Achieving Sustainability

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Although sustainability is now a common term, there has been little agreement about how it can be achieved. Most measures, such as triple bottom line reporting, do not measure sustainability at all. This research focuses on the long term nature of human society which, for sustainability, requires that we take a 1000 year perspective of development. For such a perspective, the local geology, hydrology, climate, soil and other physical factors comprise a framework which sets limitations on development that can occur without incurring significant risk to human society, such as water shortages. Once the framework has been identified, the timeframes for management of components of the framework (water, soil, energy, food production, etc.) can then be identified. Risks to sustainability can then be identified, prioritised and managed. Only with long term thinking by local and national governments, scientists, engineers and planners will we be able to achieve sustainability.

Keywords: Sustainability; risk; long term planning

Introduction

The term 'sustainability' has become a part of the common lexicon over the past decade and is used to describe economic or environmental sustainability as well as a balance of economic, environmental and social sustainability. Yet, despite the discussion of sustainable development since 'Our Common Future' (World Commission on Environment and Development, 1987), there has been no clear definition of how sustainability can be achieved or of how we should really define it. Although sustainability is discussed in various ways such as intra- and inter-generational equity (ensuring that the needs of the current generation are met without compromising the needs of future generations) and 'ensuring quality of life', the definitions lack a sense of future and there is no clear understanding of what is meant by future generations. Triple bottom line reporting of environmental, social and economic factors by corporations does not really identify the sustainability of their operations, nor does life cycle assessment. But most importantly, it is not clear if the often small, incremental changes being made are sufficient to actually achieve sustainability; whether we are doing enough to safeguard future generations. Moreover, practical means of actually making decisions and defining the directions we need to take have not been clearly identified and, for this reason, many scientists and engineers have been unable to see their role in achieving sustainability.

Considering the Future

Economists argue that we care about our children, their children and possibly their children, but beyond four generations, we do not have a sense of concern or obligation for future welfare. Most planning and research for the future considers, at most, 50 years – even research into climate change only considers potential changes to 2100 (IPCC, 2001). The recent long-range forecasts for global population to 2300 show how difficult such predictions can be – a minor change in fertility will result in significant changes in global population in 200 years (UN Population Division, 2003).

In the context of future society, four or five generations (100-125 years) is relatively short. Many societies have existed for much longer than that – some for thousands of years (Europe, Middle East, China, India, Egypt). Many of the major cities in Europe, north Africa, the Middle East and Asia have been in existence for over two thousand years; some for over 5,000 years. Some environmental impacts can last for thousands of years, particularly loss or salinisation of soil, loss of resources, degradation of ecosystems and loss of biodiversity while extinction of species and desertification may not be reversed. Some impacts can take long periods of time to develop or occur, such as loss of soil or biodiversity, desertification, deforestation and depletion of resources and, without monitoring, the severity of impact may not be apparent until significant damage or loss has occurred.

Plato, writing *Critias* 2,400 years ago, lamented the impact of deforestation and farming on the Greek island of Attica (Plato, 360 BCE):

> *..all other lands were surpassed by ours in goodness of soil, so that it was actually able at that period to support a large host which was exempt from the labors of husbandry. And of its goodness a strong proof is this: what is now left of our soil rivals any other in being all-productive and abundant in crops and rich in pasturage for all kinds of cattle and at that period, in addition to their fine quality it produced these things in vast quantity... And, just as happens in small islands, what now remains compared with what then existed is like the skeleton of a sick man, all the fat and soft earth having wasted away, and only the bare framework of the land being left. But at that epoch the country was unimpaired, and for its mountains it had high arable hills, and in place of the "moorlands," as they are now called, it contained plains full of rich soil; and it had much forestland in its mountains, of which there are visible signs even to this day; for there are some mountains which now have nothing but food for bees, but they had trees no very long time ago, and the rafters from those felled there to roof the largest buildings are still sound. And besides, there were many lofty trees of cultivated species; and it produced boundless pasturage for flocks. Moreover, it was enriched by the yearly rains from Zeus, which were not lost to it, as now, by flowing from the bare land into the sea; but the soil it had was deep, and therein it received the water, storing it up in the retentive loamy soil and by drawing off into the hollows from the heights the water that was there absorbed, it provided all the various districts with abundant supplies of springwaters and streams, whereof the shrines which still remain even now, at the spots where the fountains formerly existed, are signs which testify that our present description of the land is true.*
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> *Such, then, was the natural condition of the rest of the country, and it was ornamented as you would expect from genuine husbandmen who made husbandry their sole task, and who were also men of taste and of native talent, and possessed of most excellent land and a great abundance of water, and also, above the land, a climate of most happily tempered seasons.*

Thus, at the very least, we need to be considering a period of 1000 years and looking to the type of future we want at that point.

Future Thinking

We cannot, of course, know what technologies we will have available 1000 years into the future nor can we predict the changes that may occur over that time. However, we can make some realistic assumptions and use these to guide planning for a sustainable future. These assumptions include:

a) humans will be here;
b) most current cities will be here;
c) food will still be farmed and require water and nutrients;
d) materials and energy will still be required to meet human needs;
e) materials and energy will have to be provided from existing global resources;
f) basic human needs will not have changed (Table 1).

Using these assumptions, we can then look at the probability and consequences of negative impacts on the environment and society over the short, medium and long term and move to mitigate those risks, particularly those which have major consequences and affect the resources needed by future generations.

Table 1 Basic human needs as defined by Peet and Bossel (2000)

Human Need	
Existence	Provision of the basic biological needs of humans: food, drink, shelter, and medical care
Effectiveness	Provision for the production and distribution of goods and services
Freedom of action	
Security	Provision for the maintenance of internal and external order
Adaptability	Able to change
Coexistence	Able to exist peacefully with other races and species
Reproduction	Provision for the reproduction of new members and consider laws and issues related to reproduction
Psychological needs	Provision of meaning and motivation to its members
Ethical reference	Provision of definitions of right and wrong

Identifying the Framework

On this basis, we can then determine what we have to consider over 1000 years. Local geology, topography, hydrology, climate and soil structure, quality and depth define the local landscape and environment and the limitations that have to be taken into account for human habitation. Although they can each be changed to some extent, both by human intervention and by natural processes and events, these provide a 'framework' from which both the natural and human environment are defined (Table 2).

