GISPLM User's Guide

LaPlatte River Phosphorus Modeling Project
Vermont Department of Environmental Conservation
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Model Description

GISPLM is tool for developing cost-effective strategies to reduce phosphorus loads from watersheds. A flow chart is shown in Figure 1. The watershed is defined as a number of sub-watersheds or segments linked in a branched network. Flows and phosphorus loads are evaluated using watershed features extracted from GIS, climatological data, and other local data. Phosphorus sources include runoff, farm animal populations, and point discharges. All calculations are controlled from the *Menu* page of the *GISPLM.WB3* workbook. The *Menu* also provides access to all input and output screens.

HYDRO, a compiled Fortran program, predicts surface runoff from pervious areas for a user-defined date interval (Figure 2) . Calculations of daily runoff resulting from rainfall and snowmelt are driven by daily precipitation and air temperature data. The algorithm and parameter estimates (Table 1) are taken from *GWLF* ("Generalized Watershed Loading Functions", Haith et al., 1992). *HYDRO* generates a table relating unit area surface runoff from pervious areas to SCS Runoff Curve Number. This table is later accessed by *LOADS* and the *GISPLM* workbook.

LOADS, another compiled Fortran program, calculates flows and phosphorus loads (Figure 3). The model reads watershed data extracted from GIS data bases and creates an index based upon segment (sub-watershed) number, model land use code, and existing BMP code. *LOADS* calculates the total flow and load for each value of the index, accounting for differences in soil group, soil origin, slope, and stream proximity. Runoff concentrations are specified as a function of land use categories based upon literature review. Table 2 lists the equations used to calculate flow and phosphorus export from each area. *LOADS* produces an output file containing the total area, flow, load, impervious area, curve number, and surface runoff for each index. This file is subsequently accessed by *GISPLM* workbook for subsequent processing.

The remaining calculations are performed within the *GISPLM* workbook. Flows and loads from each source category (runoff, animal units, point sources) are totaled by model segment. Loads are adjusted to account for existing phosphorus controls. Loads and flows are totaled by segment and routed downstream to the mouth of the watershed. Empirical models (Vollenweider, 1976; Walker, 1987) are used to estimate the retention of phosphorus in lakes or impoundments optionally located at the downstream ends of segments.

The user defines load control options for each source category. Non-point-source controls (BMP's) are defined for up to 12 land use categories. Estimates of load reduction efficiency, capital cost, and annual operating cost are specified for each BMP. Point-source controls for up to 3 treatment levels are defined based upon effluent phosphorus concentration and flow-dependent costs.

The user specifies a target load reduction as a percentage of the load predicted with no controls. *GISPLM* searches for the spatial allocation of controls which achieves the target reduction with minimum cost. Total annualized costs are minimized. Estimates of capital and operating costs are also generated. Allocations can be constrained to provide equal distribution of effort across source categories. Individual control measures can be specifically included or excluded.

Several graphical and tabular output formats are provided. These can be easily customized and manipulated within the workbook to suit project needs. Model results can be displayed spatially using *ArcView 3.0* software.

