Indicators and Information Systems for Sustainable Development

by Donella Meadows

A Report to the Balaton Group

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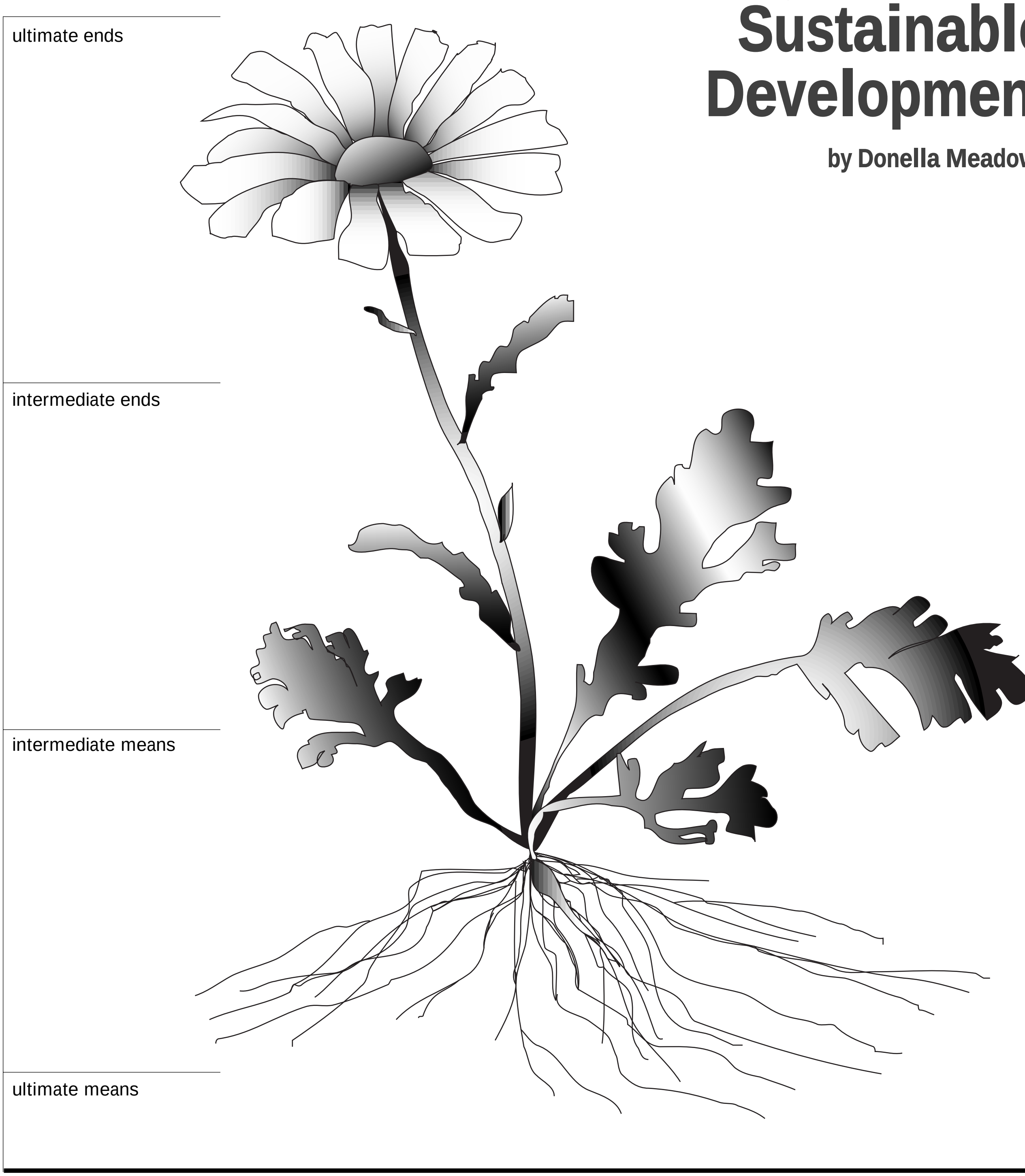

A Report to the Balaton Group • September 1998

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The origin of this work

This paper grew out of a five-day workshop on sustainable development indicators attended by a small subset of the two hundred members of the Balaton Group. The Balaton Group, founded in 1981, is an international network of scholars and activists who work on sustainable development in their own countries and regions. We come to our work from a cross-disciplinary, whole-systems perspective. Individually and jointly we have been thinking about and testing indicators of sustainable development in local, national, or international contexts for many years.

The workshop was held at the National Institute for Public Health and Environmental Protection (RIVM) in Bilthoven, the Netherlands, April 13–17, 1996. The participants (identified here by their place of employment, though we participated as individuals) were:

- Alan AtKisson, Redefining Progress, San Francisco, CA, USA;
- Alp Baysal, Programme for Systems Management, University of Cape Town, South Africa;
- Wouter Biesiot, Center for Energy and Environmental Studies, University of Groningen, the Netherlands;
- Valdis Bisters, Ecological Center, University of Latvia, Riga, Latvia;
- Hartmut Bossel, Environmental Systems Research Center, University of Kassel, Germany;
- Joan Davis, Federal Institute for Environmental Sciences and Technology, Dubendorf, Switzerland;
- Bert de Vries, RIVM, Bilthoven, the Netherlands;
- Thomas Fiddaman, System Dynamics Group, MIT, Cambridge, MA, USA;
- Genady Golubev, Faculty of Geography, Moscow State University, Russia;
- Jane King, Centre for Human Ecology, University of Edinburgh, Scotland;
- Donella Meadows, Environmental Studies Program, Dartmouth

College, Hanover, NH, USA;

- Lars Mortensen, Division for Sustainable Development, Department of Policy Coordination and Sustainable Development, United Nations, New York, NY, USA;
- Jørgen Nørgard, Department of Buildings and Energy, Technical University of Denmark, Lyngby, Denmark;
- Michael Ochieng Odhiambo, Centre for Environmental Policy and Law, Nakuru, Kenya;
- John Peet, Department of Chemical and Process Engineering, University of Canterbury, Christchurch, New Zealand;
- Laszlo Pinter, International Institute for Sustainable Development, Winnipeg, Canada;
- Rosendo Pujol, Department of Civil Engineering, University of Costa Rica, San Jose, Costa Rica;
- Aromar Revi, The Action Research Unit, New Delhi, India;
- Detlef von Vuuren, RIVM, Bilthoven, the Netherlands.

Whenever Balaton Group members get together, new ideas fly and old ideas come together in sudden and striking connections. This workshop was no exception. We emerged with a new vision of the kinds of information and indicators we would need to guide ourselves toward a sustainable world — whether on the level of a community, a nation, or the whole planet. We were all excited.

I was given the task of trying to write up the kaleidoscope of insights we had produced. I did my best, though I didn't and still don't feel adequate to the task. I prepared a draft that circulated among Balaton Group members for a year, collecting comments and amendments and starting a few heated arguments. Outside reviewers sent us primarily praise and requests for more copies. Whatever we had produced, it was clearly unfinished, still a work in progress, but equally clearly useful enough to justify compiling all the responses and putting out a final printed version. A subcommittee assembled to do that. That committee consisted of Alan AtKisson, Hartmut Bossel, Joan Davis, Bert de Vries, Donella Meadows, Jørgen Nørgard, John Peet, Laszlo Pinter, and Aromar Revi.

This is the result. It bears only my name as author, because the Balaton Group is made up of far too many diverse and independent thinkers to suggest that they are all of one mind about anything, except the basic desirability and urgency of sustainable development and more powerful indicators thereof. Some of the group strongly object to some things written here, though I think all are in agreement with the basic thrust (and I try to signal the areas of significant discord). The drafting committee decided it would be better to give me free rein to write in my own voice, choose my own emphases, and be responsible for my own quirks, rather than to try to hammer out a document that might please everyone and therefore become colorless.

So, while recognizing an enormous debt to those who were responsible for the ideas, funding, and practical efforts that made this work possible, I take personal responsibility for everything written here.

Acknowledgments

The entire group is thankful to Mariette Commadeur and Bert de Vries of RIVM and Betty Miller and Diana Wright of the Balaton Group for their efficient and cheerful logistical support.

Financial support was provided by RIVM, the Jenifer Altman Foundation, the Wallace Global Fund, and the Gellert Foundation. Special thanks to the John D. and Catherine T. MacArthur Foundation for the fellowship that allows me to work for the Balaton Group.

The workshop participants could have made no headway if we had not been able to think about and build upon years of intense discussion about indicators of sustainable development on the part of thousands of people throughout the world. In particular we would like to acknowledge:

- The program on indicators of the United Nations Commission on Sustainable Development (CSD);
- The formulation of indicators of natural, human, and social capital by the World Bank;
- Compilations of environmental indicators assembled by the United Nations Statistical Division, the OECD, the European Environment Agency, and Eurostat;
- The Project on Indicators of the Scientific Committee on Problems of the Environment (SCOPE);
- The Human Development Report of the United Nations Development Programme (UNDP);
- The initiatives of the World Resources Institute (WRI), in particular in the areas of biodiversity, georeference indicators, and materials flows;
- Studies by the Dutch National Institute of Public Health and Environmental Protection

(RIVM) in cooperation with the United Nations Environment Programme (UNEP), especially in the area of indicators supported by dynamic modeling;

- Local indicators projects in many parts of the world, most particularly Sustainable Seattle;
- The overview of sustainable development indicator initiatives published by the International Institute on Sustainable Development (IISD);
- Initiatives at the national level by countries such as Canada, Costa Rica, Japan, the Netherlands, the United States, and others, and regional initiatives in Latin America, Europe, Africa, and Asia;
- The Worldwatch Institute's annual report *Vital Signs.*

The Balaton Group owes an ongoing intellectual debt to many thinkers in the fields of systems, sustainability, and development, whose ideas influence our every meeting as well as this document. They include Jay Forrester (system dynamics), Herman Daly (the Daly triangle, the Daly laws), Amory Lovins (least-cost end-use analysis), Vassily Leontief (input-output analysis), Michael Thompson (cultural theory), Manfred Max-Neef (fundamental human needs), William Rees (ecological footprints), Hartmut Bossel (orientor theory and Scenarios A and B), E. F. Schumacher (definitions of human capital), and ecologists and ecological economists too numerous to mention.

Finally I would personally like to thank Balaton Group members at home and on-line who sent ideas, comments, and reactions, and who have helped build up over many years the intellectual capital we all brought to this exercise.

The format was designed by Meg Houston of Fonta.

Notes on the format

The summary is assembled from the main headings of the various parts of the text.

Examples of indicators are highlighted throughout, using a different font. For example:

> Suggested dynamic indicators:
>
> **Turnover time,** which is stock size relative to stock change rate. Especially relevant for understanding the time it takes for aquifers or surface water bodies (or the atmosphere) to flush out pollution, or the time it takes for industrial capital stocks (such as the automobile fleet) to be replaced.

In some cases, the indicator examples are long enough to warrant pulling them from the columnar text, in which case you will find them in a separate box with any accompanying graphic illustrations.

These examples are meant to be provocative, to be suggestive, to stimulate your own creative juices, to trigger ideas for other indicators that might be more directly useful to you for your own situation and purposes. They are not necessarily indicators recommended by the author or the Balaton Group as the ultimate or best indicators of sustainable development. We don't even claim that they can necessarily be measured easily, maybe not at all. The author's recommended indicators, which are backed by the partial but not unanimous enthusiasm of members of the working group, are summarized in the last section.

Summary

Chapter 1: The nature of indicators, the importance of indicators

Indicators are natural, everywhere, part of everyone's life.

Indicators arise from values (we measure what we care about), and they create values (we care about what we measure).

When indicators are poorly chosen, they can cause serious malfunctions.

Indicators are often poorly chosen. The choice and use of indicators are processes full of pitfalls.

The choice of indicators is a critical determinant of the behavior of a system.

Chapter 2: Indicators, models, cultures, worldviews

Indicators are partial reflections of reality, based on uncertain and imperfect models.

We need many indicators because we have many different purposes — but there may be over-arching purposes that transcend nations and cultures, and therefore there may be overarching indicators.

We need many indicators because we have many worldviews — but indicators may help narrow the differences between worldviews.

Indicators need not be purely objective, and in fact few of them are.

Despite their difficulties and uncertainties, we can't manage without indicators.

The search for indicators is evolutionary. The necessary process is one of learning.

Chapter 3: Why indicators of sustainable development?

Development and sustainability are old problems; now they come together on a global scale and in an urgent time frame.

Sustainability indicators must be more than environmental indicators; they must be about time and/or thresholds.

Development indicators should be more than growth indicators; they should be about efficiency, sufficiency, equity, and quality of life.

Chapter 4: The challenge of coming up with good indicators

It's easy enough to list the characteristics of ideal indicators.

It's not so easy to find indicators that actually meet these ideal characteristics.

Most of us already have indicators in the backs of our minds, "beloved indicators" that reflect issues of great concern to us. It's important to get them out on the table.

Indicators can take many forms. They don't have to be numbers. They can be signs, symbols, pictures, colors.

What is needed to inform sustainable development is not just indicators, but a coherent information system from which indicators can be derived.

Chapter 5: Suggestions for indicator process and linkage

Hierarchy: coherence up and down the information system

The information system should be organized into hierarchies of increasing scale and decreasing specificity.

Information from the hierarchy at all levels should be available to people at all levels.

Information should also come from all levels. The public can be important contributors to, as well as users of information and indicators.

The selection process: experts and citizens together

The process of indicator development is as important as the indicators selected.

The indicator selection process works best with a combination of expert and grassroots participation.

But integrating expert and non-expert opinion has its costs and must be done with care.

Systems: making indicators dynamic

Systems insights can help in the design of indicators that identify critical linkages, dynamic tendencies, and leverage points for action.

Distinguish between stocks and flows. Stocks are indicators of the state of a system and its response time. Flows may be leading indicators of change.

Exponential growth rates (the strengths of vicious or virtuous cycles) are sensitive points to monitor in systems.

The ratio of change rate to response rate is a critical — and usually critically missing — indicator of the degree to which a system can be controlled.

Watch for unbalanced or missing control loops.

An important indicator of the resilience of a system is the redundancy of its controlling negative feedback loops.

Nonlinearities in systems (turning points, thresholds) are key points for the placement of indicators.

A primary indicator of the long-term viability of a system is its evolutionary potential.

Wherever possible, indicators should be reported as time graphs rather than static numbers.

Indicators should be combined with formal dynamic modeling.

Chapter 6: A suggested framework for sustainable development indicators

The hierarchy from ultimate means to ultimate ends

The "Daly Triangle," which relates natural wealth to ultimate human purpose through technology, economy, politics, and ethics, provides a simple integrating framework.

Sustainable development is a call to expand the economic calculus to include the top (development) and the bottom (sustainability) of the triangle.

The three most basic aggregate measures of sustainable development are the *sufficiency* with which ultimate ends are realized for all people, the *efficiency* with which ultimate means are translated into ultimate ends, and the *sustainability* of use of ultimate means.

Extending the definition of capital to natural, human, and social capital could provide an easily understood base for calculating and integrating the Daly triangle.

Natural capital (ultimate means)

Natural capital consists of the stocks and flows in nature from which the human economy takes its materials and energy *(sources)* and to which we throw those materials and energy when we are done with them *(sinks).*

The human economy uses many kinds of throughput streams, each associated with natural capital on both the source and sink end of the flow.

Natural capital is being used unsustainably if sources are declining or sinks are increasing.

Indicators should highlight *limiting* natural capital stocks.

Natural capital should be monitored at whatever geographic level makes sense.

We need to allow estimates in our indicators for life support systems that we do not yet understand.

Built capital (intermediate means)

Built capital is human-built, long-lasting physical capacity — factories, tools, machines — that produces economic output.

The nature and amount of built capital determines the standing demand for human capital (labor and skills) and for throughput from natural capital (materials and energy). That fraction of built capital that produces more built capital (investment) determines the rate of economic growth.

Sustainability on the level of built capital means investing at least as fast as capital depreciates. Across levels it means keeping the throughput needs of built capital appropriate to the sustainable yields and absorptive capacities of natural capital and keeping labor and management needs appropriate to the sustainable use of human capital.

There are many categories of built

capital. A useful indicator would reflect the proper balance among categories to permit the most productive use of all forms of capital.

Human capital (intermediate means/ends)

The base of human capital is the population, including its age and gender structure.

Along with numbers, ages, and genders, human capital can be measured by attributes such as health and education.

Human capital is in one sense an intermediate means, in another sense an intermediate end.

Population with its attributes, like built capital, is an indicator of the necessary throughputs and potential outputs of a society.

The universal resource available to all human beings, and the currency of most value to them, is time. Time accounting may be key to human capital accounting.

Social capital (intermediate ends)

Social capital is a stock of attributes (knowledge, trust, efficiency, honesty) that inheres not to a single individual, but to the human collectivity.

Just as time is a key currency for human capital, information may be a key currency for social capital.

Another possible measure of social capital would be density or frequency or intensity of human relationships.

The “forbidden numeraire,” whose stocks, flows, and distribution could lend itself to indicators, is power.

Social capital can be a high-leverage transformative factor in the process of channeling ultimate means into ultimate ends.

Rough indicators of social capital are better than nothing.

Well-being (ultimate ends)

The most important indicator, without which the others make no sense, is an indicator of ultimate ends.

Indicators of ultimate ends may not be numerical or precise, but they are findable and usable.

Integration (translating ultimate means into ultimate ends)

The central indicators of sustainable development will integrate the whole Daly triangle.

The information system from which these central indicators can be derived will measure capital stocks at every level and the flows that increase, decrease, and connect those stocks.

There are systematic schemes for assessing the total viability of a system. These schemes can serve as checklists for sustainable development indicators.

Chapter 7: Sample indicators

Chapter 8: Implementing, monitoring, testing, evaluating, and improving indicators

Indicators don't guarantee results. But results are impossible without proper indicators. And proper indicators, in themselves, can produce results.

Indicator measurement can be a costly, bureaucratic process. But it can also be relatively simple. There may be clever ways to measure indicators that don't even require numbers or disturbing the system in any way.

The process of finding, implementing, and improving sustainable development indicators will not be done right at first. Nevertheless it is urgent to begin.

1. The nature of indicators, the importance of indicators

If we could first know where we are, and whither we are tending, we could better judge what to do, and how to do it...

— Abraham Lincoln, speech to the Illinois Republican state convention, June 16, 1858

Indicators are natural, everywhere, part of everyone's life.

Intuitively we all use indicators to monitor complex systems we care about or need to control.

Mothers are alert to the activity level of their children, the brightness of their eyes, the way they breathe in sleep.

The learning of every school child is expressed as test scores and grades.

Farmers scan the sky for weather fronts, squeeze the soil to measure its moisture, watch how many earthworms are turned over in a shovelful of earth.

Doctors take your temperature, look at your tongue, do blood tests and CAT scans.

Mechanics use calipers and pressure gauges and listen to the sound of the motor.

Pilots and power plant operators have whole panels of instruments in front of them.

Economists use leading indicators, lagging indicators, cost-of-living indicators, employment indicators, the Nikkei or Dow-Jones index, and the most famous and criticized of all indicators, the GDP.

Some indicators are legends — the canary in the coal mine, the sea bird that hints of the yet-invisible land, the puff of smoke from the Vatican chimney.

We have many words for indicator — sign, symptom, omen, signal, tip, clue, grade, rank, data, pointer, dial, warning light, instrument, measurement. Indicators are a necessary part of the stream of information we use to understand the world, make decisions, and plan our actions.

Indicators arise from values
(we measure what we care about),
and they create values
(we care about what we measure).

What do you keep an eye on, to be sure your home or workplace or community is in good shape? What would you ask about a place you might move to, to find out if you would like to live there? What would you want to know about your society fifty years from now, to be sure your grandchildren are living good lives? The answers people give to questions like these reflect their *values.*

Various U.S. communities, asked to define indicators of their own long-term welfare, have responded with:

- whether we have to lock our houses and cars;
- whether the children will go on living here or move away;
- whether wild salmon still run in the rivers (Seattle);
- whether, when we open the windows, we can smell the sage (Denver).

A group of Portuguese young people once listed as the top three questions they would ask about a strange country:

- how many days in a year does the sun shine?
- how many kilometers are there of clean beach?
- when you walk down the streets, are the people warm and friendly?

Clearly some values (and hence indicators) are place- or culture-specific, others are common to all humanity. Some are quantitatively measurable, while others, which may be equally important, can only be felt qualitatively.

Not only do we measure what we value, we also come to value what we measure. The Dow-Jones index arose from the information needs of stockholders, but now the general public sees it as an indicator of national economic health. No one cared about a blood cholesterol level over 200 until doctors started including it in our annual checkups. Opponents of the Vietnam War made converts by creating an indicator: the nightly body count.

Indicators can be tools of change, learning, and propaganda. Their presence, absence, or prominence affect behavior. The world would be a very different place if nations prided themselves not on their high GDPs but on their low infant mortality rates. Or if the World Bank ranked countries not by average GDP per capita but by the ratio of the incomes of the richest 10 percent to the poorest 10 percent.

We try to measure what we value. We come to value what we measure. This feedback process is common, inevitable, useful, and full of pitfalls.

