Width east** | |
|---|---|---|---|---|---|---|---|
| **cm** | **km** | **cm** | **km** | **cm** | **km** | **cm** | **km** |
| 320.9 | **50.83** | 5.5 | 0.87 | 319.8 | **50.66** | 9.5 | 1.50 |
| | | 3.4 | 0.54 | | | 2.1 | 0.33 |
| | | 1 | 0.16 | | | 1.2 | 0.19 |
| | | 10.7 | 1.69 | | | 5 | 0.79 |
| | | 0.7 | 0.11 | | | 3 | 0.48 |
| | | 0.5 | 0.08 | | | 1 | 0.16 |
| | | 1.4 | 0.22 | | | 2.2 | 0.35 |
| | | 1.1 | 0.17 | | | 1.7 | 0.27 |
| | | 2.5 | 0.40 | | | 9 | 1.43 |
| | | 1.1 | 0.17 | | | 6.7 | 1.06 |
| | | 2.5 | 0.40 | | | **41.4** | **6.56** |
| | | 2.3 | 0.36 | | | | |
| | | 1 | 0.16 | | | | |
| | | 1.4 | 0.22 | | | | |
| | | 5.2 | 0.82 | | | | |
| | | **40.3** | **6.38** | | | | |

# Seine River Characterization

## Ste. Anne, Hwy#12 to La Broquerie, Hwy#210

| **SCALE** | **15840** | | **56.8 km total** | | | | |
|---|---|---|---|---|---|---|---|
| **Forest west** | | **Field Width west** | | **Forest east** | | **Field Width east** | |
| **cm** | **km** | **cm** | **km** | **cm** | **km** | **cm** | **km** |
| 233.2 | **36.94** | 10.5 | 1.66 | 261.1 | **41.36** | 3.8 | 0.60 |
| | | 0.9 | 0.14 | | | 1.3 | 0.21 |
| | | 18.3 | 2.90 | | | 3.5 | 0.55 |
| | | 2.4 | 0.38 | | | 0.9 | 0.14 |
| | | 1.8 | 0.29 | | | 4.4 | 0.70 |
| | | 1 | 0.16 | | | 7.6 | 1.20 |
| | | 2.8 | 0.44 | | | 1.5 | 0.24 |
| | | 0.6 | 0.10 | | | 5.7 | 0.90 |
| | | 1.1 | 0.17 | | | 2.2 | 0.35 |
| | | 3.6 | 0.57 | | | 7.3 | 1.16 |
| | | 2.6 | 0.41 | | | 5.4 | 0.86 |
| | | 1.3 | 0.21 | | | 10.7 | 1.69 |
| | | 1.2 | 0.19 | | | 1.8 | 0.29 |
| | | 0.5 | 0.08 | | | 2.6 | 0.41 |
| | | 1 | 0.16 | | | 3.2 | 0.51 |
| | | 4.5 | 0.71 | | | 0.8 | 0.13 |
| | | 5.9 | 0.93 | | | 0.5 | 0.08 |
| | | 1.6 | 0.25 | | | 0.5 | 0.08 |
| | | 0.5 | 0.08 | | | 1.1 | 0.17 |
| | | 0.5 | 0.08 | | | 0.6 | 0.10 |
| | | 0.5 | 0.08 | | | 1.3 | 0.21 |
| | | 0.6 | 0.10 | | | 4.7 | 0.74 |
| | | 1.2 | 0.19 | | | 2.6 | 0.41 |
| | | 1 | 0.16 | | | 1 | 0.16 |
| | | 3.6 | 0.57 | | | 0.8 | 0.13 |
| | | 5.1 | 0.81 | | | 1.1 | 0.17 |
| | | 2 | 0.32 | | | 11.6 | 1.84 |
| | | 3.2 | 0.51 | | | 4.3 | 0.68 |
| | | 2.7 | 0.43 | | | 2.1 | 0.33 |
| | | 1.1 | 0.17 | | | 2.8 | 0.44 |
| | | 1.2 | 0.19 | | | **97.7** | **15.5** |
| | | 10.6 | 1.68 | | | | |
| | | 7.4 | 1.17 | | | | |
| | | 19.5 | 3.09 | | | | |
| | | 1 | 0.16 | | | | |
| | | 2.3 | 0.36 | | | | |
| | | **125.6** | **19.9** | | | | |