GISPLM is configured for application to the 137 km^2 LaPlatte River watershed in Vermont. Guidance for developing applications to other watersheds is provided.
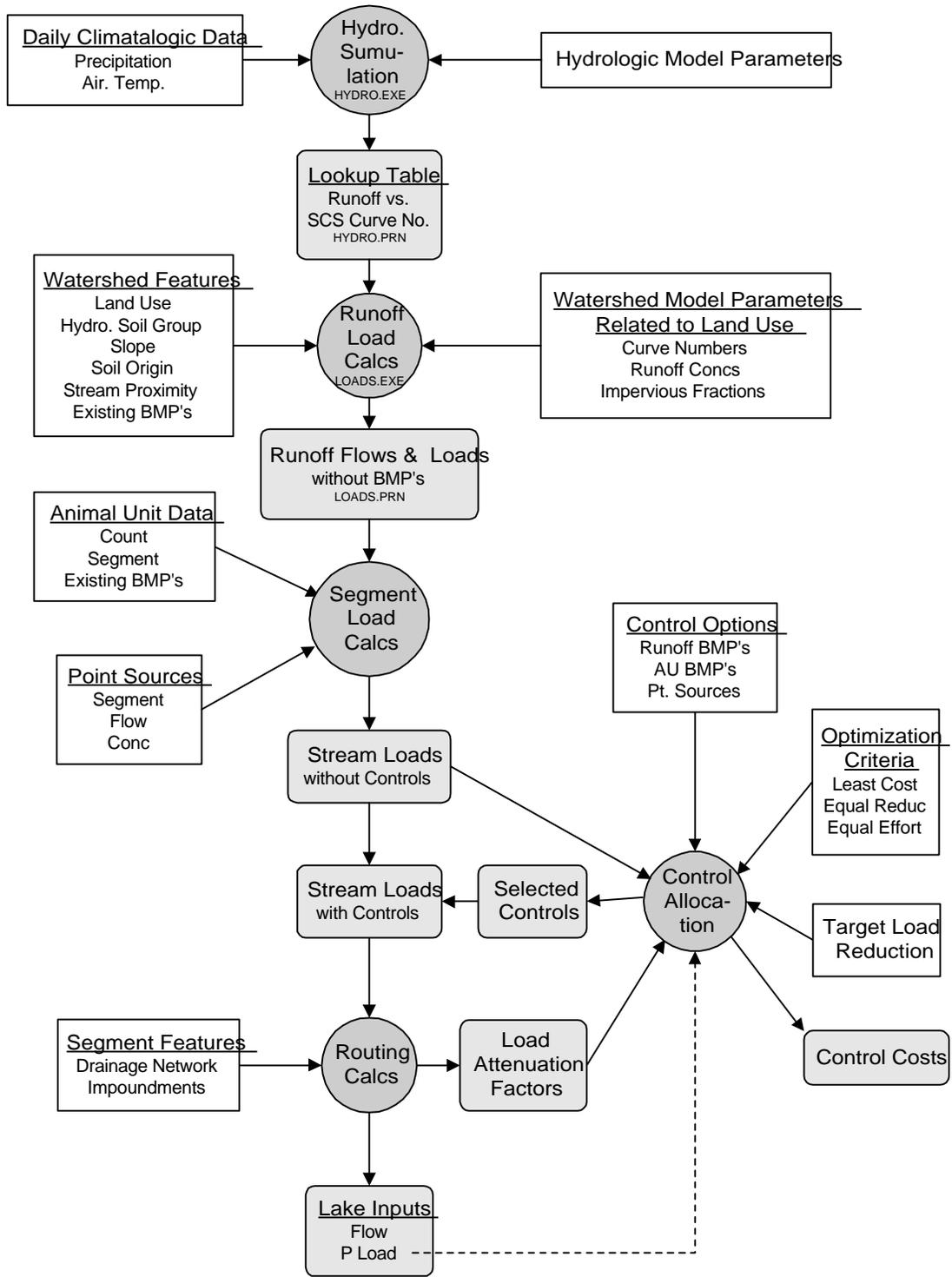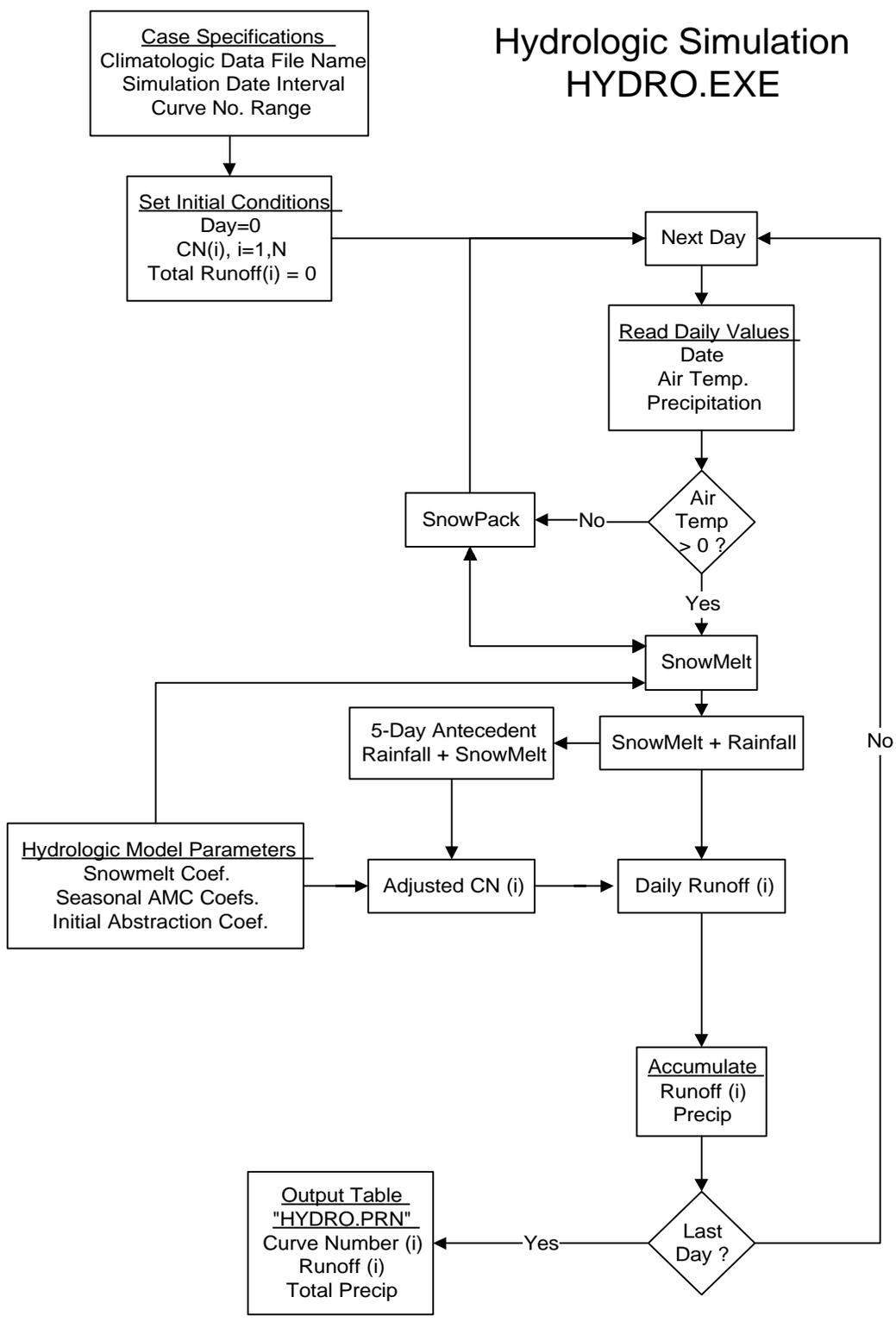
GISPLM Flowchart
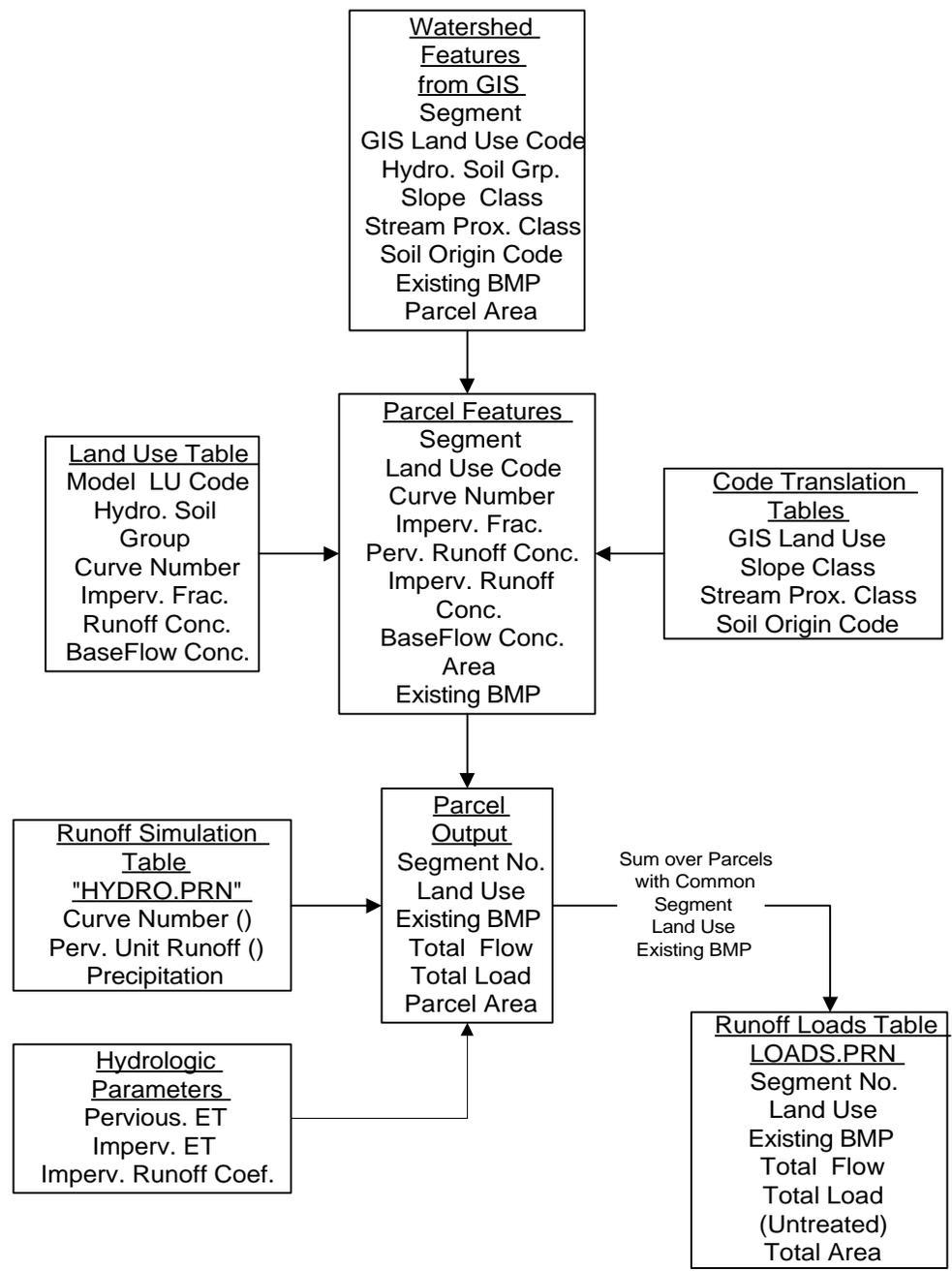

