sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkmˆ2 (64 miˆ2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary

\nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "extra": {"cited_message_idx": 56, "search_result_idx": null, "evidence_text": "source"}, "url": "file-MOPCKNpTusz4oeTcXy2EOFv9"}}, {"start_ix": 1265, "end_ix": 1276, "citation_format_type": "tether_og", "metadata": {"type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-MOPCKNpTusz4oeTcXy2EOFv9", "source": "my_files", "text": "\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction \nEcological, geochemical and human processes can be described by \nfollowing the flows of material or energy from one place or form \nto another. A "system" is any set of connected processes and \nquantities of resources. It can be as larger or as small as you want \nto set the boundaries around. Although some people use the term \n"systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that can be \napplied to any size set of processes and resources. \n\nThis text presents one specific definition of how to characterize an \nenvironmental problem as a system of stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n

\nFigure 6-1. A simple systems diagram for the increase in a population of rabbits \nillustrates the five objects that we will use. \nStocks are a quantity of something. Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the

\n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkm^2 (64 mi^2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and

might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "extra":
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"\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems
\n \n6.1 Introduction \nEcological, geochemical and human processes can be described
by \nfollowing the flows of material or energy from one place or form \nto another. A
"system" is any set of connected processes and \nquantities of resources. It
can be as larger or as small as you want \nto set the boundaries around. Although some
people use the term \n"systems approach" to be holistic and inclusive, our
use of the \nword "systems view" specifies a set of intellectual tools that
can be \napplied to any size set of processes and resources. \n\nThis text presents
one specific definition of how to characterize an \nenvironmental problem as a system
of stocks and flows. We will \nbe using a limited list of characteristics of a system
that can be \nused to describe many different structures and behaviors. Our
\nconstrained set of categories will help highlight the structural \nsimilarities and
differences between different systems.   \n\nThis "systems" approach is
useful for simplifying problems, \nlooking for significant processes and identifying
controls. The \napproach can also be used to create simulations of future \nconditions
and to communicate these to other people who are \nmaking decisions. Another of the
benefits of this approach is that it \nclearly identifies the assumptions on which
simulations are based. \nA good "systems" model is both a valuable research
tool and a \nplatform for communication and decision-making. Thus, carefully
\ngathering information to construct a stock and flow description of \nan
environmental problem is a good example of methodically \ncollecting information that
takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n
\n\n6.2 Model Components \nThere are five components that we will use to represent the
\nstructure and behavior of our chosen system: stocks, flows, \ninformation flows,
convertors/constants and a source/sink. An icon \nrepresents each component. For
example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n
\nFigure 6-1. A simple systems diagram for the increase in a population of rabbits
\nillustrates the five objects that we will use. \nStocks are a quantity of something.
Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs.
All the \nstocks that are connected with flows will have the same units, that \nis all
the stocks will be a quantity of water, or an amount of carbon, \nor the number of
people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n
\n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with
a box icon. \n\nA source or sink is either has an unlimited, unchanging
\nconcentration or a reservoir that is outside the boundaries of the \nsystem that we
are studying. In our example, the source of new \nmatter that supports rabbit growth
is not being considered. You can \nimagine another model where the amount of food
available to the \nrabbit population limited the amount of new rabbits being born. In
\nthis case, we would probably model the system to include the \nnutrients as a stock
rather than a source/sink. A source/sink is \nrepresented as a little cloud in our
diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock
that it flows into or decrease a stock that it flows out of. All \nthe flows that are
connected to a stock will have the units of \nwhatever the units of the stocks are per
time. For example this \ncould be liters of water per hour, tons of carbon per year,

or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkm^2 (64 mi^2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad

\nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships

that makes it crash. However, the \nbalance comes about because all of the relatively
rapid rates of all \nthe processes are cancelling each other out, but a minor
imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome
narratives of Easter Island decline blame the population for \ntheir resource use
strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond
wonders what the person who cut down the \nlast palm tree was thinking. Even this
simple model shows that \nthere were multiple factors in play and the path toward a
\ndownward spiral of trees could have been set in motion when there \nwere still many
trees. This should be a cautionary tale for working \nwith real and complex systems,
i.e. the controls may have delays \nand multiple factors that make them very difficult
for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter
of \ntaking the right action for the moment, but also being able to \nunderstand the
more complex interactions and consequences of our \nactions. \n \n6.10 Summary
\nMethodically constructing a stock and flow model to represent the \nprocesses
related to an environmental problem supports good \npractice for scientific
information gathering. The constraints on \nthe quantities that are being measured
and followed forces the \nclarification of assumptions. The structure of the model can
be \nvisualized with iconography that illuminates the relationship to \nparticular
functions of the overall system such as feedbacks, stock \nlimitation and possible
steady state conditions. The basic \nassumptions for using a natural resource
sustainably can be \nexplored using this approach. The goal of sustainable use would
be \nto have the input match the output and maintain a steady state for \nthe resource.
Positive feedback works to replenish the stock, but \nthis is a double-edged sword,
just one bad year can lead to an \neventual collapse unless the harvest is decreased.
\n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each
stock and flow \nand explaining how that part contributes to the overall behavior of
\nthe system. This is a very useful exercise for construction of the \nmodel and for
communication about the important features of a \nproblem. \n\nAs models become busier
they often require sub-models for \ndifferent stocks. The example of Easter Island
demonstrated \nhypothetical relationships between the stocks of palm trees, people
\nand rats. At high human populations, this system was not resilient \nto changes and
might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "extra":
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\n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction
\nEcological, geochemical and human processes can be described by \nfollowing the
flows of material or energy from one place or form \nto another. A "system"
is any set of connected processes and \nquantities of resources. It can be as larger
or as small as you want \nto set the boundaries around. Although some people use the
term \n"systems approach" to be holistic and inclusive, our use of the
\nword "systems view" specifies a set of intellectual tools that can be
\napplied to any size set of processes and resources. \n\nThis text presents one
specific definition of how to characterize an \nenvironmental problem as a system of

stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n \nFigure 6-1. A simple systems diagram for the increase in a population of rabbits \nillustrates the five objects that we will use. \nStocks are a quantity of something. Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems"

\n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkmˆ2 (64 miˆ2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the

South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses

related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n",
"cloud_doc_url": null}, {"matched_text": "\u301056\u2020source\u3011", "start_idx": 980, "end_idx": 991, "alt": null, "type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-MOPCKNpTusz4oeTcXy2EOFv9", "source": "my_files", "snippet": "\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction \nEcological, geochemical and human processes can be described by \nfollowing the flows of material or energy from one place or form \nto another. A "system" is any set of connected processes and \nquantities of resources. It can be as larger or as small as you want \nto set the boundaries around. Although some people use the term \n"systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that can be \napplied to any size set of processes and resources. \n\nThis text presents one specific definition of how to characterize an \nenvironmental problem as a system of stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n \nFigure 6-1. A simple systems diagram for the increase in a population of rabbits \nillustrates the five objects that we will use. \nStocks are a quantity of something.

Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or

\nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature.

Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkmˆ2 (64 miˆ2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on

Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this

turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "cloud_doc_url": null}, {"matched_text": "\u301056\u2020source\u3011", "start_idx":

1265, "end_idx": 1276, "alt": null, "type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-MOPCKNpTusz4oeTcXy2EOFv9", "source": "my_files", "snippet": "\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction \nEcological, geochemical and human processes can be described by \nfollowing the flows of material or energy from one place or form \nto another. A "system" is any set of connected processes and \nquantities of resources. It can be as larger or as small as you want \nto set the boundaries around. Although some people use the term \n"systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that can be \napplied to any size set of processes and resources. \n\nThis text presents one specific definition of how to characterize an \nenvironmental problem as a system of stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n \nFigure 6-1. A simple systems diagram for the increase in a population of rabbits \nillustrates the five objects that we will use. \nStocks are a quantity of something. Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe

rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied

\nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkm^2 (64 mi^2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome

narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "cloud_doc_url": null}, {"matched_text": "\u301056\u2020source\u3011", "start_idx": 1576, "end_idx": 1587, "alt": null, "type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-MOPCKNpTusz4oeTcXy2EOFv9", "source": "my_files", "snippet": "\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction \nEcological, geochemical and human processes can be described by \nfollowing the flows of material or energy from one place or form \nto another. A "system" is any set of connected processes and \nquantities of resources. It can be as larger or as small as you want \nto set the boundaries around. Although some people use the term \n"systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that can be \napplied to any size set of processes and resources. \n\nThis text presents one specific definition of how to characterize an \nenvironmental problem as a system of stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which

simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n \nFigure 6-1. A simple systems diagram for the increase in a population of rabbits \nillustrates the five objects that we will use. \nStocks are a quantity of something. Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis:

This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and

\nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkmˆ2 (64 miˆ2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following

\nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource.

Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "cloud_doc_url": null}]}, "recipient": "all", "channel": null}, "parent": "7586dd5b-9166-4018-8396-f4b831cfff8d", "children": ["aaa2b006-e1f8-46ae-9d36-9616986b12e9"]}, "aaa2b006-e1f8-46ae-9d36-9616986b12e9": {"id": "aaa2b006-e1f8-46ae-9d36-9616986b12e9", "message": {"id": "aaa2b006-e1f8-46ae-9d36-9616986b12e9", "author": {"role": "user", "name": null, "metadata": {}}, "create_time": 1716493855.601461, "update_time": null, "content": {"content_type": "text", "parts": ["\nWhen modeling flow-limited resources, the inputs to consider include:\n- **Rate of resource renewal**: How quickly the resource replenishes naturally or through managed renewal processes.\n- **Consumption rate**: The speed at which the resource is being used by various processes or entities.\n- **External factors influencing availability**: This can include environmental conditions, regulatory policies, and technological changes that affect the resource's flow.\n\nIn contrast, a model of stock-limited resources would primarily focus on:\n- **Absolute quantity of the resource available**: The total amount of resource in existence or accessible for use, such as fossil fuels or minerals.\n- **Extraction or harvest rates**: How the resource is being depleted over time.\n- **Regeneration capabilities**: Whether and how the resource can be replenished naturally or artificially over a long period.\n\nThe key difference lies in the focus on the rate of flow and renewal in flow-limited models, which are dynamic and change over time depending on usage patterns and replenishment strategies. Stock-limited models, however, focus on a finite quantity of resources with less emphasis on the dynamics of flow, as the primary concern is the depletion of a fixed stock\n\nCan you rewrite the composition above in a narrative short essay format. Hopefully about 3 paragraphs? "]}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"request_id": "888793e3e8f74c48-MXP", "message_source": null, "timestamp_": "absolute", "message_type": null}, "recipient": "all", "channel": null}, "parent": "5191b4a9-6bad-4624-bf30-64051e16b602", "children": ["24d0aff2-8269-4f88-983e-e0fccfef9fae"]}, "24d0aff2-8269-4f88-983e-e0fccfef9fae": {"id": "24d0aff2-8269-4f88-983e-e0fccfef9fae", "message": {"id": "24d0aff2-8269-4f88-983e-e0fccfef9fae", "author": {"role": "assistant", "name": null, "metadata": {}}, "create_time": 1716493882.578073, "update_time": null, "content": {"content_type": "text", "parts": ["In the realm of resource management, two distinct modeling approaches are employed to understand and predict the availability and sustainability of resources: flow-limited and stock-limited models. Flow-limited models concentrate on the dynamics of resource renewal and consumption. Key inputs for these models include the rate of resource renewal, which accounts for how quickly a resource regenerates naturally or through human intervention. Additionally, the consumption rate is analyzed to determine the speed at which the resource is being utilized by various processes or entities. Furthermore, external factors such as environmental conditions, regulatory policies, and technological changes also play a crucial role in influencing the

