

```
"timestamp_": "absolute", "recipient": "all", "channel": null, "parent": "clef6c75-a467-438a-b2e3-106b9c4b940a", "children": ["aaa23ca9-4e11-41bc-980b-b732261ae7de"]},
"aaa23ca9-4e11-41bc-980b-b732261ae7de": {"id": "aaa23ca9-4e11-41bc-980b-b732261ae7de",
"message": {"id": "aaa23ca9-4e11-41bc-980b-b732261ae7de", "author": {"role": "user",
"name": null, "metadata": {}}, "create_time": 1716490641.545785, "update_time": null,
"content": {"content_type": "text", "parts": ["From the readings, particularly
focusing on the &quot;Week 4_Systems Thinking for Life Cycle Sustainability
Assessment&quot; document, three dimensions of improvement in Life Cycle
Sustainability Assessment (LCSA) are highlighted:\n\n1. **Integration of environmental,
economic, and social dimensions**: This approach ensures a comprehensive understanding
of the impacts and dependencies of a system on these interrelated aspects. It is
crucial because isolating any of these dimensions can lead to a skewed understanding
of sustainability, potentially exacerbating other issues.\n\n2. **Systems thinking**:
This involves considering the entire life cycle of a product or service, from raw
material extraction through to disposal. This holistic perspective is essential to
identify critical leverage points for improvement and potential unintended
consequences of changes within any stage of the life cycle.\n\n3. **Stakeholder
engagement**: Engaging stakeholders across the lifecycle allows for a more accurate
representation of interests and values, ensuring that the sustainability assessments
are relevant and practical across different societal and economic contexts.\n\n###
Importance and Application to Learning from Earlier Modules:\n\nThese dimensions
resonate deeply with my own critiques and explorations of capitalist systems.
Capitalism, by its very nature, fosters competition and profit maximization, often at
the expense of environmental sustainability and social equity. The focus on
integrating diverse dimensions within LCSA offers a framework that challenges the
single-minded profit motive by advocating for environmental stewardship and social
well-being.\n\n**Integration of Multiple Dimensions** aligns with the need for a
holistic approach that I value. It ensures that environmental, economic, and social
aspects are not optimized in isolation, which can lead to transferring problems from
one area to another rather than solving them. For instance, a solution that is
economically viable and environmentally sustainable must also be socially equitable to
prevent exacerbating social inequalities.\n\n**Systems Thinking** offers a critique of
simplistic, linear thinking\u2014a common critique of capitalist approaches, which
often ignore complex interdependencies and long-term consequences for short-term gains.
By understanding the interconnectedness of systems, we can foresee and mitigate the
broader impacts of economic activities, such as the exploitation of labor and
resources.\n\n**Stakeholder Engagement** is crucial in challenging the top-down power
dynamics often found in capitalist enterprises. It ensures that the voices of
marginalized and directly impacted communities are heard and heeded in the development
of sustainable practices. This democratization of decision-making processes is
essential to counteract the often exploitative nature of unchecked capitalist systems,
which prioritize profit over people.\n\nBy applying these principles, we can develop
more equitable, sustainable, and holistic approaches to living and working together,
which is crucial in a globalized world where the actions of one can impact the many.
This approach not only critiques but actively works against the inequities perpetuated
by capitalist systems, highlighting the importance of systemic change for true
sustainability.\n\nDrawing from earlier modules, the challenges of sustainable
development are deeply rooted in systemic issues exacerbated by capitalist structures
that prioritize profit over people and planet. This critique aligns with the
```

discussions in various readings about capitalism's impact on sustainability and inequality.

1. **Integration of environmental, economic, and social dimensions:** This approach is crucial for addressing the complex interdependencies that characterize sustainability challenges. As discussed in "Beyond the Tragedy of the Commons," effective climate governance cannot be achieved through traditional market mechanisms alone, which are often recommended by capitalist ideologies. Instead, there needs to be an integration of policies that address environmental, economic, and social issues holistically. This is critical for moving beyond short-term profit motives to achieve long-term sustainability goals.

2. **Systems thinking:** The necessity of systems thinking was echoed in "A Behavioral Approach to the Rational Choice Theory of Collective Action," which explores how expanding the scope of rational choice models can better address social dilemmas through collective action. This reflects the need to look beyond the immediate economic benefits and consider broader systemic impacts, challenging the capitalist norm of individual maximization at the expense of collective well-being.

3. **Stakeholder engagement:** Engaging diverse stakeholders is essential for developing sustainable solutions that are inclusive and effective. The discussions in "Why System Dynamics Should Become Part of Secondary School Math Instruction" highlight the potential of system dynamics to involve various stakeholders in understanding and addressing complex systems. This approach counters the capitalist tendency to centralize decision-making power, promoting a more democratic and equitable process.

These dimensions, reinforced by your experiences and readings, highlight the inherent contradictions between capitalist structures and sustainable practices. Capitalism often drives decisions that prioritize immediate economic gains, undermining long-term environmental sustainability and social equity. By adopting a more integrated, systemic, and inclusive approach, as suggested by the readings, we can develop strategies that truly address the multifaceted nature of sustainability challenges.

Can you combine these two writings into one consistent narrative that answers the questions below:

What are the three dimensions of improvement in Life Cycle Sustainability Assessment suggested in the reading? Describe why these are important and relate and apply the three dimensions to your learning from earlier modules.

```
{
  "status": "finished_successfully",
  "end_turn": null,
  "weight": 1.0,
  "metadata": {
    "request_id": "8887456b68d94c50-MXP",
    "message_source": null,
    "timestamp": "absolute",
    "message_type": null,
    "recipient": "all",
    "channel": null,
    "parent": "673f5b72-4b3f-437c-8d6b-1ceb28cd3134",
    "children": [
      "dc3c41c5-84bc-4c63-9043-123c0eb3faae"
    ],
    "dc3c41c5-84bc-4c63-9043-123c0eb3faae": {
      "id": "dc3c41c5-84bc-4c63-9043-123c0eb3faae",
      "message": {
        "id": "dc3c41c5-84bc-4c63-9043-123c0eb3faae",
        "author": {
          "role": "assistant",
          "name": null,
          "metadata": {}
        },
        "create_time": 1716490678.792352,
        "update_time": null,
        "content": {
          "content_type": "text",
          "parts": [
            "In the reading 'Week 4_Systems Thinking for Life Cycle Sustainability Assessment,' three key dimensions of improvement are suggested to enhance the effectiveness of sustainability assessments. These dimensions include the integration of environmental, economic, and social dimensions, the application of systems thinking, and the active engagement of stakeholders. Each of these elements is vital for constructing a holistic and effective approach to sustainability that transcends the limitations often imposed by capitalist systems, which typically prioritize profit at the expense of environmental and social equity."
          ]
        }
      }
    }
  }
}
```

Integration of Environmental, Economic, and Social Dimensions

This approach emphasizes the necessity of considering the environmental, economic, and social impacts of products or services

throughout their lifecycle. It 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. This critique resonates with the arguments presented in “Beyond the Tragedy of the Commons,” where effective climate governance is discussed as requiring an integrated policy approach rather than reliance on market mechanisms alone, which often fail to address underlying social and environmental issues.

Systems Thinking

Systems thinking requires understanding the complete lifecycle of a product or service from raw material extraction to disposal and 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. This concept is supported by the insights from “A Behavioral Approach to the Rational Choice Theory of Collective Action,” which expands the rational choice models to incorporate collective actions that better address complex social dilemmas. It challenges simplistic, linear thinking common in capitalist approaches that often overlooks long-term consequences for immediate profit.

Stakeholder Engagement

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. The importance of stakeholder engagement is also highlighted in the module “Why System Dynamics Should Become Part of Secondary School Math Instruction,” which discusses how system dynamics modeling can involve stakeholders in understanding and managing complex systems effectively.

By applying these three dimensions, as suggested in the LCSA reading, 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.”}],

“status”: “finished_successfully”, “end_turn”: true

, “weight”: 1.0, “metadata”: {“finish_details”: {“type”: “stop”, “stop_tokens”: [100260]}, “citations”: [], “gizmo_id”: null, “message_type”: null, “model_slug”: “gpt-4”, “default_model_slug”: “gpt-4”, “pad”: “AAAAAAAAAAAAAAAAAAAAAAAA”, “parent_id”: “aaa23ca9-4e11-41bc-980b-b732261ae7de”, “is_complete”: true, “request_id”: “8887456b68d94c50-MXP”, “timestamp”: “absolute”, “recipient”: “all”, “channel”: null}, “parent”: “aaa23ca9-4e11-41bc-980b-b732261ae7de”, “children”: [“aaa2650a-889b-456b-a112-e6773811be91”]}, “aaa2650a-889b-456b-a112-e6773811be91”: {“id”: “aaa2650a-889b-456b-a112-e6773811be91”, “message”: {“id”: “aaa2650a-889b-456b-a112-e6773811be91”, “author”: {“role”: “user”, “name”: null, “metadata”: {}}, “create_time”: 1716492729.19172, “update_time”: null, “content”: {“content_type”: “text”, “parts”: [“Use the attachments to answer the question below and cite which document you took the answer from. \nWhat indicators are required to assess the systems dynamics of flow-limited resources? ”]}, “status”: “finished_successfully”, “end_turn”: null, “weight”: 1.0, “metadata”: {“attachments”: [{“id”: “file-AiGwS10AicZf3B2qBf7dlsap”, “size”: 29388, “name”: “tactiq-free-transcript-QBrmAGcMIi8.txt”, “mime_type”:

```

"text/plain"}, {"id": "file-EeszXNwz7GyPR5y3isYsJyro", "size": 356629, "name": "v7-
Rueter-chap6.pdf", "mime_type": "application/pdf"}, {"id": "file-
mvEH3SVrJpQKeNMTztYnN4YG", "size": 908286, "name": "Week 4_Systems Thinking for Life
Cycle Sustainability Assessment.pdf", "mime_type": "application/pdf"}], "request_id":
"888778638f7d0e5e-MXP", "message_source": null, "timestamp": "absolute",
"message_type": null, "recipient": "all", "channel": null, "parent": "dc3c41c5-84bc-
4c63-9043-123c0eb3faae", "children": ["c9bf0078-ela7-4aa3-a705-d6b25981c8dc"]],
"c9bf0078-ela7-4aa3-a705-d6b25981c8dc": {"id": "c9bf0078-ela7-4aa3-a705-d6b25981c8dc",
"message": {"id": "c9bf0078-ela7-4aa3-a705-d6b25981c8dc", "author": {"role": "tool",
"name": "myfiles_browser", "metadata": {}}, "create_time": 1716492749.384164,
"update_time": null, "content": {"content_type": "tether_quote", "url": "file-
EeszXNwz7GyPR5y3isYsJyro", "domain": "v7-Rueter-chap6.pdf", "text": "\n130 August 13,
2013 \n\n \n\n \n\n \n \n \n\nChapter 6 \u2013 2013 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 \ninto another. A
"system" is any set of connected processes and \nquantities of resources. It
can be as large or as small as you want \ninto set the boundaries around. Although some
people use the term "systems approach" to be holistic and inclusive, our
use of the \nword "systems view" specifies a set of intellectual tools that
can be \nplied 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 rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month. When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle. Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month. The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species. We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models.

The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback – A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

136 August 13, 2013

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation – One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

a. b. Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between

rapid input and output. With rapid fluxes, a slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points.

The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations.

Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country.

The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has led to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

August 13, 2013

Figure 6-7. Population change.

The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system.

All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change.

Economic growth in a country (which can be

the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" converter. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has led to what is called the classical demographic transition. We will revisit the systems description of demographic transitions when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere. Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The "busy" model diagram below shows how several simple models are linked.

August 13, 2013

Figure 6-9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the "greenhouse effect". The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and

combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from convertors to flows.

August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems";

another viewer/term similarities and differences

boundary scale/extent

Everything outside the boundary of the system is neither neglected or is an unlimited source or sink.

In the Scale viewer, extent relates to the size of the largest dimension considered, the word "doesn't" imply any process nor specific border.

stock network/node A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links.

Draft v7 145

flow network/link A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at neither end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity.

stability network/stability, resilience and resistance

Systems models can reach steady state that has some stability due to some form of negative feedback that keeps it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the next levels

An important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the appendices for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations

not only the parameter values can be changed, not the structure of the model itself. But these simulations are very useful for illustrating the types of predictions and uses for simulations. Simulations of this type are extremely useful in modern decision-making. For example, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

Draft v7 147

6.8 Developing a simplified Systems model of sustainable resource use

Many people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has to be stable or whether substitutions can be made. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took.

Figure 6-10.

The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered. If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.

August 13, 2013

Figure 6-11.

In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource. When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading the environment that the fish or trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.

Draft v7 149

Figure 6-12.

The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth. Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never

recover (assuming you don't stop harvesting after you see the population start to crash). Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water. August 13, 2013 The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital. Figure 6-14. With just one bad year, holding to the previous maximum unsustainable yield will eventually cause the collapse of this resource. Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital: a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield b. indirect effects from either harvest methods or use c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151 Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific. At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment. You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in unsustainable systems, it is important to attempt an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence.

In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to August 13, 2013 analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach. References to studies of the fate of Easter Island A more complete story can be found at the following sources:

- 2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island
- 2022 Discover Magazine: Jared Diamond. Easter's end. Discover magazine, August 1995. 16(8): 62-69.
- 2022 TED talks such as: http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html
- 2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/
- 2022 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 \n\namenable to examination with a systems approach. First, it is very \n\nsimilar to the systems model for sustainability that we developed in \n\nFigure 12 and 13; there are suggestions of growth, harvest, and bad \n\nluck. Second, at any time the processes seem to be close to being \n\nin balance; it is only by looking at the long term effect of these do \n\nwe see the impact of a slight over harvest or a previous year of bad \n\nluck. Third, the description contains some simple models that \n\ncould be tied together to get an integrated picture; there is \n\npopulation growth, harvest of trees, soil moisture, agriculture and \n\nfishing. These processes are related, but not directly. \n\n\n \nApplying the systems tool \n\n\nWe are going to put separate small models together and to examine \n\nhow these individual processes counter or reinforce each other. \n\nThis is an oversimplified model in which will only consider three \n\nstocks: the number of people, palm trees, and rats. \n\n\n\n\nDraft v7 153 \n\n\n\nThe number of people is the balance between birth and death rates. \n\nAs there are more people, there will be more births, i.e. the \n\npopulation growth has a positive feedback component. The number \n\nof deaths may depend on many other factors including natural \n\ncauses, famine, and disease. A simple model diagram for this is \n\ngiven below. \n\n\n \n \n \nFigure 6-15. Human population sub-model showing positive feedback for births \n\nbut a constant death rate. \n\n\n \n\n\nThe number of trees is also a balance between the number of palm \n\nnuts that germinate and grow, and the cutting down of the trees. \n\n\n \n \n \nFigure 6-16. Palm tree sub-model also have positive feedback for growth and \n\nconstant loss. \n\n\n \n\n\nThe third strand in our model will be the rat population. People \n\nbrought rodents to the island. These rats play a key role in this \n\nproblem. People eat the rats and the rats eat the palm fruit, \n\ndecreasing the tree population. Their population is just like the \n\n\n\n\n154 August 13, 2013 \n\n\n\n\nothers, there is positive feedback for rat births and several factors \n\ncontrolling death. \n\n\nNow we are going to connect these three stocks and flows models \n\nwith factors that affect either the birth or death rates. The following \n\nlist details these interactions. \n\n\n1. Rats have a positive effect on people births because this \n\nis a source of food for people. The birth rate of people will \n\nincrease with more rats (and the birth rate will decrease if \n\nrats are low). \n\n\n2. Rats have a negative effect on human death. The death \n\nrate of people will increase if rats are too low. \n\n\n3. People have a positive effect on the harvesting of trees. \n\nMore people cut down more trees because they need them \n\nfor fishing and to cultivate land for crops. \n\n\n4. Rats have a negative effect on the rate of palm fruit \n\ngermination. The number of rats decreases the percentage \n\nof new palm seeds that germinate successfully because the \n\nrats chew on the seeds. \n\n\n5. Palm trees have a positive effect on rat births, because \n\nthe rats eat the palm fruit. \n\n\n \n\n\nWe could add more detail to this model, but even with only these \n\nfive interactions this turns out to be a very interesting and \n\ninstructive model. Looking at the model diagram, below, you can \n\nsee that there are many positive feedbacks and only a few negative \n\nfeedbacks. \n\n\n\n\nDraft v7 155 \n\n\n \n\n\n \nFigure 6-17. The rat submodel interacts with both humans and trees. \n\n\n \n\n\nAccording to the historical record, as the human population grew, \n\npeople cut more and more trees. They needed these trees for \n\nmaking boats for fishing and they needed more and more land for \n\ncultivation. Over harvesting trees, just on its own would have been \n\na problem for them, but this was exacerbated by the fact that they \n\nalso ate rats, and rats depended on the trees for food. As the human \n\npopulation continued to grow, they cut enough trees such that

they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but the other food source, rats, declined. The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system. Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the more complex interactions and consequences of our actions.

6.10 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Draft v7 157

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model and for communication about the important features of a problem. As models become busier they often require sub-models for different stocks. The example of Easter Island demonstrated hypothetical relationships between the stocks of palm trees, people and rats. At high human populations, this system was not resilient to changes and might explain the decline of the resource base.