Table 2 Features of the land framework which set the limitations for human habitation

Landscape feature	Limitation to human habitation
Geology	Extent of liveable area; availability of building materials and other valuable mineral resources; fossil fuel availability; storage of ground and surface water
Topography	Extent of liveable area; water flow; surface water storage; soil erosion
Ground and surface water	Long term availability for consumption, food production; recharge rate; flooding risk to human settlement; removal of waste material; hydroenergy
Climate	Temperature extremes; shelter requirements; provision of food; ecosystem robustness; comfort and survival; storm events; solar and wind energy
Soil	Production of food, biological resources; ecosystem robustness and function
Local plate tectonics/seismology	Risk to human settlement from volcanic/earthquake activity
Proximity to coast	Transportation of goods; provision of food; risk of flooding, tsunami

The physical requirements to meet the basic human needs include water, food, clothing, energy, materials/infrastructure for shelter and transportation, health care and education and a physical location which provides for a safe and secure existence. The natural framework of the landscape and environment identifies some of the limitations that must be recognised for meeting these needs for the long term. Limited water supply or limited agricultural land will result in a requirement to import both water and food, thus requiring a reliance on external supplies. Energy is also critical, for cooking, heating, lighting, communication, transportation and manufacturing and much of the functioning of the urban environment. Materials for building shelter and infrastructure must also be considered, for if they are not locally available, again, there is a reliance on external sources and the energy requirements of transporting some materials can be high. The physical geography and location also affects the security of human existence – extremes of temperature (which will require energy to moderate); the risk of flooding, volcanic activity, seismic activity, landslide or other natural disaster.

Human habitation is thus restricted by the local framework and by how much the framework can be modified or the limitations overcome using existing technology. However, any modifications to the framework also affect the natural environment and, while one or two modifications may enable an ecosystem to survive, significant changes either rapidly or over a long period of time will result in loss of biodiversity. Thus the extent to which the framework is modified needs to be balanced against the long-term risk to sustainability. Water is a major criterion and likely a limitation for human habitation. Water can be channelled or moved over significant distances but the energy costs and the losses over those distances due to leakage and evaporation generally make it unsustainable. It would be more effective to consider local water sources and recharge rates and local environmental requirements and conditions and then seek to manage water requirements within those limitations. This means that difficult decisions regarding local population growth, local industries, agricultural needs and cooperative sharing of water supplies will have to be made by local bodies who are using common water sources. This includes not only surface water but also ground water.

Current management of water is focused on human, agricultural and industrial consumption and thus there is limited recognition or understanding of:

a) the needs of ecosystems;
b) the potential short, medium and long term fluctuations of local water supplies; and
c) the risks to the overall supply, particularly when evaluated as a watershed system.

As a result, planning for new development and industry does not often consider the long-term availability of water, thus leaving many communities at risk of water shortage over the next 20 years (UNEP, 2002). The basic science for supplying and managing water usually ignores the needs of future generations and, in many places, does not even consider the needs of existing or planned development.

The same can be said for the provision of other necessities and resources, including food, energy, building materials and living space. While many villages, towns and cities were established due to the abundance of rich soil and plentiful water, increasing urbanisation often results in the loss of prime agricultural land. As a result, much of the world's agriculture is now based on poorer quality soils and even in developed countries and with the most modern technologies, soil loss is high, thus reducing the long-term quality even more.

Even more concerning are the number of countries reliant on the few countries which provide the fossil energy needed to fuel the technology required to achieve the agricultural productivity now expected. There has been significant debate on the extent of fossil fuel resources and the abundance of these resources (Hall et al., 2003) but it is highly unlikely that fossil fuels will be available at the current economic level after this century. Transportation is likely to be most affected, which means that importing necessities will be at a high cost to individuals and severely disadvantage the survival of the poor. Therefore local authorities need to carefully consider how essential resources can be obtained locally on a long term, sustainable basis, with the import and export market being focused towards luxury or surplus items.

The 'framework' of the land and what it can provide on a long-term basis defines a number of elements of human habitation (Table 3). The framework assists in defining what can and should be followed for future development, particularly when considering the region over a millennium.

Table 3 Elements defined by the 'framework' of the land and their relevance to planning for development over a millennium

Elements	Relevance to long term planning
Land use	Defined by landscape, soil abundance, risk of flooding/seismic or other event
Food production	Risk to food production must be minimised; ability to provide local population with minimum needs essential
Soil health	Will define limits of suitable agricultural land and the abundance and type of food that can be produced
Water quality and quantity	Risk to water supply must be minimised; ability to provide local population with minimum needs essential
Energy	Provision of energy for supply of basic needs
Urbanisation	Balance must be achieved between requirement for food production and urbanisation of prime agricultural land
Greenspace	Provides for recreation, human wellbeing, assists in improving air quality
Health/robustness/ Evolution of critical ecosystems	Provides for water retention, flood control, bidiversity of natural species, clean air; recognises natural changes to ecosystems which may require management
Biodiversity	Improves ecosystem robustness; decreases risk to species and ecosystems
Waste disposal (esp. hazardous)	Affects use of land, groundwater quality
Use of hazardous materials	Can leave long term legacy of contaminated soil, water
Technological direction	Can be directed towards solving sustainability problems such as resource availability

Timeframes

The framework of the land thus establishes the long-term considerations to ensure that future generations can meet their needs. The risks from human activities to the environmental, social and economic subsystems that comprise the overall local region can then be identified, to determine how these could affect the short, medium and long-term sustainability of the region.

Each of the elements in Table 3 also require managing on shorter timeframes and the timeframes are relative to the activity and to the element. Table 4 identifies the various timeframes for managing aspects of water, soil, land and food resources for sustainability. The timeframes will also be dependent on location – for example, ecosystems develop differently in different climates and with different soils and the risk of flooding and seismic activity will vary with the local geology and hydrology.

Some elements do not require managing on a 1000-year basis. In particular, those related to social and cultural dimensions of human habitation can only be managed on a generational basis. This is due to the changing nature of human society which keeps it dynamic and vibrant. Thus while education, welfare, health, security and other aspects of society are important and the right to those aspects needs to be enshrined into society, planning for provision of those services can only be done on a 10-50 year basis. It is important to identify the timeframe for planning which is needed to achieve sustainability.

