

## DECISION ANALYSIS

# Erewhon Model, Part 1

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In today's exercise we're going to be learning how to use a spreadsheet to handle the problem Saving the Endangered Species of Erewhon. We'll start off by reviewing the handout that you received and summarizing the problem. And remember that the valley has 350 species of plants, the highland has 240. They cost different amounts of money. They create different levels of social upheaval. There are some edge effects that are required, so minimum requirements for each that are unique to each kinds of habitats. And also there are some political considerations where you cannot buy more than 2 times any of the other type.

And we're going to start off by just building a spreadsheet that would enter those considerations as inputs. So let's open up a new spreadsheet and type in the word, 'Inputs'. And we said that there were two kinds of habitats. The first being Valley, and we'll represent that with a little 'v'. And the second being Highland and we'll represent that with a little 'h'. Our goal is to find out how many hectares we should conserve for each of those. And those are going to be inputs in cells D3 and E3. And we don't know what those are. We're going to try to figure out how many valley hectares we should conserve and how many highland hectares we should conserve given the constraints that are given in the handout.

We know a couple things that we can enter as inputs. The 'Total Plant Species' in each of those plant habitats varies. For the valley it's 350. And for the highland it's 240.

We also know there is a relationship between the number of new species that are conserved with each new hectare purchases. So let's enter 'New Species per Hectare'. And we said that for the valley this was 5. And for the highland this is 3. So that means that when you purchase one hectare of a valley type, you're going to be protecting 5 new species. If you protect 2 hectares, you'd be protecting 10 species of valley plants and so on. So for every new hectare you purchase you going to be adding in 5 new plant species conserved for the valley and 3 for the highland.

We also said there were 'Edge Effects'. And we said that based on recommendations from conservation biologists, that the valley needed to have at least 15 hectares conserved, and that the highland needed to have at least 25 hectares conserved.

And there are also 'Political Considerations'. The valley could not be more than twice the number of highland hectares. And the same was true for the highlands. So if we purchased 10 hectares of valley - and that what's been purchased 10 hectares - then we can just purchase no more than twice that in the highland. So that number 2 will come into play a little bit later.

Each of these habitats also create some social upheaval when you purchase them. And so the 'Social Upheaval per Hectare' needs to be recorded. And we said that for the valley that was 5 units for every hectare purchased. And for the highland it was 2.

And these two kinds of habitats also cost different amounts of money. The 'Cost per Hectare' for the valley was 300 pickles. And the cost per hectare for the highland was 200 pickles. These are all inputs. So let's select these, shade them green and center them.

This kind of establishes what the differences are between the highlands and the valleys. And it also starts to establish what are the constraints you have in your purchasing plans. The other constraints that we started to mention, and there are others. We're going to list those over here, 'Other Constraints'. We said that you had a 'Maximum Social Upheaval Index'. And that we're going to go ahead and enter in cell J3. And that was 400 units of social upheaval.

So you can enter values in here. And for each hectare you conserve you increase the social upheaval by some amount. But when you are all finished with your purchases you may not exceed the social upheaval index of 400.

And we also said there was a 'Maximum Budget'. And that maximum budget was 24,000 pickles. These are Other Constraints, let's go ahead, merge and center those. And we will designate our highland and valley with bold headings.

That's basically the layout of the problem. And now what we are going to do is spend a tiny bit of time graphing these relationships.

We're going to start off in A12 by just setting up our axes. We're going to have a horizontal axis. And we'll have a vertical axis as well. And let me just put vertical - 'Horizontal' and

'Vertical'. On our horizontal axis is going to be the number of highland hectares that we conserve and on the vertical axis is going to be the number of valley hectares that we conserve. So let's go ahead and bold those.