Figure 1

Hydrologic Simulation
HYDRO.EXE

Figure 2

Runoff Load Calculations
LOADS.EXE

Figure 3

Table 1 - Daily Runoff Simulation Algorithm from GWLF (Haith et al, 1992)

<u>**Variables:**</u>

Q_t	=	runoff on day t (cm)
T_t	=	mean air temperature on day t (deg-C)
P_t	=	total precipitation on day t (cm) (input)
X_t	=	snowfall on day t (cm)
Y_t	=	snowpack at end of day t (cm)
T_m	=	initial snowmelt temperature (= 0 deg C)
k	=	snowmelt coefficient (cm / deg c) (input = 0.45 cm/deg-c)
R_t	=	rainfall on day t (cm)
M_t	=	snowmelt on day t (cm)
S_t	=	maximum retention (cm)
f	=	initial interception parameter (dimensionless) (input = 0.2)
CN_t	=	curve number on day t (dimensionless)
A_t	=	5-day antecedent snowmelt + rainfall (cm)
CN_1	=	curve number for antecedent moisture condition 1
CN_2	=	curve number for antecedent moisture condition 2 (input)
CN_3	=	curve number for antecedent moisture condition 3
B_2	=	A_t value corresponding to AMC 2 (cm) (input for each season)
B_3	=	A_t value corresponding to AMC 3 (cm) (input for each season)

<u>**Precipitation:**</u>

For $T_t > 0$: $\qquad R_t = P_t, \ X_t = 0.$

For $T_t <= 0$: $\qquad R_t = 0, \ X_t = P_t$

<u>**Snowmelt & Snowpack:**</u>

$M_t = $ Minimum $(\ k \ (T_t - T_m), \ X_t + Y_{t-1})$

$Y_t = Y_{t-1} + X_t - M_t$

<u>**Runoff:**</u>

$Q_t = (R_t + M_t - f S_t)^2 / (R_t + M_t + (1-f) S_t)$

$S_t = 2.54 (1000 / CN_t - 10)$

<u>**Antecedent Rainfall + Snowmelt:**</u>

$A_t = $ Sum $[R_n + M_n],$ for $n = t-5$ to $t-1$

<u>**Curve Number Adjustment for Antecedent Moisture Condition:**</u>

$CN_1 = CN_2 / (2.334 - 0.01334 \ CN_2)$

$CN_3 = CN_2 / (0.04036 + .0059 \ CN_2)$

For $A_t <= B_2$: $\qquad CN_t = CN_1 + (CN_2 - CN_1) \ (A_t / B_2)$

For $A_t < = B_3$: $\qquad CN_t = CN_2 + (CN_3 - CN_2) \ (A_t - B_2) / (B_3 - B_2)$

For $A_t > B_3$: $\qquad CN_t = CN_3$

Notes:

Algorithm is started one month prior to simulation period to initilalize snowpack & antecedent rainfall/snowmelt

Table 2 - Water & Phosphorus Balance Equations

Unit Area Flow Terms (cm/yr):

TotalFlow = ImpervRunoff + PerviousRunoff + BaseFlow

ImpervRunoff = Precipitation x *ImpervRunoffCoefficient* x (1- *ImpervETCoef*) x <u>ImpervFraction</u>

PerviousRunoff = (1- <u>ImpervFraction</u>) x Function (AdjustedCurveNumber) , from HYDRO results

AdjustedCurveNumber = <u>CurveNumber</u>, adjusted for Slope *

TotalEvapotransp = (1-<u>ImpervFraction</u>) x *PerviousET* + <u>ImpervFraction</u> x Precipitation x ImpervETCoef

BaseFlow = Maximum (0, Precipitation - PerviousRunoff - ImpervRunoff - TotalEvapotransp)

Unit Area Phosphorus Load Terms in (cm - ppb /yr), without BMP's :

TotalLoad = ImpervLoad + PerviousLoad + BaseflowLoad

ImpervLoad = ImpervRunoff x <u>ImpervRunoffConcentration</u>

PerviousLoad = PerviousRunoff x <u>PerviousRunoffConcentration</u> x *SoilOriginFactor*

BaseFlowLoad = BaseFlow x <u>BaseflowConcentration</u>

AdjustedLoad = TotalLoad x *StreamProximityFactor*

Notes:

<u>Underlined</u> values are specified as a function of Land Use on the *LU_Codes* page of GISPLM.

Italicized values are specified on the *Inputs* page of GISPLM.

The above equations are applied to each record in the GIS Input File *LRINPUT.TXT*).

The output file *LOADS.PRN* contains total values for each unique combination of *Model Segment*, *Land Use Code*, and *Existing BMP Code*.

* Curve Number Adjustment for Slope (from SWRRB, Arnold & Williams, 1994):

$$CN'_2 \quad = \quad CN_2 + (CN_3 - CN_2) [1 - 2 \exp (- 13.86 \text{ slope})] / 3$$

where,

Slope = parcel slope (fraction)

CN_2, CN_3 defined in Table 1

Table 3 - Files on GISPLM Distribution Diskette

File	Format	Cl	Description	Output From	Input To
GISPLM.WB3	Quattro Pro V7	A	GISPLM Main Program		
LOADCALC.BAT	DOS Batch File	A	Runs HYDRO & LOADS; Called by GISPLM		
INIT.BAT	DOS Batch File	A	Clears Output Files; Called by GISPLM		
HYDRO.FOR	Fortran (Source)	D	Hydrologic Simulation		
HYDRO.EXE	Fortran (Compiled)	A	Hydrologic Simulation	HYDRO.FOR	
HYDRO.PRN	ASCII	C	Runoff vs. Curve Number Table	HYDRO	LOADS/GISPLM
BURLING.WB3	Quattro Pro V7	B	Burlington Airport Daily Climatologic Data		
BURLING.TXT	ASCII - Tab Delim.	A	Burlington Airport Daily Climatologic Data	BURLING.WB3	HYDRO
LOADS.FOR	Fortran (Source)	D	Calculation of Flows and Runoff Loads		
LOADS.EXE	Fortran (Compiled)	A	Calculation of Flows and Runoff Loads	LOADS.FOR	
LOADS.PRN	ASCII	C	Flows & Loads vs. Land Use & Segment	LOADS	GISPLM
COEFS.TXT	ASCII - Tab Delim.	C	Temporary File - Model Coefficients	GISPLM	HYDRO/LOADS
GIS.TXT	ASCII - Tab Delim.	C	Temporary File - GIS LU Code Translation	GISPLM	LOADS
LANDUSES.TXT	ASCII - Tab Delim.	C	" "; Land Use Codes & Parameter Values	GISPLM	LOADS
LPAU.WB3	Quattro Pro V7	B	Pre-Processing of LaPlatte Animal Unit Data	GIS	GISPLM
LPINPUT.WB3	Quattro Pro V7	B	Pre-Processing of LaPlatte GIS Input	GIS	
LPINPUT.TXT	ASCII - Tab Delimited	A	GIS Input Data	LPINPUT.WB3	LOADS
LPINPUT.DBF	Dbase III	A	GIS Input Data (Alternative Format)	LPINPUT.WB3	LOADS
LAPLATTE.APR	Arc View 3 Project	A	ArcView Project for Displaying Results		
SEGBAS.DBF	Dbase III	C	GIS Sub-Basin → Model Segment Codes		LAPLATTE.APR
OUTFILE.DBF	Dbase III	B	Model Results for GIS Display	GISPLM	LAPLATTE.APR

