Applying EXCEL[1] Solver to a Watershed Management Goal-Programming Problem

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Abstract.— This article demonstrates the application of EXCEL® spreadsheet linear programming (LP) solver to a watershed management multiple use goal programming (GP) problem. The data used to demonstrate the application are from a published study for a watershed in northern Colorado. GP has been used by natural resource managers for many years. However, the GP solution by means of EXCEL® spreadsheet presented here is thought to be novel.

Introduction

The natural resources professions have for many years employed goal programming (GP) to solve a wide variety of management problems. Past uses include the management of small woodlands, timber production, land use planning, Christmas tree production, multiple use management, range management and outdoor recreation planning (Dykstra 1984).

GP differs from linear programming (LP) principally in that, rather than attempting to optimize a single objective function subject to several constraints, a GP will have multiple objectives as well as possibly some ordinary constraint equations (Buongiorno and Gilless 1987). Each of the multiple objectives is stated in a goal target equation. The right hand side (RHS) of each goal target equation is a goal target (i.e., a numerical production goal which the manager wants to achieve). The lefthand side (LHS) of each goal target equation contains goal deviation variables which measure the positive or negative deviations from the RHS goal target. The objective of the GP is to minimize the sum of these positive and negative deviations. In this manner, the GP works toward the achievement of multiple goals rather than, as with the traditional LP, toward the optimization of a single objective bound by inflexible constraints.

A type of LP-related software which is currently growing rapidly in popularity is the so-called "spreadsheet LP solver." These spreadsheet solvers are capable of deriving LP and GP solutions using data entered on personal computer spreadsheets. However, the GP solution requires some creativity as the procedure is not generally set forth in the software documentation.

The purpose of this article is to illustrate the application of a standard spreadsheet LP solver to a watershed management GP problem. We use as a teaching example data for a multiple use watershed in northern Colorado along with Microsoft's EXCEL® Solver.

Watershed Management Application

Problem

The problem involves a 570 acre multiple use area located in a watershed in northern Colorado. The data for this exercise were adapted, with some changes, from Bottoms and Bartlett (1975). The manager of this public land wishes to manage the area for the following multiple uses: domestic forage production, wildlife forage production, recreational fish production, and recreation visitor days. Furthermore, the manager is concerned about controlling sediment production from these activities and also about not exceeding his/her annual budget allocation for management activities. In order to achieve the management goals, a variety of management activities can be applied to portions of the 570 acres. These activities include: no action, drain wetlands, aerial spraying of herbicides and fertilizers, aerial spraying and grass seeding, mechanical removal of vegetation, mechanical removal of vegetation and grass seeding, fertilization, fish stocking and, finally, campground development. Each management activity will yield resource outputs per acre and will also carry a per acre cost in 1998 dollars (table 1).

The manager has decided that certain management objectives are to be goals: 6,000 tons per acre of sediment; 1,000,000 lbs. of domestic animal forage; 500,000 lbs. per acre of wildlife forage; and 200,000 lbs. per year of stocked fish. However, certain activities are regarded as inflexible

Table 1. Treatment yields and costs per acre or per year for land management practices on a Colorado watershed. Source: Bottoms and Bartlett (1975).

Yields	No action	Drain wetlands	Aerial spraying	Aerial spray 7 grass seeding	Mechanical removal	Mechanical removal & grass seeding	Fertili-zation	Camp-ground develop-ment
Sediment, tons per acre	2.5	6.5	5.0	4.4	9.5	8.5	2	27
Domestic forage, lbs. per acre	1270	1459	1647	1730	1786	2249	2006	0
Wildlife forage, lbs per acre	1500	975	150	75	750	375	1875	2250
Fish stocked, lbs. per acre	0	0	0	0	0	0	0	2000
RVDs, per year	0	0	0	0	0	0	575	0
Cost, 1998 dollars per acre	$0	$332.50	$9.13	$22.61	$66.50	$67.83	$15.96	$7,182.00

constraints, which must be met or exceeded. The manager must produce at least 60,000 recreation visitor days (RVDs) per year and the budget of $1,000,000 must be spent exactly.

The management question is: how many acres of land should be allocated to each management treatment so that the goal target deviations are minimized and all constraints are met? This particular goal programming problem will be one in which the manager wants to minimize the simultaneously the weighted sum of all goal target deviations. This stands in contrast to GP methods involving unweighted goal target deviations or ordinal ranking of goals (Schrage 1997). In this problem, the minimization of sedimentation in excess of the goal target is regarded as extremely important. Consequently, the goal of minimizing sedimentation over the target will be assigned a very large weight (i.e., 1000). All other goal weights will be equal to 1.