This again is just setting up some of the axes. So let's go ahead and let these range from zero through 200. Zero to 100 is fine, actually. And this is just establishing the axes that form the foundation of our graph. So what we're aiming for is a graph, where the valley hectares purchased is on the vertical axes - 'v' for valley and vertical - 'h' for highland, and horizontal. The horizontal hectares purchased will be on this axis, the x axis. And our values are going to be placed in sight. So we can purchase a certain combination of highland and valley hectares. And we will calculate what the number of species conserved as a result of that plan.

So these just establish our axes. So we're going to have again, highland and valley. And now let's start to now walk through our constraints. And our first constraint that Tony talked about were the 'Edge Effects'.

And let's start of my talking about this for the valley. So we'll label this 'Valley Edge' effects. Now let's think about what this needs to be. In the valley we said that some conservation biologists recommended at least 15 hectares of valley be conserved. So what that means is for any combination of highland, the minimum number of valley hectares that we need to conserve is referenced in cell D6. And we'll anchor that and pull this number down. And we want to use the equations here, so as we change the inputs our graphs will be updated automatically.

What we are going to do now is graph the highland, any number of highland hectares. And we're going to graph the number of valley hectares, but we're going to say that it needs to be constrained at 15. This may look a little funny, but we're going to start of my graphing nothing.

So let's go up to the Ribbon and choose Insert. And we're going to insert a Scatter graph. And we'll do a Scatter graph with just plain lines - straight lines. And then we'll right-click on the graph itself and we'll say select data. And we're going to add a Series. This series name is going to be our valley edge effect, or little v. This will be edge effects for the valley. Along the x axis, is going to be the highland hectares, the number of highland hectares. And for each of those highland hectares that are purchased, we're going to enter how many valley hectares are purchased by selecting cells C16 through C21. And that gives up our first graph, or our first line on the graph. And we'll go ahead and press OK.

Before we do anything more, let's go ahead and label our axes so we don't get confused - because this process can be a bit confusing. The graph is already highlighted so we can go to Layout. And then we can choose the Axes Titles. Let's label the horizontal axis, Highland Hectares. And then let's go ahead and choose the vertical axis and we'll label that, Valley Hectares. To keep this a little bit less confusing, let's go ahead right now, and change the axes so that they range from 0 to 100 on both axes. So right-click on that. Format axis, we'll make the minimum be 0, and the maximum 100. And then we'll do the same for the valley axis.

Now our graph shows the first constraint. What we're going to do here is let you choose any number of highland and valley hectares. And that combination is placed as a dot on this graph. So if you were to choose 40 hectares of highland and 40 hectares of valley, that would be represented right there. Now by plotting this first constraint, we know that our solution needs to be some place above this blue line. And your line might be colored differently.

The way the spreadsheet is set up, is that as we change this number the graph is automatically updated. And so the solutions space we're dealing with will change automatically as well. Let's just review what that means. For any value of highland habitat that we protect, we need to conserve at least 15 hectares of valley. So our solution space is anything above the blue line. Let's go ahead and enter in the highland edge effect. What would you put?

PAUSE the video: What would you enter for the highland edge effect?

Well the highland edge effect is referenced in cell E6. And so if we choose that. We can graph, and this cell says, for any level of valley here is the level of highland that needs to be conserved minimally. So let's go ahead and add that to our graph. Select the graph. Right-click and choose select data. We're going to add a new series. This series is going to be called, highland edge effect. The horizontal axis is going to be, highland hectares. And the vertical axis will be, valley hectares. And we press OK, and OK again.

Now we have two lines on our graph. These represent the solutions that are possible. And we know that we need to have highland habitat that is greater than 25 hectares, and so our possible solutions now fall within this section of our graph.

Now one thing that might be useful is to shade your sections and your constraints a different color just to keep it clean and easy to follow. And so you might take a minute to clean up your spreadsheet a bit.

Our next constraint dealt with political constraints. So let's enter 'Political Constraints' in cell E12. And remember that our political constraints are two. First the number of hectares that you purchase in the valley needs to be less than or equal to, 2 times the number of highland hectares. And the fourth constraint is that the highland hectares needs to be less than or equal to, 2 times the valley hectares conserved. And that was so that we didn't have to a disproportionate number of one type or other.