Table 4 Timeframes for managing water, soil, land and food.

Timeframe Years	Water	Soil	Land	Food
1	Annual rainfall, flooding, runoff, pollution	Erosion, nutrient level, organic content, pollution	Management of existing land use	Annual production, cash/food crop, pest prevention
5-10	Storage, ground water contamination	Heavy metal accumulation, soil health	Residential/commercial /industrial development	Crop rotations, disease and pest management
10-50	Climate	Salinisation, compaction, desertification, soil health	Urban/rural development	Climate suitability for crops, production energy requirements
50-100	Recharge of underground storage systems	Gradual soil loss, soil health	Floodplain development, volcanic/seismic activity	Long term crop management
100-500	Climate changes; effects on max/min rainfall	Soil loss, soil health	Infrastructure	Species diversity, social stability
1000	Local supply for drinking, sanitation, food production, ecosystem support	Soil abundance, health	Transportation corridors, development areas	Long term local production of minimum supply for local population

Identifying the Risks

In considering risk of activities to sustainability, the consequences of a number of events must be first considered. Systems can react in a number of ways to events; in some cases, once a threshold is reached, the system collapses (species loss), while in other cases the system slowly fails (soil erosion). Natural fluctuations are also important in understanding system dynamics and limitations. The systems need to be modelled to more fully understand system interactions, limitations and dynamics. Dynamic modelling of complex systems has already been initiated for both industrial processes (Costanza and Ruth, 1998) and aquatic ecosystems (Boumans et al., 2002 but needs to be extended.

The consequences of either a specific event or a number of events can then be incorporated into the model to determine the effect on the system. Consequences, however, are not merely additive; some are synergistic or positively interactive (the consequences are greater than the sum of the consequences of each event) while others are antagonistic or negatively interactive. The probability (p) of the consequences (C) exceeding the system limitations (L) over a time (t) can then be determined. This is the risk (R) to sustainability and the sustainability over time T, (S_T) of the system thus becomes:

$S_T = 1-(\Sigma R_T)$

With $R_T = p(C>L \mid t = T)$

The risk can be calculated for specific time periods – 20, 50, 100, 500, 1000 years. The assumptions on which the risk is based must be clear. For the longer term risks, however, the uncertainty is usually high and thus risk is usually identified as low, medium or high. To achieve full sustainability would require minimal risk over 1000 years or S_{1000}] 0.95.

The identification of risks requires that we understand more fully the systems we are affecting – environmental, social (including cultural) and economic. Systems thinking is critical to enable the linkages and feedbacks between systems to be identified and for planning to take all systems into account. It also requires us to identify and recognise the limitations of those systems, not only for the short term but also for the long term. Those are the limitations which we must live within if we are to achieve sustainability. At this point, we have identified some critical species or ecosystem levels, the points at which a species or an ecosystem will crash. However, the causes and factors leading to such crashes are not well known and the critical levels of many species and ecosystems remain unknown.

Time is also a critical factor in sustainability. Although an activity may be sustainable in the short term, it may result in slow, long term degradation, e.g. desertification. In addition, although an activity may be environmentally sustainable, if it is not economically feasible over the long term or is socially unsustainable, then it is not sustainable.

Using risk as a measure for sustainability means there is no threshold to sustainability. While a system may be managed or designed so that there will be little risk to its ongoing operation, there will always be some potential occurrence that will result in system collapse. This occurrence may be catastrophic such as a major natural disaster or it may be an unforeseen accumulation of minor problems or it may be the result of chaotic influences. In some cases we can mitigate disasters or, if we find them quickly enough, ameliorate the problems. However, the most that can be done is to reduce or manage the risk. The level of risk that is acceptable must be determined and this can only be done with community and government input.

Applying risk

Risk is already used, to some extent, in setting health standards and standards for construction. A risk of 1 death in 10^6 is often considered acceptable (Hunter and Fewtrell, 2001). This is more difficult to apply to environmental systems as the effect on human survival from loss of an ecosystem is not measurable nor is it direct. In fact, the effects of damage to an ecosystem in one country may result in effects on communities in other countries, especially in the case of rivers which flow through several countries.

Sustainability of Systems

Chemical/physical sustainability
In a chemical or physical sense, sustainability would imply a system which would, with the input of solar energy, be able to function continually. The input of solar energy enables continual operation without flaunting the laws of physics. Chemical and physical systems which operate globally include hydrological cycles, carbon and nutrient cycles, erosion and rock formation, climate systems, formation of ozone layers in the atmosphere and even the trapping and loss of solar heat from the earth. Such cycles operate on a variety of time scales – some could be only days long while others are thousands of years long. Some cycles experience variations which may result in changes lasting hundreds of years. Others may break down as cycles and only begin again when conditions are right.

Examples of cycles which fluctuate in regular patterns include sunspot activity as well as the Milankovich cycles which have an effect on the solar radiation intensity of up to 30% in different seasons (Imbrie and Imbrie, 1979). The resulting effect is the ice ages and other climatic fluctuations. Climate also fluctuates through shorter periods than ice ages. One of the well known examples is the El Nino Southern Oscillation which affects global climate. All climate cycles also affect the hydrological cycle, the carbon cycle, ozone formation and even nutrient cycles.

Continual change also affects the chemical and physical conditions of the planet. It is thought that carbon dioxide was much greater in the atmosphere during the Paleozoic period and that CO_2 levels decreased with the emergence of vascular plants and their uptake of CO_2 (Berner, 1997) in the Devonian. This was then followed by the extensive and long Permo-Carboniferous glaciation. There are also thought to be significant linkages between the carbon, oxygen and sulphur cycles (Berner and Petsch, 1998). However, the linkages between the different cycles are highly complex and could be classed as chaotic. In conclusion, the global cycles which operate at the chemical level require only the ongoing influx of solar energy to operate and function on a complex, chaotic level over varying timeframes, with some cycles breaking down and then re-establishing as global conditions fluctuate. The probability of a major change in climate occurring in any year is quite low but is higher when consider periods of 1000 years.