availability and flow of these resources. This model is dynamic, adapting to changes in usage patterns and replenishment strategies, providing a flexible framework to forecast future resource statuses.\n\nContrastingly, stock-limited models focus on the finite quantities of resources available. This model is primarily concerned with the absolute quantity of the resource that exists or is accessible for use, exemplified by resources like fossil fuels or minerals. It further considers the extraction or harvest rates, detailing how the resource is depleted over time. Additionally, the model evaluates the regeneration capabilities of the resource, examining whether and how it can be replenished naturally or through artificial means over an extended period. This approach tends to emphasize the depletion of a fixed stock, highlighting the limits of availability and the critical need for conservation and efficient use.\n\nThe fundamental distinction between these two models lies in their focus and application. Flow-limited models are inherently dynamic, reflecting the continuous changes in resource flows and the effects of various influencing factors. They are particularly useful in scenarios where resources can be renewed or affected by external conditions. On the other hand, stock-limited models address resources with a fixed availability, focusing on managing finite supplies and preventing exhaustion. Understanding these differences is crucial for policymakers, businesses, and conservationists to develop effective strategies for resource management, ensuring sustainability and addressing the challenges posed by limited natural resources."]}, "status": "finished_successfully","end_turn": true
, "weight": 1.0, "metadata": {"finish_details": {"type": "stop", "stop_tokens": [100260]}, "citations": [], "gizmo_id": null, "is_complete": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "pad": "AAAAAAAAAAAAAAAAAAAAAAAA", "parent_id": "aaa2b006-e1f8-46ae-9d36-9616986b12e9", "request_id": "888793e3e8f74c48-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "aaa2b006-e1f8-46ae-9d36-9616986b12e9", "children": ["aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d"]}, "aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d": {"id": "aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d", "message": {"id": "aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d", "author": {"role": "user", "name": null, "metadata": {}}, "create_time": 1716496248.051185, "update_time": null, "content": {"content_type": "text", "parts": ["### Enhanced Text:\n\nIn resource management, two distinct modeling approaches are used to predict and understand the availability and sustainability of resources: flow-limited and stock-limited models.\n\nFlow-limited models focus on the dynamics of resource renewal and consumption. These models consider key inputs like the rate at which a resource regenerates, whether naturally or through human efforts. They also analyze the consumption rate to see how quickly the resource is being used by various entities or processes. Additionally, factors like environmental conditions, regulatory policies, and technological changes play significant roles in influencing resource availability and flow. This model is dynamic, adapting to changes in usage patterns and replenishment strategies, providing a flexible framework for forecasting future resource statuses.\n\nIn contrast, stock-limited models are concerned with the finite quantities of resources available. They focus on the absolute amount of the resource that exists or can be accessed, such as fossil fuels or minerals. These models consider extraction or harvest rates, detailing how quickly the resource is depleted over time. They also evaluate the resource\u2019s regeneration capabilities, whether it can be naturally replenished or artificially sustained over long periods. This approach emphasizes the depletion of a fixed stock, highlighting the limits of availability and the critical need for conservation and efficient use.\n\nThe main

difference between these two models lies in their focus and application. Flow-limited models are dynamic, reflecting continuous changes in resource flows and the effects of various influencing factors. They are particularly useful when resources can be renewed or are affected by external conditions. On the other hand, stock-limited models deal with resources that have fixed availability, concentrating on managing finite supplies and preventing exhaustion. Understanding these differences is crucial for policymakers, businesses, and conservationists. It helps in developing effective strategies for resource management, ensuring sustainability, and tackling the challenges posed by limited natural resources.\n\n\nCan you notate in the passage above which document each paragraph seems to be citing? \n "]}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"attachments": [{"id": "file-oLaOheWJnzyCmDOIDMrVRbRl", "size": 29388, "name": "tactiq-free-transcript-QBrmAGcMIi8.txt", "mime_type": "text/plain"}, {"id": "file-zOTPP4kr8vUXBo6kFBD1ojOe", "size": 356629, "name": "v7-Rueter-chap6.pdf", "mime_type": "application/pdf"}], "request_id": "8887ce43ae134bf0-MXP", "message_source": null, "timestamp_": "absolute", "message_type": null}, "recipient": "all", "channel": null}, "parent": "24d0aff2-8269-4f88-983e-e0fccfef9fae", "children": ["eb4d940d-4b25-44a3-9e2e-abd1f07c9585"]}, "eb4d940d-4b25-44a3-9e2e-abd1f07c9585": {"id": "eb4d940d-4b25-44a3-9e2e-abd1f07c9585", "message": {"id": "eb4d940d-4b25-44a3-9e2e-abd1f07c9585", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716496261.14191, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-zOTPP4kr8vUXBo6kFBD1ojOe", "domain": "v7-Rueter-chap6.pdf", "text": "\n130 August 13, 2013 \n\n \n\n \n\n \n \n\nChapter 6 \u2013 Stock and Flow Systems \n \n6.1 Introduction \nEcological, geochemical and human processes can be described by \nfollowing the flows of material or energy from one place or form \nto another. A "system" is any set of connected processes and \nquantities of resources. It can be as larger or as small as you want \nto set the boundaries around. Although some people use the term \n"systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that can be \napplied to any size set of processes and resources. \n\nThis text presents one specific definition of how to characterize an \nenvironmental problem as a system of stocks and flows. We will \nbe using a limited list of characteristics of a system that can be \nused to describe many different structures and behaviors. Our \nconstrained set of categories will help highlight the structural \nsimilarities and differences between different systems.   \n\nThis "systems" approach is useful for simplifying problems, \nlooking for significant processes and identifying controls. The \napproach can also be used to create simulations of future \nconditions and to communicate these to other people who are \nmaking decisions. Another of the benefits of this approach is that it \nclearly identifies the assumptions on which simulations are based. \nA good "systems" model is both a valuable research tool and a \nplatform for communication and decision-making. Thus, carefully \ngathering information to construct a stock and flow description of \nan environmental problem is a good example of methodically \ncollecting information that takes place in scientific research (Pielke \n2007). \n \n\n\n\nDraft v7 131 \n\n \n\n6.2 Model Components \nThere are five components that we will use to represent the \nstructure and behavior of our chosen system: stocks, flows, \ninformation flows, convertors/constants and a source/sink. An icon \nrepresents each component. For example, look at the growth of a \npopulation of rabbits (see Figure 1). \n\n \n\n \nFigure 6-1. A simple systems diagram for the increase in a population of rabbits

\nillustrates the five objects that we will use. \nStocks are a quantity of something. Water in a tank is a good \nexample of a stock. Sometimes stocks are called reservoirs. All the \nstocks that are connected with flows will have the same units, that \nis all the stocks will be a quantity of water, or an amount of carbon, \nor the number of people, etc. In our example, the stock is the \n\n\n\n132 August 13, 2013 \n\n \n\nnumber of rabbits in the population. We represent this in a systems \ndiagram with a box icon. \n\nA source or sink is either has an unlimited, unchanging \nconcentration or a reservoir that is outside the boundaries of the \nsystem that we are studying. In our example, the source of new \nmatter that supports rabbit growth is not being considered. You can \nimagine another model where the amount of food available to the \nrabbit population limited the amount of new rabbits being born. In \nthis case, we would probably model the system to include the \nnutrients as a stock rather than a source/sink. A source/sink is \nrepresented as a little cloud in our diagrams. \n\nFlows connect stocks or source/sinks. The flow will increase any \nstock that it flows into or decrease a stock that it flows out of. All \nthe flows that are connected to a stock will have the units of \nwhatever the units of the stocks are per time. For example this \ncould be liters of water per hour, tons of carbon per year, or in our \nexample, rabbits per month. \n\nWhen we have information that is needed in the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network.

\n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability \nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkm^2 (64 mi^2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe

could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "title":

"v7-Rueter-chap6.pdf", "tether_id": null}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"command": "context_stuff", "is_visually_hidden_from_conversation": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "parent_id": "aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d", "request_id": "8887ce43ae134bf0-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "aaa206a9-e7fd-4c0d-8699-85fc0fc7ba2d", "children": ["56346275-95b5-4a3b-9c8e-72f2e1697f08"]}, "56346275-95b5-4a3b-9c8e-72f2e1697f08": {"id": "56346275-95b5-4a3b-9c8e-72f2e1697f08", "message": {"id": "56346275-95b5-4a3b-9c8e-72f2e1697f08", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716496261.142204, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-oLaOheWJnzyCmDOIDMrVRbRl", "domain": "tactiq-free-transcript-QBrmAGcMIi8.txt", "text": "# tactiq.io free youtube transcript\n# Why System Dynamics Should Become Part of Secondary School Math Instruction\n# https://www.youtube.com/watch/QBrmAGcMIi8\n\n00:00:00.719 hello my name is diana fisher\n00:00:03.040 i have been asked to present to on the\n00:00:05.839 system dynamics work\n00:00:07.200 i have done with secondary school\n00:00:08.880 students and teachers over three decades\n00:00:11.599 i have used system dynamics modeling in\n00:00:13.920 my mathematics and modeling instruction\n00:00:16.000 for 30 years\n00:00:17.520 although science instruction is the most\n00:00:19.680 natural discipline for sd modeling i\n00:00:22.080 would like to make\n00:00:23.199 an argument that if we really want sd\n00:00:25.840 modeling to become\n00:00:26.960 a more mainstream analytical tool it\n00:00:30.240 should be embedded in secondary school\n00:00:32.640 mathematics\n00:00:33.840 sd modeling can reinforce important\n00:00:37.120 mathematical concepts quite well dr\n00:00:40.320 barry m specializes in the study of\n00:00:42.399 complex systems\n00:00:43.760 to be able to analyze complex systems\n00:00:46.879 he claims that calculus and statistics\n00:00:49.120 do not have the tools to describe\n00:00:51.680 what we want to study that we need\n00:00:55.360 to work with new concepts that we need\n00:00:58.960 to\n00:00:59.359 ask different questions about system\n00:01:02.000 dynamic behavior\n00:01:03.920 he says working with complex systems\n00:01:06.799 changes how we think\n00:01:08.560 we have an opportunity to help our\n00:01:10.479 mathematics students broaden their\n00:01:12.400 thinking\n00:01:13.280 to encompass techniques that will help\n00:01:15.520 them think about\n00:01:16.479 complex dynamic problems one way to\n00:01:19.600 start\n00:01:20.240 is improving their understanding of\n00:01:22.080 functions studies in the united states\n00:01:25.200 indicate that students possess weak\n00:01:27.280 understanding of functions\n00:01:29.280 over the last several decades\n00:01:32.960 mathematics instruction in the u.s\n00:01:35.520 evolved to require\n00:01:37.040 multiple representation of function\n00:01:39.439 behavior\n00:01:40.320 including graphs and tables but now\n00:01:42.640 research indicates that mapping diagrams\n00:01:45.280 also provide a rich foundation for\n00:01:48.240 understanding functions\n00:01:50.799 the late dr james kapit proposed\n00:01:54.520 democratizing the comp concepts of\n00:01:57.280 calculus\n00:01:58.399 by providing technology-based learning\n00:02:01.280 environments\n00:02:02.479 he said new notation systems with new\n00:02:05.680 ways of\n00:02:06.479 acting upon those new notation systems\n00:02:09.840 offer dramatically new possibilities for\n00:02:12.480 mathematics learning\n00:02:14.319 sd is such a new and powerful\n00:02:18.080 notation system the audience recognizes\n00:02:21.120 these system dynamics modeling icons\n00:02:23.440 from which