```

{
  "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": "aaa2650a-889b-456b-a112-e6773811be91",
    "request_id": "888778638f7d0e5e-MXP",
    "timestamp_": "absolute",
    "recipient": "all",
    "channel": null,
    "parent": "aaa2650a-889b-456b-a112-e6773811be91",
    "children": ["d593fff7-44e9-4683-9e9a-ec07511bab81"]
  },
  "d593fff7-44e9-4683-9e9a-ec07511bab81": {
    "id": "d593fff7-44e9-4683-9e9a-ec07511bab81",
    "message": {
      "id": "d593fff7-44e9-4683-9e9a-ec07511bab81",
      "author": {
        "role": "tool",
        "name": "myfiles_browser",
        "metadata": {}
      },
      "create_time": 1716492749.384419,
      "update_time":

```

null, "content": {"content_type": "tether_quote", "url": "file-AiGwSl0AicZf3B2qBf7dlsap", "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 most basic functions studied in algebra connecting sd and traditional mathematics representation suppose we were interested in how water in a lake is increasing based on water flowing in at a constant rate using the sd structure the initial water in the lake would be placed in a stock icon and it would only have an inflow since it is only increasing with a constant value in the flow we know the behavior of the stock is growing linearly since the rate of change is constant and positive the sd software calculates the value of the stock using recursion which is shown in the table at the left we see that the flow value is added to the current value of the stock each time unit now we see the traditional closed form equation for the linear function where w represents the amount of water in the lake it starts at 100 units and grows at five units per year if we were to construct what we know is an exponential population growth behavior we could start with a stock of elephants and an inflow of new elephants born to this herd each year but this model is not correct we know the inflow cannot be constant because the number of new elephants born per year depends on knowing how many elephants are currently in the herd so we now indicate that dependency with a connector oh and now we have introduced a feedback loop the loop is reinforcing because the more elephants in the population the more new elephants are born per year adding more elephants to the herd but this model is still not complete we should indicate the number of new elephants born per elephant in the herd each year we do that by indicating a birth fraction in decimal form that will be multiplied by the number of elements in the herd each year so for exponential growth the inflow is proportional to the current amount of the stock or mathematically the rate of change the flow is defined as the stock value times some growth factor value this is exactly the differential equation that represents exponential growth but algebra students don't need to know that they are learning calculus they are just learning a different behavior pattern over time and how to create it based on its rate of change definition again quickly we would have our stock flow definition as shown with a 20 growth fraction the elephant population will grow exponentially because the inflow is proportional to the stock value if we think about what the sd software is doing we look at the recursion in the table the flow calculates the growth amount and adds it to the stock each year there are two equations that are possible mathematically the easier equation is represented at the top and is the one often

taught in first year algebra it is often used when we want to calculate values once every year or time unit the second is shown at the bottom and is often used in situations where calculating continuous change is a better choice the top equation is probably the best choice for this particular elephant heard example in sd modeling we use the same diagram for each scenario and merely increase the number of times the simulation calculates the values each time unit to differentiate which situation is being used for calculation as it is a much more intuitive process in my opinion just so you know there is a free web-based version of the sd modeling software that works on tablets computers laptops chromebooks and smartphone that will allow you to have your students build these models if they have access to this technology go to publish.icsysystems.com the software is called stella online once students learn linear and exponential model structures they can start putting them together to study new problems they could not study with equations i have used these medication models in my algebra classes over many years students really like them consider an emergency room problem you the student are a medical resident working in the emergency room and a patient comes in who needs immediate medical attention from your analysis you decide to connect this patient to an iv drip that will supply one milligram of therapeutic drug per minute this person you estimate will metabolize the drug at about 0.55 percent per minute what is the pattern of the drug level in the body over 24 hours so the diagram might look like this with an inflow of medicine and an outflow of body using and eliminating the medicine observe the left side of the diagram since there is a constant inflow the left part of the diagram is similar to a linear model structure observe the right part of the diagram the structure is similar to an exponential decay the drug is lost as a percent of the current amount of drug in the patient's systems students try to predict the behavior of the drug in the body over time giving a reason for their predictions then they build the model and see what the computer produces then they have to explain why the computer graph has the shape that it shows skipping to the skipping the second medication scenario we will go to the third drug model it involves taking medicine in the form of pills it has been a busy day in the emergency room a third patient arrives and you decide to give this patient two pills of 375 milligrams each of a therapeutic drug and tell them to continue taking two more pills every four hours this person you estimate will absorb the drug from the stomach in the bloodstream at about 4.5 percent per minute and

metabolize the drug at about point 55 percent per minute what is the pattern of drug level in the body over 24 hours this model uses two stalks because the medicine must first accumulate in the stomach and then move into the bloodstream the inflow is a pulse because the pills are taken once every four hours students are asked to anticipate the pattern of behavior of the left of just the left part of the model drug in the stomach then students are asked to anticipate the pattern of drug in the blood over time this is not a trivial analysis then different patterns of pill delivery protocol are explored and compared to the optimal therapeutic level for this medication finally in this sequence of medication models students as a class are asked to help modify the pill model so that it will calculate the blood alcohol concentration of a human male sipping beer over two hours the modified stock flow diagram is sketched as a class then students access the pre-built model online and test the following scenarios using the model influence of body weight gender type of alcohol and type of drinker now let's turn to a different sequence of models the basic population model is ubiquitous in system dynamics studies problems in health economics environmental science biology geography sociology and mathematics and more often involve the study of population dynamics the basic population model involves a stock for population since that's the value that we want to track over time it is the function an outflow of births and an inflow of births and an outflow of deaths and their attendant births and deaths fraction the basic model contains two feedback loops that control change in population dynamics over time there are three types of graphs that this structure could produce based upon which feedback is dominant assume that the birth fraction is larger than the death fraction the model could produce exponential growth but the deer population cannot grow forever there are limiting factors that would influence the growth as the deer population increases there would be more competition for food and water deer could become more aggressive as they vie for the limited resource overcrowding can also lead to aggression and to the spread of disease as waste builds up in a limited area each of these factors would lead to a higher death rate for the deer assume that the environment can support only a specific number of deer the number of deer the environment can support in any given location is called the carrying capacity we assume that the comparison the carrying capacity value is unchanging as the population grows toward the carrying capacity 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 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": "c9bf0078-ela7-4aa3-a705-d6b25981c8dc", "request_id": "888778638f7d0e5e-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "c9bf0078-ela7-4aa3-a705-d6b25981c8dc", "children": ["85324676-b68a-4bac-baaf-4161a539f079"]}, "85324676-b68a-4bac-baaf-4161a539f079": {"id": "85324676-b68a-4bac-baaf-4161a539f079", "message": {"id": "85324676-b68a-4bac-baaf-4161a539f079", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716492749.384684, "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": "d593fff7-44e9-4683-9e9a-ec07511bab81", "request_id": "888778638f7d0e5e-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "d593fff7-44e9-4683-9e9a-ec07511bab81", "children": ["1d7e9aae-5a99-441e-a0c4-3df20a69fa38"]}, "1d7e9aae-5a99-441e-a0c4-3df20a69fa38": {"id": "1d7e9aae-5a99-441e-a0c4-3df20a69fa38", "message": {"id": "1d7e9aae-5a99-441e-a0c4-3df20a69fa38", "author": {"role": "assistant", "name": null, "metadata": {}}, "create_time": 1716492749.384899, "update_time": null, "content": {"content_type": "text", "parts": ["To assess the systems dynamics of flow-limited resources, several key indicators are required:\n\n1. **Stocks**: Quantities of resources or elements in the system, such as amounts of water, carbon, or population numbers in an ecological system. Stocks are critical for understanding the amount of resource available at any time.\n\n2. **Flows**: The movement of resources between stocks or from an external source into a stock. This includes both inputs into the system and outputs from the system, measured over time (e.g., liters per hour, tons of carbon per year).\n\n3. **Converters/Constants**: Factors or parameters that influence flows or stocks but do not change dynamically with the system. These can include growth rates, conversion efficiencies, or fixed loss rates.\n\n4. **Information Flows**: Directions of influence among components of the system, which can modify flows or converter values based on the state of stocks or other variables in the system.\n\nThese components are fundamental for creating a systems dynamics model that accurately represents the behavior of resources within a system, particularly when those resources are limited by external or internal constraints. For flow-limited resources, it is essential to model not only the quantities and movements but also how information about the state of the system influences these movements and quantities\n\nsource\n"]}, "status": "finished_successfully", "end_turn": true, "weight": 1.0, "metadata": {"finish_details": {"type": "stop", "stop_tokens": [100260]}, "citations": [{"start_ix": 1373, "end_ix": 1384, "citation_format_type": "tether Og", "metadata": {"type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-EeszXNwz7GyPR5y3isYsJyro", "source": "my_files", "text": "\n130 August 13, 2013 \n\n\n\n\nChapter 6 \n2013 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 large or as small as you want \nto set the boundaries around. Although some people use the term 'systems approach' to be holistic and inclusive, our use of the 'systems view' specifies a set of intellectual tools that can be \n\napplied to any size set of processes and resources. \n\nThis text presents one

specific definition of how to characterize an environmental problem as a system of stocks and flows. We will be using a limited list of characteristics of a system that can be used to describe many different structures and behaviors. Our unconstrained set of categories will help highlight the structural similarities and differences between different systems. This "systems" approach is useful for simplifying problems, looking for significant processes and identifying controls. The approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. Another of the benefits of this approach is that it clearly identifies the assumptions on which simulations are based. A good "systems" model is both a valuable research tool and a platform for communication and decision-making. Thus, carefully gathering information to construct a stock and flow description of an environmental problem is a good example of methodically collecting information that takes place in scientific research (Pielke 2007).

6.2 Model Components

There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, converters/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1). Figure 6-1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use. Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is 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 number of rabbits in the population. We represent this in a systems diagram with a box icon. A source or sink is either has an unlimited, unchanging concentration or a reservoir that is outside the boundaries of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month. When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle. Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe

the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month.

The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species.

We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback

and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation – One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in

ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points. The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations. Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country. The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has led to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has led to what is called the classical demographic transition. We will revisit the systems description of demographic transitions

when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere. Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The “busy” model diagram below shows how several simple models are linked.

142 August 13, 2013 Figure 6–9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the “greenhouse effect”. The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the Draft v7 143 not only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from converters to flows.

144 August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems";
 nother viewer/term similarities and differences
 boundary scale/extent
 Everything outside the boundary of the system is neither neglected or is an
 unlimited source or sink. In the Scale viewer, extent relates to the size of the
 largest dimension considered, the word doesn't imply any process nor
 specific border. In stock network/node A stock must be something measurable
 that can be moved through a flow. In the network view, a node can be a quality
 that changes depending on input links. In Draft v7 145 In flow
 network/link A flow must be the movement of material or energy per unit time and
 whatever is flowing has to be the same as the stock at neither end. A link
 identifies a relationship between nodes. It can be a quantity of material
 moved but it doesn't have to be a quantity. In stability
 network/stability, resilience and resistance
 Systems models can reach steady
 state that has some stability due to some form of negative feedback that keeps
 it at a level or in some range. The type of systems model that we are using
 doesn't have a mechanism to change its own structure. A network diagram
 that has many weak interactions can shift the operational structure and show how
 a large number of weak interactions or the combination of fast and slow
 processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the
 next levels
 An important extension of the use of systems models is to create
 simulations that demonstrate overall system behavior given certain input
 conditions and constants. We will look at the components of the system, such as
 positive or negative feedback to look for very general system behavior. There are
 software applications that are useful for turning these systems diagrams into
 mathematical dynamic models (the diagrams and charts in this page were generated
 with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the
 appendices for this book to see simulations that were written in STELLA and
 simulations made available on the web (through Forio.com). In these simulations
 only the parameter values can be changed, not the structure of the model itself.
 But these simulations are very useful for illustrating the types of predictions and
 uses for simulations. Simulations of this type are extremely useful in modern
 decision-making. For example, the Northwest Power Council created a complicated
 and very busy model that contained information on fish, dams, river flows and
 electricity. This model could be run under different conditions and demands for
