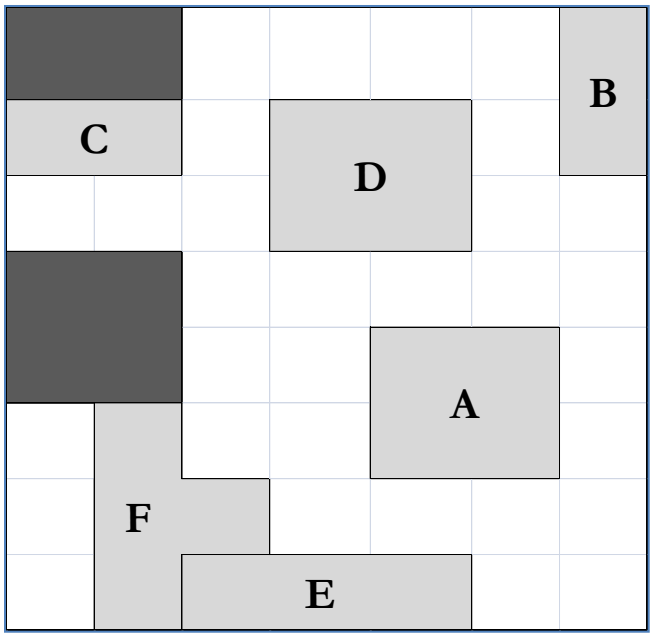
Maximizing Conservation in Pangaea

Problem

Imagine that you are the Executive Director of a non-profit conservation group named the Pangaea Conservancy, which has a budget of $10 million to purchase land from private landowners so that these lands can be permanently protected. The six parcels available for purchase are shown in light gray in the figure below, labeled A-F. Pangaea already has two protected national parks, which are shown in this figure as dark gray areas. Ecologists and conservation professionals from the Pangaea Conservancy have evaluated each of the available parcels and assigned each with a parcel-specific ecological benefit score, as shown in the table below, where a higher score indicates a higher ecological benefit. As the Executive Director, which parcels would you recommend that the Pangaea Conservancy acquire? Why?



Parcel ID	Ecological Score	Cost ($m)	Parcel Selected
A	2	$6	
B	5	$3	
C	4	$2	
D	6	$6	
E	2	$3	
F	9	$4	

As a group, research how conservation organizations and agencies determine which projects to select for funding. You should document the selection process of the USDA's Conservation Reserve Program, the Forest Legacy Program, Delaware Agricultural Lands Preservation Foundation, Baltimore County's agricultural preservation program, and at least one other organization. Also, note the annual expenditures of these programs. Comment on how similar or different these programs' selection process is compared to the process you recommended in the first part of this problem. What are the strengths and weaknesses of these approaches?

Answer

The goal of the first part of this problem is to get the students thinking independently about the problem and potential solutions. Thus, there is no 'correct' answer to this problem. Students should be graded based on the general quality of logic and reasoning behind their selection.

The purpose of the second part of the problem is to encourage students to learn more about various conservation programs and to see the differences in the selection processes. Information about the

selection process should be readily accessible on-line as these programs need to communicate clearly their rules to potential applicants. Depending upon the size off the group, teachers may want to have their students research more than one organization other than those listed explicitly. The selection processes for these programs are as follows:

- USDA Conservation Reserve Program – A variety of rules regarding eligibility and how a parcel is scored. In the end, these scores are ranked from highest to lowest and the highest are selected first. This program is the largest conservation program in the United States.

- Forest Legacy Program – As the largest forest protection program in the United States, this program uses experts to evaluate and score the potential projects, which have been recommended by each state's forestry department. After these scores are averaged (dropping out the highest and lowest scores), the program funds the highest scoring parcels until their budget is exhausted.

- Delaware Agricultural Lands Preservation Foundation – Delaware has protected the most agricultural land per capita in the United States. Selection is done by having the applicant landowners submit 'discounts' (as percentages) off of their appraised value that there would be willing to still sell their land for. For example, if a parcel is appraised at $1,000,000, then a 25% discount would mean that the landowner would be willing to sell an easement on their land for $750,000.

- Baltimore County uses Cost-Effective Analysis (sometimes referred to as optimization) to select parcels for agricultural preservation. This process divides the scored benefits by the acquisition costs and then selects the parcels with the highest ratios until the budget is exhausted.