sd models can be constructed\n00:02:26.400 the stock\n00:02:27.280 and accumulator represents a main\n00:02:29.599 function in the model\n00:02:31.200 mathematically it operates as an\n00:02:33.519 integral does in calculus the flow\n00:02:36.800 is the rate of change of the stock so it\n00:02:39.200 is essentially the first derivative\n00:02:41.120 described in calculus\n00:02:43.280 converters hold constants parameters or\n00:02:46.080 simple\n00:02:46.560 or arithmetic combinations of model\n00:02:49.040 components\n00:02:50.319 the connector indicates the influence of\n00:02:52.959 one\n00:02:53.360 model component on another\n00:02:55.400 mathematically\n00:02:56.800 the connectors identify the dependencies\n00:02:59.599 of one variable\n00:03:00.879 variable on another i will not take you\n00:03:04.319 quickly through the two\n00:03:05.599 most basic functions studied in algebra\n00:03:08.800 connecting sd and traditional\n00:03:10.720 mathematics\n00:03:11.840 representation suppose we were\n00:03:14.080 interested in how\n00:03:15.040 water in a lake is increasing based on\n00:03:17.440 water flowing in\n00:03:18.560 at a constant rate using the sd\n00:03:21.760 structure the initial\n00:03:25.280 water in the lake would be placed in a\n00:03:27.840 stock icon\n00:03:29.200 and it would only have an\n00:03:32.239 inflow since it is only increasing\n00:03:35.599 with a constant value in the flow we\n00:03:38.799 know the behavior of the stock\n00:03:40.640 is growing linearly since the rate of\n00:03:42.799 change is constant\n00:03:44.319 and positive the sd\n00:03:47.360 software calculates the value of the\n00:03:49.360 stock using recursion which is shown in\n00:03:52.000 the table at the left\n00:03:53.599 we see that the flow value is added to\n00:03:56.239 the current value of the stock\n00:03:58.080 each time unit now we see the\n00:04:00.640 traditional closed form equation for the\n00:04:02.720 linear function where w\n00:04:04.560 represents the amount of water in the\n00:04:07.439 lake\n00:04:08.400 it starts at 100 units and grows at five\n00:04:11.439 units per year\n00:04:13.040 if we were to construct what we know is\n00:04:16.000 an exponential population growth\n00:04:18.320 behavior\n00:04:19.358 we could start with a stock of elephants\n00:04:21.680 and an inflow of new elephants\n00:04:23.600 born to this herd each year but this\n00:04:26.479 model is not correct\n00:04:28.320 we know the inflow cannot be constant\n00:04:30.880 because the number of new elephants born\n00:04:32.960 per year depends on knowing how many\n00:04:34.960 elephants are currently\n00:04:36.400 in the herd so we now indicate that\n00:04:39.680 dependency with a connector\n00:04:42.560 oh and now we have introduced a feedback\n00:04:45.680 loop\n00:04:46.400 the loop is reinforcing because the more\n00:04:49.280 elephants in the population\n00:04:51.280 the more new elephants are born per year\n00:04:54.080 adding more elephants to the herd\n00:04:56.639 but this model is still not complete we\n00:04:59.759 should\n00:05:00.320 indicate the number of new elephants\n00:05:02.479 born per\n00:05:03.759 elephant in the herd each year\n00:05:06.880 we do that by indicating a birth\n00:05:09.600 fraction\n00:05:10.240 in decimal form that will be multiplied\n00:05:13.199 by the number of elements\n00:05:14.639 in the herd each year so for exponential\n00:05:17.919 growth the inflow is proportional to the\n00:05:20.479 current amount of the stock\n00:05:22.880 or mathematically the rate of change the\n00:05:25.759 flow\n00:05:26.560 is defined as the stock value times some\n00:05:29.840 growth factor value this is exactly the\n00:05:33.199 differential equation\n00:05:34.880 that represents exponential growth but\n00:05:37.039 algebra students\n00:05:38.000 don't need to know that they are\n00:05:39.759 learning calculus\n00:05:41.280 they are just learning a different\n00:05:42.880 behavior pattern over time\n00:05:44.960 and how to create it based on its rate\n00:05:47.520 of change definition\n00:05:49.840 again quickly we would have our stock\n00:05:52.479 flow definition as shown\n00:05:54.160 with a 20 growth fraction the elephant\n00:05:57.440 population will grow\n00:05:58.800 exponentially because the inflow is\n00:06:01.039 proportional to the stock value\n00:06:03.360 if we think about what the sd software\n00:06:05.680 is doing\n00:06:06.560 we look at the recursion in the table\n00:06:09.280 the flow\n00:06:10.240 calculates the growth amount and adds it\n00:06:13.360 to the stock\n00:06:14.639 each year there are two equations that\n00:06:17.919 are possible\n00:06:18.960 mathematically the easier equation is\n00:06:21.840 represented at the top\n00:06:23.520 and is the one often taught in first\n00:06:26.080 year algebra\n00:06:27.280 it is often used when we want to\n00:06:29.440 calculate values\n00:06:30.720 once every year or time unit\n00:06:33.759 the second is shown at the bottom and is\n00:06:37.280 often used in situations where\n00:06:40.000 calculating continuous change\n00:06:41.919 is a better choice the top equation is\n00:06:44.720 probably the best choice for this\n00:06:46.479 particular elephant heard example\n00:06:49.120 in sd modeling we use the same diagram\n00:06:52.240 for each scenario and merely increase\n00:06:54.800 the number of times the simulation\n00:06:56.960 calculates the values each time\n00:06:59.120 unit to differentiate which\n00:07:02.400 situation is being used for calculation\n00:07:05.599 as a it is a much more intuitive process\n00:07:09.360 in my opinion just so you know\n00:07:13.120 there is a free web-based version of the\n00:07:15.360 sd modeling software that works on\n00:07:17.680 tablets computers laptops chromebooks\n00:07:20.080 and smartphone\n00:07:21.440 that will allow you to have your\n00:07:23.759 students build these models\n00:07:25.759 if they have access to this technology\n00:07:28.639 go to publish.icsysystems.com\n00:07:31.840 the software is called stella online\n00:07:36.160 once students learn linear and\n00:07:38.479 exponential model structures they can\n00:07:40.560 start putting them together to study new\n00:07:42.720 problems\n00:07:43.680 they could not study with equations\n00:07:46.720 i have used these medication models in\n00:07:49.199 my algebra classes over\n00:07:51.199 many years students really like them\n00:07:54.639 consider an emergency room problem you\n00:07:57.759 the student are a medical resident\n00:08:00.240 working in the emergency room\n00:08:02.160 and a patient comes in who needs\n00:08:04.000 immediate medical tension\n00:08:06.160 from your analysis you decide to connect\n00:08:08.560 this patient to an iv drip that will\n00:08:10.800 supply\n00:08:11.440 one milligram of therapeutic drug per\n00:08:14.560 minute\n00:08:15.199 this person you estimate will metabolize\n00:08:17.680 the drug\n00:08:18.639 at about 0.55 percent per minute\n00:08:22.639 what is the pattern of the drug level in\n00:08:24.879 the body over 24 hours\n00:08:27.599 so the diagram might look like this with\n00:08:30.000 an inflow of medicine and an\n00:08:31.680 outflow of body using and\n00:08:34.799 eliminating the medicine observe the\n00:08:37.679 left\n00:08:38.000 side of the diagram since there is a\n00:08:40.000 constant inflow the left part of the\n00:08:41.839 diagram is similar to\n00:08:43.599 a linear model structure observe the\n00:08:47.120 right part of the diagram\n00:08:48.640 the structure is similar to an\n00:08:50.399 exponential decay\n00:08:51.760 the drug is lost as a percent of the\n00:08:54.399 current amount of drug in the patient's\n00:08:56.320 systems\n00:08:57.839 students try to predict the behavior of\n00:09:00.080 the drug\n00:09:00.959 in the body over time giving a reason\n00:09:03.440 for their predictions\n00:09:05.040 then they build the model and see what\n00:09:07.360 the computer produces\n00:09:09.360 then they have to explain why the\n00:09:12.080 computer graph\n00:09:13.200 has the shape that it shows\n00:09:16.800 skipping to the skipping the second\n00:09:18.800 medication scenario we will go to the\n00:09:21.200 third drug model\n00:09:22.959 it involves taking medicine in the form\n00:09:25.120 of pills\n00:09:26.640 it has been a busy day in the emergency\n00:09:29.200 room a third\n00:09:30.160 patient arrives and you decide to give\n00:09:32.320 this patient two\n00:09:33.519 pills of 375 milligrams\n00:09:36.959 each of a therapeutic drug and tell them\n00:09:39.680 to continue taking\n00:09:41.360 two more pills every four hours this\n00:09:44.399 person you\n00:09:45.200 estimate will absorb the drug from the\n00:09:47.760 stomach in the bloodstream\n00:09:50.080 at about 4.5\n00:09:53.360 percent per minute and metabolize the\n00:09:56.399 drug\n00:09:57.120 at about point 55 percent per minute\n00:10:00.560 what is the pattern of drug level in the\n00:10:02.640 body over 24 hours\n00:10:05.120 this model uses two stalks because the\n00:10:07.519 medicine\n00:10:08.640 must first accumulate in the stomach and\n00:10:10.880 then move into the bloodstream\n00:10:12.959 the inflow is a pulse because the pills\n00:10:15.839 are taken\n00:10:16.480 once every four hours students are asked\n00:10:19.839 to anticipate the pattern of behavior of\n00:10:22.240 the left\n00:10:23.040 of just the left part of the model drug\n00:10:26.160 in the stomach then students are asked\n00:10:28.800 to anticipate the pattern of drug in the\n00:10:31.120 blood over time\n00:10:32.640 this is not a trivial analysis then\n00:10:35.600 different patterns of pill delivery\n00:10:37.360 protocol\n00:10:38.160 are explored and compared to the optimal\n00:10:41.120 therapeutic level for this\n00:10:42.800 medication finally in this sequence of\n00:10:45.600 medication models\n00:10:47.040 students as a class are asked to help\n00:10:49.760 modify\n00:10:50.959 the pill model so that it will\n00:10:54.399 calculate the blood alcohol\n00:10:56.480 concentration\n00:10:57.760 of a human male sipping beer over two\n00:11:00.720 hours\n00:11:01.839 the modified stock flow diagram is\n00:11:04.560 sketched as a class\n00:11:06.240 then students access the pre-built model\n00:11:09.760 online and test the following scenarios\n00:11:12.560 using the model\n00:11:15.040 influence of body weight gender type of\n00:11:17.760 alcohol and type of drinker\n00:11:20.560 now let's turn to a different sequence\n00:11:22.880 of models\n00:11:23.760 the basic population model is ubiquitous\n00:11:26.480 in system dynamics studies\n00:11:28.720 problems in health economics\n00:11:30.720 environmental science biology geography\n00:11:33.360 sociology and mathematics and more often\n00:11:36.720 involve the study of population dynamics\n00:11:39.839 the basic population model involves a\n00:11:42.880 stock for population\n00:11:44.720 since that's the value that we want to\n00:11:46.480 track over time\n00:11:47.760 it is the function an outflow of births\n00:11:51.200 and an inflow of births and an outflow\n00:11:54.399 of deaths\n00:11:55.040 and their attendant births and deaths\n00:11:57.440 fraction\n00:11:58.800 the basic model contains two feedback\n00:12:01.120 loops that control\n00:12:02.480 change in population dynamics over time\n00:12:06.480 there are three types of graphs that\n00:12:08.959 this structure could\n00:12:10.000 produce based upon which feedback is\n00:12:12.959 dominant\n00:12:14.160 assume that the birth fraction is larger\n00:12:16.160 than the death fraction\n00:12:17.360 the model could produce exponential\n00:12:19.360 growth but the deer population cannot\n00:12:21.839 grow forever\n00:12:22.720 there are limiting factors that would\n00:12:24.480 influence the growth\n00:12:26.000 as the deer population increases there\n00:12:28.320 would be more competition for food and\n00:12:30.240 water\n00:12:31.200 deer could become more aggressive as\n00:12:33.279 they vie for\n00:12:34.320 the limited resource overcrowding can\n00:12:37.360 also lead to aggression\n00:12:39.120 and to the spread of disease as waste\n00:12:41.760 builds up in a limited area\n00:12:43.760 each of these factors would lead to a\n00:12:46.079 higher death rate for the deer\n00:12:48.320 assume that the environment can support\n00:12:51.360 only a specific number of deer the\n00:12:54.399 number of deer the environment can\n00:12:56.639 support in any given location is called\n00:13:00.079 the carrying capacity we assume that the\n00:13:03.200 comparison\n00:13:03.920 comparison the carrying capacity value\n00:13:07.279 is unchanging\n00:13:09.040 as the population grows toward the\n00:13:12.480 carrying capacity\n00:13:14.320 the death fraction is being increased\n00:13:18.079 as we think it should the deer\n00:13:21.120 population graph looks reasonable with\n00:13:23.360 the carrying capacity component\n00:13:25.440 at the beginning there are few deer\n00:13:28.480 and the population is growing quite a\n00:13:30.560 bit as the population gets closer to the\n00:13:33.200 carrying capacity the growth slows down\n00:13:35.760 eventually\n00:13:36.639 moving to steady state this demonstrates\n00:13:40.800 transfer of feedback loop dominance\n00:13:44.240 now look at the typical closed form\n00:13:46.399 equation for the same scenario\n00:13:48.800 it seems to me that the stock flow model\n00:13:51.519 is easier to understand and\n00:13:53.279 interpret making this scenario\n00:13:55.440 approachable by students in mathematics\n00:13:57.839 classes\n00:13:58.399 lower than precalculus where the\n00:14:00.639 equation is usually studied\n00:14:02.800 i have used this model in my algebra\n00:14:05.040 classes successfully\n00:14:06.560 with students as young as 15.\n00:14:10.480 so now we get to the meat of this\n00:14:12.880 presentation\n00:14:14.399 what overarching value does sd modeling\n00:14:17.760 approach\n00:14:18.399 add to mathematics instruction a new\n00:14:21.279 representation for some core functions\n00:14:23.839 studied in algebra and precalculus\n00:14:26.480 provides not only a different\n00:14:27.920 representation that is more visual\n00:14:30.480 for the functions but bases the new\n00:14:32.800 representation\n00:14:34.160 on the rates of change for each function\n00:14:37.199 a very important concept in calculus\n00:14:40.399 the structure the blueprint for each\n00:14:42.800 function helps describe\n00:14:44.480 why the function behavior makes sense\n00:14:47.360 that is\n00:14:48.240 constant flows create linear stock\n00:14:51.199 behavior\n00:14:52.399 proportional fro flows create\n00:14:54.800 exponential stock behavior\n00:14:56.639 etc each system dynamics icon\n00:15:00.079 uses full words or phrases in their\n00:15:03.040 names\n00:15:03.519 making it easier to remember what each\n00:15:05.920 part of the model represents\n00:15:08.000 and it has been my experience with\n00:15:10.320 students\n00:15:11.120 that they have a much easier time\n00:15:13.440 translating word problems that describe\n00:15:15.920 dynamics to the sd model structure\n00:15:20.160 take for example the representation for\n00:15:22.399 an oscillating spring behavior\n00:15:24.639 the stock flow diagram captures the\n00:15:27.360 concepts of position\n00:15:28.959 restoring force mass acceleration\n00:15:31.360 velocity etc\n00:15:33.040 all central concepts in the dynamic of a\n00:15:35.680 bouncing spring\n00:15:37.199 the closed form equation merely\n00:15:40.720 captures the appearance of the\n00:15:42.800 oscillation\n00:15:44.320 not the core structure that is causing\n00:15:46.800 the behavior to occur\n00:15:48.800 i believe that the stock flow structure\n00:15:50.880 is more educationally\n00:15:52.560 valuable than the closed form equation\n00:15:56.320 students and many adults are notoriously\n00:15:59.199