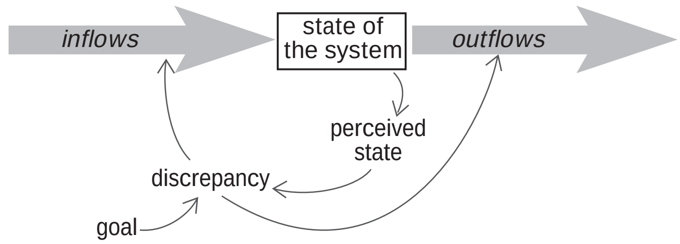
When indicators are poorly chosen, they can cause serious malfunctions.

If you manage a national economy to maximize GDP, you get GDP. You do not necessarily get justice or freedom or environmental quality or even, sometimes, real wealth.

If you run a company to increase its stock market value, you may very well produce a rise in the stock market value — perhaps at the cost of underpaid workers or poor quality products, and therefore, over the long term, a downturn in the stock market value.

When the success of the family planning program in India was measured by the number of intra-uterine devices (IUDs) inserted per month, some family planning workers, it is said, inserted IUDs in unknowing women, in infertile women, and even in women who already had IUDs. The indicator looked fine, but the birth rate, the actual target, was hardly affected.

Indicators are both important and dangerous because they sit at the center of the decision-making process. Nearly every human decision is intended to bring some important system condition or state (literacy of the population; pollution in the lake; national debt) to some desired state. Action is taken depending on the **discrepancy** between the desired state or **goal** and the **perceived state** of the system.



The **perceived state** is an indicator. It may not be measured accurately. It may measure not the actual system state, but some proxy or associated state. (It's impossible, for instance, to measure the exact population of fish in the ocean, so we measure the catch and assume the population.) The indicator may be delayed. It may be "noisy," so its central tendency is hard to deduce. It may be deliberately or accidentally biased.

If an indicator of the state of the system is poorly chosen, inaccurately measured, delayed, noisy, or biased, decisions based on it cannot be effective. Misleading indicators will cause over- or under-reactions, changes that are too weak or too strong to bring the system exactly to the desired state. We can't steer accurately, if we don't know where we are.

Indicators are often poorly chosen. The choice and use of indicators are processes full of pitfalls.

Pitfalls in the process of choosing and using indicators include:

Overaggregation. If too many things are lumped together, their combined message may be indecipherable. The GDP is the classic example, adding together money flows caused by "good" economic changes (more education, say, or better food) and "bad" changes (more hospitalizations from automobile accidents). Another example: measuring the strength of a fishery by total tons of fish caught may disguise the fact that more valuable species are diminishing, but smaller, less desirable fish are being substituted.

Measuring what is measurable, rather than what is important. The area covered by forest rather than the size, diversity, or health of the trees; tons of hazardous chemicals rather than toxicities; the amount of money people have rather than the quality of their lives; the amount spent per school child rather than actual learning.

Dependence on a false model. We may think that the birth rate reflects the availability of family planning programs, when it may actually reflect the freedom of women to use those programs. We may think the price of oil tells us about the underground abundance of oil, when it primarily tells us about the built capacity of oil wells relative to the built capacity of oil-consuming devices.

Deliberate falsification. If an index carries bad news, someone may be tempted to alter it, delay it, change terms or definitions, unfund it, lose it, or otherwise suppress it. For example, the U.S. counts as unemployed only those people who are actively looking for jobs, not those who have given up looking. Some governments have been known to report agricultural yields based on five-year plans, rather than actual harvests.

Diverting attention from direct experience. Indicators may mesmerize people with numbers and blind them to their own perceptions. The stock market is going up, so the economy must be in great shape, despite the fact that many of us are decidedly poorer.

Overconfidence. Indicators may lead people to think they know what they're doing, or to think what they're doing is working, when in fact the indicators may be faulty.

Incompleteness. Indicators are *not the real system*. They may miss many of the subtleties, beauties, wonders, warnings, diversities, possibilities, or perversities of the real system.

The choice of indicators is a critical determinant of the behavior of a system.

Indicators are leverage points. Their presence or absence, accuracy or inaccuracy, use or non-use, can change the behavior of a system, for better or worse. In fact, changing indicators can be one of the most powerful and at the same time one of the easiest ways of making system changes — it does not require firing people, ripping up physical structures, inventing new technologies, or enforcing new regulations. It only requires delivering new information to new places.

> For example, when a new U.S. law required every plant emitting toxic air pollutants to list those pollutants publicly, an indicator was created. Local newspapers began reporting the "top ten polluters." Companies acted quickly to get off that list, and toxic emissions decreased by over 40 percent in three years, *though there was no law against them.* The presence of the indicator was sufficient in itself to change behavior.[1]

> Similarly, when new Dutch houses were built with the electric meter in the front hall where it was easily visible (instead of out of sight in the cellar), electricity use in those houses went down by one-third *though there was no change in the price of electricity.* There was simply a clear indicator of electricity use situated where no one could avoid seeing it.[2]

People can't respond to information they don't have. They can't react effectively to information that is inadequate. They can't achieve goals or targets of which they are not aware. They cannot work toward sustainable development if they have no clear, timely, accurate, visible indicators of sustainable development.

Conversely, if there are good indicators of sustainable development, it will be almost impossible *not* to make decisions and take actions that make the indicators improve.

[1] Environment Today, 6, no.1 (Jan/Feb 1995): 16. The 40 percent reduction was achieved not so much by reducing the generation of toxics as by diverting them from disposal into the air to disposal by injection into the ground (and hence into groundwater). This example illustrates another hazard of indicators — bizarre behavior designed not to solve a problem but to evade revelation by an indicator.

[2] This story was told in 1973 at a system dynamics workshop in Kollekolle, Denmark, and its source is lost — but systems people tell it over and over until it has become legend.

2. Indicators, models, cultures, worldviews

The real act of discovery consists not in finding new lands but in seeing with new eyes.

— Marcel Proust

Indicators are partial reflections of reality, based on uncertain and imperfect models.

The grade is not the knowledge in the head of the student. The stock market price is not the value of the company. No indicator is the real system. Indicators are abstractions from systems. Furthermore, they are abstractions from abstractions, from **models**, or sets of assumptions about how the world works, what is important, what should be measured.

We experience the world through models, most of them filtered through our senses and hidden in our minds. We don't carry reality in our heads, we carry **mental models**, assumptions about the world, based on our personality, culture, language, training, and experience. Our mental models are enormously varied, which is one reason why we have trouble agreeing upon common indicators with which to inform our decisions.

Some of our models are **formal**, written down or otherwise expressed outwardly so others can see them. For instance spreadsheets, maps, written papers, or mathematical equations are formal models.

All our models, mental and formal, are only models. They are necessarily incomplete. None of us has perfect information. We don't understand everything that is happening. We're unclear about what causes what. Even with the help of computers, there is a limit to the degree of complexity we can comprehend or process. If we somehow could assemble all relevant information, we wouldn't be able to absorb its full buzzing complexity. We would have to abstract and simplify. The astonishing success of our species testifies to our ability to do so accurately enough to serve many purposes. The record of our failures, accidents, surprises, and disasters testifies to the limits of our modeling ability.

It helps to maintain humility about our models as we search for indicators of sustainable development. Sustainable development is a social construct, referring to the long-term evolution of a hugely complex system — the human population and economy embedded within the ecosystems and biogeochemical flows of the planet. Our models of this system are and will always be incomplete. Our indicators will be imperfect. We will be making decisions under uncertainty. Our task is to reduce that uncertainty. We will not be able to eliminate it completely, at least not any time soon.

We need many indicators, because we have many purposes — but there may be over-arching purposes that transcend nations and cultures, and therefore there may be overarching indicators.

Football scores are meaningful indicators to football fans and gibberish to everyone else. A farmer can read signals from a field of growing grain that the rest of us don't even perceive. Every jiggle in stock prices carries vital information only to those who watch the market every day. An indicator is useful only if it carries its information to a mind prepared to receive it, educated to its terms and units of measurement, and actively engaged with the system illuminated by that indicator.

Therefore we will probably never settle on a single global index of sustainable development — too many different people work on different problems and need different kinds of information. Some people are more interested in "development," others in "sustainability." Some are looking for "warning lights" telling when a key resource will become scarce or an ecosystem is likely to be driven into irreversible collapse. Others are interested in the welfare of a particular city or nation, or in bringing to public attention a particular pocket of poverty or pollution or under-capitalization.

So, rather than a single index, we need an **information system** — one at least as sophisticated as the system that presently tracks flows of money around the world — to inform various decision makers at various levels with various purposes related to sustainability and development.

Having said that, I must also say something that sounds contradictory. The comprehensive task — bringing about a socioeconomic system that enhances quality of human life while preserving natural support systems — is particular to cultures and ecosystems, but is also, in essence, the same everywhere. Planet Earth operates by just one set of physical and biological laws, though they manifest as diverse climates and ecosystems. Human beings have the same fundamental needs for sustenance and belonging and meaning, though their ways of meeting those needs are culturally varied. Global resources such as the oceans and atmosphere are important to everyone. Therefore it may be possible to derive from a multiplicity of specific local indicators an overarching set of global indicators that inform common problems and purposes. These indicators can report to all of us about the increasingly integrated global socioeconomic system contained within the undeniably integrated global biogeochemical system.

I suggest a few overarching indicators later in this document.

We need many indicators because we have many worldviews — but indicators may help narrow the differences between worldviews.

The deepest reason why people need different indicators is that they have different fundamental worldviews or paradigms. Worldviews are mental models about the very nature of reality. They tell us what the environment is (limited and fragile or infinite and robust, outside ourselves or continuous with ourselves, a luxury or the most basic of necessities), what human beings are (honest, devious, generous, greedy, fallen angels, unrecognized buddhas, competitive rationalists, myopic egotists), and how people and nature should interact (through dominion, stewardship, harmony, partnership, competition, exploitation, love). Our worldviews define what is important, what questions can be asked, what goals are possible, *what can and should be measured.*

Worldviews not only give meaning to information, they actively screen information, only admitting what fits our preconceived models. Someone who is convinced that technology can solve any problem, for example, can read the newspaper and find articles about wonderful new technologies. Someone with a skeptical view can read the *same paper* and see nothing but articles about technical foul-ups. Each is screening for the information that fits his or her paradigm. If contrary evidence does penetrate our paradigmatic screens, we have ways of dismissing it or discounting the people who present it to us. We see information that disconfirms our worldview as the exception and information that confirms our worldview as the rule.

Therefore people of different worldviews live literally in different worlds. They see different things and take their information from different indicators. Scientists who see the world as flows of energy will want different indicators than will economists who see the world as flows of money — who will want different indicators than will people who see the world as flows of time or social relationships or moral obligation or political power. Our worldviews don't even use the same currency! No wonder we argue about indicators!

Given the multiplicity of perspectives, one option is to disagree endlessly. We can promote our own indicators and ridicule others'. Another option is to acknowledge the inherent ambiguity in the choice of models and the design of indicators. If that is done, if worldviews and models are exposed to view, if their plurality is not only recognized but appreciated, indicators can play an emancipatory role. Different indicators giving conflicting reports about the state of the global system can provide an opportunity to inquire into the underlying models that produced the discrepancy. Indicators can be a tool for expanding, correcting, and integrating worldviews.

(Note: everything written here about worldviews is a worldview.)

Indicators need not be purely objective, and in fact few of them are.

It is conventional within a scientific worldview to distinguish between "objective" and "subjective" indicators. Objective indicators are sensed by instruments outside the individual — thermometers, voltmeters, counters, dials, rulers. They can be verified by others. They can be expressed in numbers. Subjective indicators are sensed only within the individual by means that may not be easily explained and in units that are probably not numerical. Objective indicators primarily measure quantity. Subjective indicators primarily measure quality.

Objective indicators are usually considered more reliable and valuable. They are certainly more easily communicated and validated by others. But there are vital purposes that depend on subjective, qualitative information. The scientific worldview is just one way to see the world, a very useful one, but not comprehensive enough to be used exclusively. A choice to pay attention only to what is measurable is itself a subjective choice, and not a wise one. Every human being knows that some of the most important things in life — freedom, love, hope, harmony, even the beauty of scientific precision — are qualities, not quantities.

All indicators are at least partially subjective. The very choice of an indicator is based upon some value, some inner human purpose that tells us what is important to measure. The choice of what is important is inherently subjective.

Indicators of quality, “subjective indicators,” are worthy of respect, however hard they may be to define. The fact that people consider something ugly or beautiful, harmonious or dissonant, noble or ignoble, is not to be swept away as “mere opinion.” If we guide our decisions only by quantitative indicators and not qualitative ones, we will produce a world of quantity without quality. Many of our social and personal problems arise from the fact that we are well on our way to doing exactly that.

Despite their difficulties and uncertainties, we can’t manage without indicators.

Indicators are hard to define. They are based on uncertain models. Their selection and use are full of pitfalls. They carry different messages to different minds. These difficulties don’t mean, however, that we shouldn’t use indicators. We have *no choice.* Without them we fly blind. The world is too complex to deal with *all* available information. We have to choose a set of indicators small and meaningful enough to comprehend. Rather than discourage us, the pitfalls and difficulties should give us ideas about how to design better indicators, and motivation to do so.

The search for indicators is evolutionary. The necessary process is one of learning.

A lot of planes crashed before people learned what instruments to put in the cockpit. Many patients died before doctors figured out how to take temperatures and blood tests. When a system is extremely complex, it takes trial, error, and learning to produce a serviceable set of indicators.

The human economy and the planet Earth together make up a system we can’t afford to crash. We have to learn from the experience of local economies and ecosystems (some of which have crashed or are crashing) and improve our indicators as best we can, using many types of human experience and knowledge and models.

That is an enormous job. While we’re learning, we should view our indicators and models with utmost humility. We should open ourselves to *disproof,* which is a faster way of learning than looking only for proof. (Scientists are trained not to prove a theory but to try to disprove it.) We should subject every model, especially our favorite ones, to as much scrutiny and as tough testing as possible. There’s no shame in having a wrong model or a misleading indicator, only in clinging to it in the face of contradictory evidence. The more flexible we can be, the faster we will find good sustainable development indicators.

3. Why indicators of sustainable development?

Indicators of sustainable development need to be developed to provide solid bases for decision making at all levels and to contribute to the self-regulating sustainability of integrated environment and development systems.

— Chapter 40.4 of Agenda 21, from the United Nations Earth Summit in Rio, 1992

Development and sustainability are old problems; now they come together on a global scale and in an urgent time frame.

The world economy is doubling roughly every twenty years. The world population is doubling every fourty to fifty years. The planet that supplies the materials and energy necessary for the functioning of the population and economy is not growing at all. That means whatever planetary resource was one-fourth-used a generation ago is half-used today. Whatever waste sink was half-full a generation ago is full today. Whatever was full a generation ago is overfull today.

Each successive doubling of the human system causes new stresses and raises new questions, or rather brings two old questions together with new urgency. Question one is *how can we provide sufficiency, security, good lives to all people?* (The development question.) The second is *how can we live within the rules and boundaries of the biophysical environment?* (The sustainability question.) With the economy globally linked, the ocean fisheries depleting, the atmosphere changing in composition, open spaces filling in, and much of the human population still living in poverty, these two questions now come together with urgency. *How can we and our children live good lives without eroding the health and productivity of the physical planet — and therefore the possibility for future generations to lead good lives?*

The indicators we need to answer that question are not immediately obvious, because the question is so new. It is new because most human history thus far has occurred in a world with few apparent limits. With twenty-year doublings, however, the human endeavor is rapidly approaching and in some cases exceeding physical limits. The unsustainability of many of our activities is becoming apparent. Suddenly we need indicators that we never needed before.

"Sustainability" and "development" are value words. Like all value words — freedom, fairness, beauty, justice, security, sufficiency, democracy — they are subjective, nearly impossible to define, nevertheless possible to sense (or to sense their absence), and vitally important. Taken together — "sustainable development" — the two words may seem contradictory but nevertheless must be achieved together.

Good lives for all people in harmony with nature. The urgency and scale of achieving that goal challenge old models and worldviews. Hence the demand for new ways of thinking and the need for new indicators.

Sustainability indicators must be more than environmental indicators; they must be about time and/or thresholds.

Governments already maintain many environmental and resource indicators, such as the emission rate of sulfur dioxide, concentration of carbon dioxide in the atmosphere, concentration of lead in drinking water, estimated reserves of fossil fuels.

An environmental indicator becomes a sustainability indicator (or unsustainability indicator) with the addition of **time, limit,** or **target.** The central questions of sustainability are: How long can this activity last? *How long do we have to respond before we run into trouble? Where are we with respect to our limits?* Therefore sustainability indicators are ideally expressed in time units. If we keep on mining or fishing or logging at this rate, how many years will the resource last? If we keep emitting this pollutant at this rate, how long before we accumulate a dangerous concentration in nature or in ourselves?

Ecological sustainability is the domain of the biologist and the physical scientist. The units of measurement are different, the constructs are different, and the context and time scale is different.

— Ismail Serageldin, Vice President, Environmentally Sustainable Development, World Bank

For example, a common resource indicator is the amount of fossil fuel reserves known and estimated — roughly 1000 billion barrels of known oil reserves globally, plus perhaps 500 billion barrels estimated but undiscovered.[3] This amount by itself is not a helpful number. It is too huge to be imaginable, and it is not related to our own activities or limits.

If we compare the estimated supply of 1500 billion barrels to recent rates of oil consumption, about 25 billion barrels per year,[4] we can put that reserve in terms of a more understandable index: years of consumption remaining:

(1000+500)/25 = **60** more years of oil at present consumption rate.

If we assume not present consumption, but a rate of growth slightly higher than population growth — let's say 2%/year on average — we get a strikingly different number:

ln (.02*60 + 1)/.02 = **39.4** years with 2% consumption growth.

We may (and will) argue about how much more oil might be discovered and about what the future growth rate might be. Different estimates will produce different indicated lifetimes for the oil resource. For example:

Suppose four times as much new oil is discovered as is currently estimated, but consumption growth proceeds at 5% per year:

(1000+2000)/25 = **120 years** at present consumption rate, but

ln(.05*120 +1)/.05 = **38.9** years at 5% consumption growth.

Suppose twice as much new oil is discovered as is currently estimated but consumption growth stays as low as 1% per year:

(1000+1000)/25 = **80** years at present consumption rate.

ln(.01*80 +1)/.01 = **58.8** years at 1% consumption growth.

Even given great uncertainties about future oil discoveries and future consumption growth, a few calculations of such an indicator of *time remaining* gets across the central message: the time is bounded and limited to decades, not centuries, if oil consumption keeps increasing.

A useful indicator in such an inherently uncertain arena ought to cover the range of possibilities. Perhaps something like this: *Known and estimated and speculative oil reserves will last roughly approximately 60 to 120 years if there is no increase in consumption, and 30 to 60 years if there is steady exponential growth in consumption.*

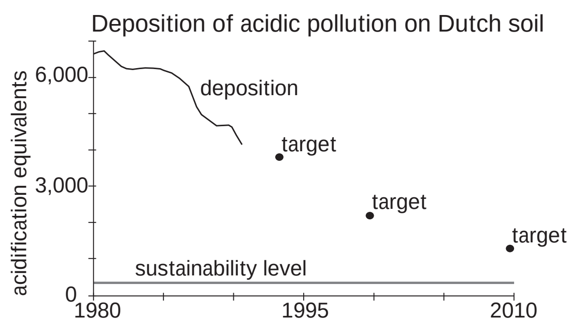
[3] Worldwide Petroleum Industry Outlook, 14th ed. Tulsa, Okla.: PennWell Pub. Co., 1997; Energy Statistics Sourcebook, 12th ed. Tulsa, Okla.: PennWell Pub. Co., 1997.

[4] Ibid.

The Intergovernmental Panel on Climate Change (IPCC) estimates that the world economy would need to cut its carbon dioxide emissions by 60% in order to stabilize the chemical composition of the atmosphere.[5] If we define the sustainable emission rate as 1.0, that means our current emission rate is 1.6 — clearly beyond sustainability.

Similarly, suppose that a fishery's biology experts estimate that the current rate of fish harvesting is about 20 percent above the rate that would allow fish populations to regenerate.[6] Sustainability index = 1.2 — over the limit.

Distance from a sustainability target can be expressed even more graphically by showing a time trend related to a target, as in the following example from the Netherlands.[7]



If they are not expressed in units of time, sustainability indicators should be related to carrying capacity or to threshold of danger or to targets. Tons of nutrient per year released into waterways means nothing to people. Amount released relative to the amount the waterways can absorb without becoming toxic or clogged begins to carry a message.

Development indicators should be more than growth indicators; they should be about efficiency, sufficiency, equity, and quality of life.

In an empty world, development can easily be confused with growth. Growth simply means getting larger — not necessarily getting better. Most of our economic indicators, es-

[5] Intergovernmental Panel on Climate Change, *Climate Change: The IPCC Scientific Assessment*, edited by J. T. Houghton, G. J. Jenkins, and J. J. Ephraums. Cambridge/New York: Cambridge University Press, 1990.