 energy to show which parameters affect fish survival most. They were able to show
 the model to people who work in this arena of fish and rivers to see if the model
 behaves in a way they think it should; does it show low fish years when expected or
 high fish years following particular events? The simulation model and the accessible
 interface were powerful tools in addressing problems and getting people to learn
 about complicated social, economic and ecological issues.

Draft v7 147

6.8 Developing a simplified Systems model of sustainable resource use
 Many people subscribe to the idea that a sustainable resource is one in which you
 reach a steady state because you don't use the resource faster than it is being
 created. Whether or not this is required for all resources to attain a sustainable
 society is a very interesting question. It maybe that you can have some resources
 decrease and be replaced by other resources. There are different definitions of
 overall sustainability that address whether the entire ensemble of capital types has
 to be stable or whether substitutions can be made. We will focus here on the

sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took. Figure 6-10. The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered. If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource. August 13, 2013 Figure 6-11. In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource. When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading the environment that the fish or trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth. Draft v7 149 Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth. Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash). Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water. August 13, 2013 The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital. Figure 6-14. With just one bad year, holding to the previous maximum sustainable yield will eventually cause the collapse of this resource. Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital: a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield b. indirect effects from either harvest methods or use c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151 Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be

sustainable than you've heard about any of the myriad of other islands in the South Pacific. At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment. You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in sustainable systems, it is important to attempt an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence. In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to 152 August 13, 2013 analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach. References to studies of the fate of Easter Island A more complete story can be found at the following sources: 2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island 2022 Discover Magazine: Jared Diamond. 201cEaster 2019s end. 201d Discover magazine, August 1995. 16(8): 62-69. 2022 TED talks such as: http://www.ted.com/talks/lang/eng/jared_diamond_on_why_so_societies_collapse.html 2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/ 2022 Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking. Salient features The story of Easter Island has particular features that make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in Figure 12 and 13; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly. Applying the systems tool We are going to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats. Draft v7 153 The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below. Figure 6-15. Human population sub-model showing positive feedback for births but a constant death rate. The number of trees is also a balance

between the number of palm nuts that germinate and grow, and the cutting down of the trees. Figure 6-16. Palm tree sub-model also have positive feedback for growth and constant loss. The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the 154 August 13, 2013. In others, there is positive feedback for rat births and several factors controlling death. Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births because this is a source of food for people. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.
3. People have a positive effect on the harvesting of trees. More people cut down more trees because they need them for fishing and to cultivate land for crops.
4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.
5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks. Draft v7 155 Figure 6-17. The rat submodel interacts with both humans and trees. According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but the other food source, rats, declined. The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population 156 August 13, 2013 could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system. Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the more complex interactions and consequences of our actions.

6.10 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Draft v7 157

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model and for communication about the important features of a problem. As models become busier they often require sub-models for different stocks. The example of Easter Island demonstrated hypothetical relationships between the stocks of palm trees, people and rats. At high human populations, this system was not resilient to changes and might explain the decline of the resource base.

extra": {"cited_message_idx": 40, "search_result_idx": null, "evidence_text": "source"}, "url": "file-EeszXNwz7GyPR5y3isYsJyro"}}, {"gizmo_id": null, "is_complete": true, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "pad": "AAAAAAAA", "parent_id": "85324676-b68a-4bac-baaf-4161a539f079", "request_id": "888778638f7d0e5e-MXP", "timestamp": "absolute", "content_references": [{"matched_text": "\u00301040\u0020source\u003011", "start_idx": 1373, "end_idx": 1384, "alt": null, "type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-EeszXNwz7GyPR5y3isYsJyro", "source": "my_files", "snippet": "\n130 August 13, 2013\n\n\n\n\nChapter 6 \u00202013 Stock and Flow Systems\n\n6.1 Introduction\n\nEcological, geochemical and human processes can be described by following the flows of material or energy from one place or form to another. A 'system' is any set of connected processes and quantities of resources. It can be as large or as small as you want to set the boundaries around. Although some people use the term 'systems approach' to be holistic and inclusive, our use of the word 'systems view' specifies a set of intellectual tools that can be applied to any size set of processes and resources.\n\nThis text presents one specific definition of how to characterize an environmental problem as a system of stocks and flows. We will be using a limited list of characteristics of a system that can be used to describe many different structures and behaviors. Our unconstrained set of categories will help highlight the structural similarities and differences between different systems.\n\nThis 'systems' approach is useful for simplifying problems, looking for significant processes and identifying controls. The approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. Another of the benefits of this approach is that it clearly identifies the assumptions on which simulations are based. A good 'systems' model is both a valuable research tool and a platform for communication and decision-making. Thus, carefully gathering information to construct a stock and flow description of an environmental problem is a good example of methodically collecting information that takes place in scientific research (Pielke 2007).

Draft v7 131

6.2 Model Components There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, convertors/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1).

Figure 6-1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use. Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is 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 number of rabbits in the population. We represent this in a systems diagram with a box icon.

A source or sink is either has an unlimited, unchanging concentration or a reservoir that is outside the boundaries of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams.

Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month.

When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle.

Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month. The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and

function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species. We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems.

a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

Draft v7 136 August 13, 2013

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray).

The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation -

One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

a. n

Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

Draft v7 139

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points.

The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations.

Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country.

The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has lead

to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

140 August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has lead to what is called the classical demographic transition. We will revisit the systems description of demographic transitions when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere. Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The "busy" model diagram below shows how several simple models are linked.

142 August 13, 2013

Figure 6-9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less

efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the "greenhouse effect". The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from converters to flows.

August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems"

viewer/term similarities and differences

boundary scale/extent

Everything outside the boundary of the system is neither neglected or is an unlimited source or sink. In the Scale viewer, extent relates to the size of the largest dimension considered, the word doesn't imply any process nor specific border.

stock network/node A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links.

Draft v7 145

flow network/link A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at neither end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity.

stability network/stability, resilience and resistance

Systems models can reach steady state that has some stability due to some form of negative feedback that keeps

it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the next levels

An important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the appendices for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations not only the parameter values can be changed, not the structure of the model itself. But these simulations are very useful for illustrating the types of predictions and uses for simulations. Simulations of this type are extremely useful in modern decision-making. For example, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

Draft v7

6.8 Developing a simplified Systems model of sustainable resource use

Many people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has to be stable or whether substitutions can be made. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took.

Figure 6-10.

The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered.

If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.

August 13, 2013

Figure 6-11.

In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource.

When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading

the environment that the fish nor trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.

Draft v7 149 Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth.

Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash).

Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water.

150 August 13, 2013 The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital.

Figure 6-14. With just one bad year, holding to the previous maximum sustainable yield will eventually cause the collapse of this resource.

Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital:

- a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield
- b. indirect effects from either harvest methods or use
- c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151 Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific.

At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment.

You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in unsustainable systems, it is important to attempt

an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence.

In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to

152 August 13, 2013

analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach.

References to studies of the fate of Easter Island

A more complete story can be found at the following sources:

2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island

2022 Discover Magazine: Jared Diamond. Easter's end. Discover magazine, August 1995. 16(8): 62-69.

2022 TED talks such as:

http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html

http://blog.ted.com/2008/10/27/why_do_societies_collapse/

2022 Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking.

Salient features

The story of Easter Island has particular features that make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in Figure 12 and 13; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly.

Applying the systems tool

We are going to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats.

Draft v7 153

The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below.

Figure 6-15. Human population sub-model showing positive feedback for births but a constant death rate.

The number of trees is also a balance between the number of palm nuts that germinate and grow, and the cutting down of the trees.

Figure 6-16. Palm tree sub-model also have positive feedback for growth and constant loss.

The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the

154 August 13, 2013

others, there is positive feedback for rat births and several factors controlling death.

Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births because this is a source of food for people. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.
3. People have a positive effect on the harvesting of trees.

More people cut down more trees because they need them for fishing and to cultivate land for crops.

4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.

5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks.

Draft v7 155

Figure 6-17. The rat submodel interacts with both humans and trees.

According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but the other food source, rats, declined.

The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population

August 13, 2013

could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system.

Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the more complex interactions and consequences of our actions.

6.10 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Draft v7 157

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model 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": "85324676-b68a-4bac-baaf-4161a539f079", "children": [{"id": "aaa2e9cb-0a49-40f3-a80f-05717987b46f"}],
"aaa2e9cb-0a49-40f3-a80f-05717987b46f": {"id": "aaa2e9cb-0a49-40f3-a80f-05717987b46f",
"message": {"id": "aaa2e9cb-0a49-40f3-a80f-05717987b46f", "author": {"role": "user",
"name": null, "metadata": {}}, "create_time": 1716492783.872601, "update_time": null,
"content": {"content_type": "text", "parts": ["Okay, can you rewrite that answer in
narrative paragraph, short essay format"]}, "status": "finished_successfully",
"end_turn": null, "weight": 1.0, "metadata": {"request_id": "888779b85d9f0e5e-MXP",
"message_source": null, "timestamp": "absolute", "message_type": null}, "recipient":
"all", "channel": null}, "parent": "1d7e9aae-5a99-441e-a0c4-3df20a69fa38", "children":
["b8798e2a-d2c7-409c-8eee-35eb4cf56c51"]}, "b8798e2a-d2c7-409c-8eee-35eb4cf56c51":
{"id": "b8798e2a-d2c7-409c-8eee-35eb4cf56c51", "message": {"id": "b8798e2a-d2c7-409c-
8eee-35eb4cf56c51", "author": {"role": "assistant", "name": null, "metadata": {}},
"create_time": 1716492811.642852, "update_time": null, "content": {"content_type":
"text", "parts": ["To effectively assess the dynamics of flow-limited resources within
a system, it's essential to incorporate several key indicators into a systems
dynamics model. These indicators include stocks, flows, converters/constants, and
information flows, each playing a crucial role in understanding and predicting system
behaviors.\n\n**Stocks** 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 the resource levels and serve as a
baseline for measuring changes over time.\n\n**Flows** 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.\n\n**Converters/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.\n\n**Information 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.\n\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 states of the system under different scenarios and for making informed
decisions about resource management and conservation. Such models are invaluable in
fields ranging from environmental science to economics, where understanding the
complex interplay of limited resources is essential for sustainability."]}, "status":
"finished_successfully", "end_turn": true