poor\n00:15:59.680 at reading and interpreting graphs sd\n00:16:02.800 modeling\n00:16:03.600 has one of its main analytical\n00:16:06.160 techniques\n00:16:07.199 to interpret the graphical output of the\n00:16:09.600 models\n00:16:10.560 multiple times as models are built\n00:16:13.279 modified\n00:16:14.079 and tested students get lots of practice\n00:16:17.839 reading and interpreting graphs moreover\n00:16:21.040 students are often required to view flow\n00:16:23.759 graphs\n00:16:24.399 on the same grid as stock graphs to help\n00:16:27.839 explain stock behavior this\n00:16:30.399 correlational\n00:16:31.360 graphical analysis is a core concept in\n00:16:34.639 calculus\n00:16:35.360 and very important for understanding\n00:16:37.600 dynamic phenomenon\n00:16:39.839 creating the stop flow diagram lays\n00:16:43.040 bare the student's mental model the\n00:16:46.160 student can\n00:16:46.959 test his or her mental model to\n00:16:49.279 determine\n00:16:50.320 if the structure produces reasonable\n00:16:52.560 results\n00:16:53.600 then if it does not the student knows he\n00:16:56.000 or she must\n00:16:57.040 modify the model structure via more\n00:16:59.839 research that often includes\n00:17:01.680 communicating with other team members\n00:17:04.319 to improve the model and obtain\n00:17:06.720 reasonable results\n00:17:08.640 as you have seen building useful and\n00:17:11.199 interesting models\n00:17:12.720 using sd modeling can allow students to\n00:17:16.319 build\n00:17:16.720 problems that would be out of their\n00:17:18.559 reach using only closed form equations\n00:17:21.839 this makes a much larger pool of\n00:17:24.880 interesting problems for students to\n00:17:26.799 study\n00:17:27.599 and makes connecting mathematics with\n00:17:30.320 real\n00:17:30.840 world more obvious\n00:17:33.840 another factor that is outside current\n00:17:36.320 mathematics instruction at the secondary\n00:17:38.320 school level\n00:17:39.039 is the importance of non-linear system\n00:17:41.919 behavior\n00:17:42.720 which is necessary to produce transfer\n00:17:45.440 of feedback loop dominance\n00:17:48.160 and of course the inclusion of delays\n00:17:50.880 the model\n00:17:51.679 on the left has been built and analyzed\n00:17:54.400 by\n00:17:55.000 non-honors algebra students and the\n00:17:58.000 delays\n00:17:58.880 represented on the right both material\n00:18:01.360 at the top\n00:18:02.080 and information delays at the bottom\n00:18:05.039 could be understood by algebra students\n00:18:08.799 this slide identifies two websites\n00:18:12.080 with resources that you may find useful\n00:18:15.520 the first is a website that contains\n00:18:17.679 some free\n00:18:18.960 sd lessons for use with secondary school\n00:18:21.600 students\n00:18:22.480 as well as where to purchase some books\n00:18:25.039 of sd lessons that are published\n00:18:27.760 it also contains examples of secondary\n00:18:30.080 school students\n00:18:31.039 original sd model diagrams and technical\n00:18:33.919 papers\n00:18:34.480 explaining the models it advertises\n00:18:37.600 online sd courses geared to secondary\n00:18:40.640 school math and science\n00:18:42.000 teachers and shows the alignment of sd\n00:18:45.120 with u.s national educational standards\n00:18:47.600 in many disciplines\n00:18:49.440 the other website contains additional\n00:18:52.640 lessons that can be downloaded or\n00:18:54.640 purchased\n00:18:55.440 and numerous lesson books appropriate\n00:18:58.320 for\n00:18:58.640 pre-college students the experience that\n00:19:02.240 greatly enhanced my opinion about the\n00:19:04.799 virtues of using the system dynamics\n00:19:07.039 modeling approach with students\n00:19:08.960 occurred when i saw what students could\n00:19:11.120 produce\n00:19:12.000 when given the freedom to choose a\n00:19:14.160 dynamic problem that\n00:19:15.520 interested them for which they could\n00:19:17.600 create an original model\n00:19:19.520 write a technical paper explaining their\n00:19:21.760 model and present their model\n00:19:24.400 to an audience\n00:19:27.600 i wanted to prepare students to identify\n00:19:31.280 and analyze\n00:19:32.240 problems in the world from which\n00:19:35.600 they could gain an understanding by\n00:19:37.760 building system dynamics models\n00:19:40.320 i wanted them to develop skill in model\n00:19:43.039 building\n00:19:43.760 in analyzing model design in output and\n00:19:47.120 feedback\n00:19:47.760 and in explaining what they learned so i\n00:19:50.480 designed a secondary school\n00:19:52.640 system dynamics modeling course that i\n00:19:54.799 taught for 20 years\n00:19:56.640 one of the most important lessons i\n00:19:58.640 included in my sd modeling course was to\n00:20:01.120 show students how to translate\n00:20:03.440 a systems problem found in a news\n00:20:05.919 article\n00:20:06.559 into a stock flow diagram students\n00:20:09.360 listed the most important variables\n00:20:11.520 they built the structure of their model\n00:20:13.280 by hand and they also sketched out the\n00:20:15.440 feedback\n00:20:16.159 students indicated that this was one of\n00:20:18.080 the most important lessons in preparing\n00:20:20.640 them to do their final project\n00:20:22.880 i'm going to magnify this bottom part\n00:20:26.000 so you can see it a little bit better\n00:20:29.760 i know it's blurry but it's because i\n00:20:32.480 just used the previous picture to\n00:20:34.159 magnify it\n00:20:35.280 but you can see the design of their\n00:20:37.280 model structure you can see their\n00:20:38.960 feedback loop\n00:20:40.159 they're doing behavior over time graphs\n00:20:42.320 all of this was part of the lesson\n00:20:44.320 for analyzing an article in the news i'm\n00:20:47.200 now going to show you\n00:20:48.559 some sample student original sd models\n00:20:52.000 in 2007 when the united states was\n00:20:54.720 experiencing an oil crisis\n00:20:57.200 this student observed that many people\n00:20:59.120 were trying unsuccessfully to buy hybrid\n00:21:02.080 cars this was his idea of why\n00:21:05.760 the problem happened it actually is\n00:21:08.000 broken into three segments\n00:21:10.559 there is the hybrid car segment at the\n00:21:13.440 top\n00:21:14.400 i'll go back hybrid car production\n00:21:18.880 hybrid inventory and active\n00:21:21.919 hybrid in vehicles\n00:21:25.360 there is a factory capacity which was a\n00:21:28.799 limiting factor on being able to produce\n00:21:31.200 enough cars\n00:21:32.400 and then there was a backlog of orders\n00:21:35.039 and perceived backlogged\n00:21:37.039 that prospective buyers weren't going to\n00:21:39.919 get\n00:21:40.559 a car very soon even if they ordered one\n00:21:44.000 his model did not start an equilibrium\n00:21:46.400 unfortunately\n00:21:47.679 so let's ignore the first part of the\n00:21:49.440 graph and and focus on the spike in oil\n00:21:52.640 prices\n00:21:53.520 at week 30. the new demand which is the\n00:21:56.720 pink\n00:21:57.440 curve spikes upward for hybrid cars\n00:22:01.760 that is quickly followed by a spike in\n00:22:04.159 the backlog demand for hybrid cars which\n00:22:06.640 is the brown graph\n00:22:08.400 the price of hybrid cars which is the\n00:22:10.880 green curve shows an\n00:22:12.480 increase as backlog increases the blue\n00:22:15.520 line\n00:22:16.080 which is on a scale by itself is the\n00:22:18.480 number of active hybrid cars\n00:22:20.720 and that is steadily increasing\n00:22:24.000 the first year i introduced material and\n00:22:26.400 information delays to my students\n00:22:28.559 many students understood the ideas\n00:22:30.559 immediately\n00:22:32.080 this student started his model on\n00:22:34.320 workforce pressure\n00:22:35.840 using the idea of three delays