Biological or environmental sustainability

Within an ecosystem, evolution occurs as the environment changes or as species which are unable to survive or adapt to changes become extinct. The changes are usually due to changes in the flow of energy and materials to a system, either an increase or decrease in the flow. Species which are unable to adapt to those changes die out or migrate and species which can adapt to the changes then take over, thus changing a component of the ecosystem. When a number of such changes occur, the ecosystem and its dynamics change.

Certainly natural ecosystems are not in a steady state. Fluctuations in abiotic factors (water, light, heat energy, sediment, air, nutrients etc.) change ecosystems as can disasters (Costanza and Patten, 1995). Marshlands gradually fill in due to an influx of sediment, creating a meadow which gradually becomes bushland then forest. Rivers constantly change in flow and in bed, thus changing the ecosystems which they encompass and which surround them. Natural disasters and changes in climate affect ecosystems, resulting in the death of some species and the proliferation of new ones. For example, changes in climate in the Arctic over the past years are causing ongoing changes in Arctic ecosystesm (Overpeck et al., 1997). Most animal species undergo fluctuations in populations due to changes in climatic, resource and other factors such as disease. It is therefore difficult to determine whether such systems are sustainable, since they are constantly fluctuating. Such changes can result in the demise of an ecosystem or can increase the biodiversity of the system, making it more robust (Costanza and Patten, 1995).

A few long lived ecosystems (400-1200 years) such as old growth forest do exist, where climate has been relatively stable and is usually benign and wet, where natural disasters are infrequent and stability can be maintained. These tend to therefore represent sustainable natural systems and can be characterised by:

a) little growth of the dominant larger species (Tyrrell and Crow, 1994);
b) infrequent disturbances (Foster, Orwig and McLachlan, 1996) and
c) adequate land area to buffer natural disturbances such as fire (Foster, Orwig and McLachlan, 1996).

There is some indication that high biodiversity also provides resilience and allows ecosystems to recover from stress more easily (Naeem et al., 1994). Yet within these forests, there are changes in the size and distribution of forest patches and canopy gap formation and growth and patterns of mortality (Foster, Orwig and McLachlan, 1996). Whereas the overall system is sustainable, subsystems are constantly changing but the overall balance is being maintained.

Chapin, Torn and Tateno (1996) defined a sustainable ecosystem 'as one that, over the normal cycle of disturbance events, maintains its characteristic diversity of major functional groups, productivity, soil fertility, and rates of biogeochemical cycling.' They also point out that few ecosystems are sustainable longer than a few tens of thousands of years. Species composition, productivity and nutrient cycling will change over short periods but, in a sustainable ecosystem, these changes are in balance over the longer term. Climate changes, soil development and evolution of species gene pools, however, change over longer time periods, resulting in the slow evolution of the ecosystem. As long as the changes to productivity, nutrient cycling and plant and animal species composition average to a steady or balanced state, the ecosystem is sustainable. However, when there is a major change in any interactive control such as local climate, soil resources supply, basic functional groups of species and the disturbance regime, the ecosystem becomes unsustainable. Negative feedbacks provide the major constraints to changes in interactive controls while positive feedbacks amplify initial changes in conditions and move the ecosystem to a new state. Ecosystems, however, are a complex interaction of both negative and positive feedbacks in both community and landscape dynamics.

The differing positive and negative feedbacks and community and landscape dynamics of different ecosystems make it difficult to define the level of change in an ecosystem which can be sustained without disruption of the system. There has been much discussion of the acceptable levels for harvesting of fish or timber, agricultural intensity, for dumping of waste materials into aquatic systems and for changes in biodiversity. Yet human society is dependant on the produce from ecosystems, both natural and anthropogenic. The extraction of produce affects interactive controls such as soil resources supply (soil fertility, ecosystem productivity, nutrient cycling), the functional groups of species (changes to species diversity) and influences the disturbance regime (prevention or causing flooding or fire). In order to be sustainable and enable long term provision of produce from ecosystems, these effects must be limited to those which will not unbalance the ecosystem.

> 'For the ultimate balance to be sustainable, the processes of maintenance, replacement and renewal must equal or exceed the processes of depreciation, degradation and loss' (Dahl, 1995).

Although the balance must be maintained over the whole ecosystem for it to continue to survive, it is likely that there are components of the ecosystem which are not in balance. If these components continually depreciate, degrade or suffer loss, then, unless the rest of the ecosystem can continue to provide sufficient resources to make up the balance, the losing component will eventually collapse. The determination of a change as being bad or good for a system is dependant on three factors according to Rapport, Costanza and McMicheal (1998) – resilience (resistance to stress), vigour (activity or primary productivity) and organisation (diversity). The effect on the overall ecosystem will therefore depend on the ecosystem – if the ecosystem is sufficiently resilient, vigorous and diversified, then it will be able to withstand change. Change, however, which reduces resilience, vigour or organisation decreases the sustainability of the ecosystem.

The sustainability of ecosystems therefore requires that 'the processes of maintenance, replacement and renewal must equal or exceed the processes of depreciation, degradation and loss' (Dahl, 1995). Positive feedbacks are detrimental to stability as they amplify changes while negative feedbacks provide the major constraints to interactive controls – ecosystems however are complex, chaotic interactions of both negative and positive feedbacks. Ecosystems must also maintain sufficient resilience, vigour and organisation to be able to withstand changes due to natural fluctuations in global and local cycles and natural disasters.

Sustainability of human society

Regardless of how human society is organised, it is still highly reliant on the environment for basic necessities such as water, air, food, clothing, etc. Human society is highly varied – it includes societies which are still primarily hunters and gatherers, those primarily dependant on agriculture, highly technological societies, societies which are based on communal sharing of goods, dictatorships, fascist regimes, highly religious, secular, democratic, socialist and capitalist societies. All are dependant on the extraction of resources from the biosphere to a varying extent and none provide a perfect example of effective government, economic distribution or equality, although some are better than others in some areas.

Societies fluctuate and evolve, depending on both internal and external circumstances. The conflicts and political unrest in Eastern Europe have seen dramatic reductions in the standard of living and people in Russia also seem to be suffering as a result of poor government following the collapse of the previous regime. Many societies have moved from a highly religious based culture to a secular society, some theoretically granting equality to all religions while others ban religious practices outright. There is also a strong move for others to become religious states, adverse to or openly banning other religions.