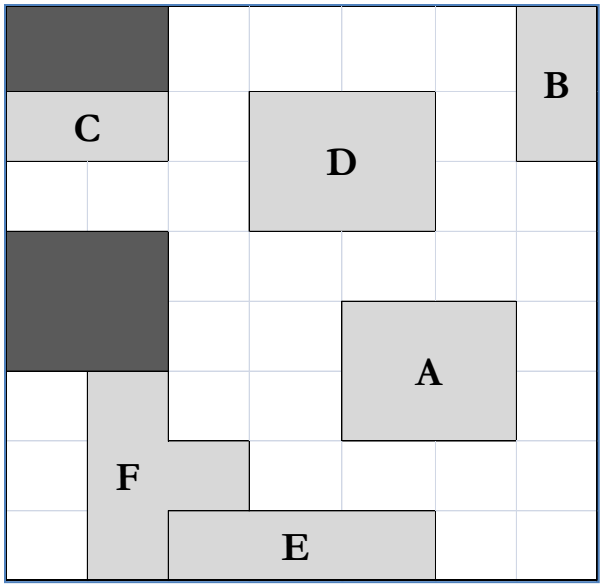
- Other programs will have a variety of different selection techniques with most non-profit environmental organizations having no explicit rules for selection.

The following exercises are related to the problem described above.

Exercise 1

Most conservation organizations and government agencies in the United States and throughout the world use what is called "Benefit Targeting" (also referred to as "Rank-Based Models") to select which parcels to acquire for conservation (Messer and Allen 2010). With Benefit Targeting, the organization prioritizes the parcels based solely on the parcels' benefits—in this case the Ecological Score—and then acquires the highest ranked parcel first, the second highest parcel second, and so forth, until the budget is exhausted.

Assume that the Pangaea Conservancy uses the Benefit Targeting approach to solving the problem. Which parcels would it select? Comment on whether these parcels are similar to or different than the selections you recommended in the problem. In your comparison of the selected parcels evaluate a number of criteria including the total ecological score achieved, the total cost, the average values of the selected parcels, and the spatial location of the parcels.



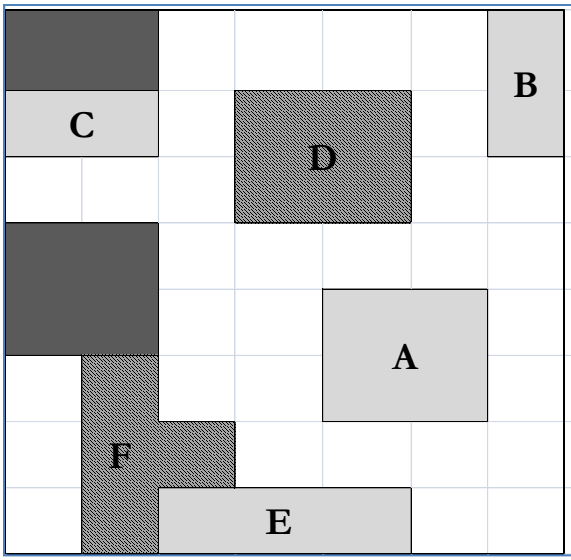
Parcel ID	Ecological Score	Cost ($m)	Parcel Selected
A	2	$6	
B	5	$3	
C	4	$2	
D	6	$6	
E	2	$3	
F	9	$4	

Answer 1

In their comparison to their answer in the main problem, in the exercises, students should be graded based on the general quality of logic and reasoning behind their selection.

Using a Benefit Targeting approach and a $10 million budget, the Pangaea Conservancy would select parcels D and F as shown in the hatched dark gray areas in the figure below. The total cost and Ecological Score are also shown in the figure. The two selected parcels have the highest Ecological Scores (6 and 9, respectively), but also have two of the three highest prices $6 million and $4 million, respectively. The average value for the ecological score of the parcels is 7.5 and the average cost is $5 million.

Answer for Exercise 1



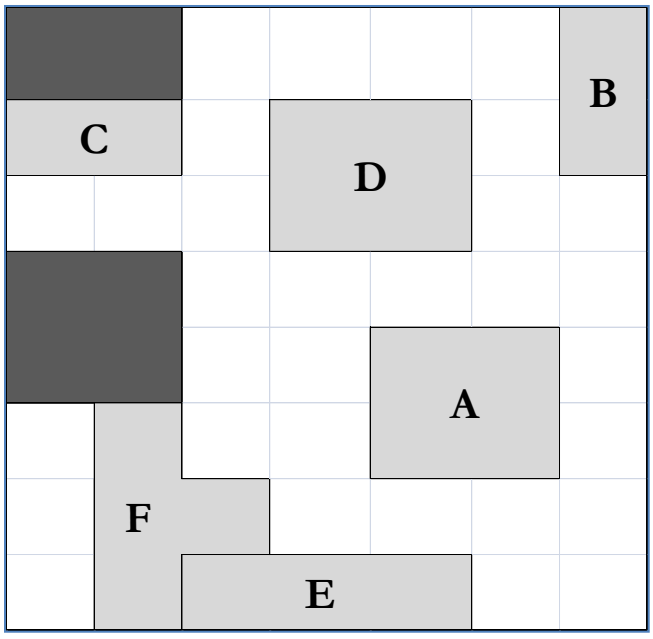
Parcel ID	Ecological Score	Cost ($m)	Parcel Selected
A	2	$6	
B	5	$3	
C	4	$2	
D	6	$6	Yes
E	2	$3	
F	9	$4	Yes
Total:	**15**	**$10**	**2 parcels**