Entering the Problem into the Spreadsheet

This GP problem can be solved with EXCEL. Figure 1 depicts the left half of the land management data matrix on an EXCEL® spreadsheet. Figure 2 depicts the right half of the same continuous matrix. The data have been separated into figures 1 and 2 because of the extreme width of the matrix. In figure 1, the upper-most row of the matrix

(cells B8 through I8) contain the decision variables (i.e., number of acres of land treated under each management option). In EXCEL® terminology these are called the "changing cells." These cells are best set, as in this case, initially to zero before solving the problem. The GP solution will eventually replace some of these zeros with positive numbers indicating the optimal acreage. The headings of each column (e.g., column B, C, etc.) indicates the management treatment applicable to that column (i.e., "no treatment," "drain wetlands," etc.). The lower six rows of the matrix (cells B9 through I14) contain the per acre treatment yield and cost coefficients. These are the data from table 1. When multiplied by the corresponding decision variable (i.e., acres in that treatment type), they will yield total cost, total lbs. of forage, etc.

Figure 2 depicts a continuation of the matrix from figure 1. The top row (cells J8 through Q8) contain the goal deviation variables which are now all set at zero. These variables indicate either under- or over- achievement of the goal targets. The lower matrix rows (cells J9 through Q12) contain the goal deviation variable coefficients. These are equal to 1 for an underachievement goal deviation variable, -1 for an over achievement goal deviation variable, and 0 if the goal deviation variable does not pertain to the goal equation on that particular row. Cells S8 through S14 contain numbers which will be used to form the RHS of the goal target and constraint equations.

Furthermore, certain cells on the spreadsheet contain hidden EXCEL® formulae as follows:

cell R8: =SUM(B8:I8)(1)

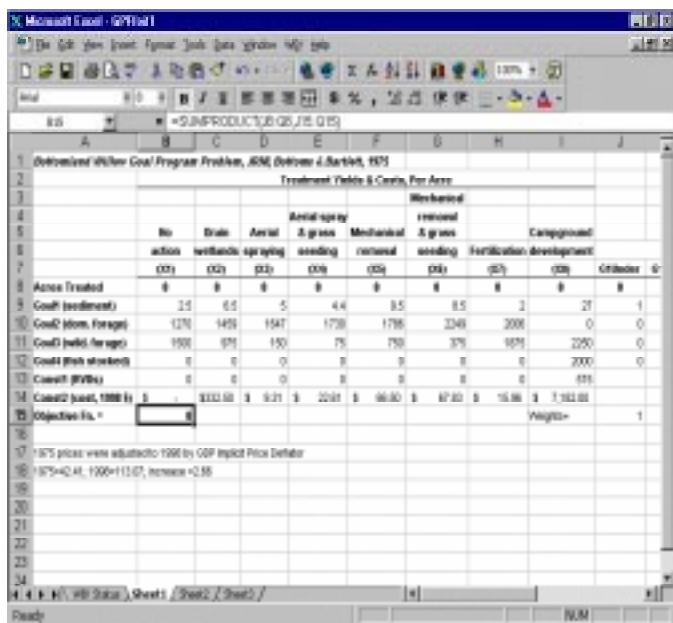cell R9: =SUMPRODUCT($B$8:$Q$8, B9:Q9)(2)

Figure 1. EXCEL® spreadsheet containing the left-half of the goal programming matrix. Cells B8 through I8 contain the acres of land in each management treatment (i.e., the decision variables). Cells B9 through I14 contain the problem coefficients. Cell B15 contains a hidden equation, which is the objective function of this weighted goal programming problem.
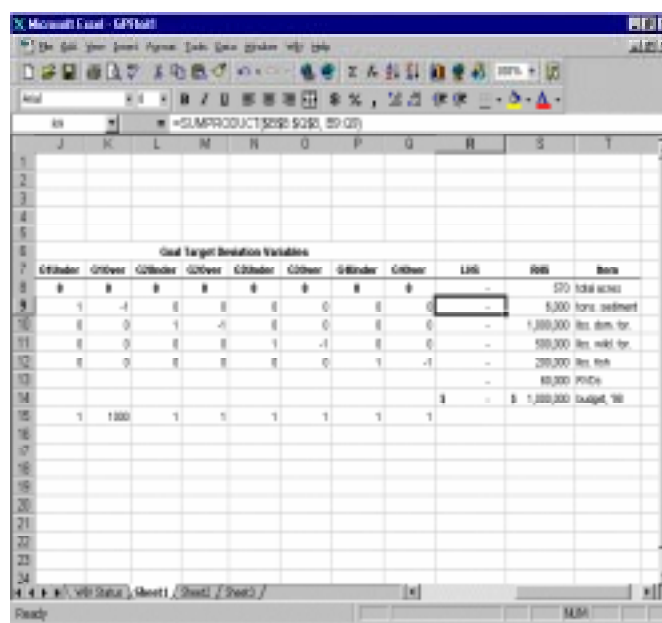