so\n00:22:38.960 here we have employees\n00:22:42.080 who are being hired and fired this is\n00:22:45.120 the amount of\n00:22:46.159 work that the company wants done\n00:22:50.080 this is the perceived satisfaction of\n00:22:53.200 the current working people\n00:22:55.120 and up here is the pay that is given\n00:22:58.960 to the workers the three\n00:23:02.320 delays here are an information delay\n00:23:06.000 down in the perceived satisfaction\n00:23:09.280 and information delay in hiring and\nThe file is too long and its contents have been truncated.\n", "title": "tactiq-free-transcript-QBrmAGcMIi8.txt", "tether_id": null}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"command": "context_stuff", "is_visually_hidden_from_conversation": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "parent_id": "eb4d940d-4b25-44a3-9e2e-abd1f07c9585", "request_id": "8887ce43ae134bf0-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "eb4d940d-4b25-44a3-9e2e-abd1f07c9585", "children": ["ab823156-ecb3-4005-9ab9-1996d94b23ba"]}, "ab823156-ecb3-4005-9ab9-1996d94b23ba": {"id": "ab823156-ecb3-4005-9ab9-1996d94b23ba", "message": {"id": "ab823156-ecb3-4005-9ab9-1996d94b23ba", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716496261.142463, "update_time": null, "content": {"content_type": "text", "parts": ["\nPlease remember to search the user's documents if an answer to their question is not contained in the above snippets.\n"]}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"is_visually_hidden_from_conversation": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "pad": "AAA", "parent_id": "56346275-95b5-4a3b-9c8e-72f2e1697f08", "request_id": "8887ce43ae134bf0-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "56346275-95b5-4a3b-9c8e-72f2e1697f08", "children": ["01bd7cf8-1f54-4140-9300-a508cfd41a79"]}, "01bd7cf8-1f54-4140-9300-a508cfd41a79": {"id": "01bd7cf8-1f54-4140-9300-a508cfd41a79", "message": {"id": "01bd7cf8-1f54-4140-9300-a508cfd41a79", "author": {"role": "assistant", "name": null, "metadata": {}}, "create_time": 1716496261.142742, "update_time": null, "content": {"content_type": "text", "parts": ["The enhanced text discussing flow-limited and stock-limited resource models draws upon the principles outlined in the document "Chapter 6 \u2013 Stock and Flow Systems" from "v7-Rueter-chap6.pdf". The descriptions of how these models handle resources\u2014whether focusing on the dynamics of flow and renewal in flow-limited models or the quantification of total resources in stock-limited models\u2014echo the concepts presented in this document. Specifically, it details the use of stocks, flows, and other system dynamics elements to model environmental and resource-based systems. This foundational understanding is key to assessing both the availability and sustainability of resources under different management scenarios."]}, "status": "finished_successfully","end_turn": true
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practices play a significant role in the availability and sustainability of olive oil production. These factors can affect the overall flow of olive oil into the market, from the cultivation of olive trees to the pressing and processing of the olives. Therefore, managing the flow of this resource involves careful consideration of both the biological growth cycles of the trees and the technological and environmental factors that influence olive production."]}, "status": "finished_successfully","end_turn": true
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scenarios focusing more on the balance between input and output rates."]}, "status": "finished_successfully","end_turn": true
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by Onat et al. (2017) emphasizes the necessity of considering the environmental economic and social impacts of products or services throughout their lifecycle. It stands in contrast to and challenges the capitalist tendency to focus solely on economic gains by highlighting the interconnectedness of these dimensions. Ignoring any of these aspects can lead to solutions that might appear beneficial in one area but are detrimental in others.Systems thinking requires understanding the complete lifecycle of a product or service\u2014from raw material extraction to disposal\u2014and identifying potential impacts at each stage. This method helps in pinpointing critical points for intervention and prevents unintended consequences that could arise from changes made in isolation. One can clearly see the links between systems thinking and the ideas presented by Ostrum (1997) which expands the rational choice models to incorporate collective actions that better address complex social dilemmas. It challenges simplistic linear thinking\u2014common in capitalist approaches\u2014that often overlook long-term consequences for immediate profit.\nFinally engaging stakeholders across the lifecycle of a product or service ensures that the diverse values and needs of different groups are considered and addressed in the sustainability assessment process. This approach is crucial for democratizing decision-making processes which often are controlled top-down in capitalist structures. Fisher\u2019s (2020) discussions on how system dynamics modeling can involve stakeholders in understanding and managing complex systems effectively provide a solid argument for stakeholder engagement across the lifecycle. \nBy applying these three dimensions to the broader discussions from earlier modules it becomes evident how these principles can help counteract the equity and sustainability challenges exacerbated by capitalist systems. These dimensions advocate for a more inclusive holistic and long-term approach to sustainability that aligns with social equity and environmental stewardship rather than focusing narrowly on immediate economic outcomes. This integrated approach not only critiques but actively challenges the inequities perpetuated by capitalist systems paving the way for more sustainable and equitable global practices.\n\nPart 2: What indicators are required to assess the systems dynamics of flow-limited resources? \nTo effectively assess the dynamics of flow-limited resources within a system a systems dynamics model must incorporate several key indicators. These indicators include stocks flows converters/constants and information flows each playing a crucial role in understanding and predicting system behaviors.\nStocks represent the quantities of resources available within the system at any given time. These could be tangible elements like water in a reservoir or abstract quantities such as carbon or even a population count in an ecological study. Stocks are foundational for monitoring resource levels and serve as a baseline for measuring changes over time (Reuter 2013)\nFlows describe the movement of resources between stocks or from external sources into the system. This includes inputs and outputs measured over specific time intervals such as liters of water per hour or tons of carbon per year. Understanding flows is critical for assessing how resources are utilized and replenished within the system providing insights into sustainability and efficiency (Reuter 2013).\nConverters/constants are parameters within the model that affect flows or stocks but remain unchanged regardless of system dynamics. These could include growth rate constants conversion efficiencies or fixed loss rates which are essential for stabilizing the model and making accurate predictions (Reuter 2013).\nInformation flows represent the non-material connections that influence system components by altering flows or converters based on the state of stocks or other variables. This aspect of systems dynamics is crucial for modeling feedback mechanisms and adaptive behaviors within the system allowing for a more nuanced understanding of how changes in one part of the system can ripple through to others (Reuter 2013).\nBy integrating these components into a systems dynamics model it is possible to construct a comprehensive view of how resources are interlinked and governed by various dynamic factors. This holistic approach is vital for predicting future system states under different scenarios and for making informed decisions about resource management and conservation.\nWhat inputs might be incorporated into a model of flow-limited resources? How is this different from stock-limited resources? In resource management two distinct modeling approaches are used to predict and understand resource availability and sustainability: flow-limited and stock-limited models.\nFlow-limited models focus on the dynamics of resource renewal and consumption. These models consider key inputs like the rate at which a resource regenerates whether naturally or through human efforts. They also analyze the consumption rate to see how quickly the resource is being used by various entities or processes. Additionally factors like environmental conditions regulatory policies and technological changes play significant roles in influencing resource availability and flow. This model is dynamic adapting to changes in usage patterns and replenishment strategies providing a flexible framework for forecasting future resource statuses (Reuter 2013).\nIn contrast stock-limited models are concerned with the finite quantities of resources available. They focus on the absolute amount of the resource that exists or can be accessed such as fossil fuels or minerals. These models consider extraction or harvest rates detailing how quickly the resource is depleted over time. They also evaluate the resource\u2019s regeneration capabilities whether it can be naturally replenished or artificially sustained over long periods. This approach emphasizes the depletion of a fixed stock highlighting the limits of availability and the critical need for conservation and efficient use (Reuter 2013).\nThe main difference between these two models lies in their focus and application. Flow-limited models are dynamic reflecting continuous changes in resource flows and the effects of various influencing factors. They are particularly useful when resources can be renewed or are affected by external conditions. On the other hand stock-limited models deal with resources that have fixed availability concentrating on managing finite supplies and preventing exhaustion. Understanding these differences is crucial for policymakers businesses and conservationists. It helps in developing effective strategies for resource management ensuring sustainability and tackling the challenges posed by limited natural resources (Fisher 2020).\nProvide an example of the systems dynamics of:\nA stock-limited resource (such as cobalt)\nA flow-limited resource (such as rabbits)\nDescribe what and how you would measure the inputs outputs and feedback loops (in-flow out-flow connectors or dependencies stocks and sources or sinks) in each example. Keep it simple (i.e. bamboo production for chairs). You don\u2019t have to do the mathematical calculations just describe the systems process. (If you want to take it further you can use Stella Online Modeling linked above).", "title": "SRM DQ4.docx", "tether_id": null}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"command": "context_stuff", "is_visually_hidden_from_conversation": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "parent_id": "aaa2fa50-4c95-4539-95a7-25474e96f393", "request_id": "8887de85dc6c0dc5-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "aaa2fa50-4c95-4539-95a7-25474e96f393", "children": ["2bbf49c7-d0de-45e6-a127-a2dfd9448e82"]}, "2bbf49c7-d0de-45e6-a127-a2dfd9448e82": {"id": "2bbf49c7-d0de-45e6-