File Classes (Cl):
  A - Essential File (Minimum Requirement for Running Model)
  B - Pre-Processing of Source Data Files
  C - Output or Temporary File
  D - Documentation

Installing Program & Data Files

Table 3 describes data files contained on the distribution diskette(s). Hardware and software requirements for installing and running the software are as follows:

- A Pentium-Class PC (>=16 megabytes of RAM recommended)
- Windows 95 or NT Operating System
- QUATTRO PRO Version 7.0 (from Corel Word Perfect Office Suite)
- ArcView 3.0 (from ESRI, Inc., for spatial display of results)
- At Least 10 megabytes of free disk space

All files are in the compressed file GISPLM.ZIP. To install, copy this file to the root directory of your *C:* drive. Then enter:>*PKUNZIP -d GISPLM.ZIP.* This will place all files in the directory *C:\GISPLM.* while preserving directory structure for display of output using ArcView.
Start *QUATTRO PRO* & load the *GISPLM.WB3* workbook. Press the *Menu* button on the *Title* page.
 Enter the name of the disk directory at top of *Menu* page.   Save the workbook using a new file name to avoid destroying the original version.

Workbook Contents

The *GISPLM* workbook contains the following pages:

Page	Description	Group
Menu	Program Menu	Main
Title	Title Page	-
Index	Page Index	Main
Flowchart	Flowchart	Main
Inputs	Model Input Variables	Inputs
Animals	Animal P Load Calculations	Inputs
Runoff	Runoff Load Calculations	Inputs
Segments	Segment Input Data & Routing Calcs	Inputs
PointSources	Point Source Data & Calculations	Inputs
PS_Controls	Cost Estimation for Point Source Controls	Controls
BMP_Def	BMP Specifications	Controls
BMP_Au	Efficiency Calcs for BMP's Based upon Animal Units	Controls
BMP_Cost	Cost Data for BMP's	Controls
Allocate	Procedures for Allocating Source Controls	Controls
Alloc_Report	BMP Allocations - Summary by Land Use Categ & Program	Controls
Runoff_BMP_Report	Runoff BMP's	Controls
AU_BMP_Report	Animal Unit BMP's	Controls
PS_Control_Report	Point-Source Controls	Controls
LU_Codes	Land Use Codes & Parameters	Inputs
LU_Categ	Land Use Categories & Runoff Concentrations	Inputs
LU_GIS	Translation of GIS Land Use Codes	Inputs
Summary	Summary of Results	Outputs
ExportCoefs	Predicted Export Coefficients vs. Land Use	Outputs
CrossTabs	Cross Tabulations of Results	Outputs
GIS_Output	GIS Output File	Outputs
Hydro	Hydrologic Simulation Results	Outputs
Rep1	Report by Segment	Reports
Rep2	Report by Land Use Category	Reports
Rep3	Report by Region	Reports
Rep4	Report by Land Use Code	Reports
Rep5	Cross-Tab Area vs. Land Use Category	Reports
Rep6	Report by Segment, Agricultural Areas Only	Reports
Macros	Program Macros	-

A pop-up menu provides direct access to most pages. To activate the menu:
> Press *Navigate* button on the *Menu* page, or
> Enter *Cntrl-Shift-N*

Program Menu

Calculations are controlled from the *Menu* page of the *GISPLM.WB3* workbook:

```
G I S P L M  -  M e n u
```

Navigate	Set File Directory --> :\CHAMP\GISPLM
Edit Input Values	Problem Title 1991
	Date Range 910101 911231
	Climate Data File Burling.Txt
Run Model	GIS Data File LPINPUT.TXT

Runoff Records	207	Update Time	101	seconds
Farms	41	Convergence Test	-0	=? 0
Segments	13	Land Use Categories	11	
BMP's	10	BMP Programs	29	

Lake Inputs	Flow	Load	Reduc.	Conc	Cost
	hm3/yr	kg/yr	%	ppb	k$/yr
Untreated	43.5	6381	0%	147	0
Existing Controls	43.5	5830	9%	134	104
New Controls	43.5	5087	20%	117	190
Maximum Controls	43.5	3776	41%	87	1917
Target	43.5	5105	20%		

Buttons: **Allocate Controls**, **Produce Reports**, **Save GIS Output File**, **View Summary**, **View Graphs**

Hit 'Cntrl-Home' to Return to This Page   Hit 'Cntrl-Shift-N' to Access Other Pages

Button	**Function**
Navigate	activate pop-up menu providing access to all pages
Edit Input Values	switch to *Inputs* page containing basic input values
Run Model	update load calculations & all reports
Allocate Controls	switch to *Allocate* page & develop control strategies
Produce Reports	update all reports in the workbook
Save GIS Output File	save GIS output file for later access by ArcView
View Summary	switch to *Summary* page
View Graphs	switch to objects page to view output graphs

To access *the Menu* page from any location in the workbook:

- Press *a Menu* button (on several screens)
- Press *the Menu* tab at bottom of screen
- Enter *Cntrl-Home* or *Cntrl-Shift-M*, or
- Select *Main Menu* from the *Navigate Menu*

Running the Model

Calculations are controlled and workbook pages are accessed from the *Menu* page. Press the *Inputs* button to review basic input values. Press the *Navigate* button to review other input pages. To start the calculations, press the *Run Model* button. Calculations are controlled by a macro and

require 1-2 minutes. The status window in the lower right hand corner of the screen tracks progress of the calculations. Ensuing events include:

- A batch file 'INIT.BAT' is executed in a DOS window to clear output files from the previous model run.   If the window hangs on the screen, click the 'x' in the upper right hand corner to close it.

- Three input files for runoff load calculations are written to disk (from *Inputs*, *LU_Codes*, & *LU_GIS* Pages).

- External programs (*HYDRO* & *LOADS*) calculate runoff flows and loads in a DOS window. Runoff loads calculated in this step do not consider BMP's; these are considered in the *GISPLM* workbook.

- When activity stops, close the DOS window by clicking on the *x* in the upper right hand corner. This may occur automatically.   If you would like to make it occur automatically, click on the MS logo in the upper left corner of the *DOS* window.   Select *Properties*. Check the box *Close on Exit*.