Figure 2. EXCEL® spreadsheet containing the right-half side of the goal programming matrix. Cells J8 through Q8 contain the goal deviation variables. Cells J9 through Q12 contain the coefficients for the goal target variables. Cells J15 through Q15 contain the weights. Cells R8 through R14 contain hidden equations expressing the left hand side of the goal and constraint equations. Cells S8 through S14 contain the right hand side of the goal and constraint equations.

cell R10: =SUMPRODUCT($B$8:$Q$8, B10:Q10)(3)

cell R11: =SUMPRODUCT($B$8:$Q$8, B11:Q11)(4)

cell R12: =SUMPRODUCT($B$8:$Q$8, B12:Q12)(5)

cell R13: =SUMPRODUCT(I8,I13)(6)

cell R14: =SUMPRODUCT(B14:I14,B8:I8)(7)

cell B15: =SUMPRODUCT(J8:Q8,J15:Q15)(8)

Items 1 through 7 above will be used later in the goal target and constraint equations. Item 8, the sum product of the goal deviation variable and weight vectors forms the objective function. In EXCEL® terminology, the cell containing the objective function is known as the "target cell."

Solving the Problem with EXCEL®

Once the matrices have been entered into EXCEL®, the analyst will click "Tools" on the EXCEL® toolbar. A drop-down menu will appear with one of the choices being "Solver." The analyst will click this also. (Note: if "Solver" does not appear on the drop-down menu, click "Add-ins" on the drop-down menu and proceed to add-in Solver.)

When Solver is clicked, the "Solver Parameters" dialogue box (figure 3) will appear. Designate the target cell (i.e., objective function) by clicking cell B15 on the spreadsheet. Designate the changing cells (i.e., the decision variables and the goal deviation variables) by clicking and dragging the cursor across cells B8 through Q8.

Constraints are entered one-by-one in a multi-step procedure as follows: 1) click "Add," and a constraint dialogue box will appear; 2) click the cell on the spreadsheet that represents the lefthand side of the goal target or constraint equation; 3) indicate whether £, ³, or =; 4) click the cell on the spreadsheet that represents the right hand side of the equation; 5) repeat these steps until all constraints have been entered. The EXCEL® goal target and constraint equations for this problem are expressed using cell locations on the spreadsheet as follows:

R8 = S8(9)

R9 = S9(10)

R10 = S10(11)

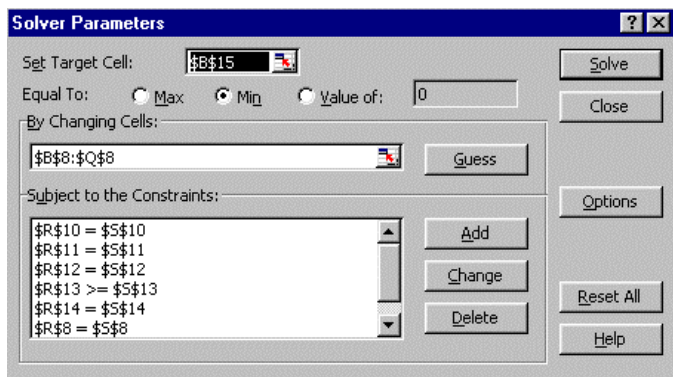R11 = S11(12)

R12 = S12(13)

R13 ³ S13(14)

R14 = S14(15)