Exercise 2

Environmental economists have raised concerns about the use of Benefit Targeting, as this method does not take into account the costs of the selected parcels except when determining whether there remain sufficient funds. As an alternative, economists often have recommended that the selection be done based on benefit-cost ratios, where the parcel with the highest ratios should be acquired first, the parcel with the second highest ratio should be acquired second, and so forth, until the budget is exhausted. This technique is frequently referred to as Cost Effectiveness Analysis or Benefit-Cost Targeting. A parcel's benefit-cost ratio is calculated by simply dividing its benefit score by its costs. For example, Parcel A would be assigned the value of 0.33, as its ecological score of 2 is divided by its cost of $6 million. (Note, to facilitate interpretation, the ratio is often multiplied by a large number. As long as the same large number is used for each parcel, then this multiplication does not change the overall results).

Given the same information that you used in the primary problem and Exercise 1, which parcels would the Pangaea Conservancy select if it used Cost Effectiveness Analysis? Comment on whether these parcels are similar or different than the selections you recommended in the primary problem and the parcels selected by Benefit Targeting in Exercise 1. In your comparison of the selected parcels, evaluate a number of criteria including the total ecological scores, the total cost, the average values of the selected parcels, and parcels' spatial location.

Given the results, what method of selection would you suggest that the Pangaea Conservancy use? Why?



Parcel ID	Ecological Score	Cost ($m)	Parcel Selected
A	2	$6	
B	5	$3	
C	4	$2	
D	6	$6	
E	2	$3	
F	9	$4	

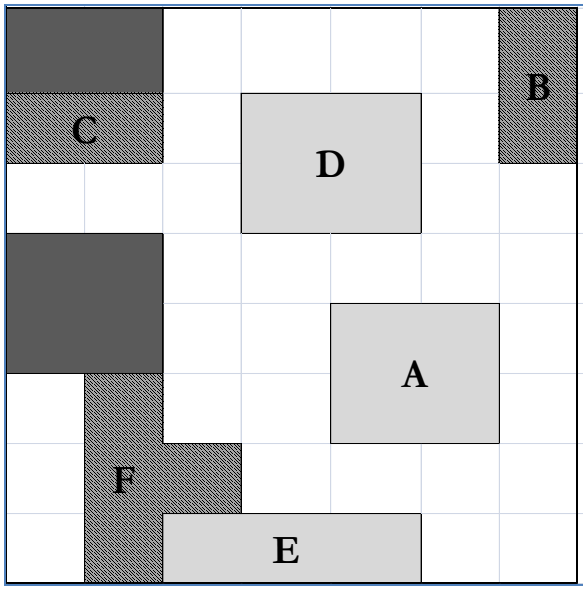
Answer 2

Using Cost Effectiveness Analysis and a $10 million budget, the Pangaea Conservancy would select parcels B, C, and F as shown in the hatched dark gray areas in the figure below. The total cost and Ecological Score are also shown in the figure. Note that parcel D is no longer selected as it was with Benefit Targeting, in large part because of its relative high cost. This type of project can be referred to as a "budget sponge" as it absorbs considerable financial resources that could be allocated to other projects.

The total ecological score from the three selected parcels is 18, which is 20% greater than the level of 15 achieved in Exercise 1. The total cost of these three parcels is also just $9 million instead of the $10 million in Exercise 1 (a 10% savings). Compared to Benefit Targeting, the average individual values for the ecological score of the selected parcels is lower (6.0) as is the average cost, $3 million. The lower individual values certainly are a disadvantage of being more cost effective.

Students might note some advantages of acquiring more parcels, which may be especially advantageous in certain political situations as more landowners are participating in conservation and receiving payments. Of course, the administrative burden of purchasing three parcels instead of two is higher. From a spatial analysis perspective, both the acquisition of parcel C and parcel F are adjacent to existing park land. This may be important from an ecological perspective as non-fragmented areas tend to provide better wildlife habitat and connected areas are easier to manage. Of course, parcel B is quite isolated relative to the other protected areas.