The complex interactions of the components of individual societies (e.g. government, business, education, religion, inherent beliefs and practices) means that different societies react differently to similar forces. For example, a comparative study of foreign investment in Asia and Latin America showed a positive effect on economic growth but a negative one in Latin America, possibly due to state coercive capacity and state direct activitism in Asian countries (Pattnayak, Sr., 1992).

In order to recognise the factors necessary for sustaining a society, the factors which cause the collapse of societies need to be understood. Much research has gone into the failure of the USSR. By the time of its demise,

> 'the rate of economic growth had fallen to zero, corruption was endemic with the black economy growing, worker productivity was falling, the neglected services sector contributed to a shortage of consumer goods and falling living standards, the social infrastructure was decaying and technological backwardness widened the performance gap with the West.' (Moorewood, 1998, p34).

Tainter (1988) undertook an analysis of the reasons for collapse of complex societies. He pointed out there appeared to be a number of reasons causing collapses such as barbarian invasion, catastrophic occurrences, climate change, resource depletion, political mismanagement, mystic factors, social dysfunction and economic factors. However, his analyses of the various reasons showed that these factors were found and overcome in many societies without causing collapse. He argues that there are four concepts which lead to understanding collapse:

1. Human societies are problem-solving organisations;
2. Sociopolitical systems require energy for their maintenance;
3. Increased complexity carries with it increased costs per capita; and
4. Investment as a problem-solving response to increasing complexity often reaches a point of declining marginal returns.

The examination of three case studies, the Roman Empire, the Mayan Civilisation and the Chacoan culture, showed that there were decreasing returns for investment as each society became more complex. Once these returns had decreased to the point that the society was weak, any additional stress would cause the society to collapse.

Tainter's examination of current society was brief but he pointed out that current societies cooperate to the extent that when a society today begins to collapse, it is either provided support from the World Bank or the International Monetary Fund to prevent that collapse or it is absorbed by a neighbour or larger state. Therefore, as long as there is funding or support available, societies will not be able to collapse or will at least be able to survive longer than usual. However, he also points out that patterns of declining marginal returns can be seen in a number of current industrial societies, in areas such as agriculture, mineral and energy production, education, health, management and productivity. Consequently, if collapse is going to occur, Tainter believes it will occur on a global scale -

> 'Collapse, if and when it comes again, will this time be global. No longer can any individual nation collapse. World civilization will disintegrate as a whole. Competitors who evolve as peers collapse in like manner.' (Tainter, 1988, p. 214).

Such doom scenarios, however, have been predicted for industrialised society over the past 100 years without yet showing signs of actually occurring (Tainter, 1988). It is still not clear if there is a specific trigger which will result in the collapse of current industrialised society today. Nor is there any clear understanding of the carrying capacity of the environment for human activities – this is difficult to determine since, once the carrying capacity has been exceeded, it may take a number of years for societies to be affected and those in lower socio-economic levels will first be affected. Those at upper levels will be able to buy their way out of most shortages of resources. However, there are indications that the human population has either reached or exceeded the carrying capacity for current industrialised country lifestyles (Wackernagel and Rees, 1996). For global society to continue without collapse, the current lifestyle will require change. Exactly how this change should occur has been a significant debate among scholars, politicians, industry and communities.

One of the major issues that has been debated is that of strong versus weak sustainability. Weak sustainability assumes that ecosystems are highly resilient to human impact, that human capital can be substituted for natural capital and that technology can overcome any environmental or resource problems that may threaten human survival. The problems with these assumptions are that:

a) ecosystems have not been shown to be highly resilient; some can be readily disturbed;
b) there is no evidence that human capital can be totally substituted for natural capital and
c) there is no evidence that technology can overcome all environmental or resource problems.

It is possible that an artificial environment can be constructed which would sustain human life at extremely high densities but the quality of life would likely be limited.

When technology is relied upon to provide resources, this requires not only capital funding and resources to provide the technology, but also resources and funding in the future to maintain and upgrade the technology. There is also the risk of the technology failing. The consequences of such a failure depend on how essential the technology is to provide the resource – for example if it is merely supplementary, a failure may not be catastrophic but if the technology is essential for delivery of an essential resource such as water, then the failure may be catastrophic for health and economic reasons. Complexity also increases the risk of breakdown, as does the 'newness' of the technology as such technology will likely require significant future upgrades as it matures. Relying on technology thus can increase risk to future generations and the greater the reliance and more complex, new and expensive the technology, the greater the risk.

If future generations are not to be compromised, then the options available to them must also not be compromised. As natural capital is depleted and ecosystems are degraded, the options available for recovering from change or disaster are reduced as only technical solutions will be available. Relying significantly on technology and declining resources for survival will result in a decreasing rate of return as well as reduce the resilience, vigour and organisation of society. Thus reductions in the options available for future generations means that society will be placed under a greater risk of collapse. Weak sustainability, therefore, increases the risk of societies collapsing; the fewer the solutions available, the greater the risk of collapse.

Energy and resources are required for the maintenance of sociopolitical systems and current society is highly dependant on energy for its technology which forms the underpinning of most developed and developing societies today. As resources are depleted, the return on investment in obtaining those resources decreases. This becomes more critical, of course, for resources which are essential for the function of the society such as water, food, land or energy.

For present industrialised societies, fossil fuels are the major energy source although nuclear energy is a source for a few countries. Therefore, industrialised societies are vulnerable to fluctuations in resources of fossil fuels, since if these resources are depleted, there is, at present, no infrastructure capable of utilising alternative energy sources on a wide scale.

Currently, there are positive feedback mechanisms operating which result in increased use of energy every year. The mechanisms include population increases, economic thrusts for increasing GDP, increasing globalisation and increasing reliance on technology. This increase in consumption results in an increase in dependency on energy which, each year, places society at greater risk of collapse due to the limitation of fossil fuel reserves. Although the extent of such reserves is not known, estimates of petroleum reserves indicate that they will be unable to meet supply by the middle of this century and be almost fully depleted by 2100 (USGS, 2001). Taking the subsequent increase in use of coal and natural gas once petroleum is in short supply, it is unlikely that these fossil fuels will be able to supply global needs for longer than 2200. The sustainability of global society therefore requires that we reduce our dependency on fossil fuels and other limited resources and begin to focus on renewable and sustainable energy sources.