- If the DOS window indicates an error, follow directions on screen. The macro will stop in this case. The *MESSAGE.LOG* file can be viewed to help track down error sources.

- If no errors occur in the *DOS* session, macro execution continues after the *DOS* window is closed. The window may hang on the screen (even after it is inactive) and will be cleared automatically when macro finishes.

- Output files from *HYDRO* & *LOADS* are read into the workbook. Routing calculations are performed to evaluate flow and phosphorus load at the mouth of the watershed. Output reports are generated.

When the macro is finished, a "*READY*" message appears in the lower right hand corner of the screen and the "*MACRO*" indicator is turned off.

If the message "*All Sheets are not Updated..*" appears at the top of the screen, press *Generate Reports* button. If the message persists, you have a problem of some sort in one or more of the input files or pages.

The user must press *Run Model* again after modifying any of the following pages:

> *Inputs*   *LU_Codes*   *LU_GIS* *LU_Categ*

Press the *Output Summary* button to see a summary of results.

Press the *Allocate Controls* button to develop strategies using the procedures described below. Once the desired allocation has been developed, return to *Menu.*

Press the *Produce Reports* button to update all output tables in the spreadsheet.

Press the *Navigate* button to view model output pages.

Press the *View Graphs* button to view output graphs. To return to the *Menu*, press *Cntrl-Home*. Press *Create GIS Output File* to generate an file which can be displayed using ArcView 3.0 and the supplied project file.

Calibrating the Model

Calibration requires observed values for flow and phosphorus load for the simulated time interval. Calibration is optional and should be attempted only by experienced water quality modelers.

Calibrate total flow to match the observed value by adjusting the evapotranspiration (ET) rate on the Inputs page.   The ET rate will influence the calculation of baseflow volumes and loads.   Total watershed loads will generally be insensitive to this parameter.

Calibrate loads by adjusting one or more of the following:

Page	Parameters
Inputs	runoff concentration scale factor (applied to all runoff loads)
BMP_AU	animal unit Load factors
LU_Categories	runoff concentrations
LU_Codes	curve numbers, runoff concentrations

A conservative approach to model calibration is suggested. Independent information should support adjustment of model coefficients to match observed loads.

Allocating Source Controls

Overview

The user supplies cost and effectiveness data for controls in the following categories:

Controls	Spatial Distribution	Defined on Pages
Point-Source Treatment	Individual Discharges	PS_Controls
Animal BMP's	Segment	BMP_Def, BMP_AU, BMP_Cost
Runoff BMP's	Segment & Land Use Code	BMP_Def, BMP_Cost

The model calculates loads and control costs for each of the following conditions:

- No Controls
- Existing Controls, as specified in GIS input file
- Maximum Controls, without regard to cost

The user specifies a target load reduction as a percentage of the load predicted with no controls. The model searches for the spatial allocation of controls which achieves the target load reduction with minimum cost. Total annualized costs are minimized. Estimates of capital and operating costs are also generated. Source categories include point sources, farm animal units, and runoff from each land use category.

The distribution of allocated controls across source categories can be shifted by applying scale factors to control costs in each category. The user can also constrain the allocation by forcing the exclusion or inclusion of specific controls.

Procedures are accessed by pressing buttons at the top of the *Allocate* page:

Allocate Source Controls	1991		**Case:**			20% Reduction	

Reset <-- recalc maximum & existing allocations
if bmp definitions are changed

Reports <-- generate final reports on allocations

Consider Existing BMP's ? 1 <--- 0 = no 1 = yes   View Graphs   Menu

New Point-Source Controls? 0 <--- 0 = no 1 = yes

Maximum Unit Cost ($/kg) —-> $165 Update <--- adjust to achieve target; set = 0 to evaluate existing controls only

Max U Cost Search Range—-> 0 500 Solve for Target Load <---- find maximum unit cost to achieve target

Allocation Strategy ----------> 0 <----- 0 = least cost, 1 = equal reduc%, 2 = equal rel. reduc%, 3 = equal rel cost%

Scale Factor for Max. Cost of Urban BMP's ------> 1.00

Scale Factor Search Range ---> 0 20 Solve for Distribution <------- find scale factor to achieve desired
distribution of agricultural vs. urban controls

Distribution of Controls

				Relative	Relative	Reduc	Cost	Unit Cost
Target Load Reduction -------->	20%	Category	Reduc%	Reduc%	Cost%	kg/yr	k$/yr	$/kg
New Treatment	20%	T Urban	0%	0%	0%	0	$0	$0
Existing Treatment	9%	T Agric	31%	86%	72%	1294	$190	$147
Maximum Treatment	41%	Point	0%	0%	0%	0	$0	$0

Button	**Function**
Reset	calculate results for existing & maximum controls
Reports	generate final reports on allocations
Update	develop new allocation for specified maximum unit cost
Solve for Target Load	solve for target load with specified cost scale factors
Solve for Distribution	solve for desired distribution of urban vs. agric controls (allocation strategy)
View Graphs	switch to objects page of workbook
Menu	return to main menu

Defining a Base Condition

Set the Maximum Unit Cost to 0.0 (Cell D10).   This value constrains the unit cost of new controls.

Set the Existing BMP Switch (*Consider Existing BMPs*, Cell D7):

    0   ignore existing BMP's (full optimization of new controls)
    1   consider existing BMP's.

Existing BMP's include runoff BMP's coded in the *LPINPUT* data file and Animal Unit BMP's listed on the *Animals* page. If the switch is set to 1, BMP's will remain in their prescribed locations, even if they do not conform to specified cost constraints.   If another BMP Program is found which conforms to the specified cost constraints and achieves a greater load reduction, the existing BMP will be replaced.

Set *Strategy Codes* for BMP's (*BMP_Def*) and point -source controls (*PS_Controls*, *Point_Sources* pages) to 1.0 (default value). Use of Strategy Codes is described in more detail below.

Press the *Run Model* button on *Menu* page. Model output will reflect a base condition (no new controls).

Defining BMP's

BMP data are defined on the following pages:

> *BMP_Def*   definitions of BMP's and BMP Programs
> *BMP_Au*   efficiency calculations for animal BMP's
> *BMP_Cost*   unit cost data

Two groups of BMP's are defined on the *BMP_Def* page:

> Runoff BMP's   costs specified on an area basis ($/ha/yr)
> Animal BMPs   costs specified on an animal unit basis ($/au/yr)

Individual BMP's are defined in the BMP Codes table (*BMP_Def*, Rows 5-16). A unique code, description, unit cost estimate, and load reduction estimate are assigned to each BMP. New BMP's may be added by inserting rows. Some of the entries in the BMP Codes table refer to values calculated on the BMP_Cost and BMP_AU pages.

The allocation process assigns a single BMP Program to each runoff or animal unit source. BMP Programs are defined in rows 20-59. A BMP Program is a combination of up to 5 individual BMP's. Up to 10 different BMP Programs may be defined for each land use category. Programs are identified as integers (1-10) appended to the category label. A program number 0 is also included in each source category to represent no BMPs.