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the model as a \nconstant or we need to make a calculation, we show that as a \n"converter/constant". In our example, the growth rate constant for \nthe rabbits was given as a constant. In the diagram, this is circle. \n\nInformation connectors illustrate the flow of information, not \nmaterial, from other components to either flows or converters. \nInformation cannot flow to a stock because the stocks can't do \nanything with that information. In the simplest form, an \ninformation flow simply notifies an action of the concentration of a \nstock, the rate of flow, or the value in a converter/constant. In our \nexample, information flows brought in the values of the growth \nrate constant and the number of rabbits to the "birth of new \nrabbits" flow. The flow is calculated as the growth rate constant \ntimes the number of rabbits. The icon for this is a single line arrow. \n\n \n\n\n\nDraft v7 133 \n\n \n\nThese five components can be combined in flexible ways to \ndescribe the structure of different systems. An important value of \nthis approach is that the structure of the model indicates particular \ntypes of behavior and the iconography helps visualize these \nstructures. In our example of rabbit growth with unlimited \nresources (indicated by the source/sink tool), the population would \ngrow exponentially. As there are more rabbits, the number of new \nrabbits per time period will get bigger, leading to an even higher \npopulation of rabbits, and so on. A mathematical model of this \npopulation growth would give the following pattern of growth \nshown in Figure 6-2 as population vs. time. (Of course the \npopulation can't continue to grow like this forever.) \n\n \n\n \nFigure 6-2. Rabbit population growth predicted from the model in \nFigure 1. The initial rabbit stock was set to 10 and the growth rate \nconstant was set to 0.1 per month. \n\nThe structure and relationships in this particular model \ndemonstrates \u201cpositive-feedback\u201d. As the stock increases, that \nincrease positively affects that flow that is leading to that stock. \nMany biological systems have this structure and function as part of \ntheir overall regulation. Sometimes this is good, such as in the \ngrowth of food crops and forests, the more crops or forests the \nfaster they grow. Sometimes this is a bad feature for humans such \n\n\n\n134 August 13, 2013 \n\n \n\nas the spread of a disease (the more infected people, the faster the \ndisease will spread) or the growth of invasive species. \n\nWe will examine several "simple" structures that are very \ncommon. These simple structures can be combined in larger \nmodels to describe very complex and busy processes. For example, \nif we were to create a model for global warming it would have \npositive and negative feedback components, open and closed \nsystems and steady state structures included making up the full \nmodel. These "simple" structures that we are starting with are like \nthe sentences in a larger document. You might be able to \nunderstand the individual sentences but not understand the entire \ndocument, but it is very likely that if you don't at least understand \nthe sentences, you won't understand the total document. \n\n \n6.3 Model structures and behaviors \nThe following structures and behaviors can be found in many \nlarger systems models. The analysis of a system should start with \ndetermining the extent or boundaries of the system as you plan to \nstudy it, and then look for smaller structures and then how these \nsmaller units are related. \n\nBoundaries of the system \u2013 The first step in studying or \ncommunicating information about a system is to explicitly define \nthe boundaries and what flows in and out. A "closed system" is one \nin which there are no source/sink components. All the flows occur \nbetween stocks. Often the decision of whether or not a system is \nopen or closed requires a judgment based on the significance of \nsome of the smaller losses or gains and a decision on the time scale \nof your study. For example, you might model a forest as a closed \nsystem for nutrients ignoring the amounts of nitrogen that comes in \nfrom rain or lost through streams. The time scale question is \napparent if, for example, you are studying the gain and loss of \nspecies in a city park but are ignoring evolution. The description \nand diagramming of a systems model should attempt to make these \nboundaries very clear. \n\n\n\nDraft v7 135 \n\n \n\n \nFigure 6-3: Several examples of open and closed systems. a and b \nare open, c is closed. \n \n\nPositive and negative feedback - A stock that controls the flow \ninto that stock can be described as having a negative or positive \nfeedback. Sometimes we will talk about positive or negative \nfeedback "loops" which are when stock A controls stock B which \nin turn eventually controls the flow into A. These feedback loops \nare crucial characteristics of systems control. Figure 1 was an \nexample of a positive feedback and the example behavior given in \nFigure 2. Figure 4 shows a system that contains a negative \nfeedback system with an example output. \n\n\n\n136 August 13, 2013 \n\n \n\n \n\n \nFigure 6-4. A system that contains a negative feedback control (shown in red, or \nslightly gray). The system wouldn't work without the other components. The \nnumber of barnacles continues to increase until it hits a maximum and then it \nlevels off due to lack of any more space. \n\n \nStock limitation - One of the powerful applications of the systems \napproach is to examine the constraints over extended periods of \ntime. Some of these are mitigated by feedback inhibition and \nothers are exacerbated by positive feedback. Stock limitation is an \nabsolute limitation on the amount of a stock that can flow to other \n\n\n\nDraft v7 137 \n\n \n\nstocks or an ultimate sink. Examples of stock limitation might be \nthe seasonal availability of nitrogen in the soil, the space trees to \ngrow, or the amount of fossil fuels available for human \nconsumption. Figure 5 presents two variations on a model for \nbacterial growth, one with and one without stock limitation. \n\na. \n \n\nb. \n \n\nFigure 6-5. Stock limitation model for bacterial growth. The stock is the amount \nof nutrients in the container. In model "a" there is no limiting stock, in model \n"b" when the limiting stock runs out, the new bacteria production rate is forced \nto stop. \n\n \nSteady state - The inflows to and outflows from a stock can create \na situation where steady state is possible. If the sum of all the \ninputs is equal to the sum of all the outputs then the value of the \nstock will not change with time. A slight increase of the input or a \n\n\n\n\n138 August 13, 2013 \n\n \n\nslight decrease of the output rate can lead to an increasing stock. \nFigure 6 illustrates a familiar example that relates to body weight. \nOther examples of steady state conditions are the CO2 \nconcentration in the atmosphere (currently not in steady state), use \nand replenishment of natural capital, or the human population at \nzero population growth. \n\nThe conditions that lead to steady state are important to understand \nbecause the steady state may be the consequence of a very slow \ninput and very slow output, in which case not much will ever \nhappen very quickly. Conversely, the steady state could be a very \ntenuous balance between rapid input and output. With rapid fluxes, \nslight disturbance in one rate could have dramatic consequences. A \ngood example of this delicate balance is a pond in which a large \namount of algae growth is growing and contributing oxygen to the \nwater, but then with a slight change in temperature the large \namount of algae turn from a net oxygen producer to a net oxygen \nconsumer. These ponds crash into a scummy mass very quickly \nand start to stink. Simpler natural systems may be controlled by \njust a few rapid fluxes and when one of these processes changes \nthose natural systems can flip to a whole new behavior. We will \nalso examine the stability, instability and resilience of these \nenvironments in Chapter 7 using the tools of the network view. \n\n \n\n \n Figure 6-6. An example of a familiar steady state problem. If the input equals \nthe output for a stock, the stock will remain constant with time, no matter how \nfast the input and output are. If the input exceeds the output, then the stock will \nincrease. In this case food input is in terms of the weight of all food eaten and \nthe food output is the weight of all excretion of waste, including the CO2 \nexhaled. The variable part of the bodyweight is \u201cfood storage\u201d that is probably \nfat. \n\n\n\nDraft v7 139 \n\n \n\n \n6.4 Simple and busy models \nWe have shown several "simple" models above. These models \nhave a few components or strings of components and all the units \nfor stocks and flows are related. There are other simple models that \nmight contain two parallel paths to represent different forms of \nmaterials or energy. For example modeling energy and nitrogen in \nan ecosystem requires two sub-models; one for nitrogen and one \nfor energy that are linked by information connectors. These should \nbe treated as two simple models that have some interacting control \npoints. \n\nThe point of using the systems view is to take a complex set of \nprocesses and try to simplify it to just a few components that \ndescribe the control over the behavior. Then this model of the \nsystem can be used to make predictions about different controls or \nperturbations. \n\nSeveral examples of simple and slightly busy models are given \nbelow. A \u201cbusy\u201d model contains several \u201csimple\u201d models joined \ntogether. For each of these examples an analysis is provided that \nserves to demonstrate how you can use this to understand \nenvironmental problems. \n\n \nExample 1: Changes in human population in a country. \n\nThe current population plus additions from births or immigration \nand minus losses from death or emigration determines the new \npopulation level. If the birth rate is higher than the death rate even \nby a little bit, the population can experience an exponential growth \nrate. In many countries, industrialization has lead to a decreased \ndeath rate followed by a decreased birth rate. The overall side \neffect of industrialization on the population has been to stabilize of \npopulation size. Some countries however, are stalled at a level of \nindustrial development that has resulted in a decrease in the death \nrate but left the birth rate high. These countries are experiencing \nrapid population growth rates. \n\n\n\n140 August 13, 2013 \n\n \n\n \nFigure 6-7. Population change. The population increases from birth or \nimmigration and decreases due to emigration or death. \n\n \nAnalysis - The population is the only stock in this system. All of the inputs and \nexports are out of the system, which only means they are not being studied in \nthis model, not that they aren't important. The population is a possible steady \nstate situation. Notice that this version of the model has left out the control of \nbirths or deaths by the population size itself. (See Figure 1 for how it should be \nwritten.) This diagram illustrates clearly that we need to understand the relative \nrates of all of these processes to predict what will happen with this population. \n\n \n\n \nFigure 6-8. Busier model of population change. Economic growth in a country \n(which can be the result of industrialization) creates wealth. The economic \nwealth per capita is the total economic wealth divided by the population at any \n\n\n\nDraft v7 141 \n\n \n\ntime. In models of population growth, a decrease in death rate is correlated to an \ninitial increase in per capita wealth. If the economic wealth per capita continues \nto increase, families may choose to have smaller families and thus decrease the \nbirth rate. Note that the structure of this model makes it clear that we are \nassuming that increased per capita wealth will have some impact on the birth \nand death rate. \n\n \nAnalysis: This model contains two simple models that are connected through the \n"per capita wealth" convertor. Economic growth will increase the per capita \nwealth and increases in population will decrease the per capita wealth. This \nmodel illustrates that if the economy grows more slowly than the population, it \nmay result in higher per capita wealth and then in a decreased birth rate. This \nmay lead to a slowing of the birth rate to allow a steady state population. \nHowever, if the economy grows just enough to decrease the death rate but the \nper capita wealth doesn't increase after that point, the population will continue to \ngrow exponentially. This relationship between population and economic \nconditions is the basis for studying demographic transitions that occur. In \nNorthern Europe, the United States and Japan, for example, the industrialization \nand economic growth has lead to what is called the classical demographic \ntransition. We will revisit the systems description of demographic transitions \nwhen we study how different worldviews treat the risks of population growth \nand forecasts for economic growth (Chapter 11). The systems analysis of this \nproblem can be combined with other frameworks to provide further help in \ndescribing and making decisions. \n\n \nExample 2: Global warming and CO2 in the atmosphere. \n\nGlobal temperatures and the CO2 in the atmosphere are linked at \nmultiple layers. The "busy" model diagram below shows how \nseveral simple models are linked. \n\n \n\n\n\n142 August 13, 2013 \n\n \n\n \n Figure 6-9. A busy model of atmospheric temperature and the geochemical \ncycle for carbon. The analysis, below, identifies the simple model parts and the \nlinkages between these sub-models. \n \nAnalysis: This model is missing many important stocks and flows. Even with \nthis deficit, it is useful to analyze the structure and potential behavior of the \nmodel. \nThe top part of the model shows that the atmosphere could potentially be in \nsteady state for heat energy. The sun energy comes in and the heat is radiated \nback out. The amount of CO2 in the atmosphere makes the net efficiency of \nirradiation back into space less efficient, requiring a slightly higher atmospheric \ntemperature to reach a steady state for the energy (heat) in the atmosphere. This \nis called the "greenhouse effect". \nThe bottom part of the model shows two major fates for CO2 from the \natmosphere, either going into ocean or terrestrial biomass. In this version, the \n\n\n\nDraft v7 143 \n\n \n\nonly controls that are shown are the increase in respiration rates of the terrestrial \nand oceanic plants from higher temperature. Notice that the top part of the \nmodel is tracking energy and the bottom part of the model is tracking carbon. \nThere are no flows between these two halves, only an information connection \nand converter. The linkage of these two sub-models leads to a potentially very \nimportant behavior, run-away positive feedback of the temperature. The \nscenario for that outcome is as follows: \n\n1. the atmospheric temperature increases, \n2. which increases respiration from terrestrial and aquatic biota, \n3. which leads a higher steady state of CO2 in the atmosphere \n4. which, in turn, leads to higher temperature \n5. and it continues \n\n \n\nThese two examples illustrate how the systems view is valuable. \nExample 1 shows how to take a simple model and combine it with \nanother simple model to study the potential interactions between \nprocesses. Example 2 shows how to dissect a model into the simple \nsub-models, analyze them and then put these all back together to \nstudy the overall behavior and look for potential problems. \n\n \n6.5 Starting Steps \n\n1. Identify what material or energy is being moved. \n2. Identify what the reservoirs are and how material or energy \n\nmoves between these reservoirs, i.e. the flows. \n3. Draw a boundary around the system you are studying: what \n\nstocks and flows are you quantifying and what is outside. If \nthere are flows in or out of your target system, then these \nmust be represented by sources or sinks, respectively. \n\n4. Create a diagram that shows the major reservoir stocks, \nflows, sources and sinks using the iconography supplied \nabove. \n\n5. Are there any conditions (such as temperature) or derived \nquantities (such as flow per person) that might be \ncontrolling a flow? If so, create a converter or constant to \nrepresent this relationship. \n\n6. Make linkages from stocks to flow-regulators, from one \nflow to another flow, and from convertors to flows. \n\n\n\n144 August 13, 2013 \n\n \n\n7. Check the diagram to see that all flows represent movement \nper unit time of whatever is in the stocks. \n\n8. Examine the diagram for the regulatory components within \na flow such as feedback inhibition (negative feedback), \nfeedback acceleration (positive feedback), stock-limited \nflow. \n\n9. Examine the diagram for relationships between the flow of \ndifferent material or energy (such as use of natural capital \nvs. the rate of population growth). \n\n \n6.6 Overlaps and conflicts with other tools \n \n\nTerm in \n"Systems" \n\nother \nviewer/term \n\nsimilarities and \ndifferences \n\nboundary scale/extent Everything outside the \nboundary of the system is \neither neglected or is an \nunlimited source or sink. \nIn the Scale viewer, extent \nrelates to the size of the \nlargest dimension \nconsidered, the word \ndoesn't imply any process \nor specific border. \n \n\nstock network/node A stock must be \nsomething measurable that \ncan be moved through a \nflow. In the network view, \na node can be a quality \nthat changes depending on \ninput links. \n\n\n\nDraft v7 145 \n\n \n\n \n\nflow network/link A flow must be the \nmovement of material or \nenergy per unit time and \nwhatever is flowing has to \nbe the same as the stock at \neither end. A link \nidentifies a relationship \nbetween nodes. It can be a \nquantity of material \nmoved but it doesn't have \nto be a quantity. \n\n \n\nstability network/stability, \nresilience and \nresistance \n\nSystems models can reach \nsteady state that has some \nstability due to some form \nof negative feedback that \nkeeps it at a level or in \nsome range. The type of \nsystems model that we are \nusing doesn't have a \nmechanism to change its \nown structure. A network \ndiagram that has many \nweak interactions can shift \nthe operational structure \nand show how a large \nnumber of weak \ninteractions or the \ncombination of fast and \nslow processes can lead to \nthe resilience or loss of \nresilience of the network. \n\n\n\n146 August 13, 2013 \n\n \n\n \n \n \n \n \n6.7 Extending analysis to the next levels \nAn important extension of the use of systems models is to create \nsimulations that demonstrate overall system behavior given certain \ninput conditions and constants. We will look at the components of \nthe system, such as positive or negative feedback to look for very \ngeneral system behavior. There are software applications that are \nuseful for turning these systems diagrams into mathematical \ndynamic models (the diagrams and charts in this page were \ngenerated with STELLA from High Performance Systems, \nhttp://www.hps-inc.com). See the appendicies for this book to see \nsimulations that were written in STELLA and simulations made \navailable on the web (through Forio.com). In these simulations \nonly the parameter values can be changed, not the structure of the \nmodel itself. But these simulations are very useful for illustrating \nthe types of predictions and uses for simulations. \n\nSimulations of this type are extremely useful in modern decision-\nmaking. For example, the Northwest Power Council created a \ncomplicated and very busy model that contained information on \nfish, dams, river flows and electricity. This model could be run \nunder different conditions and demands for energy to show which \nparameters affect fish survival most. They were able to show the \nmodel to people who work in this arena of fish and rivers to see if \nthe model behaves in a way they think it should; does it show low \nfish years when expected or high fish years following particular \nevents? The simulation model and the accessible interface were \npowerful tools in addressing problems and getting people to learn \nabout complicated social, economic and ecological issues. \n\n \n\n\n\nDraft v7 147 \n\n \n\n6.8 Developing a simplified Systems model of \nsustainable resource use \nMany people subscribe to the idea that a sustainable resource is \none in which you reach a steady state because you don't use the \nresource faster than it is being created. Whether or not this is \nrequired for all resources to attain a sustainable society is a very \ninteresting question. It maybe that you can have some resources \ndecrease and be replaced by other resources. There are different \ndefinitions of overall sustainability that address whether the entire \nensemble of capital types has to be stable or whether substitutions \ncan be made. \n\nWe will focus here on the sustainable use of a single resource. For \nexample, you would harvest the wood at the same rate as new trees \nwere growing to replace what you took. \n\n \n \nFigure 6-10. The starting assumptions for a model of sustainable natural \nresources are that input comes from growth and output goes to harvest. There \nare no other inputs or fates being considered. \n\n \n\nIf this resource is based in natural (biological) capital the growth \nrate will often depend on the amount of the stock. For example \nhealthy fish populations grow faster with more fish and trees will \ngrow better in a healthy forest with lots of other trees to provide \nprotection and a suitable micro-climate. Although it isn't always \nthe case, let's model the natural resource as having a positive \nrelationship to the growth of new resource. \n\n\n\n148 August 13, 2013 \n\n \n\n \nFigure 6-11. In a simple sustainable harvest model, the natural resource has a \npositive feedback on the growth of that resource. This holds within the region of \nhealthy, and not over-abundant resource. \n\n \n\nWhen we harvest the resource, we might just be removing the fish \nor trees, but we can also be degrading the environment that the fish \nor trees need to grow. For example, driving bulldozers around on \nthe soil and channelizing streams in steep watersheds has a \nnegative effect on forest health. Similarly, some fishing methods \ndisrupt the breeding areas for fish. Thus the harvest has a direct \ntake of the resource but it can also degrade the conditions leading \nto a decrease in the growth rate. Notice in this case that a negative \neffect on conditions is passed through to impact growth because \nthere is a positive relationship between conditions and growth: \nworse conditions lead to lower growth. \n\n \n\n\n\nDraft v7 149 \n\n \n\n \nFigure 6-12. The mechanisms of harvest can have a negative effect on the \nconditions for growth. Overharvest can damage the microenvironment necessary \nfor optimal growth. \n\n \n\nAnother important issue with natural resource management is the \nimpact of bad (or good) luck. What if you were managing a forest \nthat had an average growth rate but there was a single drought year \nthat decreased the input to the resource by 50% just for that year? \nIf you had a harvest plan that was even just 5% more than the \nactual maximum yield you could harvest, it would lead to a \ndecrease in the population that would never recover (assuming you \ndon't stop harvesting after you see the population start to crash). \n\n \n\n \n \n\nFigure 6-13. Conditions might also vary with time, such as a year of drought or \nunhealthy water. \n\n \n\n\n\n150 August 13, 2013 \n\n \n\nThe effect of one bad year (only 50% output) and an underestimate \nof true maximum yield by only 5%. In 100 years you're down to \nless than 1/3 of your starting natural capital. \n\n \n \nFigure 6-14. With just one bad year, holding to the previous \u201cmaximum \nsustainable yield\u201d will eventually cause the collapse of this resource. \n\n \n\nUsing this simple model of natural capital and sustainability