[6] That is roughly what the Food and Agriculture Organization (FAO) has estimated for excess fishing capacity on average worldwide, though such an indicator makes most sense only when it is calculated fishery by fishery. See, for example: J. A. Gulland, ed., *The Fish Resources of the Ocean.* Surrey, U.K.: Fishing News Ltd., 1971; M. A. Robinson, *Trends and Prospects in World Fisheries,* Fisheries Circular No. 772. Rome: FAO, 1984; FAO, *Marine Fisheries and the Law of the Sea: A Decade of Change*, Fisheries Circular No. 853. Rome: FAO, 1993; FAO, *The State of World Fisheries and Aquaculture 1996.* Rome: FAO, 1997.

[7] Dr. A. Adriaanse, *Environmental Policy Performance Indicators.* Sdu Uitgeverij Koninginnegracht, May 1993, pp. 33.

To take a more ambitious example, Wackernagel and Rees have defined the "ecological footprint" — a rough estimate of the average amount of land required by a given nation to supply all that nation's physical consumption (food, energy, water, materials, waste purification).[8] If the ecological footprint is larger than the actual area of the nation, then that nation must be either importing resources from outside its borders (which is fine, as long as the exporting countries' footprints are smaller than their actual area) or drawing down its own or other countries' resources (which is clearly unsustainable).

Here are some Wackernagel and Rees estimates of ecological footprints related to land capacity for selected nations of the world:[9]

Nation	Ecological Footprint (ha/cap)	Available Capacity (ha/cap)	Surplus or Deficit (ha/cap)
Australia	8.1	9.7	+1.6
Bangladesh	0.7	0.6	-0.1
Brazil	2.6	2.4	-0.2
China	1.2	1.3	+0.1
Germany	4.6	2.1	-2.5
Indonesia	1.6	0.9	-0.7
Japan	6.3	1.7	-4.6
New Zealand	9.8	14.3	+4.5
Russia	6.0	3.9	-2.0
United States	8.4	6.2	-2.1

tablished several doublings ago, are defined around growth, with the GDP per capita as the most obvious example.

In a full world, development and physical growth must be decoupled. As economist Herman Daly has pointed out, growth is about getting bigger, development is about getting better.[10] Development indicators must begin to reflect quality, equity, efficiency, and sufficiency. They must shift emphasis from money to physical units and from quantity of material throughput to quality of life. These distinctions begin to point to the real *purpose* of economic development, which is not to have money but to have better lives. This sort of rethinking can also create openings for concepts not only of under-development but of over-development, and therefore for concepts of "enough."

[8] M. Wackernagel and W. Rees, *Our Ecological Footprint*. Philadelphia: New Society Publishing, 1996.

[9] M. Wackernagel et al., "Ecological Footprints of Nations," Center for Sustainability Studies, Xalapa, Mexico, March 10, 1997.

[10] R. Goodland, H. Daly, and S. El Serafy, introduction to *Environmentally Sustainable Economic Development: Building on Brundtland*, The World Bank Environment Working Paper no. 46, July 1991, pp. 2-3.

One of the first attempts to indicate actual human development rather than money flows is the Human Development Index, pioneered by the UN Development Programme. The HDI is a (fairly complex) mathematical average of three indicators: average life expectancy, average educational attainment, and GDP per capita. Here are some sample HDI values for selected countries (1993 data).[11]

Nation	Human Development Index (HDI)
Canada	0.951
USA	0.940
Japan	0.938
Russia	0.804
Brazil	0.796
Indonesia	0.641
China	0.609
Kenya	0.473
Nigeria	0.400
Afghanistan	0.229
Somalia	0.221

In a similar vein, the health-based magazine *Prevention* has invented an index to measure the healthfulness of a nation's lifestyle. It is an aggregation of twenty-one indicators, determined largely by polling data. They include:[12]

What percent of the adult population:

- do not smoke?
- engage in frequent strenuous exercise?
- maintain proper weight?
- get 7-8 hours of sleep a night?
- fasten seat belts while riding in a car?
- refrain from excess alcohol consumption?

[11] United Nations Development Programme, *Human Development Report 1996.* New York: Oxford University Press, 1996, pp. 136-137.

[12] The "Prevention Index" is available from *Prevention* magazine, 33 East Minor Street, Emmaus, Pennsylvania.

4. The challenge of coming up with good indicators

Indicators must be simultaneously meaningful in two different domains: that of science and that of policy.

— Wouter Biesiot

It's easy enough to list the characteristics of ideal indicators.

Most study groups on indicators start by making a list of the qualities of a good indicator. Just about every indicator report contains a list similar to the following.[13]

Indicators should be:

Clear in value: no uncertainty about which direction is good and which is bad.

Clear in content: easily understandable, with units that make sense, expressed in imaginable, not eye-glazing, numbers.

Compelling: interesting, exciting, suggestive of effective action.

Policy relevant: for all stakeholders in the system, including the least powerful.

Feasible: measurable at reasonable cost.

Sufficient: not too much information to comprehend, not too little to give an adequate picture of the situation.

Timely: compilable without long delays.

Appropriate in scale: not over- or under-aggregated.

Democratic: people should have input to indicator choice and have access to results.

Supplementary: should include what people can't measure for themselves (such as radioactive emissions, or satellite imagery).

Participatory: should make use of what people can measure for themselves (such as river water quality or local biodiversity) and compile it to provide geographic or time overviews.

[13] For a definitive list agreed upon by a large international body of experts, see "The Bellagio Principles," in B. Moldan, S. Billharz, and R. Matravers, *Sustainability Indicators: A Report on the Project on Indicators of Sustainable Development* (SCOPE). Chichester and New York: John Wiley, 1997.

Hierarchical: so a user can delve down to details if desired but can also get the general message quickly.

Physical: money and prices are noisy, inflatable, slippery, and unstably exchangeable. Since sustainable development is to a large extent concerned with physical things — food, water, pollutants, forests, houses, health — it's best wherever possible to measure it in physical units. (Tons of oil, not dollars' worth of oil; years of healthy life, not expenditures on health care.)

Leading: so they can provide information in time to act on it.

Tentative: up for discussion, learning, and change. (We should have replaced the GNP index decades ago, for example, but it became too institutionalized to do so.)

It's not so easy to find indicators that actually meet these ideal characteristics.

Having made a list like the one above, the typical indicator study group disbands, encouraging someone else to come up with actual indicators that meet all these wonderful criteria. Or alternatively, the study group proceeds to recommend a long list of indicators that don't meet the criteria. As one of our Balaton colleagues has written: "International organizations, dependent on consensus of their members, assemble indicator sets that measure the noncontroversial issues in overwhelming detail, while leaving out information on controversial issues. It's like cramming an airliner's cockpit with ship chronometers, cuckoo clocks, swatches, hour glasses, and thermometers, without making sure that vital instruments like airspeed indicators and compass are on board."[14]

Having tried the exercise ourselves, however, the Balaton workshop members found ourselves in sympathy with others who have failed to come up with perfect indicators. It was easier to complain about other indicators, to spew out theoretical lists of hundreds of (mostly unmeasurable) indicators, or to philosophize about the Ideal Indicator, than it was to produce a limited, comprehensible number of compelling, effective indicators. Our understanding is im-

Oh please! Not again new indicators! I only want to see simple indicators that can be used by politicians and let the scientists stop with ever more complicated stuff!

— A very high UNEP official

[14] H. Bossel, "Finding Indicators of Sustainable Development," Center for Environmental Systems Research, University of Kassel, draft, September 1997.

perfect, our worldviews get stuck, systems are complex, people disagree, we fall back on our narrow specialties, we fail to summon the enormous creativity we need. One wants to throw up one's hands and go do something easy.

To keep ourselves from ducking the difficulties, some of us created, at irregular intervals throughout the workshop, an imaginary challenge to come up with ten, just ten, crucial indicators we would recommend to the nations of the world, "or else be shot at dawn." Under that pretended pressure, most of us did produce indicators.[15] We were unhappy with our forced lists and pleaded for more time. We repeated the exercise and our lists changed as the workshop proceeded and we thought more deeply. We didn't like to be forced to produce (who does?) but in fact even our imperfect suggestions were probably improvements on existing indicators. And the forcing exercise brought out questions, considerations, doubts, and ideas that led us to more creative indicators.

If you aren't too dignified, I would recommend the "ten indicators or be shot at dawn" exercise when you find yourself bogging down. Otherwise it's too easy to indulge in theorizing or politicizing or some other evasive activity.

Most of us already have indicators in the backs of our minds, "beloved indicators" that reflect issues of great concern to us. It's important to get them out on the table.

We noticed each time we did the forcing exercise that we each had "beloved indicators," which we kept putting back on our lists because we just plain wanted them there. (See the list on the next page.) These indicators were different for different people; they may not be the best ones to put into the cockpit of the sustainability jetliner, but they are worth paying attention to. When we try to explain *why* we want them, we find ourselves bringing out our deepest worldviews and values. They may suggest practical indicators of great importance — or at least once they've been acknowledged and talked through, our minds can be at rest and ready to think about other indicators.

[15] Some of us considered the whole exercise undignified and refused to participate. Others declared that the process of choosing indicators was more important to them than the product — and that the proper broad base of constituents was not present at the workshop.

Here are some of the beloved indicators that participants in the Balaton workshop kept insisting upon (which may tell you more about us than about sustainability indicators):

- Percent of the food supply that is grown organically. We are worried about the effects of chemical agriculture on ecosystems and human health.
- Percent of streams you can drink from safely. Seems to us it should be 100 percent.
- Average age of the trees in the forest. Old ones signify to us undisturbed ecosystems, too many young ones signify unsustainable forestry.
- Population trends of migrating songbirds. To us life would be unbearably sad without songbirds, and migrating birds are sensitive measures of environmental health over large areas.
- Food miles (average distance an item of food travels before being eaten). Local food is likely to be more fresh, nutritious, good-tasting, and resilient to supply interruptions. It has also used less packaging and transport energy.
- Average distance between creators and consumers of art and media. Preferably there is no distance at all — a measure of community, participation, identity, self-expression.
- Percent of elections in which you get to vote for a politician you really trust. This one could be an embarrassing indicator of real democracy.
- Average distance between living places of members of extended family. For affection, social resilience, and energy efficiency, the closer the better.
- Average number of minutes spent daily in prayer, meditation, or quiet time.
- Percent of people who say they have "enough." We wonder if a society is happy if significant numbers of people, however rich, constantly want "more."

Indicators can take many forms. They don't have to be numbers. They can be signs, symbols, pictures, colors.

We thought of many different types of indicators — digital and analog, monetary and physical, aggregated and disaggregated, static and dynamic, additive and multiplicative, normalized and absolute.

We particularly distinguished between three types of indicators that would be necessary in any airplane cockpit, for which there are obvious analogies in sustainable development:

• gauges and warning lights to signal obstacles or dangers ahead;

• indicators of the comfort and safety of the passengers;

• measures of the heading and distance to go toward the destination.

We got into long, hot discussions about the meaning of symbols (more about this later). We began to imagine different ways of presenting indicators — illuminated control panels, hypertexted Web pages, pictures, dynamic models, maps, compasses. We talked about the power of the famous *Bulletin of Atomic Scientists* "Minutes to Midnight" clock that powerfully, if qualitatively, measures the political tension of the nuclear arms race. We thought of the creative ways that TV weather reporters deliver complex information.

Surely as much effort and ingenuity ought to go into reporting to the people of the world about their welfare and the sustainability of their planet as goes into reporting to them about tomorrow's weather!

What is needed to inform sustainable development is not just indicators, but a coherent information system from which indicators can be derived.

As we went back and forth, suggesting specific indicators, then backing off to talk about the philosophy of what we were doing, we realized that we were searching not just for **indicators** but also for an **information system** about sustainable development, of which indicators are just one part. That is to say, we were talking about the design not only of the instrument panel (indicators) that governments and citizens need to see to steer the ship and avoid obstacles, but also the design of the background wiring (information system) that collects and sorts information and delivers it to the panel.

We saw that we were working on three levels. First, we were evolving ideas for **process, linkage,** and **worldview explication** that could aid the search for indicators. Second, we were developing a **framework** (a model) to organize and link together an entire sustainable development information system. Third, we were coming up with **indicators**. Our discussions on these three levels constitute the next three sections of this report.

5. Suggestions for indicator process and linkage

Everything should be as simple as possible, but not simpler.

— Albert Einstein

Hierarchy: coherence up and down the information system

The information system should be organized into hierarchies of increasing scale and decreasing specificity.

Whether or not the world is actually arranged in hierarchies, our mental models perceive the world that way. We see a hierarchy from the individual to the family, the neighborhood, the community, the region, the nation, the world. Or from the organism to the population to the ecosystem to the biome to the planet. Or from the employee to the division to the firm to the sector to the national economy to the global economy. At each of these levels, actions are taken and information is needed. So we picture a nested set of indicators, each informing the "system in focus" at its own level (say, actual water quality in this lake) and aggregating to inform the system at the next higher level (average water quality in the region's lakes).

Aggregation is necessary to keep from overwhelming the system at the higher levels of the hierarchy. The brain cannot and need not process everything happening to every cell in the body. The leaders of nations can't keep track of every family, species, business, or lake. But actors down the line, in the family, near the lake, need detailed information to keep their part of the system functioning well.

Aggregation must be done with care, because information is lost at each stage. Ideally only important information should be passed up to higher levels, but what information is important will change over time and with different purposes. Therefore it should always be possible to go down as many levels as necessary to see the numbers that have been put together to make the aggregate indicator and to create new indicators. (For example, it should be possible for anyone to find out not only *that* the GDP went up, but *what* went up — home construction or weapons construction, cleaning up after natural disasters or cleaning up the environment.)

"Clicking a hypertext page" is the phrase we used to indicate our vision of the way a user could navigate a hierarchical information system.

> The main "cockpit" would show the most critical and aggregated indicators (say, for example, the quality and adequacy of human capital). A "click" on that indicator would open a more detailed set of information (say, size of population and primary attributes — age, sex, health status, education, income, employment). Another "click" on health status could open boxes of information about age-specific mortality and morbidity rates and causes. Further "clicks" could give the same information about specific geographic sub-areas. And so forth.

Information from the hierarchy at all levels should be available to people at all levels.

Like a library, an information system rich at every hierarchical level yet clearly organized so that one can find one's way among the levels, would be maximally useful for matching diverse kinds of information to the diverse purposes for which people need information.

One of the pitfalls of such a flexible information system, however, is that it can be manipulated. It allows the user to choose only those indicators that serve a pre-conceived outcome. Selecting information to justify only one point of view is a trap that even well-meaning users can fall into. The only way to get around it is to be sure the information system is accessible to users with many points of view. Then multiple interpretations can emerge and can be discussed not at the futile level of throwing contradictory statistics at each other, but at the level of examining the models and purposes that cause those statistics to be selected from the full set available.

Making sure that "cockpit indicators," the aggregated ones at the top of the hierarchy, are comprehensive can also help overcome the all-too-human tendency to pay attention only to the news you want to hear. If, for example, economic productivity indicators are improving nicely, *It comes back to local knowledge. People have said that the beaches are more polluted than what they've been. I could have told you that. Because I've seen from upstairs for thirty years and looked out the window every day and seen the color of the sand change color. Whereas it used to be like everyone imagines sand, it's now a browny color.*

— focus group participant, Lancashire County, UK[16]

but indicators of the security of households, say, or the integrity of communities are falling apart, and if the cockpit indicator blends those two sources of information, then at least the question will rise, "why isn't this indicator rising, when the economy is doing so well?" Presumably a scan of the indicators at the next level down in the hierarchy will answer that question.

Information should also come from all levels. The public can be important contributors to, as well as users of information and indicators.

Governments have the scientific and financial resources to gather information that is inaccessible to citizens, such as satellite imagery or radiation leaks. Citizens can provide detailed ground-truth that is inaccessible to governments.

For example, a nongovernmental organization called River Watch in the United States organizes high school science teachers to involve students in regular chemical and biological monitoring of a stream near each school. The schools link their findings through computer networks, thereby creating monitoring networks for entire streams and rivers. They have been able to detect changes in water quality quickly, and even, by comparing data on successive reaches, to pinpoint the source of a problem emission. If enough sections of river could be covered this way, the information could be aggregated upward into, for example, an index of what percent of the nation's surface water is of swimmable and drinkable quality, and how that index is changing over time.[17]

Costa Rica has organized through its Instituto Nacional de Biodiversidad (INBio) thousands of its citizens as local naturalists, trained to collect and preserve insects, plants, birds, and to send them to taxonomists for classification. Working in their spare time, the laborers, students, housewives, and retired people in this program are cataloguing the vast biological diversity of their nation. They have discovered hundreds of new species. The species catalog is computerized and made available at libraries and schools throughout the country. When the catalog is done, the citizen naturalists can become monitors of population size, breeding success, and other attributes of biological diversity.[18]

Similarly the Christmas Bird Counts conducted by Audubon Society volunteers, originally in North America, now throughout the Western Hemisphere, are proving one of the most reliable long-term bird population data bases in existence.[19]

Citizens could survey many things at the local level: soil erosion, child nutrition, adequacy of housing, use of local energy sources, quality of roads, water, jobs, schools, or forests. Citizen monitoring not only can provide excellent information at low cost, it can also contribute to the education of the people and to widespread appreciation for natural and societal wealth.

The Selection Process: experts and citizens together

The process of indicator development for social systems is as important as the indicators selected.

As indicators are selected and defined, values are expressed, purposes are agreed upon, worldviews are at play, and models are developed and shared (implicitly or explicitly). Therefore the selection process is the place where legitimacy and comprehension are built, as people see their values and worldviews incorporated into the indicators. The process of indicator selection is also one of the key places where social learning about indicators and models takes place.

For all these reasons — to be inclusive, to gather a full compilation of viewpoints, to legitimize the product, and to enhance learning — the more people involved in indicator selection the better. Indicators for an entire social system should not be determined by a small group of experts or politicians or civil servants sitting together in rooms out of contact with the people who are expected to understand and use the indicators.

The indicator selection process works best with a combination of expert and grassroots participation.

Many indicator-defining groups have found that they made greatest headway in finding useful indicators if they put together experts on the subject in question with interested non-experts.

Experts are necessary to supply comprehensive understanding, perspective on the development of the system over time, knowledge of what data are available, realism about what can be measured, and credibility to the process. But experts, left to their own devices, can get lost in details, can want to measure everything that is intellectually interesting rather than what is policy-relevant, can invent technical indicators that carry no meaning outside the expert community, and can be blindered by the narrow specificity of one area of study.

Non-experts tend to push to make the indicator relevant and understandable. The non-expert may be more open than the expert to creative

[16] Quoted in P. Hardi and T. Zdan, eds., *Assessing Sustainable Development: Principles in Practice.* Winnipeg, Manitoba: International Institute for Sustainable Development, 1997, p. 107.

[17] River Watch Network, 153 State Street, Montpelier, VT 05602. Another such organization is the Global Rivers Environmental Network (GREEN, 206 South Fifth Ave., Suite 150, Ann Arbor, Michigan 48104, U.S.A.)

[18] INBio, Sto. Domingo 3100, Heredia Costa Rica, Tel.: (506) 36-7690, Fax: (506) 36-2816.

[19] The data are complied and maintained by the Patuxent Wildlife Research Center, Laurel, Maryland. The CBC started on Christmas Day, 1900. Today, over 45,000 people from all 50 states, every Canadian province, the Caribbean, Central and South America, and the Pacific Islands (all areas where the breeding birds of North America spend their winter) participate in about 1700 counts held during a two and one-half week period. The Christmas Bird Count has evolved into the largest and longest-running wildlife survey ever undertaken.

linkages and syntheses, more likely to capture the "big picture," more likely to be sure a diversity of interests are represented. Just as the expert brings scientific credibility to the indicator selection process, the non-expert brings political credibility.

But integrating expert and non-expert opinion has its costs and must be done with care.

Involving "everyone" can produce disproportionate representation of some stakeholders, too little technical knowledge, too much focus on immediate interests, risk of incomplete mapping of the area of interest, and no holistic understanding. Furthermore, it can be inordinately time-consuming, may be difficult to enroll sufficient participation, requires skilled facilitation, tends to get stuck in process discussions, and tends to produce low-level "concrete" indicators.

Some practitioners who have weathered these challenges suggest the following ten-step process for developing an indicator set.[20] They recommend that the process be managed by impartial facilitators whose role is to coordinate meetings, guide the discussion, prepare background documents, and synthesize results.

1. Select a small working group, responsible for the success of the entire venture. The working group needs to be multi-disciplinary, with strong ties to the community or audience for whom the indicators are intended. The working group is most effective when it combines experts and non-experts from the outset, but the critical element is long-term commitment to the process.

2. Clarify the purpose of the indicator set— whether it is meant to educate the public, provide background for key policy decisions, or evaluate the success of an initiative or plan. Different purposes give rise to different indicators and publication strategies.

3. Identify the community's shared values and vision. The indicator set must be able to speak to the hopes and aspirations of the people it is meant to serve.

4. Review existing models, indicators, and data. The working group takes a look at other indicator projects as examples to learn from. It also reviews what indicators are already published locally and what data are generally available.

5. Draft a set of proposed indicators. The working group draws on its own knowledge, the examples it has collected, and the advice of outside experts if needed to prepare a first draft. The draft may go through several revisions before it is ready for the next step. In particular, initial indicator sets tend to be very long. In later drafts, they need to be pruned down and made more focused and practicable.