Answer to Exercise 2

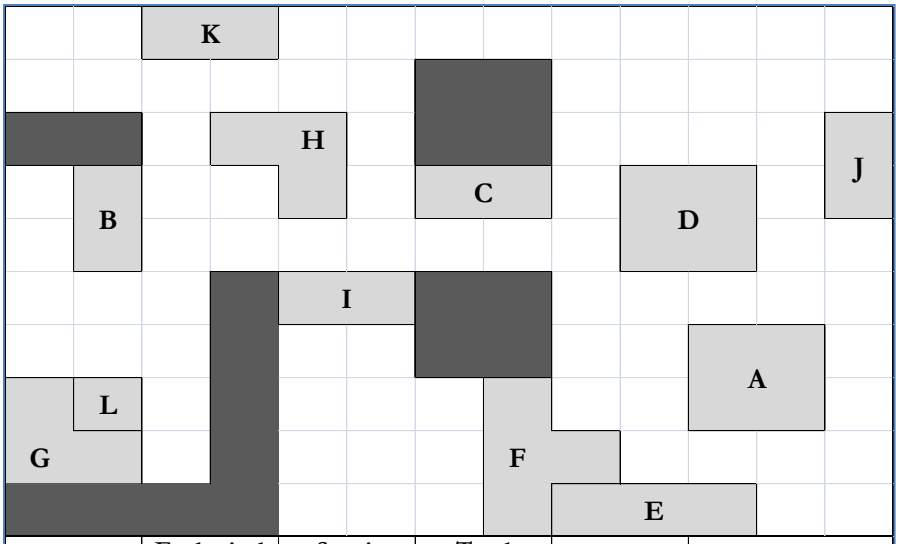


Parcel ID	Ecological Score	Cost ($m)	Parcel Selected
A	2	$6	
B	5	$3	Yes
C	4	$2	Yes
D	6	$6	
E	2	$3	
F	9	$4	Yes
Total:	**18**	**$9**	**3 parcels**

Exercise 3[1]

Now look at another area the Pangaea Conservancy is considering protecting. This area already has four protected areas, shown below in dark gray. In this area, the Pangaea Conservancy has budgeted $25 million to purchase land from private landowners so that it can permanently protect these areas. The twelve parcels available for purchase by the Pangaea Conservancy are lettered from A-L below and are shown in light gray. The Pangaea Conservancy has used a new and improved benefit assessment technique which calculates two benefit scores as shown below. For both of these measures, the higher the score signifies the higher the quality.

Assuming that the Pangaea Conservancy considers the ecological score and the scenic value to be of equal importance, which parcels would you recommend that it acquire if it wants to use Benefit Targeting? Describe the selected parcels.



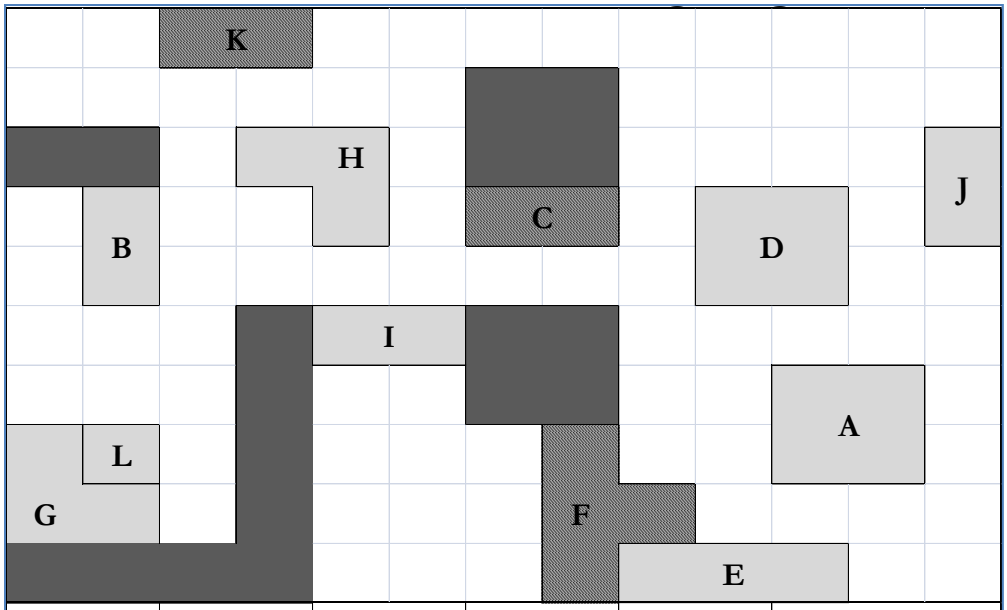
Parcel ID	Ecological Score	Scenic Value	Total Benefits	Cost ($m)	Parcel Selected
A	100	126	226	$4.5	
B	100	143	243	$5.0	
C	130	130	260	$6.0	
D	150	60	210	$5.0	
E	80	185	265	$6.5	
F	140	140	280	$7.0	
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	

Answer 3

[1] Data for this example is from Messer, 2006.

The answer to Exercise 3 is shown in the figure below. Students should provide thorough and well-written comments about the selected group of parcels.