Although energy may be a major trigger for social collapse, remediation and mitigation of other problems such as environmental degradation and climate change may become so costly (both financially and in energy) that they become unaffordable. Water can be purified for drinking even when highly contaminated but the energy and technology costs become unacceptable at a specific point. Most environmental degradation can be remediated but only at a cost, often significant. Even changes in climate can be mitigated to a certain extent – for example, people can move to better climates, change crops, increase irrigation or use desalinated sea water, but these activities may also pose a threat to environments and most would only be effective over the short term. Depleted metals can be recovered even when widely scattered, also at a cost. Environmental degradation as a whole contributes to the overall energy and financial cost of society, thus increasing the vulnerability of society to collapse.

Another factor that has come to the forefront recently is that of agricultural practices. The occurrence of diseases such as Bovine Spongiform Encephalopathy (BSE, commonly known as mad cow disease) and foot and mouth in Europe as well as in Asia and South America have led to questions about the acceptability of current high-density, high yield farming practices. Much of the contamination of ground water is a result of agricultural practices. There is also a great deal of public concern surrounding the use of genetically modified organisms, both from a scientific and an ethical perspective.

In general, however, the major environmental concerns today which could affect society on a global level include:

- Energy use;
- Water quality and quantity;
- Land use;
- Agricultural practices;
- Resource use;
- Loss of biodiversity;
- Climate change;
- Environmental degradation;
- Population increase;
- Disease.

Not all of these are issues in all parts of the globe – some countries have sufficient water resources, while others have remediated much of their past environmental degradation. Areas or regions may have other environmental concerns which are more critical than those listed. In addition, it must be recognised that some of these factors are not anthropogenically controlled; there is evidence that climate change has occurred without human intervention in the past (although not at the current rate); new diseases arise as a matter of evolution; natural disasters such as earthquakes, volcanoes and tsnamis cause environmental degradation and plants and animals do become extinct naturally. However, human exacerbation of those occurrences increases the impact and, therefore the cost, on society, thus making it more vulnerable. Overall, the balance of maintenance, replacement and renewal of ecosystems and resources must equal or exceed the depreciation, degradation and losses that occur.

The environmental requirements of societies are often only one factor cited when discussing sustainability of human systems. Peet and Bossel (1999) identified six basic orientors of system behaviour – existence, effectiveness, freedom of action, security, adaptability and coexistence, together with three additional orientors – reproduction, psychological needs and ethical reference. Each of these orientors must be considered for the human and social subsystem, the built subsystem and the natural subsystem. Sustainability indicators can then be identified for each of these orientors and used as measures for future planning.

Although these factors must be incorporated into any concept of planning, the question that arises is the rigour with which such measures need to be applied. If such measures are applied too strictly, then there may be little freedom for society to develop and evolve. If, however, the measures are not applied at all, then there is the risk that the system is not meeting the needs of the society and its individuals. Although this may not result in the collapse of the society, it may lead to civil unrest, a deterioration in the quality of life of individuals and a general impoverishing of the society, thus leaving it more vulnerable to collapse.

Although sustainability requires that the needs of future generations must be considered, this does presuppose that the wishes of those generations is known. Certainly the requirements of future generations for food, water, land and other basic needs can be accepted. However, it is likely that the morals of current society will be dramatically different from those of future generations – the morals of many societies even 100 years ago were very different from those of today. Attitudes towards individuals in general, but most particularly minorities, women and children, as well as towards animals and the environment have moved dramatically towards increasing the rights and protection of those entities and this is likely to continue. Laws are constantly being changed to reflect current ethics, morals and attitudes and to encompass new technologies such as the internet, genetic modification and cloning. Moreover, it is difficult to predict the resources and concepts which may be important to future generations but which are not considered even relevant today. A balance must therefore be maintained, between ensuring that future generations have the resources and the societal framework to enable them to make choices and providing restrictions, either through lack of resources or through legislation which restricts their ability to make those choices.

Certainly, there are aspects to societal development that are positive, such as ensuring that the basic needs for survival are provided to all members of society, improving access to education for all, decreasing violent and unlawful behaviour, providing justice and security for all. In many ways, these are linked and cannot be separated; for example, providing a good education may reduce unlawful behaviour and therefore increase societal security and enable more people to obtain their basic needs.

Measures of societal well being include both quality of life and societal development. Although many countries equate quality of life or development to GNP, it is well recognised that GNP in fact does not measure the well-being of individuals or even of the society. Rather it is a measure of economic movement in a society, which completely ignores poverty levels, education, violence and other indicators of well-being.

> ‘Real development is only when new value is added by innovation or creation, the quality of life is increased, or a larger net mass of goods and services is produced and maintained, after all the costs of production and depreciation have been subtracted. This will most likely be both a much lower percentage growth, and involve different kinds of growth, than that measured today using GNP indicators’ (Dahl, 1995).

Kelly (1998) compared the U.S. GNP with the Index of Sustainable Economic Welfare (ISEW) and the Genuine Progress Indicator (GPI). The latter two indicators take distributional inequity, the services of household labour, consumer durables, streets and highways, and public expenditures on health and education into account. Costs associated with defensive expenditures on health and education, and loss of farms and wetlands are deducted and adjustments are made either positively or negatively for net capital growth and changes in net international position which reflects the amount of monies invested overseas minus the amount of overseas monies invested in the US. The GPI includes several additional factors. Whereas the GNP indicated that US development has been successful, showing an increasing trend since 1956, the ISEW started to decline slightly in the 1980s and the GPI showed a decline from the early 1970s, thus indicating that US development has slowed dramatically. However, basing current fiscal policies on the GNP results in a positive feedback, promoting increases in fuel and material consumption to raise the GNP, which will also eventually result in depletion of resources and a society which will be at high risk of collapse. Other indicators need to be established and ascribed to which provide a better indication of quality of life, resilience, vigour and organisation of societies and include both positive and negative feedbacks.