[20] "The Community Indicators Handbook," available for US$20 from Redefining Progress, 1 Kearny Street, 4th Floor, San Francisco CA 94108. Tel.: (415) 781-1191, Fax: (415) 781-1198, Email info@RProgress.org

6. Convene a participatory selection process. The draft indicators need to be presented to a broad cross-section of the community for their input. This process serves several important goals. It educates the participants, gathers their collective creativity and expertise, and makes them stakeholders in the success of the project. Often it also gives rise to new relationships and alliances among the participants and can even generate new action initiatives to address problems identified by the indicators.

7. Perform a technical review. An interdisciplinary team of knowledgeable people sorts through the proposed final draft indicators and selects for measurability, statistical and systemic relevance, etc., trying to stay true to the intentions and preferences expressed by the citizen review process. The technical review helps to fill in gaps, weed out technical problems, and produce a final indicator set that is ready to be fleshed out with data.

8. Research the data. At this stage, the indicators are usually subject to additional revision, driven by data concerns and new learning.

9. Publish and promote the indicators. This requires translating them into striking graphics, clear language, and an effective outreach campaign. It helps to link the indicators to the policies and driving forces that affect them, to illustrate their linkages, and to point to the actions that can be taken to improve them.

10. Update the report regularly. Indicators make little difference, or indeed little sense, if they are not published periodically to show change over time. This requires an institutional base that can be relied upon to reproduce steps 8. and 9. on a regular basis, and to go back and revisit the other steps as needed. Each new version of an indicator report becomes an opportunity to revise the indicators, develop new research methods, and add linkages. If performance targets have been set, they can be assessed and, if necessary, adjusted. And when targets are met, celebrations can occur!

These steps may sound daunting, but they are being put into practice by hundreds of community- and regional-level indicator movements around the world.[21]

Systems: making indicators dynamic

We should not tackle vast problems with half-vast concepts.

— Preston Cloud

Systems insights can help in the design of indicators that identify critical linkages, dynamic tendencies, and leverage points for action.

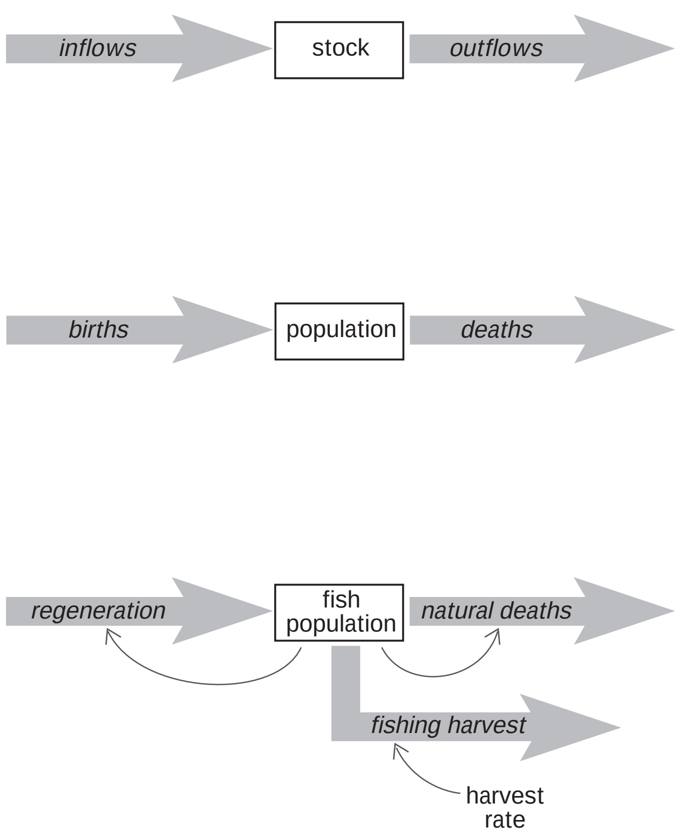
Systems change over time, and it is often exactly their dynamic behavior that we want indicators of sustainable development to tell us about. Is the population or the economy growing more or less rapidly than it used to be? Are

[21] Ibid.; and also P. Hardi and T. Zdan eds., op. cit.

weather patterns becoming more or less variable? For how long can the fish population support this rate of harvest, and what happens if it can't?

System dynamics is a field of expertise that specializes in understanding the unfolding *behavior over time of whole systems.* Therefore it can be useful in finding linkage indicators, leading indicators, and leverage points where systems are especially likely to signal change or respond to action.

This section contains a brief summary of some insights from system dynamics about how to design dynamic indicators.



Distinguish between stocks and flows. Stocks are indicators of the state of a system and its response time. Flows may be leading indicators of change.

Stocks describe the state of the system at any particular time — the amount of biomass in a forest, people in a nation, factories in an economy, money in the bank, water in an aquifer, greenhouse gases in the atmosphere. Stocks are accumulations of the past history of the system. The sources in nature from which raw materials are drawn are primarily stocks. So are the sinks in the environment into which pollutants are poured, or the factories and tools that make up the productive capital of a nation. Stocks are generally the most countable elements of systems, and hence they make obvious indicators.

Stocks are usually slow to change. Even if CFC emissions cease today, the accumulation of chlorine in the stratosphere will take decades to decline. If a new energy source is invented tomorrow, there would be a long delay before existing stocks of cars and furnaces and industrial boilers that burn the old types of energy can be replaced. Therefore the size and lifetimes of stocks can give us useful indicators of **response rates** — how long it will take a system to correct a problem, adjust to a change, or take advantage of a new opportunity.

Suggested dynamic indicators:

Turnover time, which is stock size relative to stock change rate. Especially relevant for understanding the time it takes for aquifers or surface water bodies (or the atmosphere) to flush out pollution, or for the time it takes for industrial capital stocks (such as the automobile fleet) to be replaced.

Coverage time, which is stock size relative to the drain on the stock. Especially relevant to calculate adequacy of supply. Fossil fuel reserve/ consumption is an example already given here. Food reserves relative to food consumption (number of days current supplies can cover consumption), or inventory relative to sales rate are other examples. Note always the difference between coverage at steady consumption and coverage at exponentially increasing consumption.

For **leading indicators,** we need to monitor **flows.** Flows are the inputs or outputs (measured per time unit) that increase or decrease stocks. Harvest and growth of trees, births and deaths in the population, construction and depreciation of capital are all flows that change stocks. Flows in turn are driven by other stocks. (Tree harvesting depends on the number of chainsaws and loggers and trucks, as well as on the stock of trees in the forest.)

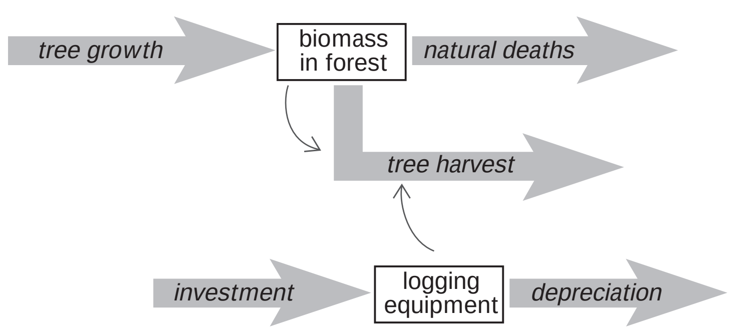
Advance warning comes from the balance of flows affecting a stock. A buildup of greenhouse gases in the atmosphere, for example, is predictable when the rates of emission of those gases begin to exceed their natural rates of recycling or absorption. Deforestation is indicated not when the forest is gone, but when the rate of harvest first exceeds the rate of regrowth.

Suggested dynamic indicators:

Harvest/regeneration, the essential measure of sustainable use of a renewable resource, whether fish, water, forest, soil. If the index is above 1.0, the harvest is not sustainable.

Emission/absorption, where absorption means any process, natural or human-mediated, that renders a pollutant harmless. This is an essential measure of the sustainability of any waste stream, with values above 1.0 indicating unsustainability.

Since some of these flows may be hard to measure directly (regeneration in a forest, absorption in the soil), they can be measured indirectly by changes over time in the relevant stock. *Any resource stock that is falling is being used unsustainably. Any pollution sink that is filling is being used unsustainably.*



The stock-flow orientation is related to the pressure-state orientation common to United Nations and other indicator systems. Stocks are measures of system states. Flows are measures of pressures that change those states.

Exponential growth rates (the strengths of vicious or virtuous cycles) are sensitive points in systems.

A revealing indicator in dynamic systems is the rapidity of exponential growth processes (which systems analysts call **positive feedback loops**). Exponential growth is growth that feeds on itself — the more you have, the more you get. The two most obvious places where that type of growth occurs are population and economic output. In fact, the most basic development indicator is the ratio between the two — the rate of growth of output per capita.

Positive feedback loops drive more than population and economy, however. Teachers teaching more teachers builds up the educational capacity of a nation. Knowledge leads to more knowledge. Natural populations, such as fish or trees, grow exponentially, when they grow at all.

Epidemics proceed through positive feedback loops — more sick people infect more people, who then infect more people. Pest populations can explode exponentially. Desertification and other erosion processes can degrade soil in a vicious downward spiral — fewer trees have fewer roots, which are less able to hold soil against erosion; less soil allows less plant growth, still fewer roots, still more erosion, and so forth. Interest on debt is also a downward exponential spiral, increasing the debt more each year than the year before, unless repayments exceed interest charges.

Whether the cycle is vicious or virtuous, small changes in growth rate can signal large potential changes in the system. For example, a growth rate of 1 percent per year means that over a century the population (or economy) will grow to 2.7 times its present value. A growth rate of 2 percent means that in a century the population or economy will grow by a factor of 7.4. A growth rate of 3 percent over a century will produce a population or economy twenty times its original size!

Suggested dynamic indicators:

Doubling time or halving time. Percent changes are hard to imagine; doubling times are more easily understood. The doubling time of an exponential growth process is 70 divided by the growth rate. So a city growing at 7% per year will double in 10 years (and double *again* in another 10 years, if that growth rate continues). A population growing at 3.5% per year will double in 20 years. An agricultural yield going up by 2% per year will double in 35 years.

Similarly, halving times of entities that are decreasing exponentially are 70 divided by the decrease rate. A forest being cut by 3.5% per year will be half gone in 20 years. Soil eroding at 1% per year will be half gone in 70 years. A fossil fuel resource being consumed at 7% per year will be half gone in 10 years.

(Calculating doubling or halving times does not imply that an exponential growth rate *will continue unchanged* over any future period. The point of a doubling or halving time calculation is usually to point out that it can't or shouldn't!)

Exponential growth against a limiting resource. A powerful way to communicate the implications of an exponential growth process is to relate it to a fixed or limiting resource — to show the exponentially shrinking resource per capita. For example, Hawaiians understood the implications of exponential population growth, when they started plotting over time the *miles of beach per person.* China took population growth seriously when it extrapolated figures for *cultivable land and available water per person.* Many cities would be shocked to plot over time their *miles of road per car.*

The ratio of change rate to response rate is a critical — and usually critically missing — indicator of the degree to which a system can be controlled.

Rates of change around positive feedback loops are even more useful indicators when they are combined with information about possible response times. *In fact, the combination of the two — change rate compared with response rate — makes an indicator of the controllability of the system.*

During the 1970s, the production of CFCs in the world was growing by about 7 percent per year. That makes a doubling time of 10 years. It takes a CFC molecule ten to fifteen years to rise from the earth's surface up to the stratosphere, where it breaks apart and starts destroying the ozone layer. Given that growth rate and that lag, *the problem doubled before it could even be measured.*

Clearly a system that is changing faster than anyone can know or react is a system that cannot be managed, controlled, or protected against damage. The concept of change/response as a measure of system safety has been highly developed in the field of nuclear engineering. The time it takes for a nuclear reactor to "go critical" and reach an irreversible rate of neutron generation (in other words an explosion) is called the **respite time.** The **response time** is the time it takes for operators to notice a problem, track down its source, and mobilize control rods to absorb and slow down neutrons. A reactor with a response time longer than its respite time is inherently unsafe.[22]

So is any system in which problems are generated faster than they can be responded to. Even if technologies are powerful, even if financial resources and political will can be summoned, if a problem comes on faster than technologies, money, or will can take effect, that problem will be unsolvable. The situation will be equivalent to driving a car too fast — though the brakes may function perfectly, obstacles can't be seen in time to stop.

Therefore a powerful warning indicator can be created from the *rate of increase of a problem divided by response rate.* This ratio could be measured as rate of change in percent per year divided by rate of response in percent per year, an index that gets critical as it approaches 1.0. Or, if, as in the ozone case, the problem is a discrete lag in detection or response, the ratio could be measured as **response time/ respite time.**

Such an indicator could be applied, for example, to:

- the depletion time of any resource relative to the time to develop a substitute;
- the rising educational needs of a growing population relative to the rate of training teachers and building schools;
- the spread of pesticide resistance relative to the time to develop a new pesticide;
- the doubling time of greenhouse gas emissions relative to the response lags in the climate system that allows climate change to be detected;
- population growth in a city relative to the rate at which the city can add infrastructure to handle sewage, garbage, or traffic.

Any system in which the rate of growth of a problem is significantly faster than the rate of response is, quite simply, out of control. There are only two ways to bring it back into the realm of manageability: either quicken the response rate (if possible) or slow the growth rate of the problem (or both).

The concept of respite time versus response time is new to many managers and missing from most indicator sets — and obviously critical to any hope of achieving a sustainable society.

[22] The respite time/response time indicator was suggested to us by Wouter Biesiot and the staff of the Center for Energy and Environmental Studies, University of Groningen, the Netherlands, November 1995, draft prepared for our workshop.

Watch for unbalanced or missing control loops.

Complex systems, whether natural or human-designed, are managed through control loops (**negative feedback loops** in systems terms) that monitor the state of a system and act to keep it in balance. A common example is the thermostat. When the temperature in a room falls, the thermostat switches on the furnace, causing the temperature to rise again. When the temperature rises, the furnace is switched off. Other common control loops maintain blood sugar level in the body, keep a plane flying in its intended direction, and adjust prices to equilibrate supply and demand in an economy.

When systems behave pathologically, it is often because balancing negative feedback loops are weak or missing. Overfishing is almost inevitable, if there is no system for regulating the catch depending on how many fish there are. Forests may be cut down uneconomically if those doing the cutting are not assessed the value of the services provided by standing trees (such as flood protection or carbon sequestration). Rivers are easily polluted if there is no way downstream populations can regulate or claim damages from upstream polluters. Those are all examples of **missing indicators**, which, once they are restored, will supply the necessary control loops to allow a system to adjust itself automatically.

The famous dilemma of "the tragedy of the commons" is an example of missing feedback control when there is a common resource and no price or penalty for use of the resource short of its exhaustion.[23]

[23] G. Hardin, "The Tragedy of the Commons," *Science* 362, no. 3858 (December 1968): 1243-48.

Examples of indicators and enforcement systems to supply missing feedback control:

A warning light on pumps taking groundwater from an aquifer, to indicate whether the aquifer is filling (green), stable (yellow), or falling (red). Ideally the cost of the water would rise steeply as the light turns red.

A meter on the dashboards of cars, showing the instantaneous rate of fuel consumption (measured in money expended) — which would give drivers feedback on more and less wasteful driving habits.

A permit system for boats in a fishery, cutting the allowed number of boats or fishing days if the fish population falls.

Required stickers (purchased from the municipality) on municipally collected garbage, so that people who generate more trash have to pay more for its disposal.

Emission quotas for large-scale pollutants such as sulfur dioxide or carbon dioxide, the total amount to be determined upon biophysical sustainability grounds, to be auctioned off regularly to the highest bidders. (Such a system would put a price on the commons of clean air and would allow the market to distribute efficiently the right to pollute. It would also provide a control mechanism to keep total pollution within health and safety guidelines.)

Notice that in the above systems, the indicator gains real force when it is coupled with a fee or regulatory system.

An important indicator of the resilience of a system is the redundancy of its controlling negative feedback loops.

When an ecosystem loses species, it may lose control mechanisms by which predators and prey keep their relative populations in balance. When a village loses access to lands from which it supplemented its food supply in times of famine, it has lost an element of emergency self-maintenance. Resilience is lost when family members are geographically scattered, or when a watershed loses wetlands that absorb floodwaters, or when a nation becomes dependent upon a single, imported source of energy, or when a government fixes a price so it can't respond to supply and demand, or when a body's immune system is compromised.

Removing or weakening feedback loops that provide resilience is equivalent to removing the fire detectors and sprinkler systems in a building, or the emergency cooling systems of a nuclear power plant, or the health care capacity of a society, or the insurance policies from a business. Resilience can be stripped away from a system without immediate cost (actually saving cost) and without affecting the functioning of the system, until a crisis comes that demands that resilience. At that point the cost can be tremendous.

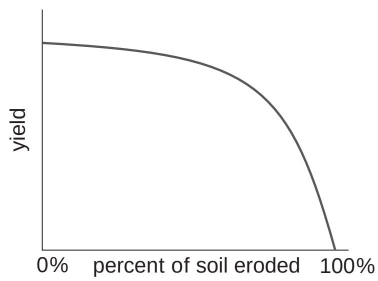
You can see why it is important to sustainable development to have indicators that measure resilience. If immediate operating cost is the only indicator, there can be great temptations to remove resilience or let it deteriorate in order to realize short-term cost-saving.

Resilience is not commonly or easily measured; it will take some creativity to invent good indicators here.

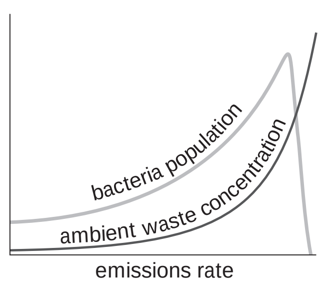
> The only specific suggestion I can think of here is to use a concept familiar to most economic-minded persons: insurance. There must be simple indicators that calculate for an enterprise how much is being expended on insurance and how adequate that insurance is. (Companies willing to cut corners in all others areas rarely seem to stint on buying insurance.) Could that concept be extended to families? Communities? Ecosystems? Planetary geophysical flows?

Nonlinearities in systems (turning points, thresholds) are key points for the placement of indicators.

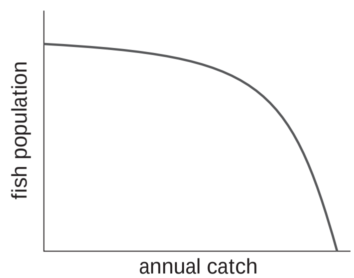
You can erode the soil right down to the depth of crop roots without much impact, but erode it a little past that point, and crop yields plummet:



You can emit nutrients into a stream and natural bacteria will clean them up, but if you emit too much too fast, the natural biota may be killed off, and the stream turned into a sewer where wastes pile up without amelioration:



You can catch fish and open up ecological space for immigration or reproduction of more fish — up to a point, after which the diminished population may be unable to breed or may be open to competitors, at which point it plummets:



Turning points like these mark thresholds beyond which the behavior of a system changes radically, sometimes irreversibly. Clearly we need indicators that signal them well in advance. These “distance from the edge” indicators are like radar warning a ship or plane of an obstacle ahead. The faster the ship or plane (or economy) is moving, the farther ahead they have to look, to allow sufficient braking or turning time. (Back to the change rate/response rate discussion!)

Suggested dynamic indicators:

Time to turning or irreversibility point. If the threshold or nonlinearity is well understood, the time to reach it, given current rate of approach, should be calculable.

Degree of risk. If the threshold is not well understood, which is often the case (how many species can you take out of an ecosystem before it collapses? how far down can you bring the fish population before it no longer can restore itself? how much money can you allow private persons to give to elected officials before all trust in democratic government is gone? how many greenhouse gases can you put into the atmosphere before you derail massive ocean currents?), the challenge is to design indicators that convey the degree of risk. One possibility is to deliver information about the full range of estimates (as the IPCC scientists have done painstakingly in communicating about climate change). Even when the uncertainties are great, considered guesses are better than no information at all.

A primary indicator of the long-term viability of a system is its evolutionary potential.

The resilience of a system is its ability to recover and repair itself from shocks. Short-term resilience depends on adequate controlling negative feedback loops, as discussed above. Long-term resilience depends on the **evolutionary potential** of a system — its ability to adapt to new conditions, to create new species, structures, technologies, or ideas — to evolve.

The most important reason why biological diversity should be preserved is because the gene pool is nature's raw material for evolution. For human societies, evolutionary potential lies in technology, knowledge, the variety of organizations in the civil society, foresight, tolerance, and the mental and social flexibility to be open to new ideas, to test them quickly, to select the ones that apply best under present and impending future conditions, and to evolve new ideas and institutions.

To measure sustainability, we need indicators of the potential for evolutionary change. These have to do with diversity, tolerance, ingenuity, open-mindedness, education, and truth-telling about the success or failure of experiments.

Possible indicators:

Ecological evolutionary potential might be measured by the rate of disappearance of species relative to the number of species originally there (equivalent to the rate of disappearance of books or journals in a library).

Technological evolutionary potential might be approximated by scientists per capita, basic research expenditures per capita, inventions or scientific prizes per capita (though the latter is a lagging indicator, reflecting the training of the past generation, not coming ones.) A better measure than any of the above would get more directly at creativity, originality, quickness of problem-solving, elegance and ingenuity of solutions. (Percent of high-school students working on solar cars? Truly original inventions patented per capita? Number of startup companies based on completely new concepts? Average length of time major technical problems persist before they are solved?)