Answer to Exercise 3



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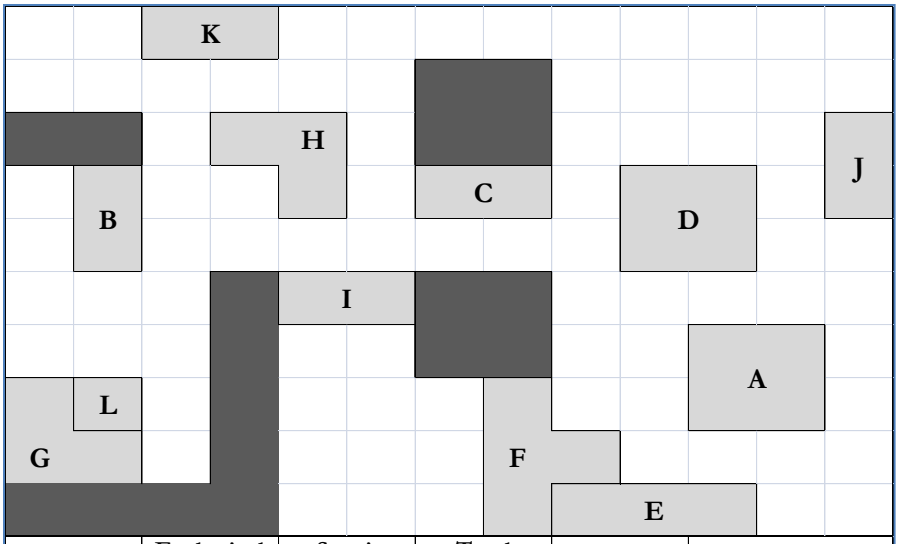
D	150	60	210	$5.0	
E	80	185	265	$6.5	
F	140	140	280	$7.0	Yes
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	Yes
L	75	75	150	$8.0	
	420	**420**	**840**	**$25.0**	

Exercise 4

Given the information provided above, identify the parcels that the Pangaea Conservancy would select if it used Cost Effectiveness Analysis. (Note that a calculator can be helpful.) Discuss these results in comparison to the results of Exercise 3.



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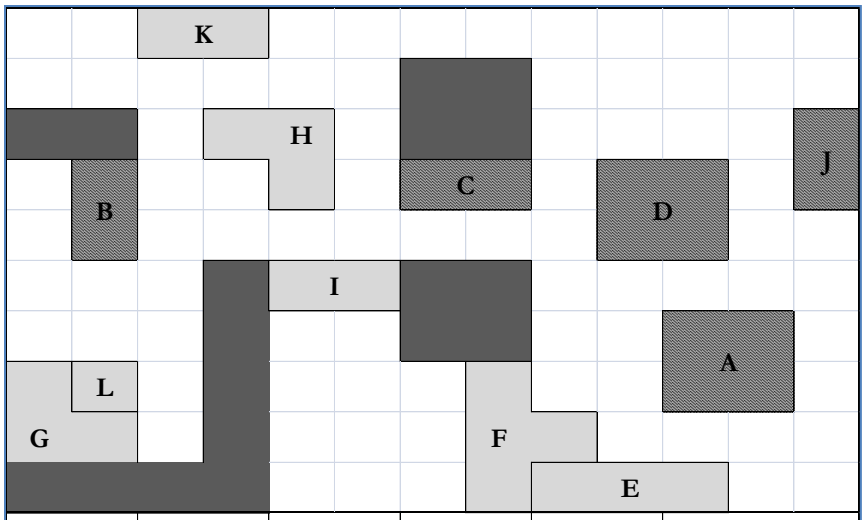
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	

Answer 4

The answer to Exercise 4 is shown in the figure below. Students should provide thorough and well-written comments about the selected group of parcels and compare these results to the answers of Exercise 3. In particular, students should discuss how Cost Effective Analysis improves the overall environmental outcome compared to Benefit Targeting.