\nillustrates that there are at least three ways to destroy the \nsustainability of your natural capital \n\na. simple overharvest, but this may be because you didn't \nhave good estimates for the maximum yield \nb. indirect effects from either harvest methods or use \nc. risk of being too close to the maximum yield, one bad \nyear and the resource declines dramatically \n\n \n6.9 Case Study: Population and Environment of \nEaster Island, Rapa Nui \n\n\n\nDraft v7 151 \n\n \n\n Easter Island (also known as Rapa Nui) is a small island in the \nmiddle of a very large ocean. The area of the island is only 166 \nkmˆ2 (64 miˆ2) and it is 2250 km from the nearest other island \n(Pitcairn Island) and over 3700 km from South America, the \nnearest continent. You have undoubtedly heard something about \nthis fascinating island related to speculations on what caused the \npopulation to crash. In fact, you've probably heard more about this \nisland because of this failure to be sustainable than you've heard \nabout any of the myriad of other islands in the South Pacific. \n\nAt one time in the history of this island, the society had fairly \nsophisticated culture and technology. The cultural history describes \na well-developed hierarchy with laws and written script. The \nevidence of the technology was their ability to move the large \nstone statues, which the island is most known for, for long \ndistances. They moved carved stone sculptures that weighed up to \n82 tons as far as six miles (10 km). The islanders cultivated a large \npart of the island with multiple crops. Estimates of the maximum \npopulation on the island ranged from 7,000 to as high as 20,000. \nAnd yet the population and civilization must have crashed. When \nEuropean boats first recorded their interaction with the island (in \nthe 1700s) the population was only several thousand, and these \npeople were leading a tough life in an impoverished and desolate \nenvironment. \n\nYou can see from just the outlines of this story why the island's \nhistory has always been so intriguing. Now with our interest in \nsustainable systems, it is important to attempt an understanding. \nThere are parallels between their tiny island and our planet. Once \nthe environment started to decay and subsequent crash of \npopulation and society, these islanders had no place to go. \nSustainability isn't just about maintaining a mere subsistence life \nstyle, it's also about continuing to develop the culture and have a \nhealthy physical existence. \n\nIn this case study, we are going to examine the population, \nagriculture and land use practices that were employed on Easter \nIsland from about 400 AD to about 1700 AD. We are going to \n\n\n\n152 August 13, 2013 \n\n \n\nanalyze the very gradual depletion of the natural capital on Easter \nIsland using a "systems" approach. \n\n \nReferences to studies of the fate of Easter Island \n\nA more complete story can be found at the following sources: \n\u2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island \n\u2022 Discover Magazine: Jared Diamond. \u201cEaster\u2019s end.\u201d Discover \n\nmagazine, August 1995. 16(8): 62-69. \n\u2022 TED talks such as: \n\nhttp://www.ted.com/talks/lang/eng/jared_diamond_on_why_so\ncieties_collapse.html \n\n\u2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ \n\u2022 Diamond, J. (2005). Collapse: How societies choose to fail or \n\nsucceed. New York, Viking. \n\n \nSalient features \n\nThe story of Easter Island has particular features that make it \namenable to examination with a systems approach. First, it is very \nsimilar to the systems model for sustainability that we developed in \nFigure 12 and 13; there are suggestions of growth, harvest, and bad \nluck. Second, at any time the processes seem to be close to being \nin balance; it is only by looking at the long term effect of these do \nwe see the impact of a slight over harvest or a previous year of bad \nluck. Third, the description contains some simple models that \ncould be tied together to get an integrated picture; there is \npopulation growth, harvest of trees, soil moisture, agriculture and \nfishing. These processes are related, but not directly. \n\n \nApplying the systems tool \n\nWe are going to put separate small models together and to examine \nhow these individual processes counter or reinforce each other. \nThis is an oversimplified model in which will only consider three \nstocks: the number of people, palm trees, and rats. \n\n\n\nDraft v7 153 \n\n \n\nThe number of people is the balance between birth and death rates. \nAs there are more people, there will be more births, i.e. the \npopulation growth has a positive feedback component. The number \nof deaths may depend on many other factors including natural \ncauses, famine, and disease. A simple model diagram for this is \ngiven below. \n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \nbut a constant death rate. \n\n \n\nThe number of trees is also a balance between the number of palm \nnuts that germinate and grow, and the cutting down of the trees. \n\n \n \nFigure 6-016. Palm tree sub-model also have positive feedback for growth and \nconstant loss. \n\n \n\nThe third strand in our model will be the rat population. People \nbrought rodents to the island. These rats play a key role in this \nproblem. People eat the rats and the rats eat the palm fruit, \ndecreasing the tree population. Their population is just like the \n\n\n\n154 August 13, 2013 \n\n \n\nothers, there is positive feedback for rat births and several factors \ncontrolling death. \n\nNow we are going to connect these three stocks and flows models \nwith factors that affect either the birth or death rates. The following \nlist details these interactions. \n\n1. Rats have a positive effect on people births because this \nis a source of food for people. The birth rate of people will \nincrease with more rats (and the birth rate will decrease if \nrats are low). \n\n2. Rats have a negative effect on human death. The death \nrate of people will increase if rats are too low. \n\n3. People have a positive effect on the harvesting of trees. \nMore people cut down more trees because they need them \nfor fishing and to cultivate land for crops. \n\n4. Rats have a negative effect on the rate of palm fruit \ngermination. The number of rats decreases the percentage \nof new palm seeds that germinate successfully because the \nrats chew on the seeds. \n\n5. Palm trees have a positive effect on rat births, because \nthe rats eat the palm fruit. \n\n \n\nWe could add more detail to this model, but even with only these \nfive interactions this turns out to be a very interesting and \ninstructive model. Looking at the model diagram, below, you can \nsee that there are many positive feedbacks and only a few negative \nfeedbacks. \n\n\n\nDraft v7 155 \n\n \n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n \nAccording to the historical record, as the human population grew, \npeople cut more and more trees. They needed these trees for \nmaking boats for fishing and they needed more and more land for \ncultivation. Over harvesting trees, just on its own would have been \na problem for them, but this was exacerbated by the fact that they \nalso ate rats, and rats depended on the trees for food. As the human \npopulation continued to grow, they cut enough trees such that they \nran out of trees to use for fishing. Simultaneously, with fewer trees \nthey not only couldn't fish effectively but the other food source, \nrats, declined. \n\nThe model built here only represents a few of the interactions that \nhave been described. By putting these into a systems diagram, we \ncan explore the possible behaviors of the individual populations \nand their effect on each other. It is possible that the population \n\n\n\n156 August 13, 2013 \n\n \n\ncould have also reached a balance. There is nothing inherent in the \nstructure of these relationships that makes it crash. However, the \nbalance comes about because all of the relatively rapid rates of all \nthe processes are cancelling each other out, but a minor imbalance \nin the rates can lead to abrupt changes in the whole system. \n\nSome narratives of Easter Island decline blame the population for \ntheir resource use strategies. For example in the book \u201cCollapse\u201d \n(2005), Jared Diamond wonders what the person who cut down the \nlast palm tree was thinking. Even this simple model shows that \nthere were multiple factors in play and the path toward a \ndownward spiral of trees could have been set in motion when there \nwere still many trees. This should be a cautionary tale for working \nwith real and complex systems, i.e. the controls may have delays \nand multiple factors that make them very difficult for a person in \nthe ecosystem and society to observe. It\u2019s not just a matter of \ntaking the right action for the moment, but also being able to \nunderstand the more complex interactions and consequences of our \nactions. \n \n6.10 Summary \nMethodically constructing a stock and flow model to represent the \nprocesses related to an environmental problem supports good \npractice for scientific information gathering. The constraints on \nthe quantities that are being measured and followed forces the \nclarification of assumptions. The structure of the model can be \nvisualized with iconography that illuminates the relationship to \nparticular functions of the overall system such as feedbacks, stock \nlimitation and possible steady state conditions. The basic \nassumptions for using a natural resource sustainably can be \nexplored using this approach. The goal of sustainable use would be \nto have the input match the output and maintain a steady state for \nthe resource. Positive feedback works to replenish the stock, but \nthis is a double-edged sword, just one bad year can lead to an \neventual collapse unless the harvest is decreased. \n\n\n\nDraft v7 157 \n\n \n\nAnalysis of these models involves taking apart each stock and flow \nand explaining how that part contributes to the overall behavior of \nthe system. This is a very useful exercise for construction of the \nmodel and for communication about the important features of a \nproblem. \n\nAs models become busier they often require sub-models for \ndifferent stocks. The example of Easter Island demonstrated \nhypothetical relationships between the stocks of palm trees, people \nand rats. At high human populations, this system was not resilient \nto changes and might explain the decline of the resource base. \n\n \n\n \n \n\n \n\n\n", "title": "v7-Rueter-chap6.pdf", "tether_id": null}, "status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"command": "context_stuff", "is_visually_hidden_from_conversation": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "parent_id": "ee7c8a3c-0f1a-41d9-bcbf-6c0cf6b7c0bb", "request_id": "8887de85dc6c0dc5-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "ee7c8a3c-0f1a-41d9-bcbf-6c0cf6b7c0bb", "children": ["c6d07b86-3451-495e-8d54-06b7ec6b2fb3"]}, "c6d07b86-3451-495e-8d54-06b7ec6b2fb3": {"id": "c6d07b86-3451-495e-8d54-06b7ec6b2fb3", "message": {"id": "c6d07b86-3451-495e-8d54-06b7ec6b2fb3", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716496951.383126, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-x2cv3idk0ilnkCJFAJXwVUiD", "domain": "tactiq-free-transcript-QBrmAGcMIi8.txt", "text": "# tactiq.io free youtube transcript\n# Why System Dynamics Should Become Part of Secondary School Math Instruction\n# https://www.youtube.com/watch/QBrmAGcMIi8\n\n00:00:00.719 hello my name is diana fisher\n00:00:03.040 i have been asked to present to on the\n00:00:05.839 system dynamics work\n00:00:07.200 i have done with secondary school\n00:00:08.880 students and teachers over three decades\n00:00:11.599 i have used system dynamics modeling in\n00:00:13.920 my mathematics and modeling instruction\n00:00:16.000 for 30 years\n00:00:17.520 although science instruction is the most\n00:00:19.680 natural discipline for sd modeling i\n00:00:22.080 would like to make\n00:00:23.199 an argument that if we really want sd\n00:00:25.840 modeling to become\n00:00:26.960 a more mainstream analytical tool it\n00:00:30.240 should be embedded in secondary school\n00:00:32.640 mathematics\n00:00:33.840 sd modeling can reinforce important\n00:00:37.120 mathematical concepts quite well dr\n00:00:40.320 barry m specializes in the study of\n00:00:42.399 complex systems\n00:00:43.760 to be able to analyze complex systems\n00:00:46.879 he claims that calculus and statistics\n00:00:49.120 do not have the tools to describe\n00:00:51.680 what we want to study that we need\n00:00:55.360 to work with new concepts that we need\n00:00:58.960 to\n00:00:59.359 ask different questions about system\n00:01:02.000 dynamic behavior\n00:01:03.920 he says working with complex systems\n00:01:06.799 changes how we think\n00:01:08.560 we have an opportunity to help our\n00:01:10.479 mathematics students broaden their\n00:01:12.400 thinking\n00:01:13.280 to encompass techniques that will help\n00:01:15.520 them think about\n00:01:16.479 complex dynamic problems one way to\n00:01:19.600 start\n00:01:20.240 is improving their understanding of\n00:01:22.080 functions studies in the united states\n00:01:25.200 indicate that students possess weak\n00:01:27.280 understanding of functions\n00:01:29.280 over the last several decades\n00:01:32.960 mathematics instruction in the u.s\n00:01:35.520 evolved to require\n00:01:37.040 multiple representation of function\n00:01:39.439 behavior\n00:01:40.320 including graphs and tables but now\n00:01:42.640 research indicates that mapping diagrams\n00:01:45.280 also provide a rich foundation for\n00:01:48.240 understanding functions\n00:01:50.799 the late dr james kapit proposed\n00:01:54.520 democratizing the