Cultural evolutionary potential might be captured in the number of different races, cultures, religions that live together *in peace* within a given geographic area. A leading indicator of the breakdown of this potential might be the frequency of ethnic or cultural hate-talk in the public media, especially when it comes from public leaders. (Monitoring this indicator would have provided early warning of the development of the fascist regimes in Europe in the 1930s and the breakdown of Yugoslavia in the 1990s.)

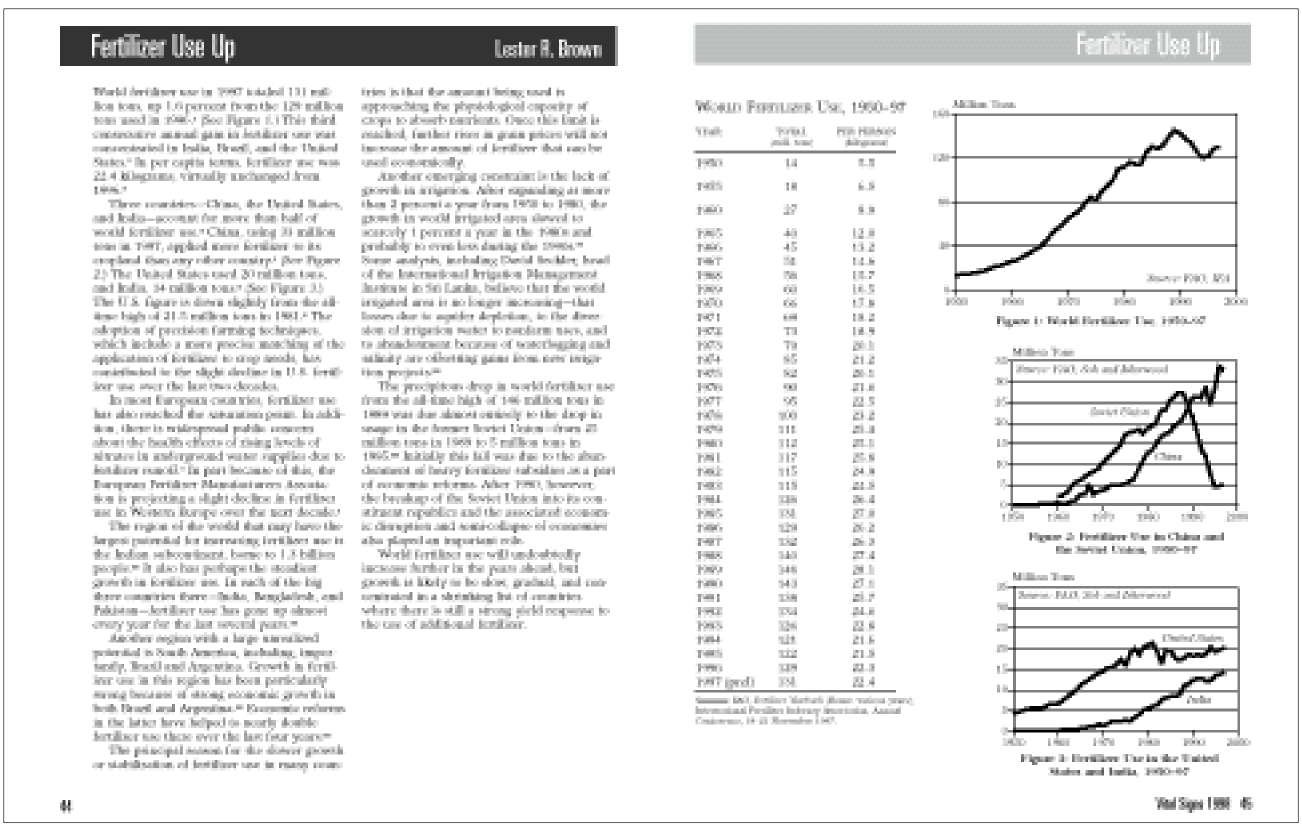
Wherever possible, indicators should be reported as time graphs rather than static numbers.

Time graphs show not only the present state of an indicator, but its trend over time — improving, declining, fluctuating, becoming more or less unstable. It's not really possible to understand an indicator unless one knows its dynamics. It is often especially illuminating to compare one time trend with another on the same graph and same scale.

Worldwatch Institute in its annual report *Vital Signs* devotes a two-page spread to each of its indicators (see below). One page is explanatory text, the other shows the development of that indicator over time, both as a table of raw data and as a time graph. Other graphs on the page may disaggregate the indicator to show its constituent parts or provide some other illuminating information.[24]

This is an economical way to communicate a great deal of information to a wide audience, and especially to give that audience a grasp of the history and potential future of each indicator.

[24] L. R. Brown et al., *Vital Signs 1998.* New York: W. W. Norton & Company, 1998, pp. 44-45.


Fertilizer Use Up

Lester R. Brown

World Fertilizer Use, 1950–97

Figure 1: World Fertilizer Use, 1950-97

Figure 2: Fertilizer Use in China and the Soviet Union, 1950-97

Figure 3: Fertilizer Use in the United States and India, 1950-97

44

Vital Signs 1998 45

Indicators should be combined with formal dynamic modeling.

Most of the indicators mentioned in this section are potentially powerful, but not easy to define or understand unless they are accompanied by a dynamic model that can help, for example, spin out the future consequences of present exponential growth rates, or calculate the ability of control loops to stabilize a system.

Models of this type are already being used to help understand climate change, fish population dynamics, changes in the stratospheric ozone layer, demographic developments in populations, and macro-economic growth.[25] The co-development of indicators and dynamic models can help not only to identify trouble spots in the system, but can help test, gauge, and time corrective actions.

Action will be taken on the basis of models in any case, mental models or formal models. The search for indicators is a search for better models, ideally dynamic models that can help us understand the timing of problems and solutions.

[25] The literature is vast. For a start, see any issue of the *System Dynamics Journal* or the following websites: http://web.mit.edu/jsterman/www/DID.html; http://home.earthlink.net/~tomfid/sdbookmarks.html; http://sysdyn.mit.edu/road-maps/rm-toc.html

6. A suggested framework for sustainable development indicators

That which is good and helpful ought to be growing and that which is bad and hindering ought to be diminishing.... We therefore need, above all else, ... concepts that enable us to choose the right direction of our movement and not merely to measure its speed.

— E. F. Schumacher

The Hierarchy from ultimate means to ultimate ends

The "Daly Triangle," which relates natural wealth to ultimate human purpose through technology, economy, politics, and ethics, provides a simple integrating framework.

So what information needs to be displayed on the cockpit, to allow society to steer successfully toward sustainable development? What organizing framework makes intuitive sense, captures the relative importance of various indicators, and illustrates their relationship to one another? What could deliver at a glance the essence of the present situation and its rate and direction of change and the policy levers that might alter the rate and direction of change?

Several tentative frameworks have been suggested and discussed — among them the "pressure-state-impact-response" model used to organize the first indicator efforts of the U.N. Commission on Sustainable Development and other international bodies,[26] the "ecological footprint,"[27] the "four capitals" (economic, natural, human, and social capital) arising from the World Bank,[28] and the idea of "genuine savings."[29] The Balaton Group workshop found these forerunners useful; each seemed to capture an important piece of the puzzle — but not the whole puzzle. We struggled to bring them together, to distill the message that each seemed to carry, and to find a more whole-system context within which to place them. We looked for a framework that would make sense on its

[26] See, for example, "Work Programme on Indicators of Sustainable Development of the Commission on Sustainable Development," United Nations Department for Policy Coordination and Sustainable Development, February 1996, and "OECD Core Set of Indicators for Environmental Performance Review," OECD Environment Directorate, October 1993.

[27] Wackernagle and Rees, op. cit.

[28] I. Serageldin, *Sustainability and the Wealth of Nations: First Steps in an Ongoing Journey,* World Bank Discussion Draft, Second Edition, March 3, 1996.

[29] World Bank, *Monitoring Environmental Progress: A Report on Work in Progress*, ESD Series, 1995.

own terms and that would lend itself both to a comprehensive underlying information system and to underlying dynamic models. We wanted a "data-base organizer" that could be comprehended at all levels, in which one would not be likely to lose one's way, in which one would never lose sight of what is most important for sustainable development.

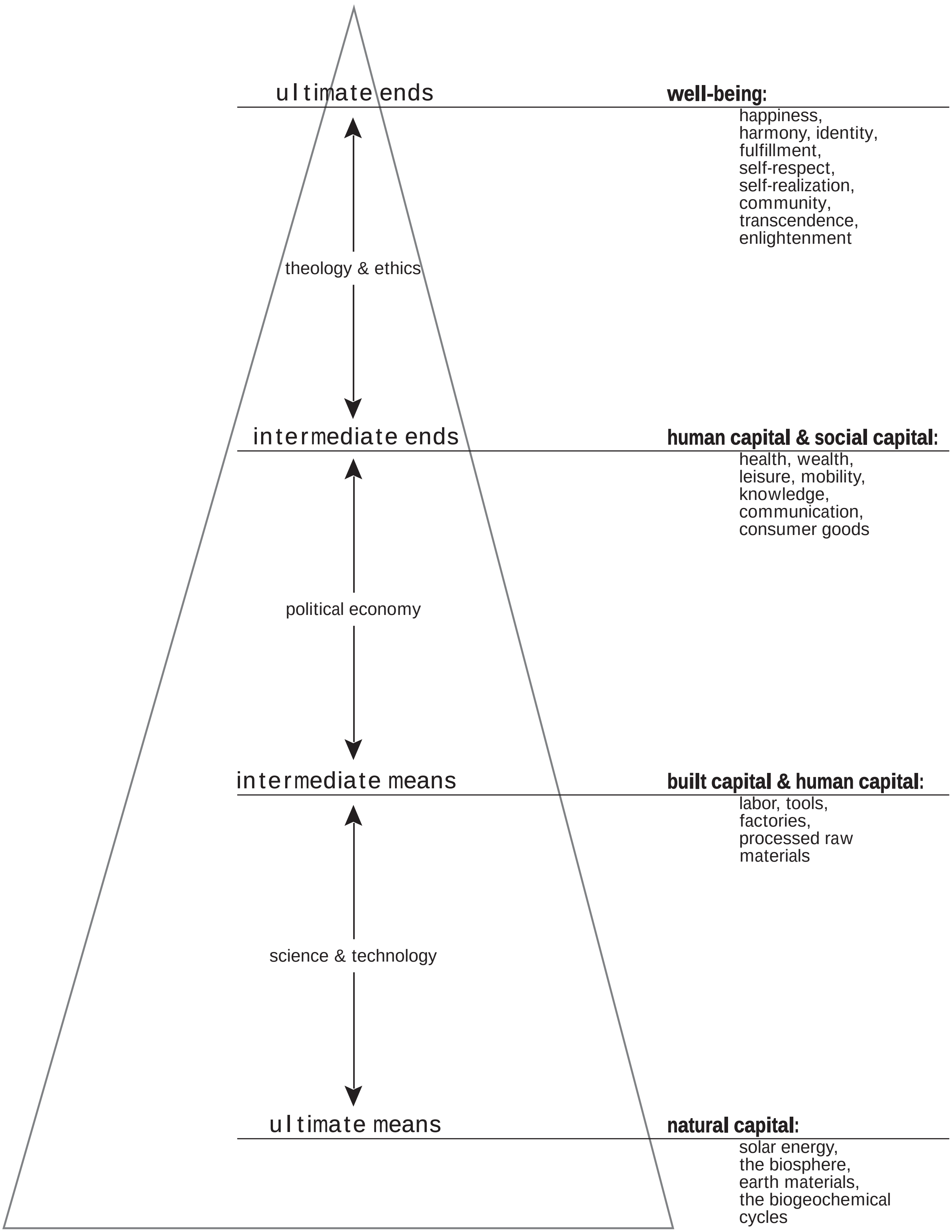
I believe we found it, but before I describe it, I must state that several of my Balaton colleagues have reservations about this scheme, more on the symbolic and philosophical levels than on the level of logical concepts. No scheme we came up with was embraced by all without reservation. Our discussions of our doubts about each scheme were revealing, showing the power of symbols and the different interpretations different cultures can bring to the same symbol. I see no way around that difficulty, except to choose a framework that seems to capture the central logic one is trying to communicate, and then, through use and example, to imbue that framework with the intended meaning. That is how every large-scale indicator, from the GDP to the Dow-Jones Index, has evolved.

The framework I suggest is based on a diagram Herman Daly drew more than twenty years ago.[30] It pictures the relationship between the human economy and the earth in a way that is, to me, logical, systematic, and clarifying. Daly originally drew it as a triangle or pyramid, and for historical purposes I will use that symbolism, though the shape is not necessary to the logic (see page 42). Daly himself abandoned it in later texts and simply drew a vertical line. The important idea is to situate the human economy within a hierarchy, resting on a foundation of natural resources and reaching to the height of ultimate purpose.

At the base of the triangle, supporting everything, are what Daly calls the **ultimate means** out of which all life and all economic transactions are built and sustained. This is **natural capital,** the matter of the planet, the sun's energy, the biogeochemical cycles, the ecosystems and the genetic information they bear, and the human being as an organism. These ultimate means are not created by us; they are the heritage we were born into, and out of them we fashion everything we have or know. They are studied by the sciences and converted through technology to intermediate means.

The **intermediate means** are tools, machines, factories, skilled labor, processed material and energy — **built capital** and **human capital** and raw material. These intermediate means define the productive capacity of the economy. Economists call them *inputs* to the economy (systematically ignoring nature's unpriced inputs from the level below). Intermediate means are necessary but not suf-

[30] H. E. Daly, *Toward a Steady-State Economy.* San Francisco: W. H. Freeman and Company, 1973, p. 8.


ultimate ends
well-being:
happiness,
harmony, identity,
fulfillment,
self-respect,
self-realization,
community,
transcendence,
enlightenment
theology & ethics
intermediate ends
human capital & social capital:
health, wealth,
leisure, mobility,
knowledge,
communication,
consumer goods
political economy
intermediate means
built capital & human capital:
labor, tools,
factories,
processed raw
materials
science & technology
ultimate means
natural capital:
solar energy,
the biosphere,
earth materials,
the biogeochemical
cycles

ficient to accomplish all higher purposes. Managing, valuing, distributing, maintaining, and using these intermediate means is the concern of economics and politics, or the political economy.

The **intermediate ends** are the goals that governments promise and economies are expected to deliver — consumer goods, health, wealth, knowledge, leisure, communication, transportation — what economists call **output.** They are what everyone wants, but they by no means guarantee satisfaction, as is revealed by societies where intermediate ends are abundant but people still feel their lives are empty. That is because intermediate ends are not ends in themselves, but instruments to achieve something yet higher. The conversion of intermediate ends to ultimate ends depends on an effective ethic or religion or philosophy that can answer the question: what are health, wealth, and education *for?*

At the top of the triangle is the **ultimate end,** desired for itself, not the means to the achievement of any other end. The definition or measurement of the ultimate end is fraught with difficulties, especially for people of Western cultures. Daly was vague about it: "Our perception of the ultimate is always cloudy, but necessary nonetheless, for without a perception of the ultimate it would be impossible to order intermediate ends and to speak of priorities."[31] He called the ultimate end the "*summum bonum,*" and insists, from his own monotheistic point of view, that it is singular, not plural.

I have added to the diagram some other words that people use to define the ultimate end of human economic activity and human life — happiness, harmony, fulfillment, self-respect, self-realization, community, identity, transcendence, enlightenment. The impossibility of defining these words, or agreeing on ultimate end or ends, demonstrates that we are discussing *quality,* not quantity, something immaterial, not material, though it requires the whole material triangle underneath to support it.

Now for the reservations. Several members of the Balaton Group have problems, not with the basic idea behind this triangle, but with its symbolism. It is too hierarchical and "Western minded" for some; too anthropocentric for others; or too static; or there's too much vagueness about the top of the triangle, where objective physical stuff somehow gets transformed into subjective human satisfaction or arguable spirituality.

We all like the idea of the economy being borne up by and drawing from nature and the idea of the economy serving higher goals and not being an end in itself. We regard those two ideas as essential to the understanding of sustainable development. We tried redrawing the Daly diagram, turning it into concentric circles of "nested dependencies," into a flower (see the title page of this re-

[31] Daly, op. cit., pp. 7-8.

port), even into a Möbius strip. We made it into a compass (a likely indicator to find on a cockpit instrument panel), with N=Nature, E=Economy, S=Society, and W=human Welfare. We got into snarls with the compass symbol too; some people interpreted it as saying that N is the best direction to go, or that if you go E, you can't simultaneously go W, etc., etc., etc. The compass, while preserving most of the content of the Daly triangle (except the ultimate end, which some people are glad to get out of the picture), loses the sequential, dependent relationships among the various levels.

The whole discussion, which became very emotional, taught us a lot about the humorlessness with which human beings take their symbols — a vital lesson for the design of indicators!

I don't insist on the triangle, though out of deference to Daly's original vision, I use it here. I certainly don't intend to convey by it the idea that the only purpose of nature is to fulfill human ends, an interpretation to which most Balaton members strongly object. (Rather, I see the triangle as saying there's no way human ends can be realized without healthy, functioning natural and economic and social systems. Others see no problem, because they assume that high human purposes must naturally include valuing nature in its own right, independent of its ability to supply human ends.) The logical relationship among the levels of the hierarchy is what's important to me, along with the challenge of orienting indicators toward the two things that ultimately count for me — the health of nature and *real* human well-being. I find the Daly pyramid the most intuitive of the many frameworks I have seen for organizing indicators, one that organizes the links among many aspects of sustainable development, and one which, as I will demonstrate here, lends itself naturally to dynamic modeling, pressure-state-response schemes, ecological footprints, and various kinds of capital.

Sustainable development is a call to expand the economic calculus to include the top (development) and the bottom (sustainability) of the triangle.

Industrial society has thousands of indicators from the middle of the pyramid, but few from the bottom and almost none from the top.

That is probably why "sustainable development" has become a global rallying cry. Obviously, the purpose of life is more than economic, and life is supported by more than that to which we can assign an economic price. Sustainable development asks us to pay attention to the bottom and the topof the pyramid, the health of nature and the well-being of people, one measured in physical terms, one measured in subjective terms; one the domain of science, the other the domain of philosophy and psychology. Seemingly incommensurable, essentially undefinable, sometimes apparently at odds with each other, the two concepts of sustainability and development clearly derive from the top and bottom of the pyramid and are linked through the intermediate steps.

Indicators can be derived from each level of the triangle separately (as I will illustrate), but the most important indicators will reflect the connections between one level and another.

The three most basic aggregate measures of sustainable development are the *sufficiency* with which ultimate ends are realized for all people, the *efficiency* with which ultimate means are translated into ultimate ends, and the *sustainability* of use of ultimate means.

It is conceivable that health, education, happiness, and harmony could increase, even if the mobilization of energy, materials, capital, and labor decreased. That would obviously be a step in the direction of sustainable development. In fact, *it would be a primary goal of a sustainable society to produce the greatest possible ends with the least possible means.*

Sustainable development indicators could rise if, say, total electricity use goes down through more efficient technology that provides light or turns motors with less current. The indicators could *rise* if more comfortable and convenient mobility were provided with fewer cars (or if unnecessary mobility were eliminated by better spatial planning.) They could *rise* if people learned to satisfy their nonmaterial needs (such as self-esteem) through nonmaterial means, instead of through heavily marketed material substitutes (such as clothes or cars).

To provide more ends with fewer means, the entire triangle, from technology through philosophy, must be balanced and integrated. If there is wisdom about ultimate ends but no technology for tapping ultimate means, the wisdom will rest on a foundation of physical scarcity. If there is technical proficiency supplying an abundance of intermediate means, but unjust politics and distorted economics, there will be plentiful capital, labor, and energy but poorly distributed health, education, and wealth. Powerful technologies and an efficient, equitable economy may make a society rich in intermediate ends, but if that society is spiritually barren, its abundance will not bring fulfillment. If technologies are destructive of the ultimate means, the entire structure will crumble at its foundation, regardless of the excellence of its upper levels.

Integration of the triangle from bottom to top requires good science *and* just and efficient political and economic systems *and* a culture that illuminates the higher purposes of life. The focus of such a society would be *wholeness,* not maximizing one part of the system at the expense of other parts. The goal of perpetual economic growth would be seen as nonsensical, partly because the finite material base cannot sustain it, partly because human fulfillment does not demand it. The focus would be on quality, not quantity, and yet quantity sufficient for the physical needs of all would not be lacking.

Therefore the most basic indicators of sustainable development would be the *sufficiency, efficiency,* and *sustainability* of the entire triangle, determined by some kind of aggregate measures of:

- real human welfare;
- environmental integrity; and
- the ratio between the two, which is a measure of the efficiency with which environmental resources are translated into human welfare.