So let's graph those. Let's start off with our valley politics. We'll enter the valley politics in cell E15. In cell E16 we need to enter an equation that would say, if the highland habitat was 0, 20, 40 and so on, what would the exact equal number of valley hectares to be conserved?

PAUSE the video: What equation would you use here?

Well, let's just follow the example here. We're entering an equation to calculate the number of valley hectares conserved. And we're going to set that to be equal to, 2 times the number of highland. So far the highland is 0. We're going to multiply that by 2, and that will tell us how many valley we could conserve at the maximum. But instead of entering in the number 2, we're going to go up and reference the value in cell D7 and anchor that. And then we're going to multiply that by the number of highland hectares. And then press Enter.

Now this line is going to give us the exact equal, valley is equal to, 2 times h. And we know that our solutions is going to be somewhere below this line. Does that make sense? If it doesn't make sense, take some time and work through it. It's wrong to plow through these without really contemplating what you are doing.

Now let's go ahead and add that to our graph. Select the graph. Select data. We're going to add a new series now. And this is going to be called our, valley politics. The x axis is the highland hectares. And the y axis, the vertical axis, is our political constraint for valley. And we press OK, and OK again.

And here we have our constraint for the valley. And we know that, for example, any level of highland the number of valley hectares needs to be below this. So let's just walk through one example, so you can convince yourself that this is actually correct.

If you purchase 40 hectares of highland, the maximum number of valley hectares you can

conserve is 80, which is 2 times the number of highland. So we need to find solutions that are now in this area of our graph.

Let's go ahead and do the highland constraints now - the highland politics. And again we're going to reference this equation. We're going to graph the line that is exactly equal to that. We're predicting and entering an equation that will give us the highland, the maximum number of highland hectares, as a function of valley. This is equal to, 2 times the number of valley. So instead of entering the number 2, we're going to reference cell E7, and then we're going to multiply that times the valley hectares conserved. Drag that formula down.

Now when we graph that, we'll again right-click. Select a new series of data. This series will be called highland politics. The x axis is going to be, as always, the horizontal axis is highland. And the vertical axis will be any combination of valley that we choose to purchase. And now we press OK, and OK again.

And you see the graph has been changed and updated. As always, let's make sure we have some reasonable knowledge of what these equations are doing and that they are in fact correct.

We can not purchase more than 2 times the number of valley for the highlands. So if we purchase 50 hectares of valley that means we can purchase, at most, 100 hectares of highland. So any solutions to the left here, are acceptable. And now our solution space is like this. Let's go ahead and shade this a different color to keep it separate from our next set of constraints. And if you would like to center those, you can do so.

Our next constraint was the social upheaval index. And this equation was, if you can refer back to your sheet, that how ever many hectares we purchase each one of the valley hectares creates 5 units of upheaval. And each highland hectare we purchase creates 2 units of upheaval. And so our equation is equal to 5 times the number of valley hectares, plus 2 times the number of highland hectares. And that needs to be less than or equal to our social upheaval index, or 400.

Now when we enter this equation, we do not want to enter it like this. We want to instead reference the values in the input section here. So let's label this Social Upheaval index. And we're going to do this by entering one - solving for either the valley or for the highland. And then letting that equation be expressed down column G. You can choose to do it however how you want to. I'm going to go ahead do it as the highland. So we end up with the highland is less

than or equal to 400. I'm going to move this term over. So I'm going to subtract minus 5 v from both sides. That gets rid of that. Now I'm left with 2 times h is less than or equal to 400 minus 5 times v, I want to divide that whole term, divided by 2. And that's the whole equation that I'll be entering, right here.