Sustainability in a societal context, therefore, requires maintenance, replacement and renewal equal to or exceeding the processes of depreciation, degradation and loss for its overall activities; environmental, social and economic. This therefore maintains the rate of return, ensuring that diminishing rates of return do not occur. Relying on weak sustainability will result in a diminishing rate of return and reduce options available to future generations, thus increasing the vulnerability of future generations to collapse and compromising those generations. A number of factors, both environmental and social, must be balanced in order to achieve sustainability of human society. Currently there are a number of positive feedback mechanisms operating which are resulting in the increased depletion of resources, most notably fossil fuels. One of these, GNP, is used as an indicator of societal development but it does not portray an accurate assessment of the living conditions of those within the society. Other indicators, which do not create positive feedbacks and which provide a better understanding of the resilience, vigour and organisation of the society, need to be developed.

Subsystems and Activities in Society

As with ecosystems, society is made up of a number of components or subsystems. The major subsystems include communities, industry, government and institutions but there are other subsystems including non-government organisations, associations, clubs etc. Individuals may belong to more than one subsystem. Each subsystem however, uses activities or tools or has basic items which they need to function within society, such as food, water, roads, laws or regulations, products (e.g. vehicles, houses etc.), manufacturing processes and services etc. It is those tools, items or activities which set the parameters of society in terms of sustainability. They can be divided into societal regulations or guidelines, services and products.

The regulations or guidelines provide direction to the society, to ensure that the orientors (as listed above) are effectively managed within society. This can include sharing of resources so that all members of society have the basic necessities to survive, that security and freedom are balanced, that society is able to be effective, adapt and coexist, psychological needs are met, reproduction is protected and overall, an ethical framework for the society is established. Although the initiation, enforcement and evolution of these guidelines requires resources, they are primarily in the form of human labour, recording materials and mechanisms of dissemination and need to be considered more as components of service. However, these guidelines can provide direction to society which defines its sustainability.

Services primarily focus on providing labour to undertake a function, rather than relying on a product. Although services use products to carry out their function, labour is employed in marketing, installation, operation, maintenance or other such activities. Since service does not involve the production of a product, it is usually considered to have a lower impact on the environment although this does vary from function to function. Despite the perception that the service economy is inherently clean and sustainable, it is in fact, ‘better characterised as an added-value layer resting upon a material intensive industrial economy’ (White, Stoughton and Feng, 1999).

Production, distribution, operation, maintenance and disposal of products provide the material items which are necessary for fulfilling the needs and demands of society. Some of the items produced provide for the basic needs such as food, shelter, clothing, water, etc. while others assist in providing transportation, communication, entertainment, education etc. It is the production, demand and use of products that places the greatest burden on society, since this requires energy and materials not only to produce the product but also to ship it to the retailer and consumer, ensure it functions during its lifespan and to either dispose of or recycle the discarded product.

Consequently, recent moves to achieve sustainability have included switching to service-oriented rather than material-oriented technologies, thus theoretically enabling the quality of life to be maintained with less impact on resources and the environment. According to White, Stoughton and Feng (1999, p1),

> 'All else equal, economic growth in services may be less environmentally problematic than growth in manufacturing.'.

Not all products can be dematerialised – food, clothing, shelter etc. all require materials and energy and even information technology, which purports to provide a material free society, is based upon an extensive, sophisticated manufacturing and maintenance infrastructure. Moreover, much of the service economy is based on a product intensive society. However, services can be used to change the ways in which products are made, used and disposed of and in some cases supplant products altogether, thus reducing both energy and material needs in supplying society (White, Stoughton and Feng, 1999).

Sustainability of products and services

For a society to become sustainable, the overall balance of activities within it must ensure that maintenance, replacement and renewal equals or exceeds the processes of depreciation, degradation and loss. Although it is feasible that an activity may be unsustainable, it could be balanced by another activity which provides maintenance, replacement or renewal exceeding the loss due to the first activity. However, by allowing activities to be unsustainable without clearly showing how the balance of sustainability is to be maintained, it is highly unlikely that sustainability will be achieved overall. Therefore, to achieve sustainability, the services and products within a system must be sustainable in their production, operation and final endpoint. Unsustainability in services and products will result in the overall system being unsustainable unless mitigation or remediation measures are put in place.

Sustainability in products and services does not, however, mean that the society is sustainable. Although products and services may be sustainable, the purpose to which they are applied may be unsustainable; a sustainable technology may have equal applications in medicine as well as in offensive warfare; construction of sustainable housing may result in environmental degradation or loss of biodiversity if the siting of the buildings is not chosen with respect to sustainability. Guidelines, rules and regulations are necessary to assist in ensuring that the overall society is sustainable but it must be recognised that to achieve such a goal also requires willing participation from all members of society.

It must also be recognised that although a product or service may be sustainable, it does not mean that it must be sustained. As technologies improve or new technologies are developed, old technologies will be phased out, a function of the evolution of society and human development. It is also likely that there will be aspects to new technologies which are unforeseen and could pose a threat to sustainability. For example, the use of both DDT and PCBs was considered to be safe and highly beneficial to humanity when they were first developed – it was only after a number of years that the detrimental environmental effects of these substances was recognised. Regardless of these issues, these products and services must be developed to be sustainable by current measures; society must then put them to use for sustainable purposes and monitor their ongoing operation and use to ensure they are sustainable.

In order to be sustainable, the activities of a society must occur without causing overall depreciation, degradation or loss. Thus, the energy and materials for services and products must be limited to sources which are maintained, replaced and renewed at a rate equal to or exceeding that of extraction, degradation or depreciation. Use of non-renewable resources therefore requires effective and efficient recycling of those resources, to ensure that material is not lost and the overall rate of return is acceptable. This definition, a strong sustainability, does not place a burden on future generations to use human capital to replace natural capital; thus it allows future generations a greater freedom of choice in making decisions. It also reduces the risks to and vulnerability of future generations.

Products and services must therefore be evaluated to determine if their ongoing function will balance maintenance, replacement and renewal with depreciation, degradation or loss. Table 1 lists those factors which must be considered at an global environmental level. Other factors may have to be evaluated for local or regional environments. Social contexts of function must also be considered. For example, the working conditions of employees, the purpose for which a company advertises and sells a product or service, the nature of the product or service to promote antisocial or criminal behaviour and the effect on quality of life must all be taken into account.

