12-1-1968

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LINEAR PROGRAMMING IN FUTURE
RANGELAND ADMINISTRATION

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A linear programming model which represents this ranching situation is presented in Table 1. In the first column, the available resources are listed. For example, in 1, there are 2,000 acres of used land. The resources which vary according to column three will be evaluated at the various activities (x). All are brought into the solution of the model, with the exception of public capital. Double capital will be added after the initial solution of the model has been accomplished.

Activity 4, represents a cow-calf unit. Every time a cow-calf unit is needed in the month 1-0 ADM (t₂) at any interval, 0.8 ADM (62.5) of growing for 180 units, and 0.5 (341.2) of hay must be

LINEAR PROGRAMMING IN FUTURE RANGELAND ADMINISTRATION

The future uses of linear programming in rangeland and other natural resource administration are as broad as the imagination of the resource manager. Linear programming has limitations, and one should be sure to use it properly. Yet there is a wide area of application of this technique which is just beginning to be explored.

Linear programming is a mathematical procedure for (1) maximizing the income from a given set of resources and possible products, or (2) minimizing the cost of a specified product given alternative inputs. Least cost rations which meet given requirements have been determined by using the cost minimizing model. However, the maximization model has more application to rangeland problems.

The application of linear programming to rangeland problems can best be presented by using an example. Let us assume an oversimplified ranching situation which still has some elements of reality.

Assume a ranching set-up where both public and private resources are used in the production of beef cattle. The rancher has grazing permits to graze from April 1 to September 30 on BLM land. He has 450 acres of meadow to produce hay for winter feed. He also has enough private range to carry his cattle through October and November (these acres not included in the model). His BLM allotment consists of 8,000 acres of rangeland; 2,000 acres are seedable, 3,000 acres are sprayable, and 3,000 acres cannot be improved by spraying or seeding. His meadow land will respond to the application of nitrogen fertilizer to increased hay production.

A linear programming model which represents this ranching situation is presented in Table 1. In the first column the available resources are listed. For example, in \( Q_1 \) there are 2,000 acres of seedable rangeland. The resources with zero entries in column three will be produced as the various activities \( (A_1 - A_{19}) \) are brought into the solution of the model, with the exception of public capital. Public capital will be added after the initial solution of the model has been accomplished.

Activity \( A_1 \) represents a cow-calf unit. Every time a cow-calf unit is added to the ranch 1.0 AUM \( (Q_6) \) of May grazing, 4.0 AUMs \( (Q_7) \) of grazing for June through September, and 2.1 tons \( (Q_8) \) of hay must be

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Table 1. Representation of the assumed ranch situation and alternative ways of utilizing the rangeland and meadow

<table>
<thead>
<tr>
<th>Resources</th>
<th>Units</th>
<th>Prices 40.00 A_1</th>
<th>A_2</th>
<th>A_3</th>
<th>A_4</th>
<th>A_5</th>
<th>A_6</th>
<th>A_7</th>
<th>A_8</th>
<th>A_9</th>
<th>A_10</th>
<th>A_{11}</th>
<th>A_{12}</th>
<th>A_{13}</th>
<th>A_{14}</th>
<th>A_{15}</th>
<th>A_{16}</th>
<th>A_{17}</th>
<th>A_{18}</th>
<th>A_{19}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q_1 Seedable Range</td>
<td>Acres</td>
<td>2000</td>
<td>0</td>
<td>25.0</td>
<td>12.5</td>
<td>12.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.0</td>
<td>3.0</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>Q_2 Sprayable Range</td>
<td>&quot;</td>
<td>3000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.0</td>
</tr>
<tr>
<td>Q_3 Other Range</td>
<td>&quot;</td>
<td>3000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25.1</td>
<td>12.5</td>
<td>12.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_4 Meadow</td>
<td>&quot;</td>
<td>450</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_5 April 1 - April 30</td>
<td>AUMs</td>
<td>0.0</td>
<td>1.0</td>
<td>-0.17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-2.5</td>
<td>-0.17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_6 May 1 - May 30</td>
<td>&quot;</td>
<td>0.0</td>
<td>1.0</td>
<td>-0.17</td>
<td>-0.2</td>
<td>0</td>
<td>-0.17</td>
<td>-0.2</td>
<td>0</td>
<td>-0.17</td>
<td>-0.2</td>
<td>0</td>
<td>0</td>
<td>-1.7</td>
<td>-0.2</td>
<td>0</td>
<td>-2.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_7 June 1 - June 30</td>
<td>&quot;</td>
<td>0.0</td>
<td>4.0</td>
<td>-0.67</td>
<td>-0.8</td>
<td>-1.0</td>
<td>-0.67</td>
<td>-0.8</td>
<td>-1.0</td>
<td>0</td>
<td>0</td>
<td>-0.67</td>
<td>-0.8</td>
<td>-1.0</td>
<td>-0.8</td>
<td>-1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_8 Hay</td>
<td>Tons</td>
<td>0.0</td>
<td>2.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1.0</td>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Q_9 Public Capital</td>
<td>$</td>
<td>0.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.80</td>
</tr>
</tbody>
</table>

a Assumes an additional expense of feeding of $2.50 per ton for hay fed in April.