Under any condition of valley, this equation will tell us what the highland purchases can be. So let's go ahead and do that. Equals now, instead of 400, we're going to reference cell J3. Minus, instead of entering the number 5, we're going to reference cell D8. Times the number of valley hectares conserved, we'll reference from our axis here. That entire term then would be divided by the social upheaval index for the highland. Let's go ahead and place anchors on that, as well. And then press OK. So that gives us our social upheaval score. We'll go ahead and center that and color that series some different color.

Okay, so let's walk through this once more. We have two variables here. We need to express this as a function of either highland or valley. We just said, let's let the valley range from 0 to 100. And for each of these let's compute what the maximum number of highland hectares could be in order to give us a social upheaval index of 400.

Let's add that to our graph. Select the data. Add a new series. This is the social upheaval index. The x value or the horizontal is going to be our highland score, which we have calculated here. And our vertical axis is the valley scores, which are over here. And then we press OK, and OK again.

So here is our new line. This gives us our social upheaval score. We know that anything below this line will result in fewer hectares purchased that would be acceptable in terms of social upheaval.

Take some time, plug in a couple of numbers, a couple of scenarios both above and below. And make sure you really understand what this graph is doing.

Let's just walk through a hypothetical example. Suppose I purchased 40 units of highland. 40 units of highland, each of those creates 2 units of upheaval. Now I'm at 80 units of upheaval. At 80 units of upheaval, the most I can purchase of the valley is going to be roughly 65 hectares. Otherwise I'm going to have too much social upheaval and that will not be an acceptable solution. So now our solution space is in this area.

Okay, we're nearly done. Let's add in another constraint here and that was our budget. We'll type in our budget. And again for the budget, we know that our total budget is 24,000 pickles. And our equation is just the number of pickles, times the number of valley hectares. So  $300$ , times the number of valley hectares purchased, plus  $200$ , times the number of highland hectares purchased, needs to be less than  $24,000$ .

And again we need to write this in terms of one of these, so we can graph it as a function of some other combination of habitats. So I'm going to go ahead and solve this for  $h$  once more. The highland hectares conserved. The first thing we're going to do is subtract off  $300$  times  $v$ . And then that entire term would be divided by  $200$  to give us our answer.

Let me scooch this graph out of the way here. So that means that given these entries for valley, we can compute what is the maximum number of highland hectares that can be conserved in order for us to meet this pickle constraint. Let's go ahead and enter that.

This is our budget constraint, we're going to just follow this equation, is equal to our pickle number, maximum pickle number, minus the cost in pickles for the valley. That whole thing goes in parentheses. And then we'll divide that by the cost in pickles per highland. Let's go ahead and anchor everything that is shaded in the green cells here. And now we can add this constraint to our graph as well.

We'll add a new series. This one is our budget constraint. The  $x$  values are the highland, which we have calculated here. So the  $x$  values are in cells H16 to H21. The  $y$  values or the vertical axis are the valley hectares. And then we press OK, and OK again.

And now our graph has the budget constraints like so. And our solution is within this area here.

We also said, as the last two constraints, that we don't need to purchase a huge amount of habitat. We have upper limits for what we need to purchase to conserve everything. And so I'm going to move this over. Let's go ahead and label these upper limits. And our upper limits, our upper limits for the valley is just  $350$  divided by  $5$ . So these would be the valley upper limits. Now how did we get this number?

The valley has  $350$  plant species total. And every time we add a hectare we are conserving  $5$  of them. So our upper limit is just  $350$  divided by  $5$  and that tells us that all we need to do is conserve  $70$  hectares regardless. So let's go ahead and anchor those in our formula and then

drag that down. So that is our upper limit for valley. That means no matter how much highland habitat we protect, we are only going to consider at the most, 70 hectares of valley habitat.

Let's go ahead and add that to our graph. Select the data. Add a new series. The series is the valley upper limit. The x axis is the horizontal axis. This would be the number of highland habitats, or highland hectares. And that is referenced in cells A16 to A21. And our y axis is the vertical axis. And that is the valley response to that, and provides us with our upper limit.

How about the highland upper limit? What would that be? This is the last constraint that we need to add.