```
[{"weight": 1.0, "metadata": {"finish_details": {"type": "stop", "stop_tokens": [100260]}, "citations": [], "gizmo_id": null, "message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "pad": "AAAAAAAA", "parent_id": "aaa2e9cb-0a49-40f3-a80f-05717987b46f", "request_id": "888779b85d9f0e5e-MXP", "timestamp_": "absolute", "is_complete": true}, "recipient": "all", "channel": null}, {"parent": "aaa2e9cb-0a49-40f3-a80f-05717987b46f", "children": [{"id": "aaa20419-9de6-4c61-904f-eb2833d610f0"}], [{"id": "aaa20419-9de6-4c61-904f-eb2833d610f0", "message": {"id": "aaa20419-9de6-4c61-904f-eb2833d610f0", "author": {"role": "user", "name": null, "metadata": {}}, "create_time": 1716493403.927225, "update_time": null, "content": {"content_type": "text", "parts": ["Use the attachments to answer the questions below. Site the source of the info. \n\nWhat inputs might be incorporated into a model of flow-limited resources? How is this different from stock-limited resources? "]}}, {"status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"attachments": [{"id": "file-Sm7n1bk04weXq4ifGYZ3M6EA", "size": 29388, "name": "tactiq-free-transcript-QBrmAGcMIi8.txt", "mime_type": "text/plain"}, {"id": "file-CM9JPesSEBT9mRtsKrIbKZHR", "size": 356629, "name": "v7-Rueter-chap6.pdf", "mime_type": "application/pdf"}, {"id": "file-lhaHcc9ZPRuDoZAgYLEq6Y0", "size": 908286, "name": "Week 4_Systems Thinking for Life Cycle Sustainability Assessment.pdf", "mime_type": "application/pdf"}]}, {"request_id": "888788dcad9aba9f-MXP", "message_source": null, "timestamp_": "absolute", "message_type": null}, {"recipient": "all", "channel": null}, {"parent": "b8798e2a-d2c7-409c-8eee-35eb4cf56c51", "children": [{"id": "e78dd7c6-4a18-4121-8f0a-290fb0def232"}], [{"id": "e78dd7c6-4a18-4121-8f0a-290fb0def232", "message": {"id": "e78dd7c6-4a18-4121-8f0a-290fb0def232", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716493422.95525, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-CM9JPesSEBT9mRtsKrIbKZHR", "domain": "v7-Rueter-chap6.pdf", "text": "\n130 August 13, 2013 \n\n \n\n \n\n \n\n \n\nChapter 6 \u2013 2013 Stock and Flow Systems \n\n \n6.1 Introduction \n\nEcological, geochemical and human processes can be described by \n\nfollowing the flows of material or energy from one place or form \n\ninto another. A \n\n"system" is any set of connected processes and \n\nquantities of resources. It can be as large or as small as you want \n\ninto set the boundaries around. Although some people use the term \n\n"systems approach" to be holistic and inclusive, our use of the \n\nword "systems view" specifies a set of intellectual tools that can be \n\napplied to any size set of processes and resources. \n\n\nThis text presents one specific definition of how to characterize an \n\nenvironmental problem as a system of stocks and flows. We will \n\nbe using a limited list of characteristics of a system that can be \n\nused to describe many different structures and behaviors. Our \n\nunconstrained set of categories will help highlight the structural \n\nsimilarities and differences between different systems. \n\n\nThis "systems" approach is useful for simplifying problems, \n\nlooking for significant processes and identifying controls. The \n\napproach can also be used to create simulations of future \n\nconditions and to communicate these to other people who are \n\nmaking decisions. Another of the benefits of this approach is that it \n\nclearly identifies the assumptions on which simulations are based. \n\nA good "systems" model is both a valuable research tool and a \n\nplatform for communication and decision-making. Thus, carefully \n\ngathering information to construct a stock and flow description of \n\nan environmental problem is a good example of methodically \n\ncollecting information that takes place in scientific research (Pielke \n\n2007). \n\n \n\n \n\n \n\n \n\nDraft v7 131 \n\n \n\n ]}]
```

6.2 Model Components There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, convertors/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1).

Figure 6-1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use. Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is 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 number of rabbits in the population. We represent this in a systems diagram with a box icon.

A source or sink is either has an unlimited, unchanging concentration or a reservoir that is outside the boundaries of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams.

Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month.

When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle.

Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month. The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and

function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species. We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems.

a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

Draft v7 136 August 13, 2013

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray).

The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation -

One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

a. n

Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

Draft v7 139

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points.

The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations.

Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country. The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has lead

to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

140 August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has lead to what is called the classical demographic transition. We will revisit the systems description of demographic transitions when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere. Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The "busy" model diagram below shows how several simple models are linked.

142 August 13, 2013

Figure 6-9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less

efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the "greenhouse effect". The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from converters to flows.

August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems"

Another viewer/term similarities and differences

boundary scale/extent

Everything outside the boundary of the system is neither neglected or is an unlimited source or sink. In the Scale viewer, extent relates to the size of the largest dimension considered, the word doesn't imply any process nor specific border.

stock network/node A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links.

Draft v7 145

flow network/link A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at neither end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity.

stability network/stability, resilience and resistance

Systems models can reach steady state that has some stability due to some form of negative feedback that keeps

it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the next levels

An important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the appendices for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations not only the parameter values can be changed, not the structure of the model itself. But these simulations are very useful for illustrating the types of predictions and uses for simulations. Simulations of this type are extremely useful in modern decision-making. For example, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

Draft v7 147

6.8 Developing a simplified Systems model of sustainable resource use

Many people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has to be stable or whether substitutions can be made. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took.

Figure 6-10.

The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered.

If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.

August 13, 2013

Figure 6-11.

In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource.

When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading

the environment that the fish nor trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.

Draft v7 149 Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth.

Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash).

Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water.

150 August 13, 2013 The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital.

Figure 6-14. With just one bad year, holding to the previous maximum sustainable yield will eventually cause the collapse of this resource.

Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital:

- a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield
- b. indirect effects from either harvest methods or use
- c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151 Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific.

At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment.

You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in unsustainable systems, it is important to attempt

an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence.

In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to

152 August 13, 2013

analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach.

References to studies of the fate of Easter Island

A more complete story can be found at the following sources:

2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island

2022 Discover Magazine: Jared Diamond. Easter's end. Discover magazine, August 1995. 16(8): 62-69.

2022 TED talks such as:

http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html

2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/

2022 Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking.

Salient features

The story of Easter Island has particular features that make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in Figure 12 and 13; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly.

Applying the systems tool

We are going to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats.

Draft v7 153

The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below.

Figure 6-15. Human population sub-model showing positive feedback for births but a constant death rate.

The number of trees is also a balance between the number of palm nuts that germinate and grow, and the cutting down of the trees.

Figure 6-16. Palm tree sub-model also have positive feedback for growth and constant loss.

The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the

154 August 13, 2013

others, there is positive feedback for rat births and several factors controlling death.

Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births because this is a source of food for people. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.
3. People have a positive effect on the harvesting of trees.

More people cut down more trees because they need them for fishing and to cultivate land for crops.

4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.

5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks.

Draft v7 155

Figure 6-17. The rat submodel interacts with both humans and trees.

According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but the other food source, rats, declined.

The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population

August 13, 2013

could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system.

Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the more complex interactions and consequences of our actions.

6.10 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Draft v7 157

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model 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": "aaa20419-9de6-4c61-904f-eb2833d610f0", "request_id": "888788dcad9aba9f-MXP", "timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "aaa20419-9de6-4c61-904f-eb2833d610f0", "children": [{"f3db11af-1a20-4abe-8a68-a69214255986"}], "f3db11af-1a20-4abe-8a68-a69214255986": {"id": "f3db11af-1a20-4abe-8a68-a69214255986", "message": {"id": "f3db11af-1a20-4abe-8a68-a69214255986", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716493422.955492, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-Sm7nlbk04weXq4ifGYZ3M6EA", "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\n\n00:00:03.040 i have been asked to present to on the\n\n00:00:05.839 system dynamics work\n\n00:00:07.200 i have done with secondary school\n\n00:00:08.880 students and teachers over three decades\n\n00:00:11.599 i have used system dynamics modeling in\n\n00:00:13.920 my mathematics and modeling instruction\n\n00:00:16.000 for 30 years\n\n00:00:17.520 although science instruction is the most\n\n00:00:19.680 natural discipline for sd modeling i\n\n00:00:22.080 would like to make\n\n00:00:23.199 an argument that if we really want sd\n\n00:00:25.840 modeling to become\n\n00:00:26.960 a more mainstream analytical tool it\n\n00:00:30.240 should be embedded in secondary school\n\n00:00:32.640 mathematics\n\n00:00:33.840 sd modeling can reinforce important\n\n00:00:37.120 mathematical concepts quite well dr\n\n00:00:40.320 barry m specializes in the study of\n\n00:00:42.399 complex systems\n\n00:00:43.760 to be able to analyze complex systems\n\n00:00:46.879 he claims that calculus and statistics\n\n00:00:49.120 do not have the tools to describe\n\n00:00:51.680 what we want to study that we need\n\n00:00:55.360 to work with new concepts that we need\n\n00:00:58.960 to\n\n00:00:59.359 ask different questions about system\n\n00:01:02.000 dynamic behavior\n\n00:01:03.920 he says working with complex systems\n\n00:01:06.799 changes how we think\n\n00:01:08.560 we have an opportunity to help our\n\n00:01:10.479 mathematics students broaden their\n\n00:01:12.400 thinking\n\n00:01:13.280 to encompass techniques that will help\n\n00:01:15.520 them think about\n\n00:01:16.479 complex dynamic problems one way to\n\n00:01:19.600 start\n\n00:01:20.240 is improving their understanding of\n\n00:01:22.080 functions studies in the united states\n\n00:01:25.200 indicate that students possess weak\n\n00:01:27.280 understanding of functions\n\n00:01:29.280 over the last several decades\n\n00:01:32.960 mathematics instruction in the u.s\n\n00:01:35.520 evolved to require\n\n00:01:37.040 multiple representation of function\n\n00:01:39.439 behavior\n\n00:01:40.320 including graphs and tables but now\n\n00:01:42.640 research indicates that mapping diagrams\n\n00:01:45.280 also provide a rich foundation for\n\n00:01:48.240 understanding functions\n\n00:01:50.799 the late dr james kapit proposed\n\n00:01:54.520 democratizing the comp concepts of\n\n00:01:57.280 calculus\n\n00:01:58.399 by providing technology-based learning\n\n00:02:01.280

environments he said new notation systems with new ways of acting upon those new notation systems offer dramatically new possibilities for mathematics learning sd is such a new and powerful notation system the audience recognizes these system dynamics modeling icons from which sd models can be constructed the stock and accumulator represents a main function in the model mathematically it operates as an integral does in calculus the flow is the rate of change of the stock so it is essentially the first derivative described in calculus converters hold constants parameters or simple or arithmetic combinations of model components the connector indicates the influence of one model component on another mathematically the connectors identify the dependencies of one variable on another i will not take you quickly through the two most basic functions studied in algebra connecting sd and traditional mathematics representation suppose we were interested in how water in a lake is increasing based on water flowing in at a constant rate using the sd structure the initial water in the lake would be placed in a stock icon and it would only have an inflow since it is only increasing with a constant value in the flow we know the behavior of the stock is growing linearly since the rate of change is constant and positive the sd software calculates the value of the stock using recursion which is shown in the table at the left we see that the flow value is added to the current value of the stock each time unit now we see the traditional closed form equation for the linear function where w represents the amount of water in the lake it starts at 100 units and grows at five units per year if we were to construct what we know is an exponential population growth behavior we could start with a stock of elephants and an inflow of new elephants born to this herd each year but this model is not correct we know the inflow cannot be constant because the number of new elephants born per year depends on knowing how many elephants are currently in the herd so we now indicate that dependency with a connector oh and now we have introduced a feedback loop the loop is reinforcing because the more elephants in the population the more new elephants are born per year adding more elephants to the herd but this model is still not complete we should indicate the number of new elephants born per elephant in the herd each year we do that by indicating a birth fraction in decimal form that will be multiplied by the number of elements in the herd each year so for exponential growth the inflow is proportional to the current amount of the stock or mathematically the rate

of change the flow is defined as the stock value times
some growth factor value this is exactly the differential
equation that represents exponential growth but algebra
students don't need to know that they are learning
calculus they are just learning a different behavior
pattern over time and how to create it based on its rate
of change definition again quickly we would have our stock
flow definition as shown with a 20 growth fraction the
elephant population will grow exponentially because the
inflow is proportional to the stock value if we think
about what the software is doing we look at the
recursion in the table the flow calculates the growth
amount and adds it to the stock each year there are two
equations that are possible mathematically the easier
equation is represented at the top and is the one often
taught in first year algebra it is often used when we want
to calculate values once every year or time
unit the second is shown at the bottom and is often used
in situations where calculating continuous change is a
better choice the top equation is probably the best choice for
this particular elephant herd example in sd modeling we
use the same diagram for each scenario and merely increase
the number of times the simulation calculates the values each
time unit to differentiate which situation is being used
for calculation as it is a much more intuitive process
in my opinion just so you know there is a free web-based version of
the sd modeling software that works on tablets computers
laptops chromebooks and smartphone that will allow you to
have your students build these models if they have access
to this technology go to publish.icsysystems.com the
software is called stella online once students learn linear
and exponential model structures they can start putting
them together to study new problems they could not study
with equations i have used these medication models in my
algebra classes over many years students really like them
consider an emergency room problem you the student are a medical
resident working in the emergency room and a patient comes
in who needs immediate medical attention from your analysis
you decide to connect this patient to an iv drip that will
supply one milligram of therapeutic drug per minute
this person you estimate will metabolize the
drug at about 0.55 percent per minute what is the pattern
of the drug level in the body over 24 hours so the diagram
might look like this with an inflow of medicine and an
outflow of body using and eliminating the medicine observe
the left side of the diagram since there is
a constant inflow the left part of the diagram is similar
to a linear model structure observe the right part of the
diagram the structure is similar to an 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 than the death fraction the model could produce exponential growth but the deer population cannot grow forever there are limiting factors that would influence the growth as the deer population increases there would be more competition for food and water deer could become more aggressive as they vie for the limited resource overcrowding can also lead to aggression and to the spread of disease as waste builds up in a limited area each of these factors would lead to a higher death rate for the deer assume that the environment can support only a specific number of deer the number of deer the environment can support in any given location is called the carrying capacity we assume that the comparison the carrying capacity value is unchanging as the population grows toward the carrying capacity the death fraction is being increased as we think it should the deer population graph looks reasonable with the carrying capacity component at the beginning there are few deer and the population is growing quite a bit as the population gets closer to the carrying capacity the growth slows down eventually moving to steady state this demonstrates transfer of feedback loop dominance now look at the typical closed form equation for the same scenario it seems to me that the stock flow model is easier to understand and interpret making this scenario approachable by students in mathematics classes lower than precalculus where the equation is usually studied i have used this model in my algebra classes successfully with students as young as 15. so now we get to the meat of this presentation what overarching value does sd modeling approach add to mathematics instruction a new representation for some core functions studied in algebra and precalculus provides not only a different representation that is more visual for the functions but bases the new representation on the rates of change for each function a very important concept in calculus the structure the blueprint for each function helps describe why the function behavior makes sense that is constant flows create linear stock behavior proportional flows create exponential stock behavior etc each system dynamics icon uses full words or phrases in their names making it easier to remember what each part of the model represents and it has been my experience with students that they have a much easier time translating word problems that describe dynamics to the sd model structure take for example the representation for an oscillating spring behavior the stock flow diagram captures the concepts of position restoring force mass acceleration velocity etc all central concepts in the dynamic of a bouncing spring 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 for pre-college students the experience that greatly enhanced my opinion about the virtues of using the system dynamics modeling approach with students occurred when i saw what students could produce when given the freedom to choose a dynamic problem that interested them for which they could create an original model write a technical paper explaining their model and present their model to an audience i wanted to prepare students to identify and analyze problems in the world from which they could gain an understanding by building system dynamics models i wanted them to develop skill in model building in analyzing model design in output and feedback and in explaining what they learned so i designed a secondary school system dynamics modeling course that i taught for 20 years one of the most important lessons included in my sd modeling course was to show students how to translate a systems problem found in a news article into a stock flow diagram students listed the most important variables they built the structure of their model by hand and they also sketched out the feedback students indicated that this was one of the most important lessons in preparing them to do their final project i'm going to magnify this bottom part so you can see it a little bit better i know it's blurry but it's because i just used the previous picture to magnify it but you can see the design of their model structure you can see their feedback loop they're doing behavior over time graphs all of this was part of the lesson for analyzing an article in the news i'm now going to show you some sample student original sd models in 2007 when the united states was experiencing an oil crisis this student observed that many people were trying unsuccessfully to buy hybrid cars this was his idea of why the problem happened it actually is broken into three segments there is the hybrid car segment at the top i'll go back hybrid car production hybrid inventory and active hybrid in vehicles there is a factory capacity which was a limiting factor on being able to produce enough cars and then there was a backlog of orders and perceived backlogged that prospective buyers weren't going to get a car very soon even if they ordered one his model did not start an equilibrium unfortunately so let's ignore the first part of the graph and focus on the spike in oil prices at week 30. the new demand which is the pink curve spikes upward for hybrid cars that is quickly followed by a spike in the backlog demand for hybrid cars which is the brown graph the price of hybrid cars which is the green curve shows an increase as backlog increases the blue line which is on a scale by itself is