The combined efficiency and cost of each program are calculated in Columns A-Q. Two methods are available for calculating the combined efficiency:

> *Additive*   BMP's are independent $R_c = R_1 + R_2 + R_3$
> *Series*   BMP's are sequential $R_c = 1 - (1-R_1)(1-R_2)(1-R_3)$

The user selects the method by assigning cells in Column L to formula cells in Column M or N. Otherwise, direct estimates of combined efficiency can be entered into Column L.

Rows may be inserted or deleted from the BMP Program table. Formulas in Columns A-Q should be copied to any newly inserted rows.

Defining Point-Source Controls

Point-source control options and costs are defined on the *PS_Controls* page. Up to three treatment levels may be defined. Unit costs are calculated as a function of flow. The methodology and parameter estimates are taken from the Lake Champlain Diagnostic-Feasibility Study (VTDEC & NYDEC, 1994).

Finding Least-Cost Allocation of Controls

Initializing

If BMP's or Point-Source Controls have been modified since the last time the model as been executed (via *Run Model* button on *Menu* page), press the *Initialize* button to recalculate results for existing and maximum controls. Results are summarized in Rows 79-123 of the *Allocate* page.

Set Point-Source Control Switch (*New Point Source Controls*, Cell D9):

> 0   Do not consider new Point-Source Controls

    1   Consider new Point-Source Controls

If the switch is set to 0, only non-point controls (BMP's) will be considered in developing new allocations. If the switch is set to 1, both non-point and point source controls will be considered.

Set the *Allocation Strategy Code* (D15) to 0 (Least Cost). This sets the *Maximum Unit Cost Scale Factors* for urban land use categories to 1.0 (Cells D35-37). Set all other scale factors in Cells D31-D44 to 1.0.

Enter a *Target Load Reduction* (D23) as a percent of the load without controls (Cell C49). If the target exceeds maximum reduction (C26), the target is not achievable with available BMP's and point-source control options.

Assign a case title for labeling output   (Cells I1..L1)

Manual (Trial & Error) Solution Method

Assign (guess) a *Maximum Unit Cost* in $/kg removed (D11).

Press the *Update* button to the right of Cell D11.

Compare the new load reduction with the target reduction (C23 vs. C24).

If the new reduction is too low (or high), increase (or decrease) the *Maximum Unit Cost* & repeat.

Stop when the calculated & target reductions agree to within an acceptable tolerance.

Automatic Solution Method

Assign a *Search Range* for *Maximum Unit Cost* likely to contain solution (D13-E13).

Press the *Solve for Target Load* button to the right of Cell D11.

Compare the new load reduction with the *Target* reduction (C23 vs. C24)

Possible outcomes are as follows:

        Agree   done, review results

        Disagree   solution does not exist or is outside of specified range
                        repeat above procedure specifying a higher *Search Range*

        Almost   repeat above procedure, specifying a narrower *Search Range*

Graphs on the lower right (F32.L41) show predicted and target loads over the specified *Search Range*. If the red (search) and green (target) lines cross, the Search Range contains the solution.

Finding Least-Cost Allocations with Equal Distribution of Effort

A detailed breakdown by source category is given in the *New Treatment* table (Rows 56-77). Agricultural source categories include *Animals*, runoff from cropland (*AgCrop*), and runoff from other agricultural areas (*AgOther*).   Urban source categories include *UrbLow*, *UrbHigh*, and *ComInd*. Load reductions and costs for Agricultural Nonpoint, Urban Nonpoint, & Point sources are listed in the Distribution of Controls Table (F22..I27).

A macro is provided for balancing the distribution of agricultural and urban non-point controls. The macro searches for the allocation which meets the target load reduction with minimum cost and with equal distribution of *Effort* between agricultural and urban source categories. *Effort* can be defined as percentage load reduction, relative load reduction (percent of maximum load reduction possible with the defined control programs), or relative cost (percent of maximum cost).

To balance agricultural vs. urban effort, select an *Allocation Strategy Code* (D15):

0	Least Cost, Unconstrained
1	Least Cost with Equal Percentage Load Reduction
2	Least Cost with Equal Relative Load Reduction
3	Least Cost with Equal Relative Cost

Assign a *Search Range* for *Maximum Unit Cost* likely to contain solution (D13-E13).

Assign a *Search Range* for the *Urban Cost Scale Factor* like to contain solution (D19-E19). Higher values of the factor will shift the distribution of effort towards urban sources. A starting range of 1 to 10 is suggested.

Press the *Solve for Distribution* button. The program searches for the *Maximum Unit Cost* (D11) and *the Scale Factor for Maximum Cost of Urban BMP's* (F17) which achieve the *Target Reduction* with least cost and with the desired distribution of *Effort*. The procedure is finished when *READY* appears in the lower left corner of the screen.

Compare the predicted load reduction with the *Target* (D23 vs. D24). Examine the *Distribution of Controls* table (F22..L27). If results do not agree to within acceptable tolerance, narrow the *Search Ranges* to more closely bracket the intermediate solutions and press *Solve for Distribution* again. Depending upon watershed, specified controls, and specified target load the desired distribution may not be achievable.

The *Cost Scale Factors* in (D31..D44) can also be manually adjusted to shift the distribution of effort among individual *Source Categories*. To increase (decrease) the load reduction for a given *Source Category*, increase (decrease) its *Cost Scale Factor*. The product of the *Scale Factor* & *Maximum Unit Cost* (D11) sets the *Maximum Unit Cost* for each category.

Strategy Codes

Strategy Codes can be set for each *BMP* and *BMP Program* (Page *BMP_Def*) to further constrain allocations:

0	do not use
1	use if control conforms to cost constraints (default)
2	always use (override cost constraints)

Valid *Strategy Codes* for individual BMP's (Rows 7-16 of Page *BMP_Def*) are 0 or 1. If 0 is selected, any references to the corresponding BMP in the *BMP Program* list are ignored.

Valid *Strategy Codes* for individual BMP Programs are 0,1, or 2. If a value of 2 is selected, the *BMP Program* is applied, regardless of cost, and all other BMP programs in the same *Land Use Category* are ignored. A *Strategy Code* of 2 can be set for only one *BMP Program* in a given *Land Use Category.*

BMP Programs referenced in the input GIS file are applied, regardless of *Strategy Code,* unless the *Existing BMP Switch* on the Allocate Page is set to 0.

Strategy Codes can also be set for each Point Source (Page *PointSources, 0 or 1*) & treatment level (Page *PS_Controls, 0,1 or 2*).

Special Conditions

During the allocation process, ties may be encountered in selecting controls for a specific source. Ties will occur when the unit costs of two or more alternative controls are identical. In these cases, the program providing the greatest load reduction is selected. If there is a tie in load reduction, the highest *BMP Program* (1 -10) or *Point-Source Treatment Level* (1-3) will be selected.

Reviewing Allocation Results

Distributions of load reductions and costs across source categories are summarized in three tables on the *Allocate* page:

New Treatment	Rows 56..	New Allocation
Existing Treatment	Rows 79..	No New Controls
Maximum Treatment	Rows 102..	No Cost Constraints

Press *the Reports* button on the *Allocate* page to update the following detailed reports, all of which refer to the *New Treatment*

Alloc_Report	summary of non-point controls by *BMP Program*
Runoff_BMP_Report	list of runoff BMP's
AU_BMP_Report	list of animal-unit BMP's
PS_Control_Report	list of new point-source controls

Press the *View Graphs* button to view allocation graphs

Press the *Generate Reports* button on the *Menu* Page to update all other reports in the workbook to reflect the new allocation.