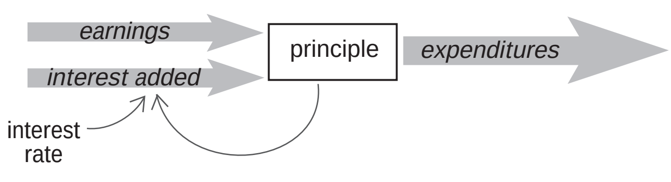
It's easy enough to say "some kind of aggregate measures of human welfare and environmental integrity," but not at all easy to produce these measures. The rest of this document is an attempt to begin to think through how to do it. I invite others to join in the thinking.

In order to develop these aggregate indicators, we need an *information system* for each step in the triangle. Those information systems depend upon the notion of several kinds of capital.

Extending the definition of capital to natural, human, and social capital could provide an easily understood base for calculating and integrating the Daly triangle.

To a bank or a university or a business or an endowed charitable foundation, "development" means increasing your stock of wealth, and "sustainability" means living on the income from that wealth, not eating into principle. No accountant would credit as "income" a temporary burst of money that comes from the drawing down of capital faster than it is replenished.

That idea extends easily to "natural capital." We should draw water from the outflow of a lake, not drain down the lake; catch fish at the rate at which they regenerate, not consume the breeding population; harvest for-



ests no faster than they can grow back; farm so the soil doesn't erode.

Herman Daly captured the concept of natural capital in the three basic "Daly Rules" for sustainability:[32]

Renewable resources (fish, forests, soils, groundwaters) must be used no faster than the rate at which they regenerate;

Nonrenewable resources (mineral ores, fossil fuels, fossil groundwaters) must be used no faster than renewable substitutes for them can be put into place;

Pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless.

These three rules suggest sustainability indicators for each resource that flows through the human economy. More on that in the next section.

The World Bank is now trying not only to establish natural capital accounts, but also to extend the concept to human and social capital.[33] Surely there is a stock or endowment of health, skills, and knowledge that can be invested in, enhanced, and used to produce a steady stream of productivity, or that can be overused, eroded, allowed to depreciate. Surely there must be social capital in the form of functioning civic organizations, cultures of personal and community responsibility, efficient markets and governments, tolerance and public trust.

The Balaton working group agreed unanimously that the idea of capital — all forms of capital — is central to information systems for sustainable development. Combined with the Daly triangle, various capital structures can capture development and sustainability and their relation to each other. They allow the stock-flow analysis that can make indicators dynamic. And they begin to suggest a conceptual framework to keep track of the linkages among many forms of capital and to derive indicators that could help people and nations build up the several kinds of wealth that are necessary for a people-enriching, nature-preserving system.

Natural Capital (ultimate means)

Natural capital consists of the stocks and flows in nature from which the human economy takes its materials and energy *(sources)* and to which we throw those materials and energy when we are done with them *(sinks).*

The materials and energy used in the human economy do not appear from nowhere. Nor, when we are done with them, do they disappear. They are taken from and return to the Earth's biogeochemical systems.

To borrow some useful but unbeautiful terms from engineering,

[32] Herman Daly, "Toward Some Operational Principles of Sustainable Development, *Ecological Economics* 2 (1990): 1-6.

[33] Serageldin, op. cit.

It would be a real achievement if … capital assets, natural assets, and environmental assets were equally "real" and subject to the same scale of values, indeed the same bookkeeping conventions. Deeper ways of thinking might be affected.

— Robert Solow

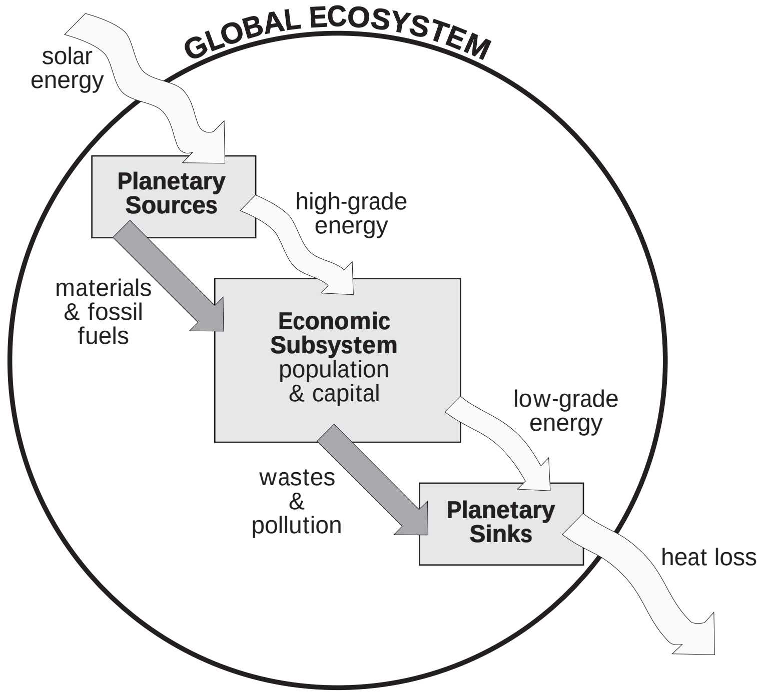


Illustration after: R. Goodland, et al., op. cit.

we can call the flows of material and energy from nature into the economy **inputs,** the flows of wastes back to nature **outputs,** and the combined flows **throughputs.** Then the capital/income idea can be stated clearly. Throughput is the income derived from a natural capital stock. A throughput stream of lumber and paper and wood fuel comes from the natural capital of a forest. Groundwater is pumped up from the natural capital in the aquifer. A stream of food can be obtained from the natural capital of the nutrients in the soil. On the sink side, an output flow of sewage can be released to the natural capital of organisms that break the sewage back down to nutrients. The carbon dioxide from burning fossil fuels can be removed from the atmosphere by the natural capital of green plants photosynthesizing.

Notice that forests are source capital for the input of wood products and sink capital for the output of carbon dioxide. Many forms of natural capital play both source and sink roles. Aquifers provide drinking water but also may be sinks for leached pesticides or leaked petroleum. Soil provides nutrients for growing crops and receives deposits of heavy metals from the atmosphere. The connections among the elements of natural capital — the *oneness* of the global system — is a major cause of sustainability problems and a major reason why indicators (and formal models of our complex natural support systems) are so badly needed.

The human economy uses many kinds of throughput streams, each associated with natural capital on both the source and sink end of the flow.

Think of the throughput flows summoned continuously and in great volume by any city or nation. Water and many kinds of food. Oil, coal, natural gas and other fuels. Construction lumber, plywood, cardboard, paper. Steel, copper, aluminum, and a host of other metals. Rubber, plastics, glass, cement. Tens of thousands of kinds of chemicals.[34]

All these substances flow in from nature and flow out after use, usually in haphazard mixes, into air, water, soils.

To keep track of these many throughput flows is a large but not impossible task, no worse in principle than keeping track of the money flows through all industrial sectors that make up the GDP. Input-output tables are easily adapted to the task. Material and energy flow tables, combined with money flow tables, should and could be an essential part of national accounting.[35]

Material and energy flows through the economy are at least theoretically measurable, even though they are not yet always measured. It is more difficult to keep track of the natural capital stocks that are the sources and sinks of the flows — difficult because for some we haven't done it before, for others the people who do the measuring (foresters, soil scientists, atmospheric chemists) are not in regular contact with national accountants, and for some (ocean fish, soil bacteria, oil under the ground) accurate measurement is very difficult to do.

Nevertheless, we could compile and organize many kinds of natural capital measures and relate them to their associated throughput flows. That would form the basis for a natural capital accounting system.

Natural capital is being used unsustainably if sources are declining or sinks are increasing.

The indicators of the sustainability of use of most forms of natural capital are obvious; they are the directions and rates of change of sources and sinks. As previously discussed, they could be expressed dynamically as the ratio between use rate and restoration rate (with 1.0 standing for sustainability) or as the amount of time until the resource can no longer be a source or sink.

[34] For illustrative throughput numbers for the city of London, see H. Girardet, *The Gaia Atlas of Cities: New Directions for Sustainable Urban Living.* New York: Doubleday, June 1993; for Hongkong, see S. Boyden, *An Integrative Ecological Approach to the Study of Human Settlements.* Paris: Unesco, International Co-ordinating Council of the Programme on Man and the Biosphere, 1979.

[35] For a pioneering example, see A. Adriaanse et al., *Resource Flows: The Material Basis of Industrial Economies.* Washington DC: World Resources Institute, 1997.

If a forest is cut faster than it grows, the throughput stream of products from the forest will not be sustained. Natural capital is being spent, reducing future productivity. Whatever the indicator, the value of the excess harvest should be counted not as income but as depletion of capital.[36]

If groundwater is pumped down to irrigate farmland and there is no investment in an alternative water source to keep that land in production after the groundwater is gone, that is drawdown of capital.

On the sink side, if an output stream builds up wastes that are not recycled or rendered harmless, then that practice cannot be sustained without serious repercussions somewhere. An indicator can signal how far above a sustainable absorption rate the output is, or how long it will be until an unacceptable level of waste accumulates. The value of the throughput stream creating the waste ought to be discounted either by the eventual cost of dealing with the pollution or by the actual damage that pollution is causing to built capital, human capital (such as health), or some other form of natural capital.

Indicators can signal unsustainability long before a resource "runs out" or a sink overflows, even if natural capital cannot be measured directly. It's hard to measure ocean fish populations, for example, but a leading indicator of their decline is decreasing catch per fishing effort (per boat, per hour of trawling, per dollar of operating or investment cost, per gallon of fuel burned). We do not know the exact size of undiscovered petroleum reserves, but a drop in yield per discovery effort is a leading indicator of a depleting resource.

"Daly rule" indicators such as these are simple, leading sustainability measures easily understood and readily measured for many throughput streams. They should be implemented wherever possible.

However, it is important to note that the "Daly rules" are static, and they are stated with regard to quantitative flows of separate throughput streams. They may not capture either qualitative degradation nor interactions between one form of natural capital and another, nor do they necessarily reveal the seriousness of unsustainability through "time to exhaustion" or "time to unacceptable threshold." Indicators that reveal these important factors will require integrated dynamic models.

[36] See R. Repetto et al., *The Forest for the Trees? (Government Policies and the Misuse of Forest Resources); Wasting Assets (National Resources in the National Income Accounts);* and *Accounts Overdue (Natural Resource Depreciation in Cost Rica).* Washington, DC: World Resources Institute, 1988-1991.

Indicators should highlight *limiting* natural capital stocks.

If nitrogen is lacking in the soil, it doesn't help that there is plenty of phosphate. If chromium is lacking to make stainless steel, it doesn't matter that there's an excess of iron. If the output from burning coal stresses an atmospheric sink, it is of little comfort to know that on the source side coal is abundant. Like all complex systems, the physical economy depends not on its most abundant throughputs, but on its most limiting. The limits can come from either the source or the sink side of the flow.

> Ideally a complete information system would keep track of all forms of natural capital and their throughputs, but cockpit indicators would emphasize the most limiting factors. (Like lights on an instrument panel, you only need to pay attention to the ones blinking red.)

The warning lights must blink far enough in advance to allow preventive action and must illustrate interconnections, so the preventive action will not simply throw the load onto another natural capital stock, which would then become limiting. Again, this is a research agenda and a task for dynamic modeling.

Natural capital should be monitored at whatever geographic level makes sense.

The stock of nutrients in soil is measured most meaningfully at the field or farm level. It can be aggregated to the national level as the percentage of agricultural land that is losing nutrients faster than they are replaced.

The stock of greenhouse gases in the atmosphere makes sense only at the global level. At the national level one can keep track of the national contribution to the global imbalance in that stock.

The appropriate geographic level for measurement is obvious for most resources. More tricky is the question of imported resources. It should be a concern at the national level to know the sustainability of whatever natural capital outside the country supplies a critical stream of resources to the country. This could be done by calculating a national Ecological Footprint.

The Ecological Footprint, invented by William Rees of the University of British Columbia, measures a person's, city's, industry's, or nation's environmental impact by the amount of land (anywhere on earth) that entity requires for its maintenance.[37] For example, Rees calculates that the city of Vancouver, through its food, water, energy, and waste-disposal demands, actually occupies an area of land (an Ecological Footprint) fourteen times the area of the city.

The use of land as a numeraire, rather than money or energy, makes the footprint easy to understand and also permits provocative calculations. For example, Rees calculates that if all people on earth had the same footprint as the average American (5 hectares), we would need three Earths to supply everyone! He calculates a "fair earthshare" (total productive land area divided by world population) of 1.5 hectares, a number that goes down as the population grows. He points out that the average footprint of a citizen of India is just 0.5 hectares, but because there are 910 million Indians, the total footprint of India is 35% greater than the actual area of India.

The Ecological Footprint captures many useful ideas within one number, and it has a strong intuitive and metaphorical appeal. It is an excellent summary indicator of sustainable development, with the following caveats. There needs to be a considered scientific review to codify its calculation. (Rees's method is rough and ready, fairly easy to implement, but oversimplified.) As Rees himself points out, it should have a marine resources equivalent. And it needs to be made dynamic, so it reflects not only present footprints, but implications for future ones.

We need to allow estimates in our indicators for life support systems that we do not yet understand.

Most of us didn't understand the life-sheltering function of the stratospheric ozone layer, until scientists noticed that that layer was eroding.

Whole communities of poorly understood soil microbes serve as fertilizer-generating factories in healthy organic soils.

The unpriced value of nature's direct services to the human economy (through pollination, flood control, drought protection, pest control, waste recycling, species protection, nutrient regeneration, soil formation, and a dozen other critical functions) has been conservatively estimated at $33 trillion per year (as compared with the economic system's output of $18 trillion per year).[38]

We only dimly understand the intricately woven web of geophysical processes and life forms that make up Planet Earth and support our endeavors.

> Therefore we should create at least one indicator to measure the amount of nature we have left untouched, an "insurance factor" for the knowledge we don't yet have about the forms of natural capital we don't know enough to value.

[37] Wackernagel and Rees, op. cit.

[38] R. Costanza, R. d'Arge, R. de Groot, "The Value of the World's Ecosystem Eervices and Natural Capital," *Nature* 387 (May 15 1997): 253-60; G. Daily, ed., *Nature's Services: Societal Dependence on Natural Ecosystems.* Washington, DC: Island Press, 1997.

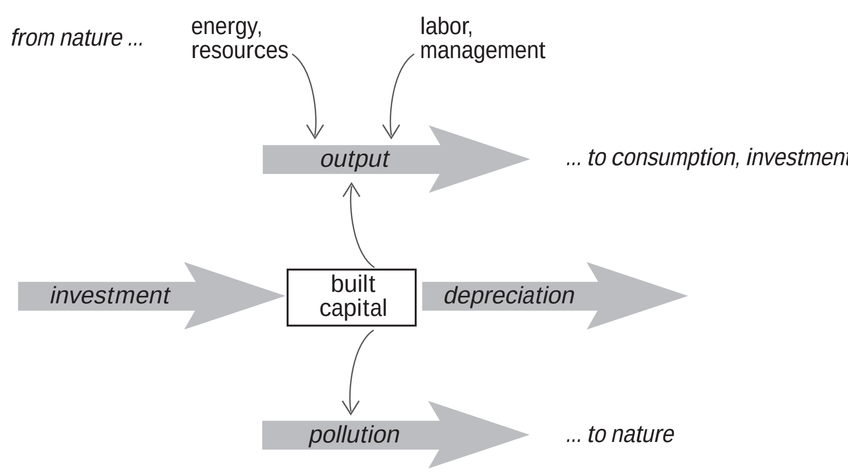
Built Capital (intermediate means)

Built capital is human-built, long-lasting physical capacity — factories, tools, machines — that produces economic output.

We have come to think of money capital as interest-bearing — able to produce a steady stream of income without itself being depleted — because there is a form of real capital that can behave that way. It is "built capital" — the human-made tools, machines, factories, smelters, electric generators, pumps, trucks that create output without themselves being consumed (or at least that create output while themselves depreciating only slowly).

Built capital is the physical stock of productive capacity of an economy. It is steel mills, cement plants, car factories, construction equipment, lathes, tractors, buildings, oil wells, chainsaws, power plants, the most solid measures of economic development. Built capital is increased by investment (usually after a construction delay). It is decreased by depreciation or obsolescence (which can be postponed by maintenance and retrofitting). Built capital usually lasts for decades, providing both stability and inflexibility to the economy. Built capital has an age structure just as population does. New steel mills age into old steel mills that may be technically obsolete long before they actually wear out.

One simple development indicator is built capital per person. An efficiency indicator would measure the amount of built capital (and throughput) necessary to meet final demand for intermediate ends — the lower the number, the more efficient the capital. Capital lifetime is another good indicator — the longer the lifetime, the more value over time each piece of capital supplies (assuming no technical obsolescence).



The nature and amount of built capital determines the standing demand for human capital (labor and skills) and for throughput from natural capital (materials and energy). That fraction of built capital that produces more built capital (investment) determines the rate of economic growth.

Built capital sits on the second level of the Daly pyramid; it is intermediate means. It is a key element in integrating the pyramid, because a piece of built capital — a furnace, say, or a paper mill, or an irrigation system — requires a specific stream of throughput from natural capital (materials, energy, water) in order to function. It releases a specific stream of waste and pollution. It requires particular types of labor and management (human capital). As long as it is running to capacity, it produces a known stream of output, which is either consumption (on the next level of the Daly pyramid, intermediate ends) or investment (some other form of capital).

Built capital is usually measured in money terms — the accumulated amount invested in it, or the amount it would take to replace it at current prices. There are problems with this way of measuring, primarily because money is an insufficient proxy for something that is actually concrete, that comes in many different forms and capacities, that does not inflate but does wear out physically, that does not physically change even if prices change. For the moment we probably must construct indicators of built capital in money terms, but in a more elaborate information system for sustainable development, we may want to specify them in terms of output capacity (megawatts, tons of steel per year, cars per year) and input requirements (fuel, labor, material per year).

Sustainability on the level of built capital means investing at least as fast as capital depreciates. Across levels it means keeping the throughput needs of built capital appropriate to the sustainable yields and absorptive capacities of natural capital and keeping labor and management needs appropriate to the sustainable use of human capital.

To sustain built capital, investment must replace depreciation (in actual productive capacity, not in money terms). Capital grows if investment is faster than depreciation. The self-generating growth of built capital (it takes capital to produce more capital; the more capital you have, the more new capital you can build) is one of the sensitive positive feedback loops that provides a central indicator of both sustainability and development.

Development indicator: real investment (measured in concrete productive capacity) divided by real depreciation (measured in physical terms). If greater than 1., productive capacity is growing. If equal to 1., productive capacity is just being maintained. If less than 1., the built capital stock of the economy is not being sustained.

Note: such an indicator is common in money terms, but doing it in physical terms would reveal new information — for example it would signal the erosion of capital through deferred maintenance much faster than money accounts can do.

Sustainability indicator: throughput need of built capital divided by sustainable yield from natural capital. If greater than 1., the economy has built itself beyond the capacity of the resource base to supply it.

Sustainability *and* development indicator: labor and management need of built capital divided by labor and management capacities of human capital (which will be discussed in the next section). Greater than 1. indicates insufficient human capacity to run and maintain the capital plant. Less than 1. indicates human resources going unused. (An information system that tracks built capital could also track jobs and employment relatively easily.)

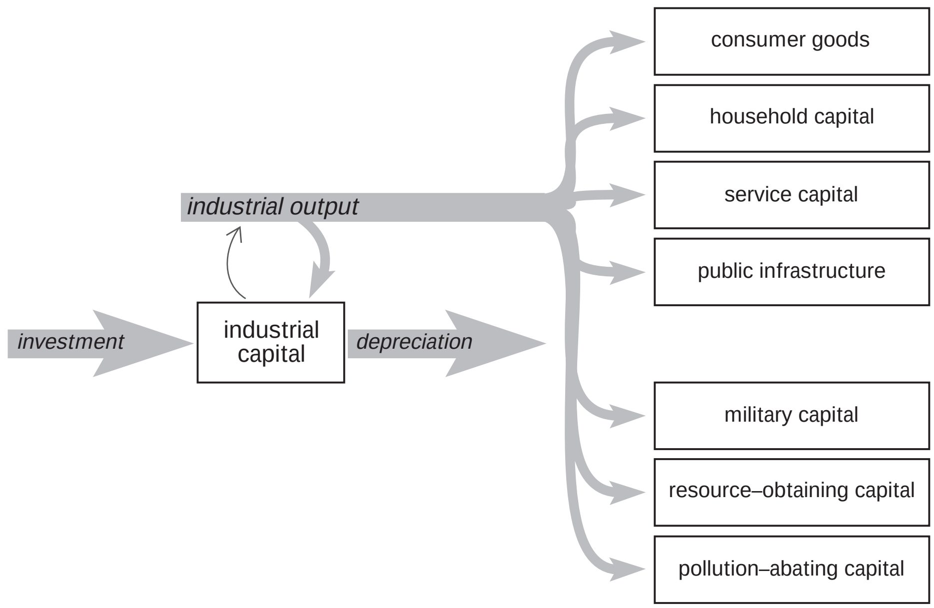
There are many categories of built capital. A useful indicator would reflect the proper balance among categories to permit the most productive use of all forms of capital.

Built capital accounts could be kept for every industrial sector, every city, every company. In some countries, they are already measured on all those levels, because on each level there are decision-makers who need to monitor capital accounts. (The job is not only similar to keeping accounts for GDP, or national input-output tables, it naturally complements those accounts.)