```

\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": "e78dd7c6-4a18-
4121-8f0a-290fb0def232", "request_id": "888788dcad9aba9f-MXP", "timestamp_":
"absolute"}, "recipient": "all", "channel": null}, "parent": "e78dd7c6-4a18-4121-8f0a-
290fb0def232", "children": [{"67c6ff88-735e-42b9-b64f-01aa855d9e17"}], "67c6ff88-735e-
42b9-b64f-01aa855d9e17": {"id": "67c6ff88-735e-42b9-b64f-01aa855d9e17", "message":
{"id": "67c6ff88-735e-42b9-b64f-01aa855d9e17", "author": {"role": "tool", "name":
"myfiles_browser", "metadata": {}}, "create_time": 1716493422.955675, "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":
"f3db1laf-1a20-4abe-8a68-a69214255986", "request_id": "888788dcad9aba9f-MXP",
"timestamp_": "absolute"}, "recipient": "all", "channel": null}, "parent": "f3db1laf-
1a20-4abe-8a68-a69214255986", "children": [{"7e018ef2-0798-4fa6-8a6c-057fcbbc794d"}],
"7e018ef2-0798-4fa6-8a6c-057fcbbc794d": {"id": "7e018ef2-0798-4fa6-8a6c-057fcbbc794d",
"message": {"id": "7e018ef2-0798-4fa6-8a6c-057fcbbc794d", "author": {"role":
"assistant", "name": null, "metadata": {}}, "create_time": 1716493422.955835,
"update_time": null, "content": {"content_type": "text", "parts": ["When 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\u301051\u2020source\u3011.~}], "status": "finished_successfully", "end_turn":
true
, "weight": 1.0, "metadata": {"finish_details": {"type": "stop", "stop_tokens":
[100260]}, "citations": [{"start_ix": 1258, "end_ix": 1269, "citation_format_type":
"tether_og", "metadata": {"type": "file", "name": "tactiq-free-transcript-
QBrmAGcMIi8.txt", "id": "file-Sm7n1bk04weXq4ifGYZ3M6EA", "source": "my_files", "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 each of a therapeutic drug and tell them to continue taking two more pills every four hours this person you estimate will absorb the drug from the stomach in the bloodstream at about 4.5 percent per minute and metabolize the drug at about point 55 percent per minute what is the pattern of drug level in the body over 24 hours this model uses two stalks because the medicine must first accumulate in the stomach and then move into the bloodstream the inflow is a pulse because the pills are taken once every four hours students are asked to anticipate the pattern of behavior of the left part of the model drug in the stomach then students are asked to anticipate the pattern of drug in the blood over time this is not a trivial analysis then different patterns of pill delivery protocol are explored and compared to the optimal therapeutic level for this medication finally in this sequence of medication models students as a class are asked to help modify the pill model so that it will calculate the blood alcohol concentration of a human male sipping beer over two hours the modified stock flow diagram is sketched as a class then students access the pre-built model online and test the following scenarios using the model influence of body weight gender type of alcohol and type of drinker now let's turn to a different sequence of models the basic population model is ubiquitous in system dynamics studies problems in health economics environmental science biology geography sociology and mathematics and more often involve the study of population dynamics the basic population model involves a stock for population since that's the value that we want to track over time it is the function an outflow of births and an inflow of births and an outflow of deaths and their attendant births and deaths fraction the basic model contains two feedback loops that control change in population dynamics over time there are three types of graphs that this structure could produce based upon which feedback is dominant assume that the birth fraction is larger than the death fraction the model could produce exponential growth but the deer population cannot grow forever there are limiting factors that would influence the growth as the deer population increases there would be more competition for food and water deer could become more aggressive as they vie for the limited resource overcrowding can also lead to aggression and to the spread of disease as waste builds up in a limited area each of these factors would lead to a higher death rate for the deer assume that the environment can support only a specific number of deer the number of deer the environment

can support in any given location is called the carrying capacity we assume that the comparison the carrying capacity value is unchanging as the population grows toward the carrying capacity the death fraction is being increased as we think it should the deer population graph looks reasonable with the carrying capacity component at the beginning there are few deer and the population is growing quite a bit as the population gets closer to the carrying capacity the growth slows down eventually moving to steady state this demonstrates transfer of feedback loop dominance now look at the typical closed form equation for the same scenario it seems to me that the stock flow model is easier to understand and interpret making this scenario approachable by students in mathematics classes lower than precalculus where the equation is usually studied i have used this model in my algebra classes successfully with students as young as 15. so now we get to the meat of this presentation what overarching value does sd modeling approach add to mathematics instruction a new representation for some core functions studied in algebra and precalculus provides not only a different representation that is more visual for the functions but bases the new representation on the rates of change for each function a very important concept in calculus the structure the blueprint for each function helps describe why the function behavior makes sense that is constant flows create linear stock behavior proportional flows create exponential stock behavior etc each system dynamics icon uses full words or phrases in their names making it easier to remember what each part of the model represents and it has been my experience with students that they have a much easier time translating word problems that describe dynamics to the sd model structure take for example the representation for an oscillating spring behavior the stock flow diagram captures the concepts of position restoring force mass acceleration velocity etc all central concepts in the dynamic of a bouncing spring the closed form equation merely captures the appearance of the oscillation not the core structure that is causing the behavior to occur i believe that the stock flow structure is more educationally valuable than the closed form equation students and many adults are notoriously poor at reading and interpreting graphs sd modeling has one of its main analytical techniques to interpret the graphical output of the models multiple times as models are built modified and tested students get lots of practice reading and interpreting graphs moreover 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 stock 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", "extra":
{"cited_message_idx": 51, "search_result_idx": null, "evidence_text": "source"}, "url":
"file-Sm7n1bk04weXq4ifGYZ3M6EA"}]], "gizmo_id": null, "is_complete": true,
"message_type": null, "model_slug": "gpt-4", "default_model_slug": "gpt-4", "pad":
"AAAAAAAAAAAAAAAAAAAAAAAAAAAA", "parent_id": "67c6ff88-735e-42b9-b64f-01aa855d9e17",
"request_id": "888788dcad9aba9f-MXP", "timestamp_": "absolute", "content_references":
[{"matched_text": "\u301051\u2020source\u3011", "start_idx": 1258, "end_idx": 1269,
"alt": null, "type": "file", "name": "tactiq-free-transcript-QBrmAGcMIi8.txt", "id":
"file-Sm7n1bk04weXq4ifGYZ3M6EA", "source": "my_files", "snippet": "# 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\n00:00:00.040 i have been asked to present to on the\n00:00:00.839
system dynamics work\n00:00:00.200 i have done with secondary school\n00:00:00.880
students and teachers over three decades\n00:00:00.599 i have used system dynamics
modeling in\n00:00:00.920 my mathematics and modeling instruction\n00:00:00.600 for 30
years\n00:00:00.520 although science instruction is the most\n00:00:00.680 natural
discipline for sd modeling i\n00:00:00.080 would like to make\n00:00:00.199 an
argument that if we really want sd\n00:00:00.840 modeling to become\n00:00:00.960 a
more mainstream analytical tool it\n00:00:00.240 should be embedded in secondary
school\n00:00:00.640 mathematics\n00:00:00.840 sd modeling can reinforce
important\n00:00:00.120 mathematical concepts quite well dr\n00:00:00.320 barry m
specializes in the study of\n00:00:00.399 complex systems\n00:00:00.760 to be able to
analyze complex systems\n00:00:00.879 he claims that calculus and
statistics\n00:00:00.120 do not have the tools to describe\n00:00:00.680 what we want
to study that we need\n00:00:00.360 to work with new concepts that we
need\n00:00:00.960 to\n00:00:00.359 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 described in calculus converters hold constants
 parameters or simple or arithmetic combinations of
 model components the connector indicates the influence
 of one model component on another mathematically the connectors identify the dependencies of
 one variable on another i will not take you quickly through the two most basic functions studied in
 algebra connecting sd and traditional mathematics representation suppose we were interested in
 how water in a lake is increasing based on water flowing
 in at a constant rate using the sd structure the
 initial water in the lake would be placed in a stock
 icon and it would only have an inflow since it is only
 increasing with a constant value in the flow we know the
 behavior of the stock is growing linearly since the rate
 of change is constant and positive the sd software calculates the value of the stock using recursion which is
 shown in the table at the left we see that the flow value
 is added to the current value of the stock each time unit
 now we see the traditional closed form equation for the linear function where w represents the amount of water in
 the lake it starts at 100 units and grows at
 five units per year if we were to construct what we know
 is an exponential population growth behavior we could start with a stock of elephants and an inflow of new
 elephants born to this herd each year but this model is
 not correct we know the inflow cannot be constant because
 the number of new elephants born per year depends on knowing how
 many elephants are currently in the herd so we now
 indicate that dependency with a connector oh and now we
 have introduced a feedback loop the loop is reinforcing
 because the more elephants in the population the more new
 elephants are born per year adding more elephants to the
 herd but this model is still not complete we should
 indicate the number of new elephants born
 per elephant in the herd each year we do that by
 indicating a birth fraction in decimal form that will be
 multiplied by the number of elements in the herd each year
 so for exponential growth the inflow is proportional to
 the current amount of the stock or mathematically the rate
 of change the flow is defined as the stock value times
 some growth factor value this is exactly the differential
 equation that represents exponential growth but algebra
 students don't need to know that they are learning
 calculus they are just learning a different behavior
 pattern over time and how to create it based on its rate
 of change definition again quickly we would have our stock
 flow definition as shown with a 20 growth fraction the
 elephant population will grow 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 room a third patient arrives and you decide to give this patient two pills of 375 milligrams each of a therapeutic drug and tell them to continue taking two more pills every four hours this person you estimate will absorb the drug from the stomach in the bloodstream at about 4.5 percent per minute and metabolize the drug at about point 55 percent per minute what is the pattern of drug level in the body over 24 hours this model uses two stalks because the medicine must first accumulate in the stomach and then move into the bloodstream the inflow is a pulse because the pills are taken once every four hours students are asked to anticipate the pattern of behavior of the left part of the model drug in the stomach then students are asked to anticipate the pattern of drug in the blood over time this is not a trivial analysis then different patterns of pill delivery protocol are explored and compared to the optimal therapeutic level for this medication finally in this sequence of medication models students as a class are asked to help modify the pill model so that it will calculate the blood alcohol concentration of a human male sipping beer over two hours the modified stock flow diagram is sketched as a class then students access the pre-built model online and test the following scenarios using the model influence of body weight gender type of alcohol and type of drinker now let's turn to a different sequence of models the basic population model is ubiquitous in system dynamics studies problems in health economics environmental science biology geography sociology and mathematics and more often involve the study of population dynamics the basic population model involves a stock for population since that's the value that we want to track over time it is the function an outflow of births and an inflow of births and an outflow of deaths and their attendant births and deaths fraction the basic model contains two feedback loops that control change in population dynamics over time there are three types of graphs that this structure could produce based upon which feedback is dominant assume that the birth fraction is larger than the death fraction the model could produce exponential growth but the deer population cannot grow forever there are limiting factors that would influence the growth as the deer population increases there would be more competition for food and water deer could become more aggressive as they vie for the limited resource overcrowding can also lead to aggression and to the spread of disease as waste builds up in a limited area each of these factors would lead to a higher death rate for the

deer\00:12:48.320 assume that the environment can support\00:12:51.360 only a specific number of deer the\00:12:54.399 number of deer the environment can\00:12:56.639 support in any given location is called\00:13:00.079 the carrying capacity we assume that the\00:13:03.200 comparison\00:13:03.920 comparison the carrying capacity value\00:13:07.279 is unchanging\00:13:09.040 as the population grows toward the\00:13:12.480 carrying capacity\00:13:14.320 the death fraction is being increased\00:13:18.079 as we think it should the deer\00:13:21.120 population graph looks reasonable with\00:13:23.360 the carrying capacity component\00:13:25.440 at the beginning there are few deer\00:13:28.480 and the population is growing quite a\00:13:30.560 bit as the population gets closer to the\00:13:33.200 carrying capacity the growth slows down\00:13:35.760 eventually\00:13:36.639 moving to steady state this demonstrates\00:13:40.800 transfer of feedback loop dominance\00:13:44.240 now look at the typical closed form\00:13:46.399 equation for the same scenario\00:13:48.800 it seems to me that the stock flow model\00:13:51.519 is easier to understand and\00:13:53.279 interpret making this scenario\00:13:55.440 approachable by students in mathematics\00:13:57.839 classes\00:13:58.399 lower than precalculus where the\00:14:00.639 equation is usually studied\00:14:02.800 i have used this model in my algebra\00:14:05.040 classes successfully\00:14:06.560 with students as young as 15.\00:14:10.480 so now we get to the meat of this\00:14:12.880 presentation\00:14:14.399 what overarching value does sd modeling\00:14:17.760 approach\00:14:18.399 add to mathematics instruction a new\00:14:21.279 representation for some core functions\00:14:23.839 studied in algebra and precalculus\00:14:26.480 provides not only a different\00:14:27.920 representation that is more visual\00:14:30.480 for the functions but bases the new\00:14:32.800 representation\00:14:34.160 on the rates of change for each function\00:14:37.199 a very important concept in calculus\00:14:40.399 the structure the blueprint for each\00:14:42.800 function helps describe\00:14:44.480 why the function behavior makes sense\00:14:47.360 that is\00:14:48.240 constant flows create linear stock\00:14:51.199 behavior\00:14:52.399 proportional flows create\00:14:54.800 exponential stock behavior\00:14:56.639 etc each system dynamics icon\00:15:00.079 uses full words or phrases in their\00:15:03.040 names\00:15:03.519 making it easier to remember what each\00:15:05.920 part of the model represents\00:15:08.000 and it has been my experience with\00:15:10.320 students\00:15:11.120 that they have a much easier time\00:15:13.440 translating word problems that describe\00:15:15.920 dynamics to the sd model structure\00:15:20.160 take for example the representation for\00:15:22.399 an oscillating spring behavior\00:15:24.639 the stock flow diagram captures the\00:15:27.360 concepts of position\00:15:28.959 restoring force mass acceleration\00:15:31.360 velocity etc\00:15:33.040 all central concepts in the dynamic of a\00:15:35.680 bouncing spring\00:15:37.199 the closed form equation merely\00:15:40.720 captures the appearance of the\00:15:42.800 oscillation\00:15:44.320 not the core structure that is causing\00:15:46.800 the behavior to occur\00:15:48.800 i believe that the stock flow structure\00:15:50.880 is more educationally\00:15:52.560 valuable than the closed form equation\00:15:56.320 students and many adults are notoriously\00:15:59.199 poor\00:15:59.680 at reading and interpreting graphs sd\00:16:02.800 modeling\00:16:03.600 has one of its main analytical\00:16:06.160 techniques\00:16:07.199 to interpret the graphical output of the\00:16:09.600 models\00:16:10.560 multiple times as models are built\00:16:13.279