Setting Up a New Project

Primary Data Sets

Primary data sets required for developing a new model application include the following:

- Daily climatological data, ASCII tab-delimited format, (e.g., *BURLING.TXT*, created from *BURLING.WB3* spreadsheet)
- Farm animal population data, pasted onto *Animals* page (e.g., copied from *LPAU.WB3* spreadsheet)
- GIS data , ASCII tab-delimited or DBF format (e.g., *LPINPUT.TXT* or *LPINPUT.DBF* created from *LPINPUT.WB3*)

Review *BURLING.WB3, LPAU.WB3,* & *LPINPUT.WB3* to see how files have been created for the LaPlatte. Tab-delimited files can be created from QUATTRO by saving or extracting with a *TXT* file extension. *DBF* files can be created from QUATTRO by saving them with a *DBF* extension.

Creating a GIS Input File

GIS Input files can be in either tab-delimited ASCII format (*LPINPUT.TXT*) or Dbase-III format (*LPINPUT.DBF*). The *LPINPUT.WB3* workbook shows how the GIS frequency table *LPFRE.DBF* created in ArcInfo has been manipulated to generate the model input files *LPINPUT.TXT* & *LPINPUT.DBF*. As discussed below, these intermediate file manipulations should not be necessary in future applications.

The *LPINPUT* file contains the following fields:

Variable Label	Description	Type	Range	Default
SEGMENT	Subwatershed Number	Integer	1-	required
LANDUSE	Land Use Code	Integer	1-9999	required
HDGRP	Hydrologic Soil Group	Char(1)	A,B,C,D,W,M	user-specified
ORIGIN	Soil Origin	Char(2)	L, VT, MT	user-specified
SLOPECLASS	Slope Class	Integer	1-5	user-specified
PRXCLASS	Stream Proximity Class	Integer	1-3	user-specified
AREA	Surface Area	Real	>0	required
BMP	BMP Program Code	Integer	0-10	0

Variable labels are specified on the *Input* page (Rows 67-74) to match fields in the *LPINPUT*. Case is not significant. Fields can occur in any order in the data file. The file does not have to be sorted in any particular way. Calculations will be slightly faster if the file if sorted by *SEGMENT, LANDUSE,* & *BMP Code*. There is no limit to file length.

Leave the *Variable Label* blank if it is not included in the GIS file. Default values specified on the *Inputs* page will be used if the *Variable Label* is blank or if a missing values are encountered in the data records. Labels & values for *SEGMENT, LANDUSE,* & *AREA* are required. Others are optional.

The *LU_GIS* table translates land use codes used in the GIS data base to land use codes used in the model. Each GIS code must be matched with one of the model land use codes listed in the *LU_Codes* table. The latter includes a wide range of functional land uses likely to be encountered and their associated parameter values. The *LU_Codes* table is designed to be fairly general, but can be modified to reflect site-specific conditions.

BMP Program Codes used in creating the GIS data file must be consistent with those defined on page *BMP_Def* of the *GISPLM* workbook.

Steps involved in reducing GIS data for the LaPlatte River are summarized below:

Program	File	Description	Records	Size (Kbytes)
	Many	Individual Coverages	Many	Large
ArcInfo	v			
	LPFINAL.DBF	Intersections	37679	9571
ArcInfo	v			
	LPFRE.DBF	Frequency Table	6906	1009
LPINPUT.WB3	v			
	LPINPUT.DBF	GISPLM Input file	6906	476
LOADS.EXE	v			
	LOADS.PRN	Loads & Flows	227	25
GISPLM.WB3				

If the original coverages conform with the specifications outlined above, *LOADS.EXE* can read the GIS intersected coverage (*LPFINAL.DBF*) or frequency table (*LPFRE.DBF*) directly. This eliminates intermediate processing steps. Using the *LPFINAL* (vs. *LPFRE*) file increases execution

time. Preprocessing was necessary for the LaPlatte because coverages were created before the model was developed.

LOADS.EXE creates an index value for each unique combination of *Segment*, *Model Land Use Code*, and existing *BMP Code*. *LOADS* is dimensioned to handle a maximum of 4000 index values. Only 227 are used in the LaPlatte case.

General Guidelines for Entering & Editing Data

The following guidelines should be followed when entering and editing data in the workbook:

- Areas for user input are blue and usually outlined.
- Do not insert, delete, or move columns.
- Be especially careful not to modify formats or structures of *Inputs*, *LU_Codes*, or *LU_GIS* pages.
- Do not alter the variable field labels at the top of any table (first line above the numbers).
- Rows within the tables can be deleted (except for the *LU_Categ* table, which as a fixed length of 12). Do not delete the *End* statement at the bottom of any table.
- If a table does not have an *End* statement and you want to remove the last row, do not delete the row, erase its contents instead using the *Edit Clear* command.
- To expand a table, insert new rows between the heading and the *' End* statement. Do not add new rows to a table by writing over the *'End'* statement.

If the model crashes, most likely it will because one or more of the named ranges in the workbook have been altered or lost. Create a fresh list of named ranges somewhere in the workbook and compare it with the one at the end of the Macro Page. You may be able to redefine the lost variables and resume, but you will probably have to restart with a fresh copy of *GISPLM.WB3* & re-enter your data.

Revising Model Input Pages

Most of the site-specific inputs in the *GISPLM* workbook are located on the following pages:

Inputs   especially, *Case Definitions* & *GIS File* blocks
Animals   paste or enter data into columns A-D
PointSources   paste or enter data into columns A-E
Segments   paste or enter data into columns A-I
LU_GIS   assign model land use codes in column C, referenced to *LU_Codes* page.

The remaining input tables contain more general information and are less likely to require revision when developing a new application:

LU_Categ   land use categories & associated P concentrations
LU_Codes   model land use codes, curve numbers, etc.
BMP_Def   potential BMP's & BMP programs for each land use category
BMP_Costs   BMP cost assumptions & calculations
BMP_AU   animal P export & BMP load reductions
PS_Controls   potential point-source controls & costs

A macro attempts to adjust report (output) table dimensions automatically if input table dimensions change to reflect a new case. Reports are located on pages *REP1-REP10*. The macro is not guaranteed to work. Report tables may require manual modification by an experienced spreadsheet programmer, following the table structures provided for the LaPlatte case.

If *Land Use Categories* are re-defined, the following have to be adjusted:

- *Categories* entered in the Model Land Use Table (*LU_Codes* page)
- Formulas for calculating agricultural & urban loads (*Allocate,* Rows 73-74, in red)
- *BMP Program* definitions (*BMP_Def*)

The *Summary* and *Cross-Tab* pages were created explicitly for the LaPlatte and will have to be revised manually for other projects. Revision will generally involve inserting, deleting rows, and/or copying rows to reflect revised table dimensions.