For indicators of sustainable development at the national level, a few categories of built capital can be aggregated according to their large-scale system function:

Industrial capitals capital that can build more capital — the steel mills that make steel for more steel mills, the machine tools that make machine tools. This is the fraction of built capital that provides real physical investment, the engine of economic growth.

Household capitalonsists of homes, cars, refrigerators, home computers, durable goods owned by families. It is a supporter or enhanc& r of human capital and a better measure of material well-being than income.



Service capital is hospitals, schools, government buildings, banks — capital that provides services, some of which enhance the functioning of other kinds of capital, some of which enhance human and social capital.

Consumer goods capital produces nondurable consumer products (food, paper, clothing), another measure of material well-being.

Public infrastructure is roads, bridges, ports, water lines, and other public investments that serve the whole economy.

Resource-obtaining capital consists of mines, oil wells, and other built equipment that extracts throughput from natural capital.

Pollution-abating capital, such as sewage treatment plants, trash incinerators, or stack scrubbers, ameliorate damage when throughput is released back to nature.

Military capital maintains the security of natural capital, economy, and society.

The last three types of capital are not directly productive; they are costs of supplying or keeping safe other kinds of capital. An efficient society will be structured to need as little of them as possible.

So a useful indicator would be the ratio of the last three protective kinds of capital to the first five productive kinds of capital. (But if, for example, necessary pollution-abating capital is not built, some other form of capital, probably natural or human capital, will be degraded. A proper capital accounting system should assess those costs.)

For some kinds of capital, national accounts would need to distinguish that which is used for 1) domestic production, 2) export production, and 3) import production ("virtual capital" in other countries). The first two of these generate in-country jobs, pressure on natural capital, and pollution. The first and third generate in-country consumption.

Another important indicator would be the *balance* among various kinds of capital. There are countries, for example, with roads so bad that vehicles get shaken apart by potholes. This is unnecessary depreciation of household capital because of an under-investment in public infrastructure capital. In other countries, under-investment in energy production (resource-obtaining capital) occasionally shuts down industrial or household capital. There are places where insufficient service capital hampers the functioning of all other forms of capital because of an unskilled or unhealthy labor force.

Therefore, an indicator should measure the balance among the kinds of capital (what fraction of total capital is represented by each), to reflect the extent to which they enhance rather than undermine each other's productivity. Ideally, lights should start to blink on the social instrument panel, when over- or under-investment in one kind of capital degrades the effectiveness of another kind of capital. (It is widely believed that the free market automatically takes care of such capital imbalances, but the widespread existence of capital imbalances illustrates that delays and imperfections keep the actual market a long way from fulfilling theoretical expections.)

Human Capital (intermediate means/ends)

Human and social capital are difficult to define; indeed, it is a significant question whether "capital" is the right conceptual framework for them. Neither human nor social capital can be adequately denominated in terms of materials, energy, or money. Furthermore, drawing a line between the "human" and the "social" is dependent on worldview. What is seen in some cultures as human capital (because it is carried within the minds and bodies of individuals) is seen by others as social capital, because the individual is only given identity and purpose by the group.

However, given those caveats, it is possible and useful to talk about and create indicators for human and social capital, both of which can accumulate over time, can be invested in, can depreciate, and must be essential factors in sustainable development.

The base of human capital is the population, including its age and gender structure.

Demographic models, derived from fairly accurate censuses in most countries, are already available. Populations are countable stocks, increased by births and inmigrations, decreased by deaths and outmigrations. Each person in the population carries with

Development does not start with goods; it starts with people and their education, organisation, and discipline. Without these three, all resources remain latent, untapped, potential.... We have had plenty of opportunity to observe the primacy of the[se] invisible factors after the war. Every country, no matter how devastated, which had a high level of education, organization, and discipline, produced an "economic miracle."

— E. F. Schumacher[39]

[39] E. F. Schumacher, *Small is Beautiful.* New York: Harper & Row, 1973.

him or her a set of attributes, the most obvious of which — age and sex — are already reported in the census.

Because of the long lifetimes of most people, populations change only slowly, with great momentum. Much about their future is predictable from their age structures — this year's five-year olds will be (minus migration and mortality) the twenty-year olds of fifteen years from now and the sixty-five-years olds of sixty years from now. Demographic modeling can spin out the future implications of today's population events.

Modeling can also calculate the future consequences of a crucial exponential growth indicator: net population growth rate. (See the discussion of positive feedback loops earlier in this report.)

Along with numbers, ages, and genders, human capital can be measured by attributes such as health and education.

Demographic databases can also include information about attributes imbued within the minds and bodies of people — most obviously their levels of education and health. Investment (especially in service and human capital) can build up those attributes. Neglect can allow them to depreciate. Investment in human capital can also be seen as a positive feedback loop — the more education in a population, the more educated parents and teachers build that education level still further.

I will define attributes that inhere not to individuals but to groups as social capital and discuss them in a moment.

Human capital is in one sense an intermediate means, in another sense an intermediate end.

Seen as a labor force, human capital is an intermediate means, a factor of production, which interacts with built capital and throughput from natural capital to produce economic output. As the health and education of a population increase, other forms of capital can be more productive. Human capital, if we had a way of accounting for it in money terms, might prove to be at various stages of development the most lucrative possible investment on pure grounds of economic return. (That becomes again a matter of balancing the various types of capital so they do not hold each other back.)

Human capital is also, however, an intermediate end. Education and health (and other individual attributes) have purposes beyond making a person more productive in the economy. They also serve the top of the triangle — the ability to lead a joyful, fulfilling life. If we could measure the degree to which human capital serves ultimate goals, investment in it might look like an even better deal. Relative to built capital, human capital probably delivers more well-being from less money, less built capital, and less material and energy throughput than any other investment (with the possible exception of social capital).

Population with its attributes, like built capital, is an indicator of the necessary throughputs and potential outputs of a society.

Human capital relates to the top of the triangle through well-being. It relates to the bottom of the triangle through the flows of material and energy necessary to maintain a person. It relates to the middle of the triangle through the flows of economic output that a person (with the aid of built capital) is capable of producing and consuming.

Thus human capital, like built capital, can be seen as a standing demand for material and energy throughput. Different people with different attributes and in different cultures require very different throughputs. (They have very different Ecological Footprints.) They are capable of producing very different outputs. (They have different labor productivities.)

In order to avoid double counting, we need to distinguish the throughput needs and output potential attributable to human capital and to built capital. Economists have been trying to untangle this knot for years. It might be clearer not to try to make a clean separation of what is actually a systematic partnership. Throughputs and outputs might best be specified for the human-and-built-capital system as a whole.

The universal resource available to all human beings, and the currency of most value to them, is time. Time accounting may be key to human capital accounting.

We each have an equal endowment of twenty-four hours a day. Much of real economics has to do with commandeering the time endowments of some people to serve other peoples' intermediate or ultimate ends. We had the feeling in the workshop that time budgets could be even more revealing than money budgets, especially as we begin to relate to the top of the triangle. We're not sure yet how to integrate them, but clearly another attribute that could be correlated with each person in a human capital stock would be the allocation of that person's time.

Human time can be sorted into many possible categories, such as:

Survival tasks: eating, sleeping, preparing food, gathering fuel, etc.;

Leaming: acquiring the skills necessary to survive and to exchange in the time economy;

Wage wok: time exchanged in the market for compensation;

In the table is an example from India of the kinds of information revealed by data systems built upon time.[40] Notice the strong differences between women and men and between landless and landed women.

TIME USE (% of total hours)

Women	forest tribe	hill tribe	landless rural	landed rural	urban slum	middle class
sleep	40	33	34	50	34	39
survival	12	27	17	13	17	11
reprod. work	12	17	13	8	14	10
wage work	13	10	26	—	19	17
learning	2	3	2	8	4	7
recreation	17	5	5	8	8	11
religion	4	4	3	13	4	5
Men						
sleep	43	49	47	48	47	48
survival	9	6	6	2	3	2
reprod. work	6	2	2	1	2	1
wage work	19	22	30	26	28	26
learning	5	4	3	6	6	8
recreation	15	14	10	13	11	13
religion	4	4	2	4	4	3
Life Expectancy (years)						
	45	60	60	60	60	75

Child rearing: time invested in the next generation of human capital;

Leisure: time spent on psychological maintenance, spiritual development, building and maintaining relationships, entertainment, sports, etc. Viewed in some cultures as time of little value; viewed in others as time invested in health, productivity, and realization of the top of the triangle;

Community time: time devoted to the needs of others, to community functions, volunteer groups, neighborhood duties, discussion and coordination of work in groups.

A key indicator is how much healthy time is available to people (subtracting time spent sick, immobile, or aged to the point of feebleness).[41] A second would be how that healthy time is distributed among different genders, ages, and social classes or income groups. Time spent on survival tasks, indexed for equity, is essentially a proxy for depreciation rates of human capital.

A set of indicators based on "time" could be a fruitful topic for research, for indicators of sustainable use of human capital and indicators of sustainable development. Some of us think the prime characteristic of a

[40] Aromar Revi, TARU, New Delhi, personal communication.

[41] C. J. L. Murray, "Quantifying the Burden of Disease: The Technical Basis for DALYs," *Bulletin of the World Health Organization* 72, no. 3 (1994) :429-445.

sustainable society would be that life would slo-o-o-w down so there would not be a perpetual sense of scarcity about time. But we didn't have time in our hectic five-day workshop to develop this idea!

Social Capital (intermediate ends)

Social capital is a stock of attributes (knowledge, trust, efficiency, honesty) that inheres not to a single individual, but to the human collectivity.

When you start thinking about social capital, you begin seeing it around you. Knowledge is clearly an accumulated stock, which grows through inflows of research, experiment, new understanding and is drained by outflows of forgetting. Parliamentary rules and other social behaviors that allow large groups to have fair and purposeful discussions are learned painstakingly over time and must be maintained against depreciation. The ability of a household to clean itself, of a community to police itself, of businesses to make and enforce contracts, of citizens to propose, debate, pass, and obey laws — all these could be considered social capital. They can be invested in. They depreciate. They don't change quickly. They bear the history of all past investments and depreciations.

We could think of public trust as a stock of capital, decreased by telling lies and increased by telling the truth. (Perhaps each lie or truth should be weighed by the number of people who hear it. That way each of us every day builds or depreciates the public trust, but public figures who speak to millions can build or erode the public trust far more quickly than can ordinary citizens.)

Tolerance of ethnic, religious, or other diversity might be a social capital stock, built up by actions and words that demonstrate good will, torn down by actions and words that express hatred.

Efficient, well-regulated markets.

Technology and the ability to evolve new technology.

Orderliness, reliability, creativity, culture.

The ability to treasure what is valuable in the old and to seize what is useful in the new.

Museums, folksongs, jokes, city parks, sports teams, scouts.

All these things must have something to do with social capital. Adaptability, resilience, the capacity to learn and reorganize, repair damage or change direction, maintain a steady course, muster resources for major efforts, all of these are dependent on having an adequate "stock" of social "capital."

Indicator selection for social capital is difficult indeed. Suggested social capital indicators often measure depletion or malfunction: crime, for example. Crime is surely an indicator of decline in social capital, driven by inadequate investment in other kinds of capital.

Equally important is the social side, and here we mean equity, social mobility, social cohesion, participation, empowerment, cultural identity, and institutional development.... It is, to my mind, an essential part of the definition of sustainability, because, let me remind you, the neglect of that side leads to institutions that are incapable of responding to the needs of society. We see the consequences of that in tragedies from Somalia to Rwanda and from Liberia to Bosnia.

— Ismail Serageldin

Social capital is terrifically varied, incredibly hard to measure, but most of us not only acknowledge its existence but can sense its presence or absence. "You can feel it when you walk down the street," one member of our workshop said. It is based in the integrity and efficiency of institutions, information systems, and human relationships.

Just as time is a key currency for human capital, information may be a key currency for social capital.

Social capital is generally understood in terms of "cohesion," but its primary component is information. More accurately, social capital is embodied in dense, meaningful, and truthful information flows.

Indicators of social capital would be especially useful if they could discriminate not only *quantity* of information (which can be measured by stocks and flows of megabytes), but *quality* of information — the difference between **data, information, knowledge,** and **wisdom.** Data are bits of information, which can rapidly become distracting, overwhelming, stupefying, or a management nuisance (as is currently the case with most of the Worldwide Web). Information is data sorted and selected to "make a difference" to some system or some decision. Knowledge is understanding of the way information streams are organized and accessed. Wisdom is the capacity to utilize knowledge in decision-making, to integrate knowledge and information with new experience, to see the system whole, to grasp the necessity and yet the uncertainty of models, to move between and within levels in a model, to be able to distinguish between the system itself and models of the system, and to make adjustments to models as necessary.

Trust, relational capacity, and the efficacy of a society's institutions all depend on the quality of information flows within a society. It is a central tenet of systems theory that a system cannot be managed without adequate flows of information.

Another possible measure of social capital would be density or frequency or intensity of human relationships.

How often do you see your relatives, and for what length of time? Does that measure the stability, resilience, functionality of your family?

How many neighbors do you know by name, talk to often, understand something about their lives? Does that give an idea of the social integrity of your neighborhood?

Do you have a face-to-face human relationship with your employer or employees? With the makers and suppliers of the things you buy? With the people who teach your children, who heal your body, to whom you grant the power of governance? Is social capital enhanced or decreased as institutions become bigger and more powerful but human relationships become more distant and abstract?

Decentralized, relatively immobile societies such as traditional villages have a high density and frequency of face-to-face interactions, which builds up a palpable, functional social capital. A society based on long-term personal relationships needs few if any contracts, papers, lawyers, rules, courts, judges. It's probably the absence of such relationship-based interactions in our lives that makes us romanticize such a decentralized system — and it does have real advantages.

On the other hand, a decentralized society can suffer from insularity, inbreeding, narrowness of ideas and viewpoints, suspiciousness of innovation, suppression of deviance. Perhaps a "cosmopolitan-ness" index could counterbalance the human relationship index, to measure the breadth of a society's information contacts and idea-base.

Then comes the question, is it possible to devise a society that could score high on both indices?

The "forbidden numeraire," whose stocks, flows, and distribution could lend itself to indicators, is power.

I have no idea how to measure power. I don't think many of us do. I suspect that is not so much because it is unmeasurable as because it is not politically acceptable to raise the topic (especially among those who have accumulated large quantities of power).

All the more reason to try to measure it. Clearly power has to do with the ability to force people to do things they would not independently choose to do. (It may be inversely related to freedom, creativity, social resilience, and evolutionary potential.)

Here are some ideas for measures of power:

- number and strength of weapons and distribution among the population;
- ratio of number of employers to number of employees;
- income distribution, particularly the ratio of extremely rich to extremely poor;
- concentration of ownership of the media (public and private);
- political prisoners as percent of the population;
- percent of GDP earned by the ten or fifty largest corporations.

If the world's population had the productivity of the Swiss, the consumption habits of the Chinese, the egalitarian instincts of the Swedes, and the social discipline of the Japanese, then the planet could support many times its current population without privation for anyone. On the other hand, if the world's population had the productivity of Chad, the consumption habits of the United States, the inegalitarian instincts of India, and the social discipline of Argentina, then the planet could not support anywhere near its current numbers.

— Lester Thurow, T*echnology Review,* Aug/Sept 1986

Social capital can be a high-leverage transformative factor in the process of channeling ultimate means into ultimate ends.

If a society has a low crime rate, a history of common endeavor, and habits of timeliness and cleanliness, then it probably can organize a pleasant, efficient mass transportation system that gives its citizens high mobility with minimal cost in household capital (cars) and natural capital (steel, glass, rubber, fossil fuels, concrete, air pollution). High mobility can be obtained at low cost because of the high level of social capital.

If a culture allows men to feel manly without having to be surrounded by tons of polished steel propelled at high speeds, that culture could allow the realization of an important ultimate end with great savings of all kinds of ultimate and intermediate means.

It is well established for most of the industrialized nations that efficiency in the design of built capital can produce the same amounts of economic output with half as much, or even one-tenth as much, energy.[42] It could be true that efficiency in the design of social capital could produce equivalent well being with one-hundredth or one-thousandth as much energy, materials, and built capital. This possibility gives hope that truly sustainable means of meeting the highest and most important ends could be attained for all people on Earth. Somewhere within the concept of social capital, combined with clever technical design of built capital and loving development of human capital, is the capacity to meet material needs materially and non-material needs non-materially with great efficiency in the use of ultimate means.

Rough indicators of social capital are better than nothing.

It is tempting to refuse to deal with anything so messy (and politically touchy) as social capital. It's all too easy for experts in science or economics, who like to deal in clean concepts and precise numbers, to shift the topic quickly to prices or kilojoules or numbers of species.

While we didn't make enormous headway on social capital in our own workshop, we recommend that this topic become a major area of discussion, involving many kinds of people.

We believe it is possible and vitally important to find ways to measure social capital, even if those ways are subjective (remember, all indicators are subjective). It is important partly because social capital can be such a powerful mediator in the translation of ultimate means to ultimate ends, and partly because without any measure of social capital, many purported "development" plans may eat

[42] See E. von Weiszacker, A. Lovins, and H. Lovins, *Factor Four: Doubling Wealth - Halving Resource Use.* Washington, DC: Island Press, 1997.

Examples of social capital indicators from community indicator projects:

Sustainable Seattle's participants were determined to measure "neighborliness" somehow. They invented a telephone survey to ask: How do you define "neighbor?" How many neighbors would you say you have? How many of them do you know by name? What kinds of interactions do you have with them? The answers revealed strong differences by neighborhood and by income class, and suggested that the city was not actually very neighborly.[43]

Among draft indicators in the "social" dimension for the U.S. Interagency Working Group on Sustainable Development Indicators are:[44]

- percent of children living in one-parent families;
- percent contributing time or money to charities;
- crime rate;
- participation in the arts and recreation;
- number in census tracts with over 40% poverty.

The World Bank provides a long list of possible indicators of social capital, among them:[45]

- index of democracy;
- index of corruption;
- independence of court system;
- contract enforceability;
- strikes, riots, protests;
- prisoners per 100,000 people;
- extent of trust in government, trade unions;
- small credit availability;
- index of political and/or economic discrimination;
- index of civil liberties;
- voter turnout.

Social capital is, essentially, a "shared wisdom index." Defining it requires a significant amount of wisdom!

into this kind of capital without counting the cost. (Dams that flood out long-standing communities, employment patterns that break up families, mass information systems that swamp local cultures.)

Participatory indicator selection processes can be especially creative in coming up with indicators of social capital. Even if they can only produce agreement about the general *direction of change* (pedestrian streets in cities increase social capital, freeways decrease it; many small, local-based retail stores increase social capital, one or two large "chain" distributors decrease it), the exercise is worth doing.

[43] Sustainable Seattle, *Indicators of Sustainable Community 1995*, available from Sustainable Seattle, 909 Fourth Avenue, Seattle, WA 98104.

[44] U.S. Interagency Working Group on Sustainable Development Indicators, *Sustainable Development in the United States*, Interim Report, draft, April 1998.

[45] The World Bank, *Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development*, 1997.

It [the GNP] does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It allows neither for the justice in our courts, nor the justness in our dealings with one another. The Gross National Product measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to country. It measures everything, in short, except that which makes life worthwhile.

— Robert Kennedy

Well-Being (ultimate end)

If social capital was hard, how are we ever going to define ultimate human fulfillment?

Not by going around doing shallow polls that ask, simply, "are you happy?" (Think what answers might come forth if we asked, "Does your life allow you to contribute all you have to give to society? If you had complete control of your own time, would you spend it the way you do now? Do you see a purpose to your life and are you able to achieve that purpose? Are you lonely? Are you loved? Is there beauty in your life? Joy? Transcendence? If you knew you would die tomorrow, would you be satisfied?")

The question of ultimate ends, happiness, well-being has been a topic of discussion for thousands of years. That discussion has not produced nothing. Through many different cultures and historical periods it has produced some strikingly constant insights, one of which is that "man does not live by bread alone." Well-being requires a basic amount of material throughput to sustain life, but after that point, more wealth is only loosely associated, if at all, with more happiness.

So how to measure the most qualitative, personal, culture-bound, subjective, and important part of the pyramid? We're not sure. We suspect that it should be a participatory, not an expert-dominated activity. We do know that, however uncomfortable or difficult the topic, discussing the top of the pyramid is the most important task on the road to sustainable development.

The most important indicator, without which the others make no sense, is an indicator of ultimate ends.

If we can't define what our ultimate ends are, how can we know whether we are approaching them, or with what efficiency, or even whether we're going the right direction? The qualitativeness, subjectiveness, elusiveness, and culture-specificity of the ultimate ends does not for a moment diminish their importance. If the system orients itself around indicators that do not reflect real well-being, then it will produce whatever those indicators do measure (money flow, size of the economy, personal material possessions) rather than real well-being.

We need to press courageously to discuss well-being and define indicators that reflect it, even if we suspect that this process will shake up our worldviews and challenge our power structures and our lives. If those power structures and lives are in fact creating well-being, then they won't be challenged. If they are not, then they should be shaken.

Indicators of ultimate ends may not be numerical or precise, but they are findable and usable.