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 they could gain an understanding by building system dynamics models i wanted them to develop skill in model building in analyzing model design in output and feedback and in explaining what they learned so i designed a secondary school system dynamics modeling course that i taught for 20 years one of the most important lessons i included in my sd modeling course was to show students how to translate a systems problem found in a news article into a stock flow diagram students listed the most important variables they built the structure of their model by hand and they also sketched out the feedback students indicated that this was one of the most important lessons in preparing them to do their final project i'm going to magnify this bottom part so you can see it a little bit better i know it's blurry but it's because i just used the previous picture to magnify it but you can see the design of their model structure you can see their feedback loop they're doing behavior over time graphs all of this was part of the lesson for analyzing an article in the news i'm now going to show you some sample student original sd models in 2007 when the united states was experiencing an oil crisis this student observed that many people were trying unsuccessfully to buy hybrid cars this was his idea of why the problem happened it actually is broken into three segments there is the hybrid car segment at the top i'll go back hybrid car production hybrid inventory and active hybrid in vehicles there is a factory capacity which was a limiting factor on being able to produce enough cars and then there was a backlog of orders and perceived backlogged that prospective buyers weren't going to get a car very soon even if they ordered one his model did not start an equilibrium unfortunately so let's ignore the first part of the graph and focus on the spike in oil prices at week 30. the new demand which is the pink curve spikes upward for hybrid cars that is quickly followed by a spike in the backlog demand for hybrid cars which is the brown graph the price of hybrid cars which is the green curve shows an increase as backlog increases the blue line which is on a scale by itself is the number of active hybrid cars and that is steadily increasing the first year i introduced material and information delays to my students many students understood the ideas immediately this student started his model on workforce pressure using the idea of three delays so here we have employees who are being hired and fired this is the amount of work that the company wants done this is the perceived satisfaction of the current working people and up here is the pay that is given 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", "cloud_doc_url": null}}], "recipient": "all", "channel": null}, {"parent": "67c6ff88-735e-42b9-b64f-01aa855d9e17", "children": [{"aaa210c0-9c97-48b4-93dd-a33d6e7900e7"}]}, {"aaa210c0-9c97-48b4-93dd-a33d6e7900e7": {"id": "aaa210c0-9c97-48b4-93dd-a33d6e7900e7", "message": {"id": "aaa210c0-9c97-48b4-93dd-a33d6e7900e7", "author": {"role": "user", "name": null, "metadata": {}}, "create_time": 1716493655.608258, "update_time": null, "content": {"content_type": "text", "parts": ["To effectively assess the dynamics of flow-limited resources within a system, it's essential to incorporate several key indicators into a systems dynamics model. These indicators include stocks, flows, converters/constants, and information flows, each playing a crucial role in understanding and predicting system behaviors.\n\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 the resource levels and serve as a baseline for measuring changes over time.\n\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.\n\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.\n\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.\n\nAre the assertions here directly supported by the info in the attachment?"]}}, {"status": "finished_successfully", "end_turn": null, "weight": 1.0, "metadata": {"attachments": [{"id": "file-MOPCKNpTusz4oeTcXy2EOFv9", "size": 356629, "name": "v7-Rueter-chap6.pdf", "mime_type": "application/pdf"}]}, "request_id": "88878f015a940e6f-MXP", "message_source": null, "timestamp": "absolute", "message_type": null}, {"recipient": "all", "channel": null}, {"parent": "7e018ef2-0798-4fa6-8a6c-057fcbbbc794d", "children": [{"7586dd5b-9166-4018-8396-f4b831cfff8d"}]}, {"7586dd5b-9166-4018-8396-f4b831cfff8d": {"id": "7586dd5b-9166-4018-8396-f4b831cfff8d", "message": {"id": "7586dd5b-9166-4018-8396-f4b831cfff8d", "author": {"role": "tool", "name": "myfiles_browser", "metadata": {}}, "create_time": 1716493678.426442, "update_time": null, "content": {"content_type": "tether_quote", "url": "file-MOPCKNpTusz4oeTcXy2EOFv9", "domain": "v7-Rueter-chap6.pdf", "text": "\n130 August 13, 2013 \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 following 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 large or as small as you want \nto set the boundaries around. Although some people use the term "systems approach" to be holistic and inclusive, our use of the \nword "systems view" specifies a set of intellectual tools that

can be applied to any size set of processes and resources. This text presents one specific definition of how to characterize an environmental problem as a system of stocks and flows. We will be using a limited list of characteristics of a system that can be used to describe many different structures and behaviors. Our unconstrained set of categories will help highlight the structural similarities and differences between different systems. This "systems" approach is useful for simplifying problems, looking for significant processes and identifying controls. The approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. Another of the benefits of this approach is that it clearly identifies the assumptions on which simulations are based. A good "systems" model is both a valuable research tool and a platform for communication and decision-making. Thus, carefully gathering information to construct a stock and flow description of an environmental problem is a good example of methodically collecting information that takes place in scientific research (Pielke 2007).

Draft v7 131

6.2 Model Components

There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, convertors/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1). Figure 6-1. A simple systems diagram for the increase in a population of rabbits illustrates the five objects that we will use. Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is 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 number of rabbits in the population. We represent this in a systems diagram with a box icon. A source or sink is either has an unlimited, unchanging concentration or a reservoir that is outside the boundaries of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month. When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle. Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

Draft

v7 133

These five components can be combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month. The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species. We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial

characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

August 13, 2013

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation – One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

a. b. Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

Draft v7 139

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different

forms of materials or energy. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points. The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations. Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country. The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has led to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has led 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\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\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\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 \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\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\n6.6 Overlaps and conflicts with other tools \n\nTerm in "Systems"; \n\nother viewer/term \n\nsimilarities and differences \n\nboundary scale/extent Everything outside the boundary of the system is neither neglected or is an unlimited source or sink. \n\nIn the Scale viewer, extent relates to the size of the largest dimension \n\nconsidered, the word doesn't imply any process nor specific border. \n\nstock network/node A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links. \n\nDraft v7 145 \n\nflow network/link A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at neither end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity. \n\nstability network/stability, resilience and resistance \n\nSystems models can reach steady state that has some stability due to some form of negative feedback that keeps it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

August 13, 2013 \n\n6.7 Extending analysis to the next levels \n\nAn important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the appendices for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations only the parameter values can be changed, not the structure of the model itself. But these simulations are very useful for illustrating the types of predictions and uses for simulations. Simulations of this type are extremely useful in modern decision-making. For example, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

Draft v7 147 \n\n6.8 Developing a simplified Systems model of sustainable resource use \n\nMany people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has

to be stable or whether substitutions can be made. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took. Figure 6-10. The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered. If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.

August 13, 2013 Figure 6-11. In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource. When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading the environment that the fish or trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.

Draft v7 149 Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth. Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash). Figure 6-13. Conditions might also vary with time, such as a year of drought or unhealthy water.

August 13, 2013 Figure 6-14. The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital. Figure 6-14. With just one bad year, holding to the previous maximum sustainable yield will eventually cause the collapse of this resource. Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital: a. simple overharvest, but this may be because you didn't have good estimates for the maximum yield b. indirect effects from either harvest methods or use c. risk of being too close to the maximum yield, one bad year and the resource declines dramatically

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151 Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact,

you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific. At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment. You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in sustainable systems, it is important to attempt an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence. In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach. References to studies of the fate of Easter Island A more complete story can be found at the following sources: Wikipedia: http://en.wikipedia.org/wiki/Easter_Island Discover Magazine: Jared Diamond. Easter's end. Discover magazine, August 1995. 16(8): 62-69. TED talks such as: http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html http://blog.ted.com/2008/10/27/why_do_societies_collapse/ Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking. Salient features The story of Easter Island has particular features that make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in Figure 12 and 13; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly. Applying the systems tool We are going to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats. Draft v7 153 The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below. Figure 6-15. Human population sub-model showing positive feedback

for births but a constant death rate. The number of trees is also a balance between the number of palm nuts that germinate and grow, and the cutting down of the trees. Figure 6-16. Palm tree sub-model also have positive feedback for growth and constant loss. The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the 154 August 13, 2013. Others, there is positive feedback for rat births and several factors controlling death. Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births because this is a source of food for people. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.
3. People have a positive effect on the harvesting of trees. More people cut down more trees because they need them for fishing and to cultivate land for crops.
4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.
5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks.

Draft v7 155 Figure 6-17. The rat submodel interacts with both humans and trees. According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees the rats not only couldn't fish effectively but the other food source, rats, declined.

The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population 156 August 13, 2013 could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system.

Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the

more complex interactions and consequences of our \n\nactions. \n\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 \nthethe 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 \nthethe resource. Positive feedback works to replenish the stock, but \nththis 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 \nthethe 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": "aaa210c0-9c97-48b4-93dd-a33d6e7900e7", "request_id": "88878f015a940e6f-MXP", "timestamp_": "absolute"}, {"recipient": "all", "channel": null}, {"parent": "aaa210c0-9c97-48b4-93dd-a33d6e7900e7", "children": ["5191b4a9-6bad-4624-bf30-64051e16b602"]}], [{"id": "5191b4a9-6bad-4624-bf30-64051e16b602", "message": {"id": "5191b4a9-6bad-4624-bf30-64051e16b602", "author": {"role": "assistant", "name": null, "metadata": {}}, "create_time": 1716493678.426769, "update_time": null, "content": {"content_type": "text", "parts": ["Yes, the assertions in your description about the components of a systems dynamics model\u2014stocks, flows, converters/constants, and information flows\u2014are directly supported by the information in the attached document, "Chapter 6 \u2013 Stock and Flow Systems" from the "v7-Rueter-chap6.pdf" document.\n\n**Stocks** are indeed described as quantities of resources available within the system, akin to your example of water in a reservoir or a population count in an ecological study. They are foundational for monitoring resource levels and are represented as boxes in systems diagrams\u2014source\u2014Flows** are characterized exactly as you described, as the movement of resources between stocks or from external sources into the system, and they are crucial for assessing how resources are utilized and replenished. The document specifies that flows should be measured in consistent units related to the stocks they connect, such as liters of water per hour or tons of carbon per year\u2014Converters/constants** are explained as parameters that affect flows or stocks and remain unchanged regardless of system dynamics, which aligns with your description. These are typically shown as circles in the diagrams and include elements like growth rate constants\u2014Information flows** represent non-material connections influencing system components by altering flows or converters based on the

"}]}]

A state of stocks or other variables. The document details that information flows cannot directly influence stocks because stocks do not process information directly.

Overall, your description closely matches the detailed explanations provided in the document regarding how these elements function within a systems dynamics model, emphasizing their importance in understanding and predicting system behaviors.

"status": "finished_successfully", "end_turn": true, "weight": 1.0, "metadata": {"finish_details": {"type": "stop", "stop_tokens": [100260]}, "citations": [{"start_ix": 577, "end_ix": 588, "citation_format_type": "tether_og", "metadata": {"type": "file", "name": "v7-Rueter-chap6.pdf", "id": "file-MOPCKNpTusz4oeTcXy2EOFv9"}, "source": "my_files", "text": "\n\nChapter 6 \n\n6.1 Introduction\n\nEcological, geochemical and human processes can be described by following the flows of material or energy from one place or form\n\ninto another. A "system" is any set of connected processes and\nquantities of resources. It can be as large or as small as you want\n\ninto 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\n\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\n\nbe using a limited list of characteristics of a system that can be\n\nused to describe many different structures and behaviors. Our\n\nconstrained set of categories will help highlight the structural\nsimilarities and differences between different systems.\n\nThis "systems" approach is useful for simplifying problems,\n\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.\n\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).

rather than a source/sink. A source/sink is represented as a little cloud in our diagrams. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month. When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle. Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month. The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species. We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then

how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback – A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

August 13, 2013

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation – One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees take to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model "a" there is no limiting stock, in model "b" when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a

large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

6.4 Simple and busy models

We have shown several "simple" models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in an ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points.

The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations.

Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country.

The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has led to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any

time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" converter. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has led to what is called the classical demographic transition. We will revisit the systems description of demographic transitions when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere.

Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The "busy" model diagram below shows how several simple models are linked.

August 13, 2013

Figure 6-9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the "greenhouse effect". The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models,

analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from converters to flows.

August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems";
 another viewer/term similarities and differences
 boundary scale/extent
 Everything outside the boundary of the system is neither neglected or is an unlimited source or sink.
 In the Scale viewer, extent relates to the size of the largest dimension considered, the word doesn't imply any process nor specific border.

stock network/node A stock must be something measurable that can be moved through a flow. In the network view, a node can be a quality that changes depending on input links.