b Thirty pounds of elemental N per acre are assumed to increase hay production to 1.4 tons per acre at a cost of $5.05 per acre.

c Sixty pounds of elemental N per acre are assumed to increase hay production to 1.7 tons per acre at a cost of $9.45 per acre.

d Estimated cost of $12 per acre for seeding was assumed to last 15 years for an annual cost of $.80 per acre per year.

e Estimated cost of $3 per acre for spraying was assumed to last 10 years for an annual cost of $.30 per acre per year.
available. Each cow-calf unit adds $40 to net ranch income. The remaining activities are alternative ways of meeting the feed requirements for the cow-calf unit. For example, activity A_1 requires 25.0 acres of seedable range to produce one AUM of grazing if this AUM is used April 1 to September 30. One-sixth (0.17) of it being used in April, one-sixth of it being used in May, and four-sixths (0.67) of it being used June 1 through September 30. Activity A_2 represents the situation where we hold off grazing the range until May 1. This reduces the acres required per AUM from 25.0 to 12.5 with one-fifth of an AUM in May and four-fifths of an AUM being used June 1 through September 30. If grazing is held off until June 1, the acreage is again reduced to 12.0 acres per AUM with all of it being used June 1 through September 30. This same idea holds for activities 1 through 10. Activity 11 indicates 1.0 acre of meadow (Q_4) is required to produce 1.0 ton of hay in Q_4. Activity 12 adds versatility to the use of the resources. One ton of hay (Q_8) can be used to replace 2.5 AUMs of April grazing at a cost of $2.90 per ton to cover the extra costs of feeding hay in April.

Activities 13 through 17 deal with improvements on public rangelands. For example, 6.0 acres of seeded rangeland are required to produce one AUM of grazing if used season-long (A_12). However, in order for this activity to come into the solution $4.80 of public capital must be available (6.0 x $.80 = $4.80). The seeding cost of $12 per acre, and it will last 15 years: thus the annual cost is $12 + 15 = $.80 per acre. If grazing is postponed on this range until May 1, the acres of seeded range is reduced to 3.0, with an annual cost for seeding of $2.40 (3.0 x $.80 = $2.40). The AUMs from seeded ranges are distributed over the respective season as explained above.

Rangeland spraying is considered in activities 16 and 17. If 4.0 acres of the sprayable range is sprayed at an annual cost of $1.20 (4.0 x $.30 = $1.20) it will produce one AUM of grazing if used from May 1 through September 30 (A_17). April grazing of sprayed rangeland is not considered in this model because this was not a biologically feasible time to graze it. Activity 17 requires 3.5 acres of sprayed range if grazed June 1 through September 30 at an annual cost of $1.05 per acre.

Meadow improvement is considered in activities 18 and 19. Since this type of improvement is made on private lands, the costs are deducted from net ranch income. The application of 30 lbs. of N will increase hay production from 1.0 tons per acre to 1.4 tons per acre at an annual cost of $5.05 per acre (A_18). If 60 lbs. of nitrogen are used the increase in hay production will be from 1.0 tons per acre to 1.7 tons per acre at an annual cost of $9.45 per acre.

All of the above alternatives are considered simultaneously such that the number of cow-calf units produced from these resources is maximized. Solution of a linear programming model can be accomplished by hand using a desk calculator. However, this job becomes almost

Spraying costs $3.00 per acre and lasts 10 years, thus $3.00 + 10 = $30 per acre per year.
impossible as the size of the model increases. Computer programs have been developed to solve the linear programming problem. This enables one to consider far more alternatives than was feasible prior to the use of the computer.

The example problem was solved on the IBM 1620 computer. The solution required about ten minutes of computer time. On the new advanced computers the solution could be arrived at in less than a minute.

Results from the Solution of the Linear Programming Model

Initially this model was solved with zero public capital available. Thus, this solution gives the optimum use of these resources without considering range improvements.

The resources will support 140 cows which yields an income of $5,462. All of the public rangeland resources are being used. However, the 140 cows only require 350 acres of the meadow, leaving 100 acres unused. A hay selling or a meadow pasture activity could have been included in a larger model.

All of the public rangeland use from May 1 to September 30. None of it is grazed in April. It is more profitable to feed hay in April. The feed production and feed requirements for our example are given in Table 2.