Entering Segment Data

Model segments (sub-watersheds) are defined on the *Segments* page. The first 10 columns are input fields. The rest of the columns are calculated fields. When the model is executed (*Run Models* button), formula cells will be copied automatically to the appropriate locations.

Segment entries include:

A	*Segment*	consecutive integers starting with 1, in downstream order
B	*Name*	identifier for subwatershed
C	*Region*	segments grouped into regions for summary of output
D	*Pond Area*	surface area of impoundment at downstream end of segment (ha)
E	*Pond Depth*	mean depth of impoundment (meters)
F	*Routing Formula*	rule for linking segments in downstream order
G	*Outflow Segment*	receives outflows from current segment
H	*Retention Model*	enter 1 for reservoir model, 2 for lake model
I	*Calibration Factor*	modifies predicted impoundment P retention (default = 1)
J	*BMP Switch*	allow (1) or prohibit(0) new runoff BMP's

Segments are linked in a one-dimensional, branched network defined by the user-specified *Outflow Segment* numbers (Col G) and *Routing Formulas* (Col F).

The *Routing Formula* for any segment calculates the sum of the *Outflow Segment Numbers* discharging into that segment. Enter 0 for a segment which receives no inflows from upstream segments. Otherwise, the formula for Segment X sums all cells in Col. G which equal X. For example, the formula for Segment 5 points to each cell in Col. G equaling 5. The last segment discharges to the Lake and is assigned an *Outflow Segment Number* of 0.

The appropriate number of segments depends upon the complexity of the watershed. There is no defined maximum for the number of segments. The upper limit would depend upon computer memory. Lakes or impoundments should be located at the downstream ends of segments. Since BMP's are allocated by segment and land use, segment definitions may influence control allocations. Segments should at least reflect major subwatersheds or hydrologic units. More detailed resolution may be appropriate if there is a clear spatial delineation of soil hydrologic groups, slope, animal unit density, or presence/absence of existing BMP's within a given subwatershed. Defining more segments will increase the spatial resolution of the model and increase the extent to which BMP allocations reflect local variations in soil characteristics, animal unit density, and existing BMP's. The size of the workbook will increase and computation speed will decrease as the number of segments is increased.

Options for estimating phosphorus retention in impoundments include:

1   Reservoir Model (Walker, 1987)

2   Lake Model (Vollenweider, 1976)

If present, impoundments are assumed to be located at the downstream ends of segments. If the specified *Pond Area*, *Pond Depth*, or *Calibration Factor* is 0, retention calculations are not performed**.**

Entering Animal Unit Data

Animal Unit data are entered in Columns A-E of the *Animals* page. The following fields are included:

A	*Farm*	for reference only; not used in calculations; should not be blank.
B	*Animal Units*	number of animal units associated with Farm (1 AU = 1000 lbs)
C	*Segment*	model segment or subwatershed number
D	*BMP Code*	integer (0-10) refers to BMP Programs defined on page BMP_Def.

The algorithm used for calculating animal P loads is described on the *BMP_AU* page. Animal P loads are evaluated at the *Segment* scale. Therefore, entering the total number of animal units in each *Segment* (instead of values for individual farms) would not influence the load calculations or BMP allocations. If animal unit data are entered on GIS, the required input data can be obtained by summing the animal units for each unique combination of segment & BMP Code. If the locations (segments) of animal units within a given watershed can be determined without GIS (e.g. from a watershed map), then AU data can be compiled in a separate spreadsheet without entering it into GIS.

Viewing Graphs

Press the *View Graphs* button on the *Menu* page to view selected output graphs.   Graph icons are displayed on the *Objects* page of the QUATTRO workbook.   To display or edit a particular graph, double-click on its icon.   Click the *Slide Show* icon to display all graphs in sequence.

To return to the workbook *Menu* page, enter *Cntrl-Home.*

Creating a GIS Output File

A GIS output file is created by pressing a button on the Menu page. The file name is specified on the Inputs page (e.g. *OUTFILE.DBF*).   An ArcView project file for the LaPlatte (*LAPLATTE.APR*) and required coverages (*LPWS* & *LPRIV*) are supplied.   Another data file (*SEGBAS.DBF*) is used to translate GIS Sub -Basin numbers into model segment numbers.   When the project is loaded, *OUTFILE.DBF* & *SEGBAS.DBF* area automatically joined with the basin coverages. *SEGBAS.DBF* is specific for the LaPlatte River application.   Results from different model runs can be saved with different file names, as specified on *Inputs Page*.   To avoid having to redefine the *ArcView Project* when viewing a different output file, rename the output file to *OUTFILE.DBF* (using *Windows Explorer* or *DOS* prompt) before loading ArcView.

ArcView Themes for displaying most of these variables are included in the project file:

Variable	Description	Units
Segment	Model Segment Number	
Uflow	Unit Area Flow	cm/yr
Conc	Concentration	ppb
Export	Unit Area Load	kg/ha-yr
Runoff	Surface Runoff	cm/yr
Imperv	Impervious Area	%
Curve_No	Runoff Curve Number	-
Area_ha	Sub-Watershed Area	ha
AUDens	Animal Unit Density	AU/ha
ReducP	Load Reduction Percentage	%
Reduc	Load Reduction	kg/yr
Cost	Total Annualized Cost of Controls	k$/yr
Animal_Load	Total Animal Unit Load	kg/yr
Agric_Load	Total Agricultural Runoff Load	kg/yr
Urban_Load	Total Urban Load	kg/yr
Undev_Load	Total Undeveloped Load	kg/yr
Point_Load	Total Point-Source Load	kg/yr
Total_Load	Total Load from Segment	kg/yr
UnitCost	Unit Cost of Controls	$/ha-yr

Program Units

Variable	Units
Area	hectares
Depth	meters
Concentration	ppb
Flow	hm3/yr = million m3/yr
Load	kg/yr
Export	kg/ha-yr
Runoff	cm/yr
Animal Units	AU = 1000 lbs

Glossary

Term	Definition
Animal Unit	farm animal equivalent, 1000 lbs
BMP	best management practice or non-point source control
BMP Program	collection of BMP's applied to a particular land use category
Delivered Load	reaching mouth, after attenuation by load controls & impoundments
Existing Load	after application of existing controls
Existing Treatment	apply existing controls, as specified in GIS input file
Export	phosphorus load per unit area
GIS Code	land use code used in GIS data base
Load to Stream	after attenuation by controls, before attenuation by impoundments
LU Category	group of LU Codes with similar land uses
LU Code	land use code used in model
Maximum Treatment	apply maximum controls for each source category, without regard to cost
New Treatment	apply new allocation of controls
Relative Cost	ratio of total annualized control cost to maximum possible cost, given the control options specified for a specific source category
Relative Reduction	ratio of predicted load reduction to maximum possible load reduction, given the control options specified for a specific source category
Routing Formula	rule for linking watersheds in downstream order
Runoff	surface runoff per unit area
Segment	sub-watershed or hydrologic unit
Source Categories	runoff loads for each landuse category, animal unit loads, & point-source loads
Strategy Code	code used to force inclusion or exclusion of specific source controls
Treated Load	after application of new controls
Unit Flow	total flow per unit area
Untreated Load	before application of controls

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