Figure 3. EXCEL® spreadsheet "Solver Parameters" dialogue box. The "target cell" contains the objective function. The "changing cells" contain the decision variables.
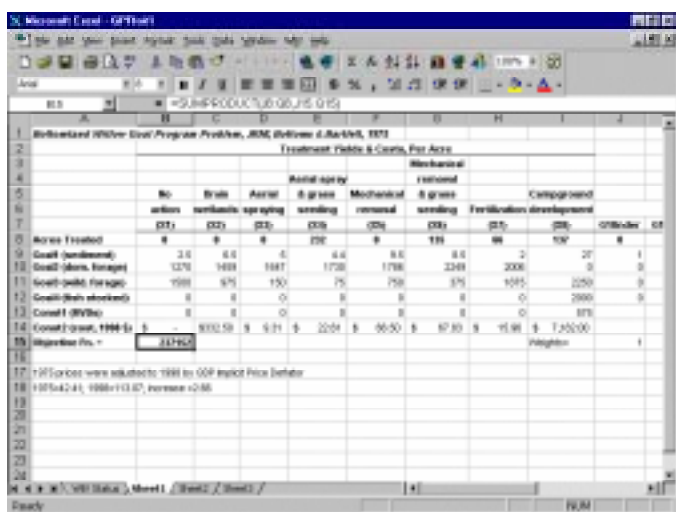

Figure 4. EXCEL® spreadsheet with the optimal GP solution. Cell B15 contains the value of the objective function (i.e., the minimized sum of the deviation variables). Cells B8 through I8 contain the optimal acreage allocations.
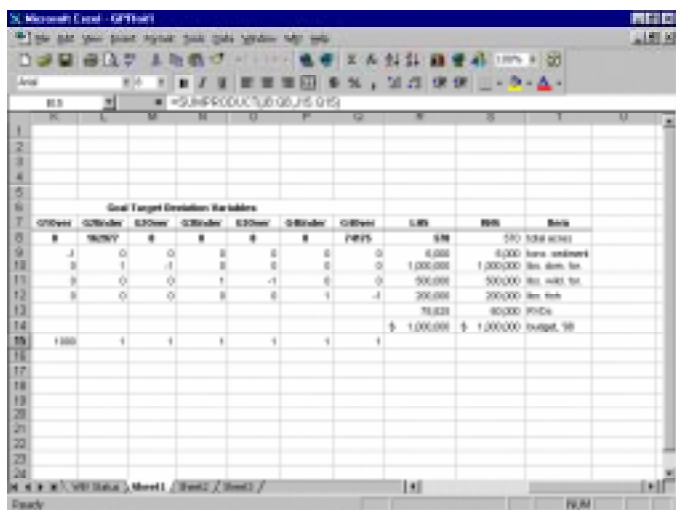

Figure 5. EXCEL® spreadsheet with deviation variables (cells K8 through Q8). Cells R9 through R14 contain the lefthand side values of the goal target and constraint equations.

Once all goal and constraint equations have been entered, return to the main Solver Parameters dialogue box (figure 3) and click "Options." The "Solver Options" dialogue box will appear. Using the cursor, click "Assume Linear Model" (this will insure a simplex algorithm solution), and also click "Assume Non-Negative" (insures that all Xs ³0). Click "OK" and the Solver Parameters dialogue box (Figure 3) will reappear. Click the "Solve" button and the GP should find a solution. In this case it does, and the optimal solution (237,152 deviation units) now appears in cell B15 while the optimal acreage treatment of management treatments, the answers of principal interest, appears in cells B8 through I8 (figure 4). The optimal solution indicates that the land manager should treat 232 acres with aerial spraying and grass seeding, 135 acres with mechanical removal and grass seeding, 66 acres with fertilization and 137 acres should be developed as a campground. All other treatment types indicated zero acres.

Inspection of cells K8 through Q8 in figure 5 indicate how well the manager did with respect to the specific values of the goal targets and constraints. Cell L8 indicates that the target domestic animal forage goal was underachieved by 162,977 lbs. Cell Q8 indicates that the target fish stocking goal was underachieved by 74,175 lbs. All other goals were met in accordance with the specified constraints.

Conclusion

Savage (1997) has stated that spreadsheet LP/GP solvers appear to be the new direction in LP/GP software. This is based on the widespread use of spreadsheet software and the fact that students are increasingly being exposed to spreadsheets in the college classroom. One of the desirable features of LP/GP problems formulated on spreadsheets is the highly visible display of the problem which seems to invite inquiry and experimentation. Also, the spreadsheet method facilitates a very flexible approach to LP/GP solving; the problems can be structured and solved in many different ways.

Acknowledgments

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