Table 2. Feed requirements and availability with no investment in range improvements

<table>
<thead>
<tr>
<th>Activity</th>
<th>Feed Produced</th>
<th>Feed Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May - Sept.</td>
<td>May 1 - Sept. 30</td>
</tr>
<tr>
<td>A3</td>
<td>160 AUMs</td>
<td>700 AUMs</td>
</tr>
<tr>
<td>A5</td>
<td>300 AUMs</td>
<td></td>
</tr>
<tr>
<td>A9</td>
<td>240 AUMs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>700 AUMs</td>
<td></td>
</tr>
<tr>
<td>All Hay</td>
<td>350 tons</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hay fed in April 56 tons</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal hay feeding 294 tons</td>
<td></td>
</tr>
<tr>
<td></td>
<td>350 tons</td>
<td></td>
</tr>
</tbody>
</table>

Linear programming solutions provide other valuable information that can be used by the natural resource administrator. Shadow prices are computed for each of the limiting resources. The shadow price is the amount of money one more unit of the resource would add to the net income. The shadow prices for the example problem are given in Table 3.
Table 3. Shadow prices for the limiting resources.

<table>
<thead>
<tr>
<th>Resource</th>
<th>Shadow Price</th>
<th>Resource</th>
<th>Shadow Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedable Range</td>
<td>$ .62/acre</td>
<td>Apr. Grazing</td>
<td>$ 1.00</td>
</tr>
<tr>
<td>Sprayable Range</td>
<td>$ .78/acre</td>
<td>May Grazing</td>
<td>11.70</td>
</tr>
<tr>
<td>Other Range</td>
<td>$ .62/acre</td>
<td>June - Sept. Grazing</td>
<td>6.82</td>
</tr>
<tr>
<td>Meadow</td>
<td>0.0</td>
<td>Hay</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public Capital</td>
<td>3.90</td>
</tr>
</tbody>
</table>

If we could lease one more acre of seedable range for less than $ .62 it would pay us to lease it because one more acre would return $ .62. Another acre of meadow land would not do us any good because we have 100 acres more than we can use; thus, it has a shadow price of zero. This same idea follows for the other resources. Public capital has a shadow price of $ 3.90, which says an additional dollar of public capital will return $ 3.90.

Public capital is added to our model next to see what effect it will have on the use of the resources. The next solution of the model has $ 403 of public capital available for range improvements.

According to the definition of the shadow price, each one of the $ 403 should add $ 3.90 to the income. This amounts to $ 1,573. The original income to the system was $ 5,462. The new solution should then have an income of $ 7,035. A quick check can be made to see if the theory is valid. The new solution has 180 cow units at $ 40/hd, equals $ 7,215. The $ 2.50 per ton for the hay feed in April has to be deducted from this figure. About 72 tons of hay were fed in April, so $ 2.50 x 72 = $ 180 from $ 7,215 equals $ 7,035 which agrees with the amount calculated above.

The $ 403 of public capital was used by A16, which is an activity for spraying rangeland. Spraying is a more profitable use of public capital than seeding. If seeding had been a better use of public capital, it would have come into the solution first. The $ 403 would spray 336 acres of the sprayable rangeland. The cost would then be $ 403 x 10 years = $ 4030 for spraying.

An investment of $ 4030 would give a return of $ 1573 per year for 10 years. If we do not consider time the return of $ 3.90 per dollar invested would indicate a 290 percent return on investment. However, time must be considered. The income stream of $ 1573 per year for 10 years has to be put in terms of its present value. The process by which the flow of future returns are brought to the present is called discounting.

The discount rate which makes the discounted returns equal to the cost of obtaining the income stream is called the internal rate of return. The decision to invest would be based on the magnitude of
the internal rate of return. The internal rate of return would be computed as follows:

\[ I = R \left( \frac{1 - (1 + i)^{-n}}{i} \right) \]

Where:
- \( I \) = initial investment
- \( R \) = annual income stream
- \( 1 - (1 + i)^{-n} \) = discounting factor

In the example for spraying this equation is:

\[
\begin{align*}
4030 &= 1573 \left( \frac{1 - (1 + i)^{-n}}{i} \right) \\
2.56 &= \left( \frac{1 - (1 + i)^{-n}}{i} \right)
\end{align*}
\]

The discounting factor has been computed in tables so that it is not necessary to solve it for \( i \). A Present Value of $1 Received Annually for N Years table will give us the internal rate of return. Look along the 10 year row until the number nearest 2.56 is found. When this number is found, go up that column to find the internal rate of return. In this case, 2.56 falls between 35 and 40 percent.

Linear programming models have been developed which can encompass the resources associated with BLM grazing allotments. The allotment under study consisted of about 50,000 acres of BLM rangeland and the commensurate properties of four cattle permittees. Each of the permittees were considered separately in the same model. Several range improvement programs were considered in this study. The results obtained from each model were set up in such a way that they could be used as a decision criterion for making range improvements.

Data, both economic and biological, are limiting the use of linear programming in many areas of natural resource administration. If we knew the prices or values of recreation, watershed, and wildlife on some workable unit and the biological relationships that exist between and among these uses, we could determine the optimum allocation of resources to the various uses.

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