Draft v7

flow network/link A flow must be the movement of material or energy per unit time and whatever is flowing has to be the same as the stock at neither end. A link identifies a relationship between nodes. It can be a quantity of material moved but it doesn't have to be a quantity.

stability network/stability, resilience and resistance

Systems models can reach steady state that has some stability due to some form of negative feedback that keeps it at a level or in some range. The type of systems model that we are using doesn't have a mechanism to change its own structure. A network diagram that has many weak interactions can shift the operational structure and show how a large number of weak interactions or the combination of fast and slow processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the next levels

An important extension of the use of systems models is to create simulations that demonstrate overall system behavior given certain input conditions and constants. We will look at the components of the system, such as positive or negative feedback to look for very general system behavior. There are software applications that are useful for turning these systems diagrams into mathematical dynamic models (the diagrams and charts in this page were generated with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the appendices for this book to see simulations that were written in STELLA and simulations made available on the web (through Forio.com). In these simulations only the parameter values can be changed, not the structure of the model itself. But these simulations are very useful for illustrating the types of predictions and

uses for simulations. Simulations of this type are extremely useful in modern decision-making. For example, the Northwest Power Council created a complicated and very busy model that contained information on fish, dams, river flows and electricity. This model could be run under different conditions and demands for energy to show which parameters affect fish survival most. They were able to show the model to people who work in this arena of fish and rivers to see if the model behaves in a way they think it should; does it show low fish years when expected or high fish years following particular events? The simulation model and the accessible interface were powerful tools in addressing problems and getting people to learn about complicated social, economic and ecological issues.

6.8 Developing a simplified Systems model of sustainable resource use

Many people subscribe to the idea that a sustainable resource is one in which you reach a steady state because you don't use the resource faster than it is being created. Whether or not this is required for all resources to attain a sustainable society is a very interesting question. It maybe that you can have some resources decrease and be replaced by other resources. There are different definitions of overall sustainability that address whether the entire ensemble of capital types has to be stable or whether substitutions can be made. We will focus here on the sustainable use of a single resource. For example, you would harvest the wood at the same rate as new trees were growing to replace what you took.

Figure 6-10. The starting assumptions for a model of sustainable natural resources are that input comes from growth and output goes to harvest. There are no other inputs or fates being considered.

If this resource is based in natural (biological) capital the growth rate will often depend on the amount of the stock. For example healthy fish populations grow faster with more fish and trees will grow better in a healthy forest with lots of other trees to provide protection and a suitable micro-climate. Although it isn't always the case, let's model the natural resource as having a positive relationship to the growth of new resource.

August 13, 2013

Figure 6-11. In a simple sustainable harvest model, the natural resource has a positive feedback on the growth of that resource. This holds within the region of healthy, and not over-abundant resource.

When we harvest the resource, we might just be removing the fish or trees, but we can also be degrading the environment that the fish or trees need to grow. For example, driving bulldozers around on the soil and channelizing streams in steep watersheds has a negative effect on forest health. Similarly, some fishing methods disrupt the breeding areas for fish. Thus the harvest has a direct take of the resource but it can also degrade the conditions leading to a decrease in the growth rate. Notice in this case that a negative effect on conditions is passed through to impact growth because there is a positive relationship between conditions and growth: worse conditions lead to lower growth.

Figure 6-12. The mechanisms of harvest can have a negative effect on the conditions for growth. Overharvest can damage the microenvironment necessary for optimal growth.

Another important issue with natural resource management is the impact of bad (or good) luck. What if you were managing a forest that had an average growth rate but there was a single drought year that decreased the input to the resource by 50% just for that year? If you had a harvest plan that was even just 5% more than the actual maximum yield you could harvest, it would lead to a decrease in the population that would never recover (assuming you don't stop harvesting after you see the population start to crash).

Figure 6-13. Conditions might also vary with time, such as

a year of drought or unhealthy water.

150 August 13, 2013

The effect of one bad year (only 50% output) and an underestimate of true maximum yield by only 5%. In 100 years you're down to less than 1/3 of your starting natural capital.

Figure 6-14. With just one bad year, holding to the previous maximum sustainable yield will eventually cause the collapse of this resource.

Using this simple model of natural capital and sustainability illustrates that there are at least three ways to destroy the sustainability of your natural capital:

- simple overharvest, but this may be because you didn't have good estimates for the maximum yield.
- indirect effects from either harvest methods or use.
- risk of being too close to the maximum yield, one bad year and the resource declines dramatically.

6.9 Case Study: Population and Environment of Easter Island, Rapa Nui

Draft v7 151

Easter Island (also known as Rapa Nui) is a small island in the middle of a very large ocean. The area of the island is only 166 km² (64 mi²) and it is 2250 km from the nearest other island (Pitcairn Island) and over 3700 km from South America, the nearest continent. You have undoubtedly heard something about this fascinating island related to speculations on what caused the population to crash. In fact, you've probably heard more about this island because of this failure to be sustainable than you've heard about any of the myriad of other islands in the South Pacific.

At one time in the history of this island, the society had fairly sophisticated culture and technology. The cultural history describes a well-developed hierarchy with laws and written script. The evidence of the technology was their ability to move the large stone statues, which the island is most known for, for long distances. They moved carved stone sculptures that weighed up to 82 tons as far as six miles (10 km). The islanders cultivated a large part of the island with multiple crops. Estimates of the maximum population on the island ranged from 7,000 to as high as 20,000. And yet the population and civilization must have crashed. When European boats first recorded their interaction with the island (in the 1700s) the population was only several thousand, and these people were leading a tough life in an impoverished and desolate environment.

You can see from just the outlines of this story why the island's history has always been so intriguing. Now with our interest in unsustainable systems, it is important to attempt an understanding. There are parallels between their tiny island and our planet. Once the environment started to decay and subsequent crash of population and society, these islanders had no place to go. Sustainability isn't just about maintaining a mere subsistence life style, it's also about continuing to develop the culture and have a healthy physical existence.

In this case study, we are going to examine the population, agriculture and land use practices that were employed on Easter Island from about 400 AD to about 1700 AD. We are going to

152 August 13, 2013

analyze the very gradual depletion of the natural capital on Easter Island using a "systems" approach.

References to studies of the fate of Easter Island

A more complete story can be found at the following sources:

2022 Wikipedia: http://en.wikipedia.org/wiki/Easter_Island

2022 Discover Magazine: Jared Diamond. Easter's end. Discover magazine, August 1995. 16(8): 62-69.

2022 TED talks such as:

http://www.ted.com/talks/lang/eng/jared_diamond_on_why_societies_collapse.html

2022 http://blog.ted.com/2008/10/27/why_do_societies_collapse/

2022 Diamond, J. (2005). Collapse: How societies choose to fail or succeed. New York, Viking.

Salient features

The story of Easter Island has particular features that

make it amenable to examination with a systems approach. First, it is very similar to the systems model for sustainability that we developed in Figure 12 and 13; there are suggestions of growth, harvest, and bad luck. Second, at any time the processes seem to be close to being in balance; it is only by looking at the long term effect of these do we see the impact of a slight over harvest or a previous year of bad luck. Third, the description contains some simple models that could be tied together to get an integrated picture; there is population growth, harvest of trees, soil moisture, agriculture and fishing. These processes are related, but not directly.

Applying the systems tool

We are going to put separate small models together and to examine how these individual processes counter or reinforce each other. This is an oversimplified model in which will only consider three stocks: the number of people, palm trees, and rats.

Draft v7 153

The number of people is the balance between birth and death rates. As there are more people, there will be more births, i.e. the population growth has a positive feedback component. The number of deaths may depend on many other factors including natural causes, famine, and disease. A simple model diagram for this is given below.

Figure 6-15. Human population sub-model showing positive feedback for births but a constant death rate.

The number of trees is also a balance between the number of palm nuts that germinate and grow, and the cutting down of the trees.

Figure 6-16. Palm tree sub-model also have positive feedback for growth and constant loss.

The third strand in our model will be the rat population. People brought rodents to the island. These rats play a key role in this problem. People eat the rats and the rats eat the palm fruit, decreasing the tree population. Their population is just like the

154 August 13, 2013

Others, there is positive feedback for rat births and several factors controlling death.

Now we are going to connect these three stocks and flows models with factors that affect either the birth or death rates. The following list details these interactions.

1. Rats have a positive effect on people births because this is a source of food for people. The birth rate of people will increase with more rats (and the birth rate will decrease if rats are low).
2. Rats have a negative effect on human death. The death rate of people will increase if rats are too low.
3. People have a positive effect on the harvesting of trees. More people cut down more trees because they need them for fishing and to cultivate land for crops.
4. Rats have a negative effect on the rate of palm fruit germination. The number of rats decreases the percentage of new palm seeds that germinate successfully because the rats chew on the seeds.
5. Palm trees have a positive effect on rat births, because the rats eat the palm fruit.

We could add more detail to this model, but even with only these five interactions this turns out to be a very interesting and instructive model. Looking at the model diagram, below, you can see that there are many positive feedbacks and only a few negative feedbacks.

Draft v7 155

Figure 6-17. The rat submodel interacts with both humans and trees.

According to the historical record, as the human population grew, people cut more and more trees. They needed these trees for making boats for fishing and they needed more and more land for cultivation. Over harvesting trees, just on its own would have been a problem for them, but this was exacerbated by the fact that they also ate rats, and rats depended on the trees for food. As the human population continued to grow, they cut enough trees such that they ran out of trees to use for fishing. Simultaneously, with fewer trees they not only couldn't fish effectively but the other food source, rats, declined.

The model built here only represents a few of the interactions that have been described. By putting these into a systems diagram, we can explore the possible behaviors of the individual populations and their effect on each other. It is possible that the population could have also reached a balance. There is nothing inherent in the structure of these relationships that makes it crash. However, the balance comes about because all of the relatively rapid rates of all the processes are cancelling each other out, but a minor imbalance in the rates can lead to abrupt changes in the whole system. Some narratives of Easter Island decline blame the population for their resource use strategies. For example in the book *Collapse* (2005), Jared Diamond wonders what the person who cut down the last palm tree was thinking. Even this simple model shows that there were multiple factors in play and the path toward a downward spiral of trees could have been set in motion when there were still many trees. This should be a cautionary tale for working with real and complex systems, i.e. the controls may have delays and multiple factors that make them very difficult for a person in the ecosystem and society to observe. It's not just a matter of taking the right action for the moment, but also being able to understand the more complex interactions and consequences of our actions.

6.10 Summary

Methodically constructing a stock and flow model to represent the processes related to an environmental problem supports good practice for scientific information gathering. The constraints on the quantities that are being measured and followed forces the clarification of assumptions. The structure of the model can be visualized with iconography that illuminates the relationship to particular functions of the overall system such as feedbacks, stock limitation and possible steady state conditions. The basic assumptions for using a natural resource sustainably can be explored using this approach. The goal of sustainable use would be to have the input match the output and maintain a steady state for the resource. Positive feedback works to replenish the stock, but this is a double-edged sword, just one bad year can lead to an eventual collapse unless the harvest is decreased.

Draft v7 157

Analysis of these models involves taking apart each stock and flow and explaining how that part contributes to the overall behavior of the system. This is a very useful exercise for construction of the model and for communication about the important features of a problem. As models become busier they often require sub-models for different stocks. The example of Easter Island demonstrated hypothetical relationships between the stocks of palm trees, people and rats. At high human populations, this system was not resilient to changes and might explain the decline of the resource base.

“extra”:
 {“cited_message_idx”: 56, “search_result_idx”: null, “evidence_text”: “source”}, “url”: “file-MOPCKNpTusz4oeTcXy2EOFv9”}}, {“start_ix”: 980, “end_ix”: 991, “citation_format_type”: “tether_og”, “metadata”: {“type”: “file”, “name”: “v7-Rueter-chap6.pdf”, “id”: “file-MOPCKNpTusz4oeTcXy2EOFv9”, “source”: “my_files”, “text”: “130 August 13, 2013 Chapter 6 2013 Stock and Flow Systems 6.1 Introduction Ecological, geochemical and human processes can be described by following the flows of material or energy from one place or form to another. A “system” is any set of connected processes and quantities of resources. It can be as large or as small as you want to set the boundaries around. Although some people use the term “systems approach” to be holistic and inclusive, our use of the “systems view” specifies a set of intellectual tools that can be applied to any size set of processes and resources. This text presents

one specific definition of how to characterize an environmental problem as a system of stocks and flows. We will be using a limited list of characteristics of a system that can be used to describe many different structures and behaviors. Our unconstrained set of categories will help highlight the structural similarities and differences between different systems. This "systems" approach is useful for simplifying problems, looking for significant processes and identifying controls. The approach can also be used to create simulations of future conditions and to communicate these to other people who are making decisions. Another of the benefits of this approach is that it clearly identifies the assumptions on which simulations are based. A good "systems" model is both a valuable research tool and a platform for communication and decision-making. Thus, carefully gathering information to construct a stock and flow description of an environmental problem is a good example of methodically collecting information that takes place in scientific research (Pielke 2007).

6.2 Model Components

There are five components that we will use to represent the structure and behavior of our chosen system: stocks, flows, information flows, converters/constants and a source/sink. An icon represents each component. For example, look at the growth of a population of rabbits (see Figure 1).

Figure 6-1. A simple systems diagram for the increase in a population of rabbits

illustrates the five objects that we will use. Stocks are a quantity of something. Water in a tank is a good example of a stock. Sometimes stocks are called reservoirs. All the stocks that are connected with flows will have the same units, that is 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 number of rabbits in the population. We represent this in a systems diagram with a box icon. A source or sink is either has an unlimited, unchanging concentration or a reservoir that is outside the boundaries of the system that we are studying. In our example, the source of new matter that supports rabbit growth is not being considered. You can imagine another model where the amount of food available to the rabbit population limited the amount of new rabbits being born. In this case, we would probably model the system to include the nutrients as a stock rather than a source/sink. A source/sink is represented as a little cloud in our diagrams. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time. For example this could be liters of water per hour, tons of carbon per year, or in our example, rabbits per month. When we have information that is needed in the model as a constant or we need to make a calculation, we show that as a "converter/constant". In our example, the growth rate constant for the rabbits was given as a constant. In the diagram, this is circle. Information connectors illustrate the flow of information, not material, from other components to either flows or converters. Information cannot flow to a stock because the stocks can't do anything with that information. In the simplest form, an information flow simply notifies an action of the concentration of a stock, the rate of flow, or the value in a converter/constant. In our example, information flows brought in the values of the growth rate constant and the number of rabbits to the "birth of new rabbits" flow. The flow is calculated as the growth rate constant times the number of rabbits. The icon for this is a single line arrow.