comp concepts of\n00:01:57.280 calculus\n00:01:58.399 by providing technology-based learning\n00:02:01.280 environments\n00:02:02.479 he said new notation systems with new\n00:02:05.680 ways of\n00:02:06.479 acting upon those new notation systems\n00:02:09.840 offer dramatically new possibilities for\n00:02:12.480 mathematics learning\n00:02:14.319 sd is such a new and powerful\n00:02:18.080 notation system the audience recognizes\n00:02:21.120 these system dynamics modeling icons\n00:02:23.440 from which sd models can be constructed\n00:02:26.400 the stock\n00:02:27.280 and accumulator represents a main\n00:02:29.599 function in the model\n00:02:31.200 mathematically it operates as an\n00:02:33.519 integral does in calculus the flow\n00:02:36.800 is the rate of change of the stock so it\n00:02:39.200 is essentially the first derivative\n00:02:41.120 described in calculus\n00:02:43.280 converters hold constants parameters or\n00:02:46.080 simple\n00:02:46.560 or arithmetic combinations of model\n00:02:49.040 components\n00:02:50.319 the connector indicates the influence of\n00:02:52.959 one\n00:02:53.360 model component on another\n00:02:55.400 mathematically\n00:02:56.800 the connectors identify the dependencies\n00:02:59.599 of one variable\n00:03:00.879 variable on another i will not take you\n00:03:04.319 quickly through the two\n00:03:05.599 most basic functions studied in algebra\n00:03:08.800 connecting sd and traditional\n00:03:10.720 mathematics\n00:03:11.840 representation suppose we were\n00:03:14.080 interested in how\n00:03:15.040 water in a lake is increasing based on\n00:03:17.440 water flowing in\n00:03:18.560 at a constant rate using the sd\n00:03:21.760 structure the initial\n00:03:25.280 water in the lake would be placed in a\n00:03:27.840 stock icon\n00:03:29.200 and it would only have an\n00:03:32.239 inflow since it is only increasing\n00:03:35.599 with a constant value in the flow we\n00:03:38.799 know the behavior of the stock\n00:03:40.640 is growing linearly since the rate of\n00:03:42.799 change is constant\n00:03:44.319 and positive the sd\n00:03:47.360 software calculates the value of the\n00:03:49.360 stock using recursion which is shown in\n00:03:52.000 the table at the left\n00:03:53.599 we see that the flow value is added to\n00:03:56.239 the current value of the stock\n00:03:58.080 each time unit now we see the\n00:04:00.640 traditional closed form equation for the\n00:04:02.720 linear function where w\n00:04:04.560 represents the amount of water in the\n00:04:07.439 lake\n00:04:08.400 it starts at 100 units and grows at five\n00:04:11.439 units per year\n00:04:13.040 if we were to construct what we know is\n00:04:16.000 an exponential population growth\n00:04:18.320 behavior\n00:04:19.358 we could start with a stock of elephants\n00:04:21.680 and an inflow of new elephants\n00:04:23.600 born to this herd each year but this\n00:04:26.479 model is not correct\n00:04:28.320 we know the inflow cannot be constant\n00:04:30.880 because the number of new elephants born\n00:04:32.960 per year depends on knowing how many\n00:04:34.960 elephants are currently\n00:04:36.400 in the herd so we now indicate that\n00:04:39.680 dependency with a connector\n00:04:42.560 oh and now we have introduced a feedback\n00:04:45.680 loop\n00:04:46.400 the loop is reinforcing because the more\n00:04:49.280 elephants in the population\n00:04:51.280 the more new elephants are born per year\n00:04:54.080 adding more elephants to the herd\n00:04:56.639 but this model is still not complete we\n00:04:59.759 should\n00:05:00.320 indicate the number of new elephants\n00:05:02.479 born per\n00:05:03.759 elephant in the herd each year\n00:05:06.880 we do that by indicating a birth\n00:05:09.600 fraction\n00:05:10.240 in decimal form that will be multiplied\n00:05:13.199 by the number of elements\n00:05:14.639 in the herd each year so for exponential\n00:05:17.919 growth the inflow is proportional to the\n00:05:20.479 current amount of the stock\n00:05:22.880 or mathematically the rate of change the\n00:05:25.759 flow\n00:05:26.560 is defined as the stock value times some\n00:05:29.840 growth factor value this is exactly the\n00:05:33.199 differential equation\n00:05:34.880 that represents exponential growth but\n00:05:37.039 algebra students\n00:05:38.000 don't need to know that they are\n00:05:39.759 learning calculus\n00:05:41.280 they are just learning a different\n00:05:42.880 behavior pattern over time\n00:05:44.960 and how to create it based on its rate\n00:05:47.520 of change definition\n00:05:49.840 again quickly we would have our stock\n00:05:52.479 flow definition as shown\n00:05:54.160 with a 20 growth fraction the elephant\n00:05:57.440 population will grow\n00:05:58.800 exponentially because the inflow is\n00:06:01.039 proportional to the stock value\n00:06:03.360 if we think about what the sd software\n00:06:05.680 is doing\n00:06:06.560 we look at the recursion in the table\n00:06:09.280 the flow\n00:06:10.240 calculates the growth amount and adds it\n00:06:13.360 to the stock\n00:06:14.639 each year there are two equations that\n00:06:17.919 are possible\n00:06:18.960 mathematically the easier equation is\n00:06:21.840 represented at the top\n00:06:23.520 and is the one often taught in first\n00:06:26.080 year algebra\n00:06:27.280 it is often used when we want to\n00:06:29.440 calculate values\n00:06:30.720 once every year or time unit\n00:06:33.759 the second is shown at the bottom and is\n00:06:37.280 often used in situations where\n00:06:40.000 calculating continuous change\n00:06:41.919 is a better choice the top equation is\n00:06:44.720 probably the best choice for this\n00:06:46.479 particular elephant heard example\n00:06:49.120 in sd modeling we use the same diagram\n00:06:52.240 for each scenario and merely increase\n00:06:54.800 the number of times the simulation\n00:06:56.960 calculates the values each time\n00:06:59.120 unit to differentiate which\n00:07:02.400 situation is being used for calculation\n00:07:05.599 as a it is a much more intuitive process\n00:07:09.360 in my opinion just so you know\n00:07:13.120 there is a free web-based version of the\n00:07:15.360 sd modeling software that works on\n00:07:17.680 tablets computers laptops chromebooks\n00:07:20.080 and smartphone\n00:07:21.440 that will allow you to have your\n00:07:23.759 students build these models\n00:07:25.759 if they have access to this technology\n00:07:28.639 go to publish.icsysystems.com\n00:07:31.840 the software is called stella online\n00:07:36.160 once students learn linear and\n00:07:38.479 exponential model structures they can\n00:07:40.560 start putting them together to study new\n00:07:42.720 problems\n00:07:43.680 they could not study with equations\n00:07:46.720 i have used these medication models in\n00:07:49.199 my algebra classes over\n00:07:51.199 many years students really like them\n00:07:54.639 consider an emergency room problem you\n00:07:57.759 the student are a medical resident\n00:08:00.240 working in the emergency room\n00:08:02.160 and a patient comes in who needs\n00:08:04.000 immediate medical tension\n00:08:06.160 from your analysis you decide to connect\n00:08:08.560 this patient to an iv drip that will\n00:08:10.800 supply\n00:08:11.440 one milligram of therapeutic drug per\n00:08:14.560 minute\n00:08:15.199 this person you estimate will metabolize\n00:08:17.680 the drug\n00:08:18.639 at about 0.55 percent per minute\n00:08:22.639 what is the pattern of the drug level in\n00:08:24.879 the body over 24 hours\n00:08:27.599 so the diagram might look like this with\n00:08:30.000 an inflow of medicine and an\n00:08:31.680 outflow of body using and\n00:08:34.799 eliminating the medicine observe the\n00:08:37.679 left\n00:08:38.000 side of the diagram since there is a\n00:08:40.000 constant inflow the left part of the\n00:08:41.839 diagram is similar to\n00:08:43.599 a linear model structure observe the\n00:08:47.120 right part of the diagram\n00:08:48.640 the structure is similar to an\n00:08:50.399 exponential decay\n00:08:51.760 the drug is lost as a percent of the\n00:08:54.399 current amount of drug in the patient's\n00:08:56.320 systems\n00:08:57.839 students try to predict the behavior of\n00:09:00.080 the drug\n00:09:00.959 in the body over time giving a reason\n00:09:03.440 for their predictions\n00:09:05.040 then they build the model and see what\n00:09:07.360 the computer produces\n00:09:09.360 then they have to explain why the\n00:09:12.080 computer graph\n00:09:13.200 has the shape that it shows\n00:09:16.800 skipping to the skipping the second\n00:09:18.800 medication scenario we will go to the\n00:09:21.200 third drug model\n00:09:22.959 it involves taking medicine in the form\n00:09:25.120 of pills\n00:09:26.640 it has been a busy day in the emergency\n00:09:29.200 room a third\n00:09:30.160 patient arrives and you decide to give\n00:09:32.320 this patient two\n00:09:33.519 pills of 375 milligrams\n00:09:36.959 each of a therapeutic drug and tell them\n00:09:39.680 to continue taking\n00:09:41.360 two more pills every four hours this\n00:09:44.399 person you\n00:09:45.200 estimate will absorb the drug from the\n00:09:47.760 stomach in the bloodstream\n00:09:50.080 at about 4.5\n00:09:53.360 percent per minute and metabolize the\n00:09:56.399 drug\n00:09:57.120 at about point 55 percent per minute\n00:10:00.560 what is the pattern of drug level in the\n00:10:02.640 body over 24 hours\n00:10:05.120 this model uses two stalks because the\n00:10:07.519 medicine\n00:10:08.640 must first accumulate in the stomach and\n00:10:10.880 then move into the bloodstream\n00:10:12.959 the inflow is a pulse because the pills\n00:10:15.839 are taken\n00:10:16.480 once every four hours students are asked\n00:10:19.839 to anticipate the pattern of behavior of\n00:10:22.240 the left\n00:10:23.040 of just the left part of the model drug\n00:10:26.160 in the stomach then students are asked\n00:10:28.800 to anticipate the pattern of drug in the\n00:10:31.120 blood over time\n00:10:32.640 this is not a trivial analysis then\n00:10:35.600 different patterns of pill delivery\n00:10:37.360 protocol\n00:10:38.160 are explored and compared to the optimal\n00:10:41.120 therapeutic level for this\n00:10:42.800 medication finally in this sequence of\n00:10:45.600 medication models\n00:10:47.040 students as a class are asked to help\n00:10:49.760 modify\n00:10:50.959 the pill model so that it will\n00:10:54.399 calculate the blood alcohol\n00:10:56.480 concentration\n00:10:57.760 of a human male sipping beer over two\n00:11:00.720 hours\n00:11:01.839 the modified stock flow diagram is\n00:11:04.560 sketched as a class\n00:11:06.240 then students access the pre-built model\n00:11:09.760 online and test the following scenarios\n00:11:12.560 using the model\n00:11:15.040 influence of body weight gender type of\n00:11:17.760 alcohol and type of drinker\n00:11:20.560 now let's turn to a different sequence\n00:11:22.880 of models\n00:11:23.760 the basic population model is ubiquitous\n00:11:26.480 in system dynamics studies\n00:11:28.720 problems in health economics\n00:11:30.720 environmental science biology geography\n00:11:33.360 sociology and mathematics and more often\n00:11:36.720 involve the study of population dynamics\n00:11:39.839 the basic population model involves a\n00:11:42.880 stock for population\n00:11:44.720 since that's the value that we want to\n00:11:46.480 track over time\n00:11:47.760 it is the function an outflow of births\n00:11:51.200 and an inflow of births and an outflow\n00:11:54.399 of deaths\n00:11:55.040 and their attendant births and deaths\n00:11:57.440 fraction\n00:11:58.800 the basic model contains two feedback\n00:12:01.120 loops that control\n00:12:02.480 change in population dynamics over time\n00:12:06.480 there are three types of graphs that\n00:12:08.959 this structure could\n00:12:10.000 produce based upon which feedback is\n00:12:12.959 dominant\n00:12:14.160 assume that the birth fraction is larger\n00:12:16.160 than the death fraction\n00:12:17.360 the model could produce exponential\n00:12:19.360 growth but the deer population cannot\n00:12:21.839 grow forever\n00:12:22.720 there are limiting factors that would\n00:12:24.480 influence the growth\n00:12:26.000 as the deer population increases there\n00:12:28.320 would be more competition for food and\n00:12:30.240 water\n00:12:31.200 deer could become more aggressive as\n00:12:33.279 they vie for\n00:12:34.320 the limited resource overcrowding can\n00:12:37.360 also lead to aggression\n00:12:39.120 and to the spread of disease as waste\n00:12:41.760 builds up in a limited area\n00:12:43.760 each of these factors would lead to a\n00:12:46.079 higher death rate for the deer\n00:12:48.320 assume that the environment can support\n00:12:51.360 only a specific number of deer the\n00:12:54.399 number of deer the environment can\n00:12:56.639 support in any given location is called\n00:13:00.079 the carrying capacity we assume that the\n00:13:03.200 comparison\n00:13:03.920 comparison the carrying capacity value\n00:13:07.279 is unchanging\n00:13:09.040 as the population grows toward the\n00:13:12.480 carrying capacity\n00:13:14.320 the death fraction is being increased\n00:13:18.079 as we think it should the deer\n00:13:21.120 population graph looks reasonable with\n00:13:23.360 the carrying capacity component\n00:13:25.440 at the beginning there are few deer\n00:13:28.480 and the population is growing quite a\n00:13:30.560 bit as the population gets closer to the\n00:13:33.200 carrying capacity the growth slows down\n00:13:35.760 eventually\n00:13:36.639 moving to steady state this demonstrates\n00:13:40.800 transfer of feedback loop dominance\n00:13:44.240 now look at the typical closed form\n00:13:46.399 equation for the same scenario\n00:13:48.800 it seems to me that