Our upper limit for the highland is just equal to 240 divided by the number of plants species in the highland. And so if we enter that as an equation it would be cell E4 divided by E5. Anchor both of those. And then we'll drag that down and add this. And this will be the last constraint that we will have to deal with.

We'll add this one [series]. We'll call this the highland upper limit. The horizontal axis is our highland hectares. And the vertical axis will be the number of valley hectares. And then we'll press OK, and OK again.

And this graph, how we actually constructed this graph, might be a little bit hard to understand. But what we did is we created some general axes here. And then what we plot are either the highland result or the valley result, as a result of any combination of highland or valley. So for example, if I'm dealing with a valley calculation then my equations tell me, under every possible scenario of highland, what does the valley result give us. And if I'm dealing with calculating a highland result, then I want to calculate that result under any combination of valley. So every single one of these graphical equations used either this series or this series is part of the graph. If we graph highland as one series, then valley calculations would be computed and graphed. If we calculated highland results then we would graph those as any result or combination of valley.

After all that, we can see that we are left with a solution space that is in this area.

One thing that Tony mentioned is that we can arrive and figure out where our solution space would be. He mentioned already that it's going to end up being at one of these corners. But we can perhaps, now that we know what is an acceptable space, we can just enter a very simple

equation. And try to see which one of these would be maximized – which would be the maximal solution.

So let's do that by entering an equation. So let's say that we wanted to conserve, say, 150 species. And we can enter that in cell G5, Total Species Conserved. And we'll let that be an input in cell J5.

And let's just say you wanted to conserve 150 species in total. We need to then just enter an equation here. And we'll do this down here, and graph this as well. This will be our Total Species Conserved. And the equation is 5 times the number of valley hectares conserved, plus 3 times the number of highland hectares conserved, equals 150. So we don't know where those 150 are distributed. But we want to conserve 150.

Let's think about what that would look like on this graph. We just need to solve for one of these variables and plot it against each and every level of the second variable. Let's solve for h. h then is equal to 150. Let's move this 5 v term over. So we're going to subtract off 5 times v from each side. And then we're going to divide the entire result by 3.

Let's go ahead and enter that now. We've entered an equation for h, under any condition of v. So we'll use our spreadsheet and enter that now. h is equal to 150 minus 5 times v. That whole term divided by, that whole term I need to put parentheses around that, divided by cell E5. And we'll go ahead and anchor the entries that are shaded in green, and then pull that down. In this case, we don't need to see all of the decimal points. Let's turn those into numbers, and then hide the decimal points.

Let's go ahead and graph that once, as well. This will be the final thing we add to this. We'll select some data. We'll add a new entry. We'll call this species conserved. Our x value is always the highland, which we have calculated right here. So for each of these highland hectares in this series, we're going to graph those as a function of the valley hectares in this series. And then we press OK, and OK once more.

And this is this line right here. Now what we wanted to show you was, and Tony demonstrated this, is that as you change this number and say, well suppose I want to protect 200 species, that line starts to move up parallel. And it starts to tell you, at any point in this line, we're going to conserve 200 species. If we purchase 60 hectares of highland and about 5 hectares of valley we will conserve 200 species. If we protect 40 hectares of highland and roughly 18 hectares of

valley we will protect 200 species. And as we increase this a bit we can watch this line move forward and we will see how it's moving through our acceptable solution space, which is this space right here.

And let's see how that advances forward. So we're seeing that now we can maximize, we're getting more and more, we're still within our solution space. We've passed these two places here that were acceptable solutions, but are not optimal. And let's see where our result ends up. So we have passed this solution, but we can still do better. Because these are still acceptable solutions in this thin little slice here. And it looks like it's roughly 390.

At this point, this has all been a graphical look at this problem. These graphs tell you a lot more than you think. And we're going to head back to hear Tony talk about this approach a bit more. And then we'll come back to the spreadsheet and do some sensitivity analyses.

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