These five components can be combined in flexible ways to describe

the structure of different systems. An important value of this approach is that the structure of the model indicates particular types of behavior and the iconography helps visualize these structures. In our example of rabbit growth with unlimited resources (indicated by the source/sink tool), the population would grow exponentially. As there are more rabbits, the number of new rabbits per time period will get bigger, leading to an even higher population of rabbits, and so on. A mathematical model of this population growth would give the following pattern of growth shown in Figure 6-2 as population vs. time. (Of course the population can't continue to grow like this forever.)

Figure 6-2. Rabbit population growth predicted from the model in Figure 1. The initial rabbit stock was set to 10 and the growth rate constant was set to 0.1 per month.

The structure and relationships in this particular model demonstrates positive-feedback. As the stock increases, that increase positively affects that flow that is leading to that stock. Many biological systems have this structure and function as part of their overall regulation. Sometimes this is good, such as in the growth of food crops and forests, the more crops or forests the faster they grow. Sometimes this is a bad feature for humans such as the spread of a disease (the more infected people, the faster the disease will spread) or the growth of invasive species.

We will examine several "simple" structures that are very common. These simple structures can be combined in larger models to describe very complex and busy processes. For example, if we were to create a model for global warming it would have positive and negative feedback components, open and closed systems and steady state structures included making up the full model. These "simple" structures that we are starting with are like the sentences in a larger document. You might be able to understand the individual sentences but not understand the entire document, but it is very likely that if you don't at least understand the sentences, you won't understand the total document.

6.3 Model structures and behaviors

The following structures and behaviors can be found in many larger systems models. The analysis of a system should start with determining the extent or boundaries of the system as you plan to study it, and then look for smaller structures and then how these smaller units are related.

Boundaries of the system

The first step in studying or communicating information about a system is to explicitly define the boundaries and what flows in and out. A "closed system" is one in which there are no source/sink components. All the flows occur between stocks. Often the decision of whether or not a system is open or closed requires a judgment based on the significance of some of the smaller losses or gains and a decision on the time scale of your study. For example, you might model a forest as a closed system for nutrients ignoring the amounts of nitrogen that comes in from rain or lost through streams. The time scale question is apparent if, for example, you are studying the gain and loss of species in a city park but are ignoring evolution. The description and diagramming of a systems model should attempt to make these boundaries very clear.

Draft v7 135

Figure 6-3: Several examples of open and closed systems. a and b are open, c is closed.

Positive and negative feedback - A stock that controls the flow into that stock can be described as having a negative or positive feedback. Sometimes we will talk about positive or negative feedback "loops" which are when stock A controls stock B which in turn eventually controls the flow into A. These feedback loops are crucial characteristics of systems control. Figure 1 was an example of a positive feedback

and the example behavior given in Figure 2. Figure 4 shows a system that contains a negative feedback system with an example output.

Figure 6-4. A system that contains a negative feedback control (shown in red, or slightly gray). The system wouldn't work without the other components. The number of barnacles continues to increase until it hits a maximum and then it levels off due to lack of any more space.

Stock limitation – One of the powerful applications of the systems approach is to examine the constraints over extended periods of time. Some of these are mitigated by feedback inhibition and others are exacerbated by positive feedback. Stock limitation is an absolute limitation on the amount of a stock that can flow to other stocks or an ultimate sink. Examples of stock limitation might be the seasonal availability of nitrogen in the soil, the space trees need to grow, or the amount of fossil fuels available for human consumption. Figure 5 presents two variations on a model for bacterial growth, one with and one without stock limitation.

Figure 6-5. Stock limitation model for bacterial growth. The stock is the amount of nutrients in the container. In model 'a' there is no limiting stock, in model 'b' when the limiting stock runs out, the new bacteria production rate is forced to stop.

Steady state – The inflows to and outflows from a stock can create a situation where steady state is possible. If the sum of all the inputs is equal to the sum of all the outputs then the value of the stock will not change with time. A slight increase of the input or a slight decrease of the output rate can lead to an increasing stock. Figure 6 illustrates a familiar example that relates to body weight. Other examples of steady state conditions are the CO₂ concentration in the atmosphere (currently not in steady state), use and replenishment of natural capital, or the human population at zero population growth.

The conditions that lead to steady state are important to understand because the steady state may be the consequence of a very slow input and very slow output, in which case not much will ever happen very quickly. Conversely, the steady state could be a very tenuous balance between rapid input and output. With rapid fluxes, slight disturbance in one rate could have dramatic consequences. A good example of this delicate balance is a pond in which a large amount of algae growth is growing and contributing oxygen to the water, but then with a slight change in temperature the large amount of algae turn from a net oxygen producer to a net oxygen consumer. These ponds crash into a scummy mass very quickly and start to stink. Simpler natural systems may be controlled by just a few rapid fluxes and when one of these processes changes those natural systems can flip to a whole new behavior. We will also examine the stability, instability and resilience of these environments in Chapter 7 using the tools of the network view.

Figure 6-6. An example of a familiar steady state problem. If the input equals the output for a stock, the stock will remain constant with time, no matter how fast the input and output are. If the input exceeds the output, then the stock will increase. In this case food input is in terms of the weight of all food eaten and the food output is the weight of all excretion of waste, including the CO₂ exhaled. The variable part of the bodyweight is food storage that is probably fat.

6.4 Simple and busy models

We have shown several 'simple' models above. These models have a few components or strings of components and all the units for stocks and flows are related. There are other simple models that might contain two parallel paths to represent different forms of materials or energy. For example modeling energy and nitrogen in

ecosystem requires two sub-models; one for nitrogen and one for energy that are linked by information connectors. These should be treated as two simple models that have some interacting control points. The point of using the systems view is to take a complex set of processes and try to simplify it to just a few components that describe the control over the behavior. Then this model of the system can be used to make predictions about different controls or perturbations. Several examples of simple and slightly busy models are given below. A busy model contains several simple models joined together. For each of these examples an analysis is provided that serves to demonstrate how you can use this to understand environmental problems.

Example 1: Changes in human population in a country. The current population plus additions from births or immigration and minus losses from death or emigration determines the new population level. If the birth rate is higher than the death rate even by a little bit, the population can experience an exponential growth rate. In many countries, industrialization has led to a decreased death rate followed by a decreased birth rate. The overall side effect of industrialization on the population has been to stabilize of population size. Some countries however, are stalled at a level of industrial development that has resulted in a decrease in the death rate but left the birth rate high. These countries are experiencing rapid population growth rates.

August 13, 2013

Figure 6-7. Population change. The population increases from birth or immigration and decreases due to emigration or death.

Analysis - The population is the only stock in this system. All of the inputs and exports are out of the system, which only means they are not being studied in this model, not that they aren't important. The population is a possible steady state situation. Notice that this version of the model has left out the control of births or deaths by the population size itself. (See Figure 1 for how it should be written.) This diagram illustrates clearly that we need to understand the relative rates of all of these processes to predict what will happen with this population.

Figure 6-8. Busier model of population change. Economic growth in a country (which can be the result of industrialization) creates wealth. The economic wealth per capita is the total economic wealth divided by the population at any time. In models of population growth, a decrease in death rate is correlated to an initial increase in per capita wealth. If the economic wealth per capita continues to increase, families may choose to have smaller families and thus decrease the birth rate. Note that the structure of this model makes it clear that we are assuming that increased per capita wealth will have some impact on the birth and death rate.

Analysis: This model contains two simple models that are connected through the "per capita wealth" convertor. Economic growth will increase the per capita wealth and increases in population will decrease the per capita wealth. This model illustrates that if the economy grows more slowly than the population, it may result in higher per capita wealth and then in a decreased birth rate. This may lead to a slowing of the birth rate to allow a steady state population. However, if the economy grows just enough to decrease the death rate but the per capita wealth doesn't increase after that point, the population will continue to grow exponentially. This relationship between population and economic conditions is the basis for studying demographic transitions that occur. In Northern Europe, the United States and Japan, for example, the industrialization and economic growth has led to what is called the classical demographic transition. We will revisit the systems description of demographic transitions

when we study how different worldviews treat the risks of population growth and forecasts for economic growth (Chapter 11). The systems analysis of this problem can be combined with other frameworks to provide further help in describing and making decisions.

Example 2: Global warming and CO₂ in the atmosphere. Global temperatures and the CO₂ in the atmosphere are linked at multiple layers. The “busy” model diagram below shows how several simple models are linked.

142 August 13, 2013 Figure 6–9. A busy model of atmospheric temperature and the geochemical cycle for carbon. The analysis, below, identifies the simple model parts and the linkages between these sub-models.

Analysis: This model is missing many important stocks and flows. Even with this deficit, it is useful to analyze the structure and potential behavior of the model. The top part of the model shows that the atmosphere could potentially be in steady state for heat energy. The sun energy comes in and the heat is radiated back out. The amount of CO₂ in the atmosphere makes the net efficiency of irradiation back into space less efficient, requiring a slightly higher atmospheric temperature to reach a steady state for the energy (heat) in the atmosphere. This is called the “greenhouse effect”. The bottom part of the model shows two major fates for CO₂ from the atmosphere, either going into ocean or terrestrial biomass. In this version, the Draft v7 143 not only controls that are shown are the increase in respiration rates of the terrestrial and oceanic plants from higher temperature. Notice that the top part of the model is tracking energy and the bottom part of the model is tracking carbon. There are no flows between these two halves, only an information connection and converter. The linkage of these two sub-models leads to a potentially very important behavior, run-away positive feedback of the temperature. The scenario for that outcome is as follows:

1. the atmospheric temperature increases,
2. which increases respiration from terrestrial and aquatic biota,
3. which leads a higher steady state of CO₂ in the atmosphere
4. which, in turn, leads to higher temperature
5. and it continues

These two examples illustrate how the systems view is valuable. Example 1 shows how to take a simple model and combine it with another simple model to study the potential interactions between processes. Example 2 shows how to dissect a model into the simple sub-models, analyze them and then put these all back together to study the overall behavior and look for potential problems.

6.5 Starting Steps

1. Identify what material or energy is being moved.
2. Identify what the reservoirs are and how material or energy moves between these reservoirs, i.e. the flows.
3. Draw a boundary around the system you are studying: what stocks and flows are you quantifying and what is outside. If there are flows in or out of your target system, then these must be represented by sources or sinks, respectively.
4. Create a diagram that shows the major reservoir stocks, flows, sources and sinks using the iconography supplied above.
5. Are there any conditions (such as temperature) or derived quantities (such as flow per person) that might be controlling a flow? If so, create a converter or constant to represent this relationship.
6. Make linkages from stocks to flow-regulators, from one flow to another flow, and from converters to flows.

144 August 13, 2013

7. Check the diagram to see that all flows represent movement per unit time of whatever is in the stocks.
8. Examine the diagram for the regulatory components within a flow such as feedback inhibition (negative feedback), feedback acceleration (positive feedback), stock-limited flow.
9. Examine the diagram for relationships between the flow of different material or energy (such as use of natural capital vs. the rate of population growth).

6.6 Overlaps and conflicts with other tools

Term in "Systems";
 nother viewer/term similarities and differences
 boundary scale/extent
 Everything outside the boundary of the system is neither neglected or is an
 unlimited source or sink. In the Scale viewer, extent relates to the size of the
 largest dimension considered, the word doesn't imply any process nor
 specific border. In stock network/node A stock must be something measurable
 that can be moved through a flow. In the network view, a node can be a quality
 that changes depending on input links. In Draft v7 145 In flow
 network/link A flow must be the movement of material or energy per unit time and
 whatever is flowing has to be the same as the stock at neither end. A link
 identifies a relationship between nodes. It can be a quantity of material
 moved but it doesn't have to be a quantity. In stability
 network/stability, resilience and resistance
 Systems models can reach steady
 state that has some stability due to some form of negative feedback that keeps
 it at a level or in some range. The type of systems model that we are using
 doesn't have a mechanism to change its own structure. A network diagram
 that has many weak interactions can shift the operational structure and show how
 a large number of weak interactions or the combination of fast and slow
 processes can lead to the resilience or loss of resilience of the network.

August 13, 2013

6.7 Extending analysis to the
 next levels
 An important extension of the use of systems models is to create
 simulations that demonstrate overall system behavior given certain input
 conditions and constants. We will look at the components of the system, such as
 positive or negative feedback to look for very general system behavior. There are
 software applications that are useful for turning these systems diagrams into
 mathematical dynamic models (the diagrams and charts in this page were generated
 with STELLA from High Performance Systems, <http://www.hps-inc.com>). See the
 appendices for this book to see simulations that were written in STELLA and
 simulations made available on the web (through Forio.com). In these simulations
 only the parameter values can be changed, not the structure of the model itself.
 But these simulations are very useful for illustrating the types of predictions and
 uses for simulations. Simulations of this type are extremely useful in modern
 decision-making. For example, the Northwest Power Council created a complicated
 and very busy model that contained information on fish, dams, river flows and
 electricity. This model could be run under different conditions and demands for
 energy to show which parameters affect fish survival most. They were able to show
 the model to people who work in this arena of fish and rivers to see if the model
 behaves in a way they think it should; does it show low fish years when expected or
 high fish years following particular events? The simulation model and the accessible
 interface were powerful tools in addressing problems and getting people to learn
 about complicated social, economic and ecological issues.

Draft v7 147

6.8 Developing a simplified Systems model of sustainable resource use
 Many people subscribe to the idea that a sustainable resource is one in which you
 reach a steady state because you don't use the resource faster than it is being
 created. Whether or not this is required for all resources to attain a sustainable
 society is a very interesting question. It maybe that you can have some resources
 decrease and be replaced by other resources. There are different definitions of
 overall sustainability that address whether the entire ensemble of capital types has
 to be stable or whether substitutions can be made. We will focus here on the