The literature on human happiness/fulfillment/purpose/satisfaction/quality-of-life is far too extensive to review in this short paper. I will quote here only one scheme by which indicators could be derived, more to illustrate that such schemes are possible than to defend this particular one as best — though I personally find it thought-provoking and as good a basis for building "quality of life" indicators as any other I know.

> Manfred Max-Neef, after many cross-cultural studies, has come up with a list of nine universal "basic human needs."[46] Only the first of them — subsistence — is clearly material. The others may have material underpinnings, but they are essentially qualitative:
>
> - subsistence;
> - protection (security);
> - affection;
> - understanding;
> - participation;
> - idleness (leisure, rest);
> - creation;
> - identity;
> - freedom.

Max-Neef insists that these needs are not hierarchical or substitutable. All are necessary; none is more important than the others. One can't compensate for a deficiency in one by an excess in another — for lack of affection, say, by an increase in protection, or for a loss of freedom by an improvement in material subsistence.

Cultures differ, says Max-Neef, not in these needs, which are essentially human, but in their **satisfiers,** their specific ways of satisfying the needs. Participation may be realized in some societies by democratic voting, in others by long discussion, in others by a formal process of consensus. Identity could be established by particular kinds of decoration or clothes, by possessions such as cars or houses, by celebrity in the mass media, by local nicknames or affectionate jokes or a small community knowing and respecting one's unique set of strengths and weaknesses. Some satisfiers can meet multiple needs. (Max-Neef cites breast-feeding, which serves subsistence and affection, or barefoot-doctor programs, which serve subsistence, participation, understanding, and identity.) Some **pseudo-satisfiers** can appear to meet needs but actually fail to meet them or even undermine them. (Expensive brand-name sneakers may purport to establish identity or freedom, but actually make their wearers look alike and manipulate them for the benefit of corporations that make and market the sneakers.)

Satisfiers are the equivalent of intermediate ends on the Daly triangle. The list of basic needs might be a fruitful beginning for indicators of

[46] M. A. Max-Neef, *Human Scale Development.* New York: Apex Press, 1991.

We will know we're really talking about sustainable development when the conversation shifts from efficiency to sufficiency. Efficiency is quantifiable and satisfies the Cartesian mind. Sufficiency will drive the Cartesian mind crazy.

— Wes Jackson

ultimate ends. (I could think of others I might add, such as beauty and transcendence/enlightenment/grace.)

If we search sincerely and if we are open to answers that may not look like scientific formulae, I believe that ultimate ends *can* be defined, at least qualitatively, and that the definitions are not so different from one human soul to another. We may disagree hotly about our models of what means can lead to the ends, but when it comes to the ends themselves, the essential human values, we are, quite simply, all human.

Even if we agree on no more than this — that the dominant cultures are mobilizing enormous flows of resources, spewing out unsupportable quantities of wastes, building huge capital structures, and *not clearly achieving happiness* — then there is already a strong reason to stop using indicators that count a larger physical economy as "good" and to search for indicators of more importance.

Integration (translating ultimate means into ultimate ends)

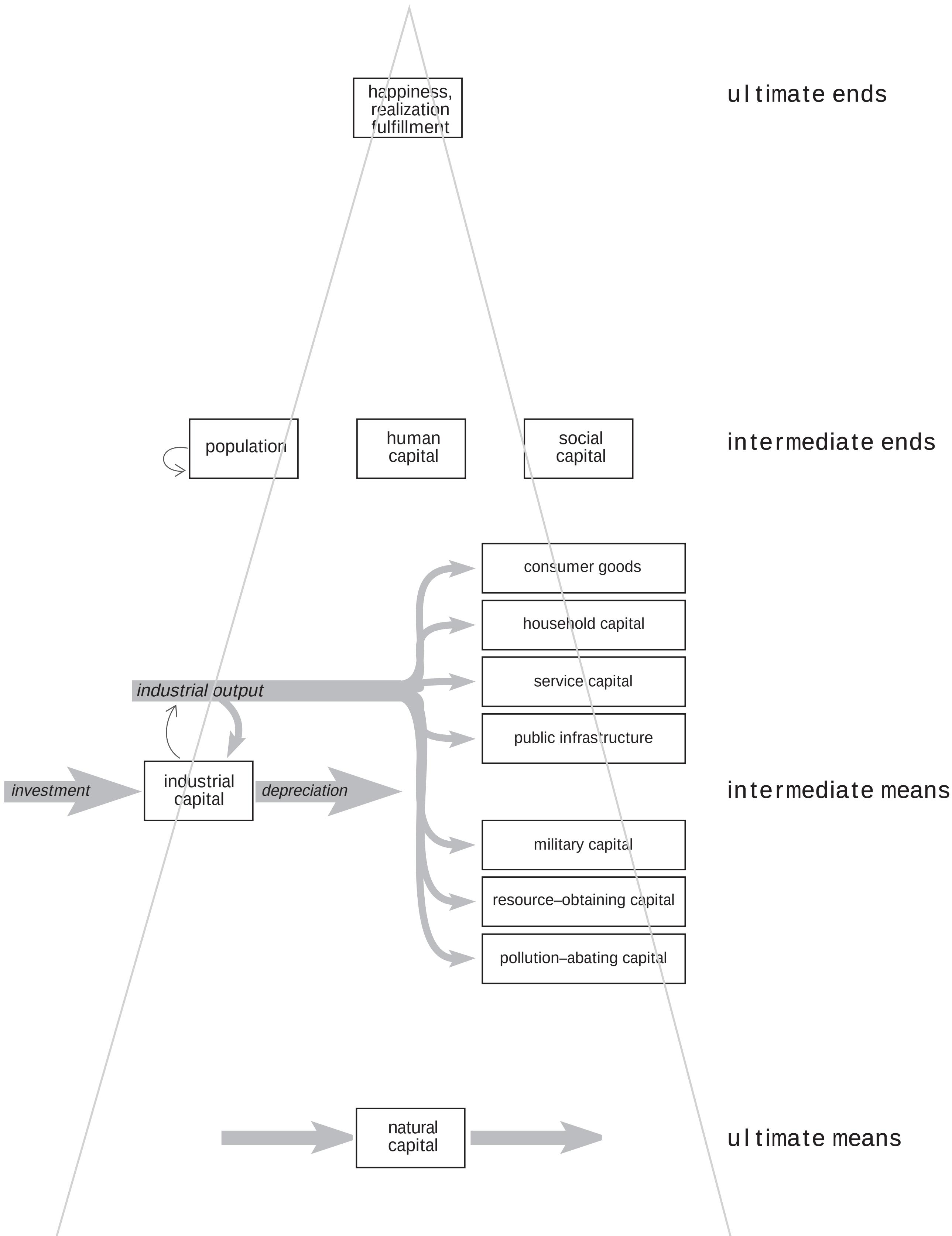
The central indicators of sustainable development will integrate the whole Daly triangle.

Suppose that we could, by whatever means you can imagine, assess the well-being of a given society. And suppose we could measure the throughput from nature that is being used to achieve that well-being. Then we would be able to come close to the three indicators that answer the central questions of sustainable development.

- Are people well-off, satisfied, happy? (*Sufficiency and equity* — top of the triangle.)
- Is the most possible well-being achieved with the least possible throughput of material and energy? (*Efficiency* of the translation mechanisms from the bottom to the top of the triangle.)
- Are the natural systems that support the material and energy throughput healthy, resilient, and full of evolutionary potential? (*Sustainability,* bottom of the triangle.)

The information system from which these central indicators can be derived will measure capital stocks at every level and the flows that increase, decrease, and connect those stocks.

An integrated account of the interlinked stocks and flows at all levels of the pyramid, quantified where possible, estimated otherwise, could provide the information base from which sustainable development indicators are derived. (Just as underlying accounts of interlinked money flows provide the base from which the GDP is derived.)


happiness, realization fulfillment
ultimate ends
population
human capital
social capital
intermediate ends
consumer goods
household capital
service capital
public infrastructure
industrial output
investment
industrial capital
depreciation
intermediate means
military capital
resource–obtaining capital
pollution–abating capital
natural capital
ultimate means

These stocks and flows should be measured in whatever units make sense; units that will be quite different at different levels of the system. There is a tendency in economics, which measures almost everything with the numeraire of money, to assume that because money is interchangeable, then all forms of capital are intersubstitutable. If there is not enough labor, substitute built capital. If there are not enough resources, compensate with more resource-obtaining capital.

To some extent intersubstitutability is possible, and within that possibility arise all the marginal cost and benefit questions that are interesting to economists. But, as Herman Daly points out, it just doesn't work to substitute fishing boats for fish, or sawmills for trees. The absence of trees renders sawmills valueless, as the absence of fish does for fishing boats. Larger pumps can counter a falling groundwater table for awhile, but this substitution is not sustainable. Built capital and natural capital are more *complementary* than *substitutable.* The same could be said for human and social capital and built capital.

The assumption of total substitutability of any form of capital for any other is just as simple-minded as is the assumption of no substitutability. Therefore indicators should be sought that capture, up and down the pyramid, the extent to which the various forms of capital complement and enhance or undermine and undercut each other.

There are systematic schemes for assessing the total viability of a system. These schemes can serve as checklists for sustainable development indicators.

One of these schemes is Hartmut Bossel's set of orientors, which measure the ability of any system to meet environmental challenges by appropriate system responses.[47] There are seven Bossel orientors, which can be measured for systems at any level, from a single organism to a whole society. They are:

- existence (the ability to sustain physical needs);
- psychological needs (the ability to generate internal well-being, satisfaction, happiness — applicable to human systems only);
- effectiveness (the ability to take actions that produce desired effects);
- freedom of action;
- security;
- adaptability;
- coexistence (the ability to live in harmony; not to create costs from incompatibility with others or with the environment.

Though Bossel derived these orientors from systems theory rather than from social science, they bear a resemblance to Max-Neef's list of basic needs. Like Max-Neef, Bossel emphasizes that *these orientors are complementary, not substitutable.* Each of the orientors has to be satisfied to

[47] H. Bossel, *Concepts and Tools of Computer-Assisted Policy Analysis.* Basel: Birkhaeuser, 1977.

a certain degree if the system (or person or society) is to be functional. A viable system requires balanced attention to all needs. Where one attempts to compensate a needs deficit by excess satisfaction of another need, pathological behavior results.

I find the Bossel scheme a useful checklist to see that a proposed set of indicators is comprehensive. It suggests to me areas I might not have thought about, parts of the system that must be monitored, to be sure that the entire system can achieve sustainable development.

Other more informal kinds of “integrative checks” emerged from our workshop conversations. We invented the “Nazi test” — if we applied any suggested set of indicators to Nazi Germany, would it have revealed the obvious problems of that society? Or the “Maya test” — if we could have measured these indicators for the Maya empire, would they have revealed its incipient collapse? In time to prevent that collapse?

7. Sample indicators

While you and I have lips and voices which
are for kissing and to sing with
who cares if some one-eyed son of a bitch
invents an instrument to measure Spring with?

— e e cummings

The proof of any indicator scheme is in the indicators it produces, and the societal behavior those indicators help to inform. The scheme suggested in this report calls not only for indicators, but for an underlying information system and set of dynamic models, none of which currently exist (though there are plenty of prototypes).

Where to start? What indicators to start with?

There is no "best" answer to that question. I have given many sample indicators throughout this report, hoping to stimulate creative thinking and even outrageousness on the part of many people, in order to shake loose old thinking, welcome new worldviews, and begin to suggest indicators that can actually move us toward sustainable development. I'll give some more examples here.

The Balaton Group workshop participants came up with this list:

For natural capital

- Renewable resources used/total natural resources used
- Time to oil or gas depletion / lead time for renewable substitute
- Agricultural land loss (to urbanization, desertification, erosion)/ total arable land
- Loss of primary forests / total primary forests remaining
- Unit of effort (money, labor, investment, time) necessary to add a unit to identified reserves of nonrenewables
- Fish caught per unit of fishing effort
- Soil organic matter content (time trend)
- Output to sink / capacity of sink to absorb or assimilate (especially for CO_2)
- CO_2 emission per capita, relative to "fair earthshare"
- Quality of river water entering country or city / quality leaving country or city
- Number of synthetic chemicals in use
- Area used for organic agriculture/ area used for chemical intensive agriculture

For built capital

- Average productive lifetime of capital
- Maintenance inputs to capital stock / productive output of capital stock
- Capital stock / end use output
- Resource (material and energy) throughput / end use output
- Ratios (balance) between various forms of built capital

For human and social capital

- Infant and child mortality rate
- Total fertility rate (births per woman over that woman's expected lifetime)
- Education level of the bottom 10 percent of twenty-year-olds
- Education and skills attributes of population matched with education and skills requirements of built capital
- Average layers of management between employees and owners
- Income of the top 10 percent / income of the bottom 10 percent
- Percent of government officeholders' total income coming from bribes, payoffs, and private campaign contributions
- Percent of time necessary to secure survival needs
- Percent of time contributed to civic, religious, and other nonprofit causes
- Juvenile crime rate

For ultimate ends

- Population of the local "totem" species (salmon in Seattle, eagles in Maine, seals in the Netherlands)
- Proportion of leisure time per person (and equity of its distribution)
- Human openness in the streets and squares
- Number and size of places of rest and beauty (e.g., forests, parks, temples)
- Flexibility in choosing transport mode and housing
- Percent of people who say they have "enough"

A thoughtful list of fourty-one indicators developed for the United States includes the following, all of which are available with significant time series.[48] Notice that many are grounded in critical capital stocks and in leading-indicator rates of flow.

Economic

- Capital assets
- Labor productivity
- Federal debt to GDP ratio
- Investment as a percent of GDP
- Energy consumption per capita and per $ of GDP
- Materials consumption per capita and per $ of GDP
- Inflation
- Investment in R&D as a percent of GDP
- GDP per capita
- Income distribution
- Consumption expenditures per capita
- Unemployment
- Percentage of households in problem housing

Environmental

- Surface water quality
- Acres of major terrestrial ecosystems intact
- Contaminants in biota
- Accumulated quantity of spent nuclear fuel
- Status of stratospheric ozone
- Greenhouse gas emissions
- Ratio of renewable water supply to withdrawals
- Fisheries utilization (percent overfished)
- Invasive exotic species
- Conversion of cropland to other uses
- Soil erosion rates
- Timber growth/removal
- Identification and management of toxic waste sites
- Outdoor recreational activities
- Extreme weather events

Social

- Population
- Children living in families with only one parent
- Teacher training level
- Contributions of time and money to charity
- Births to single mothers
- School enrollment by level
- Participation in arts and recreation
- People in census tracts with 40 percent or more poverty
- Crime rate
- Life expectancy
- Educational achievement rates
- Homeownership rate

[48]U.S. Interagency Working Group on Sustainable Development Indicators, op. cit.

If I played the "ten indicators or you'll be shot at dawn" game with myself, I'd come up with a list like the following (assuming that I am working on national-level indicators). I am aware that many items on this list are hard to define and measure. I'd use any quick and dirty surrogate measure I could find to start with and then work to make them better. I assume that these would be aggregate indicators, with a "click" revealing the disaggregated source data.

- Ecological footprint and rate of change (ultimate means)
- Aggregate measures of natural, built, human, and social capitals and rates of change (ultimate and intermediate means, intermediate ends)
- Real well-being — measured by survey data if necessary — and rate of change (ultimate ends)
- Physical throughput/well-being (throughput efficiency from ultimate means to ultimate ends)
- Four kinds of capital/well-being (intermediate means and ends to ultimate ends)
- Built capital balances (intermediate means)
- Most limiting sources and sinks and rates of change (ultimate means)
- Most critical respite/response areas (throughout the triangle)
- Untouched natural areas and rates of change (ultimate means)
- Something wacky and human — smiles on faces on the street, hugs per day, clowns per capita (ultimate ends)

I present all these lists not as final, considered opinions, but as challenges. What would *you* choose?

8. Implementing, monitoring, testing, evaluating, and improving indicators

Where there is no reliable accounting and therefore no competent knowledge of the economic and ecological effects of our lives, we cannot live lives that are economically and ecologically responsible.

— Wendell Berry

Indicators don't guarantee results. But results are impossible without proper indicators. And proper indicators, in themselves, can produce results.

Designing the instrument panel is just one small step in the journey of sustainable development. Getting indicators actually measured, reported, institutionalized, evaluated, and improved are further steps that require enormous creativity, tact, and energy. Whole books can be (and have been) written about these steps.[49]

Then, beyond the indicators, is the challenge of *action*, the connection of indicators to actual instruments of change, the creation of political will, the compilation of resources, the evaluation of results, etc., etc.

I can't presume to launch into those topics here; the Balaton workshop did not get into them; and we need not apologize for that. It is sufficient to take one step at a time. The design of the instrument panel is obviously a critical step, without which the whole system can never fly. There is a good reason why so many policy bodies, international agencies, funders, and systems thinkers are focusing upon the design of indicators of sustainable development. They all sense that if the indicators aren't right, then no amount of measuring, reporting, funding, action, political will, or evaluation will lead toward sustainable development. A system without an accurate information system, without information clearly related to its real goals, cannot reach those goals.

Of course, conversely, having the indicators right does not guarantee implementation, action, resources, or

[49] See, for example, P. Hardi and T. Zdan eds., and "The Community Indicators Handbook", both op. cit.

results. But I think the right indicators actively help. The presence of clear, powerful information almost automatically stimulates problem-solving and action.

> If you need one last example of that dictum, I just heard one on public radio. An animal shelter in Maryland was distraught at the fact that it had to kill 13,000 lost or abandoned animals per month. Pleas for people to adopt animals, stronger pleas to neuter pets, produced no visible results. So the shelter took to televising, once a week, on a local cable TV channel, in unblinking detail, the euthanization of a dog. The adoption rate immediately tripled. (It was too soon to tell what happened to the rate of neutering pets.)

Informing people clearly, honestly, and compellingly of the full consequences of their actions can change those actions. It is the absence of such information, especially about consequences over the long term and over long distances, that has led to our present state of unsustainable, inequitable development.

AND there are a few useful last things to say about the steps beyond indicator design — about the actual measurement, reporting, institutionalizing, evaluating, and improving of indicators.

Indicator measurement can be a costly, bureaucratic process. But it can also be relatively simple. There may be clever ways to measure indicators that don't even require numbers or disturbing the system in any way.

> Chicago's Museum of Science and Industry knows which are its most popular exhibits by the wear and tear on its floor tiles. The tiles around the hatching chicks have to be replaced every six weeks. In other parts of the museum the tiles last for years.
>
> A car repair shop, wanting to know how to spend its advertising money, learned what the popular radio stations were by asking its mechanics to jot down the dial setting on the radio of every car that came in for repairs.
>
> You can tell which journal articles are most read in a library by the dirt smudges on the edge of the pages. Turn a bound journal sideways, and you can find the important articles immediately by the dark-edged pages.[50]

These examples are included simply to open the discussion beyond the usual vision of computerized data bases. Computerized data bases are fine things, without which my own work could not be done, but they are expensive to maintain and more useful for research and study than for informing a society and leading to action. Long lists of numbers may underlie an effective instrument panel, but the most immediate indicators need to be graphic, sensual,

[50] These examples and many more are contained in E. J. Webb, D. T Campbell, R. D. Schwarz, and L. Sechrest, *Unobtrusive Measures: Nonreactive Research in the Social Sciences.* Chicago: Rand McNally, 1966.

real, compelling. Perhaps they need not require a corps of bureaucrats to obtain or maintain. People with training in advertising, public relations, focus groups, graphic art may be more helpful than people with expertise in database management.

The process of finding, implementing, and improving sustainable development indicators will not be done right at first. Nevertheless, it is urgent to begin.

It's important to remind ourselves of the magnitude of our task. We don't know what an advanced, sustainable, equitable society looks like. We have never seen one. We are required to envision a cultural, technical, social revolution, or evolution, as thoroughgoing as the Agricultural Revolution or the Industrial Revolution, and then to invent the instruments and information feedbacks that will guide us through this tremendous transformation.

We will not get it right the first time.

Even if there were consensus tomorrow on a selection of indicators and shared understanding of their application, still there is a high probability that some or all indicators may turn out to be misleading. Or maybe the monitoring system will not be adequate, or the interpretation of indicators will be faulty, or the actors and decision-makers in the system will clarify their information needs, and come to new understandings of how to implement change. Maybe (almost certainly) we will learn as we go that the whole notion of sustainable development opens up a larger and more challenging set of opportunities than we had realized.

So it is tempting, given all the caveats and challenges in this report and, indeed, in every report on sustainable development indicators, to be daunted, to postpone the task, to wait for more thinking, more modeling, more agreement — to wait for perfection.

While we are waiting for perfection, fisheries are collapsing, greenhouse gases are accumulating, species are disappearing, soils are eroding, forests are overcut, people are suffering.

So it is important to get some preliminary indicators out there and into use, the best we can do at the moment. That way, as long as we are willing to evaluate and make corrections, we can start to learn, which is the only way we can ever achieve sustainable development.

It should not be so difficult to come up with indicators that are already better than the ones we now use. As long as we regard them with humility, as tentative, subject to correction and improvement, tools for learning rather than final, expert pronouncements, we will be on our way.

We need to learn, but we need to waste no time with our learning.