Answer to Exercise 4



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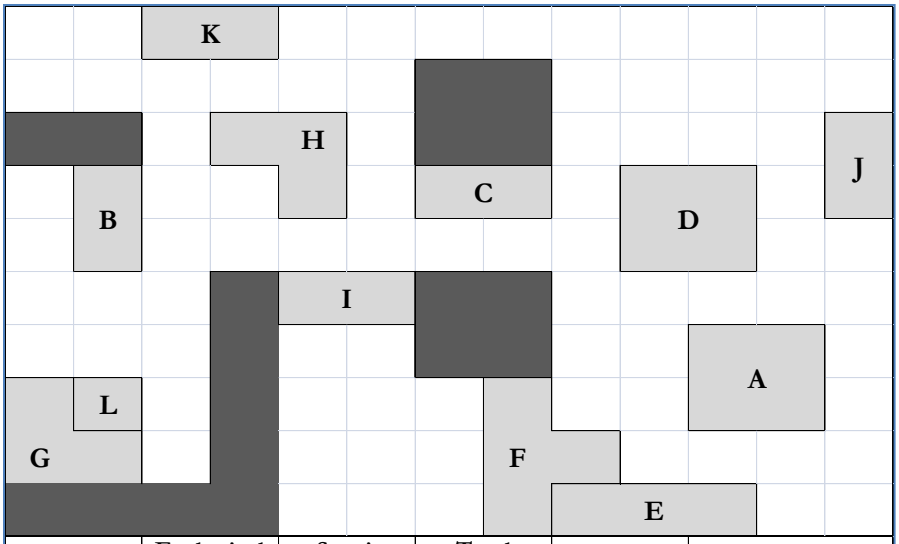
F	140	140	280	$7.0	
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	Yes
K	150	150	300	$12.0	
L	75	75	150	$8.0	
	495	**469**	**964**	**$25.0**	

Exercise 5 *(Advanced)*

Given the information provided above, identify the parcels that the Pangaea Conservancy would select if it used Binary Linear Programming using Solver.[2] The binary variables should be either 0 (not selected) or 1 (selected), and can be multiplied to the original environmental benefits scores to calculate the overall benefits of the selected parcels. For example, if Parcel A is selected then by multiplying the Total Benefits score of 226 by 1 the entire amount can be added into the aggregate Total Benefits calculated for the selected parcels. If Parcel A is not selected, then by multiplying the Total Benefits score by 0, makes the resulting value zero. For more information on binary linear programming and the branch-and-bound algorithm used to solve these types of problems see Chapter 7 of Kaiser and Messer (2011). Discuss these results in comparison to the results of Exercises 3 and 4.



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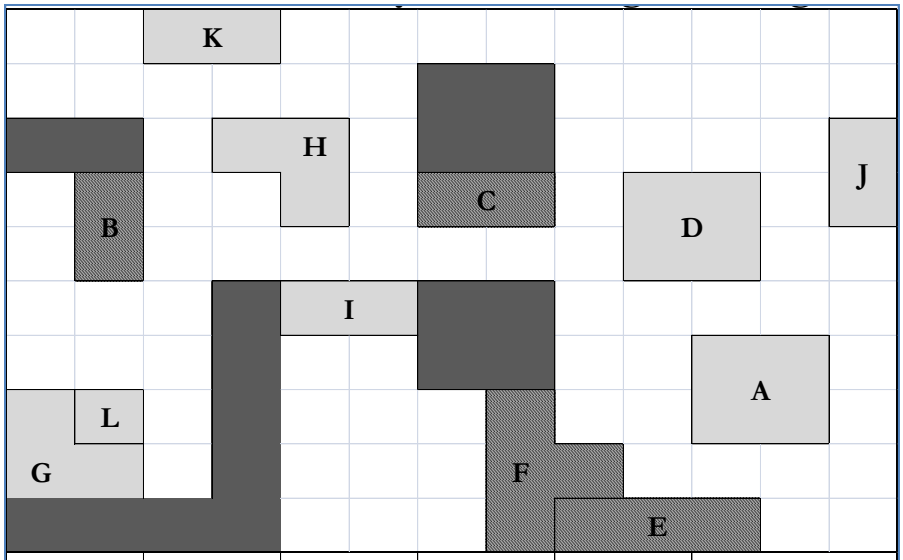
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	

[2] Note that Microsoft's Excel program includes a basic Solver program as a free add-in that can solve this problem. For more information on installing this program, see the help menu in Excel or visit http://office.microsoft.com/en-us/excel-help/load-the-solver-add-in-HP010021570.aspx.)

Answer 5

The answer to Exercise 5 is shown in the figure below. Students should provide thorough and well-written comments about the selected group of parcels and compare these results to the answers of Exercises 3 and 4. In particular, students should discuss how Binary Linear Programming improves the overall environmental outcome compared to Benefit Targeting, and in this case, provides an improvement compared to Cost Effectiveness Analysis. This latter improvement is in large part due to the fact that Binary Linear Programming does a better job at managing the overall budget and seeking the best opportunities that fit within the budget. In contrast, Cost Effectiveness does a good job allocating the majority of the budget, but does not always lead to optimal results when allocating the last amounts of the budget, especially when the individual project costs are high.

Answer to Exercise 5



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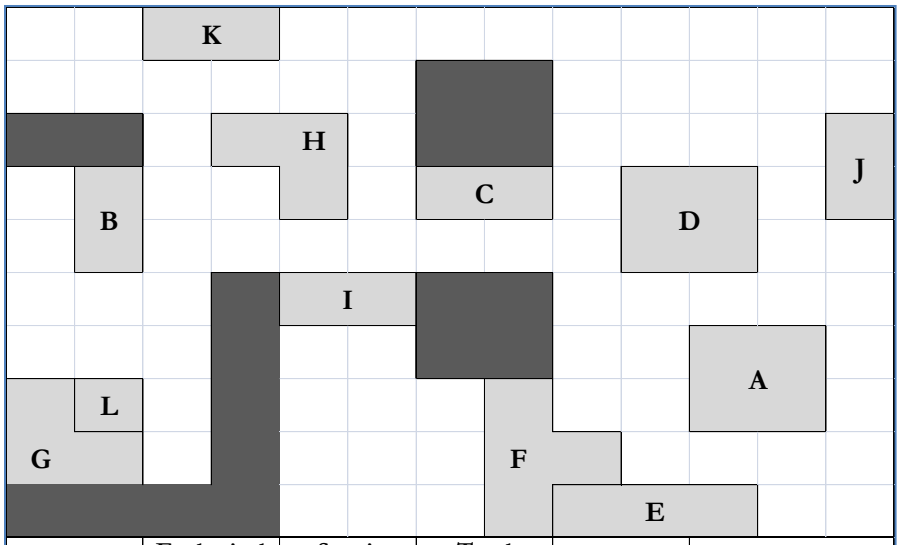
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	
	450	**598**	**1048**	**$24.5**	

Exercise 6*(Advanced)*

The Board of Directors for the Pangaea Conservancy are concerned that the aggregate ecological scores are lower in the analysis than desired. They would like to see that the selected parcels achieve a minimum value of 500 for the Ecological Score. Which method – Benefit Targeting, Cost Effective Analysis or Binary Linear Programming – is best able to solve this problem? Using your preferred technique, identify a solution that addresses this concern while continuing to maximize the weighted total of the ecological score and scenic values given a budget of $25 million. Discuss the advantages and disadvantages of adding this type of minimum value threshold.



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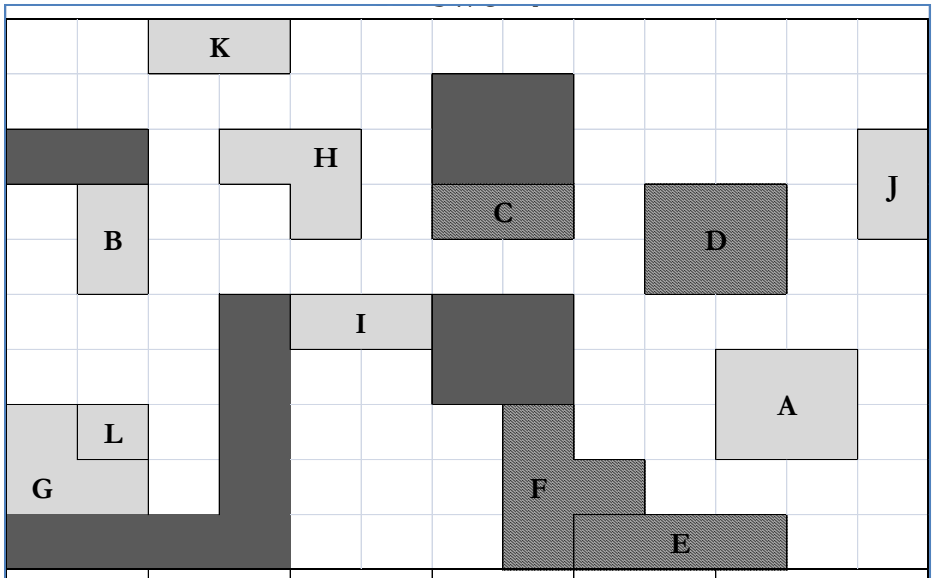
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	

Answer 6

Students should be able to identify that Binary Linear Programming is the best method for solving this problem. Neither Benefit Targeting nor Cost Effectiveness Analysis can solve this problem and meet this Board of Directors' minimum constraint on Ecological Score. Binary Linear Programming can readily handle this problem by simply adding a constraint that requires that the total value of the ecological score exceeds 500.

Students should note that there is some trade-off with adding this constraint as the total benefits from the selection that accounts for this constraint is 1,015 instead of 1,048. However, this is only a 3.1% decrease, so perhaps the trade-off is not very large, especially if the Board of Directors believes that this constraint is important. After all, the goal is to set up a model that best represents the needs and preferences of the Pangaea Conservancy such that the end results help them achieve their goals in the best way possible.

Answer to Exercise 6



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E	80	185	265	$6.5	Yes
F	140	140	280	$7.0	Yes
G	110	95	205	$7.0	
H	50	60	110	$6.5	
I	60	25	85	$9.0	
J	15	10	25	$4.5	
K	150	150	300	$12.0	
L	75	75	150	$8.0	
	500	**515**	**1015**	**$24.5**	

Student Learning Objectives:
Upon completing this exercise, students will:

1. Understand how the vast majority of conservation organizations and government agencies in the United States and throughout the world select lands and projects for preservation.

2. Understand how alternative selection techniques can yield superior environmental outcomes without costing additional money.

3. Appreciate some of the major advantages and disadvantages of the different selection techniques.

4. Be able to apply the techniques of Cost Effective Analysis and Binary Linear Programming to a variety of conservation settings for which data is available on various benefit levels and project costs.

Format of Delivery
For successful delivery of this problem, I recommend the following preparations and procedures:

1. Print out and distribute the primary problem to the class.

2. Explain the procedures for these two classes to the entire class.

3. Have students work in groups on the problem as homework.

4. In the following class period, lead a group discussion where the different groups report about their research and how different programs would approach the primary problem in different ways.

5. Distribute the exercises for student to do in-class. Allow students to use calculators. Students often have basic calculators on their cell phones.

6. The use of computers is important to solve the binary linear programming problems of Exercises 5 and 6.

7. Have the students work in their same small groups so that the students have to explain the answers to each other and discuss the results.

8. Allow students upwards of 45 minutes to solve the problems. Allow more time for Exercises 5 and 6, especially if students are not familiar with using Excel and Solver. If computers are not available in the class, then Exercises 5 and 6 can be assigned as another homework assignment.

Student Resources

This problem does not make any assumptions about students' previous knowledge about conservation or techniques traditionally employed by conservation organizations and government agencies. To learn more about the topic, students are encouraged to conduct their own research related to the problem and to read the papers listed in the reference section.

The Solver program is available as a free add-in to Microsoft's Excel program.

Instructor Resources

This problem does not make any assumptions about students' previous knowledge about conservation. In preparation for this problem, instructors may want to consult with their environmental studies textbook regarding the type of conservation activities that are going on in their area, the United States, and throughout the world, and what organizations are involved in these activities. Instructors may also want to note that conservation organizations traditionally work with limited financial resources and as a result are frequently unable to protect as much land as they would desire.

Teaching Notes

I have successfully conducted this problem and associated exercises in a variety of settings for over six years at both the University of Delaware and Cornell University. I have led this exercise in my introductory class in environmental studies, a graduate class in conservation planning, and in my graduate course on the mathematical programming with economic applications. I have also successfully led this exercise with conservation professionals for over five years. Based on this experience, the first thing that I would recommend is that teachers assess the level of quantitative skill of their students to determine how many of the exercises would be appropriate. For students not familiar with Excel and Solver, it may make most sense to have them just complete the primary problem and Exercise 1 through 4. However, given the small dataset and the availability of Solver as a free add-in with Excel on PC machines, even relatively inexperienced students should be able to solve Exercises 5 and 6 with sufficient time.

Students with strong ecological backgrounds will likely be interested in the spatial distributions of the protected areas, as many studies have highlighted the ecological importance of protecting areas that are adjacent to each other and thereby avoiding habitat fragmentation and preserving continuous lands to encourage species migration and genetic diversity. The problem is designed so that these issues can be discussed by examining the maps of Pangaea. However, this is not necessary to understand the main points of the exercise.

As an advanced extension of this problem, students could be encouraged to think of ways of using optimization to encourage agglomeration of protected areas or the establishment of contiguous hubs and corridors to support ecological systems.

In my experience working with conservation professionals on this topic, I note a reluctance for them to use techniques that might suggest that they should forgo acquiring the highest ranked parcel, even if it comes at a higher price. In my follow-up discussions on this problem, I often remind people of this history of environmental preservation, which initially focus on protecting unique natural amenities, such as Yellowstone, the Grand Canyon, and Yosemite, where protecting these resources

regardless of the cost may have made more sense. However, modern conservation activities are focused on protecting forest lands, farms, wetlands, and wildlife habitat, where there are often numerous high quality substitutes, such that ignoring costs often results in less environmental protection.

I have found that my students can have a hard time understanding why conservation organizations continue to pursue selection techniques that lead to sub-optimal results from the environmental perspective. There is no definitive answer to this question, and the instructor may want to consider making this a topic of discussion and possibly further research. For example, students could be encouraged to talk with local and state conservation leaders about why they are not using more cost effective strategies in their conservation efforts.

In my graduate course, I have often had my students work with conservation organization on applying optimization to a specific dataset as part of a broader course project or research paper. This helps the students get a better understanding of the techniques and the challenges of applying these models to real-world data. My experience has been that conservation organizations are generally interested in seeing how optimization would work in their context. Therefore a student project may be good for all involved. I have compiled the best student reports and published them as an on-line resource.

Assessment Strategies

This problem can be easily incorporated into the general course grading system and can be assessed by the instructor directly based on accuracy and quality.

Acknowledgements

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References

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