With current lifestyles, very few activities would be sustainable over 1000 years, i.e. have a low probability of breaching system limitations and causing damage. Most activities fail immediately due to their reliance on fossil fuels, which have a high probability (67-90%) of affecting climates due to the release of CO_2 (IPPC, 2001). Even more importantly, the loss of fossil fuel energy, either due to social disruption or resource depletion, will have a significant impact on supply of water, production of food and other essential goods, heating, transportation and communication, thus disrupting any society dependant on fossil fuels. Water is also a major concern and shortages will affect food production and goods manufacture. Most of our technology is not sustainable even within this century; research indicates that efficiency and resource use need to improve by up to a factor of 50 to achieve sustainability over the next 50 years (Weaver et al., 2000).

However, the first step to achieving sustainability is to understand and acknowledge what is not sustainable. Only then can activities be changed to reduce risks to future generations and activities.

Conclusions

Consideration of a 1000-year scenario for a city does not mean that the city should not change. Change allows for revitalisation and encourages development of new ideas, thus strengthening society. However, long-term thinking on resource availability and infrastructure planning is essential as are paradigm shifts in economics and technology design. Clearer and better understanding of provision of quality of life without quantity of goods is required. Individual responsibility for the future also needs to be clarified and accepted.

To achieve sustainability both local and national governments need to consider the long term, 1000 year future of their respective regions, understand and recognise the limitations and risks to supply of essential resources and the risks this places on development, particularly over the long term. Once the long-term framework of the region has been identified, shorter timeframes for planning and managing risk to sustainability can then be identified. Scientists, engineers and planners need to identify and recognise the limitations posed by local geology, climate and other factors and work with recognition of those limitations for long term sustainability. Any development will have to work within those limitations and technological development will need to provide necessities over the long term. A 1000-year framework will enable a more realistic, sustainable and secure future for societies.

References

Berner, R.A. 1997. The rise of plants and their effect on weathering and atmospheric CO_2. *Science* 276(5312):544-547.

Berner, R.A. and S.T. Petsch. 1998. The Sulfur Cycle and Atmospheric Oxygen. *Science*, 282(5393):1426

Boumans , R.M, F. Villa, R. Costanza, A. Voinov, H. Voinov and T. Maxwell, 2002. Non-spatial calibrations of a general unit model for ecosystem simulations. *Ecological Modelling* 146 (2001) 17–32.

Brundtland Commission, 1987. *Our Common Future*. Oxford University Press, Oxford, UK.

Costanza, R., and R.C. Patten, 1995. Defining and Predicting Sustainability. *Ecological Economics* 15: 193-196.

Costanza, R. and M. Ruth, 1998. Using Dynamic Modeling to Scope Environmental Problems and Build Consensus. Environmental Management Vol. 22, No. 2, pp. 183–195.

Dahl, A.L., 1995. Towards Indicators of Sustainability. Paper presented at *Scope Scientific Workshop on Indicators of Sustainable Development*. Wuppertal, 15-17 November 1995.

Daly, H.E., 1996. *Beyond Growth: The Economics of Sustainable Development*. Beacon Press, Boston.

England, R.W., 2000. Natural capital and the theory of economic growth. *Ecological Economics* 34 (2000): 425–431.

Foster, D.R., D.A. Orwig and J.S. McLachlan, 1996. Ecological and conservation insights from reconstructive studies of temperate old-growth forests. *Trends in Ecology and Evolution* 11(10):419-424.

Hall, C. et al., 2003. Hydrocarbons and the Evolution of Human Culture. Nature 426:318-323.

Hunter, P. and L. Fewtrell, 2001. Acceptable Risk. In Fewtrell, L. and J. Bartram, *Water quality - guidelines, standards and health: Assessment of risk and risk*

management for water-related infectious disease. IWA Publishing, Ltd., London.
Imbrie, J. and K.P. Imbrie, 1979. *Ice ages: solving the mystery*. Enslow Publishers, New Jersey
IPCC, 2001. *Climate Change 2001 Scientific Report*. Intergovernment Panel on Climate Change. http://www.ipcc.ch
Kelly, K. 1998. A systems approach to identifying decisive information for sustainable development. *European Journal of Operational Research* 109(1998): 452-464
Merriam-Webster Inc., 2001. *Merriam-Webster Collegiate Dictionary*, Merriam-Webster Inc., http://www.m-w.com/.
Moorewood, S., 1998. Gorbachev and the collapse of communism. *History Review* 31:33-39.
Naeem, S. et al., 1994. Declining biodiersity can alter the performance of ecosystems. *Nature* 368 734-737.
Overpeck, J., K. Hughen, D. Hardy, R. Bradley; R. Case; M. Douglas; B. Finney; K. Gajewski; G. Jacoby; A. Jennings; S. Lamoureux; A. Lasca; G. MacDonald; J. Moore; M. Retelle; S. Smith; A. Wolfe; G. Zielinski, 1997. Arctic environment change of the last four centuries. *Science* 278(5341): 1251-1257
Pattnayak, Sr., 1992. Direct Foreign-Investment, State and Levels of Manufacturing Growth in Asia and Latin America. *Journal of Political and Military Sociology* 20(1):83-106.
Peet, J. & Bossel, H., 2000. An Ethics-Based System Approach to Indicators of Sustainable Development. *International Journal of Sustainable Development*3(3):221-238.
Plato, 360 BCE. Critias. In *Plato in Twelve Volumes, Vol. 7,* translated by R.G. Bury. Cambridge, MA, Harvard University Press; London, William Heinemann Ltd. 1966. The Perseus Digital Library, Tufts University. http://www.perseus.tufts.edu/cgi-bin/ptext?lookup=Plat.+Criti.+110e
Rapport, D.J., R. Costanya and A.J. McMicheal, 1998. Assessing Ecosystem Health. *Trends in Ecology and Evolution* 13(19)397-401.
Tainter, J.A., 1988. *The Collapse of Complex Societies*. Cambridge University Press, Cambridge, UK.
The Natural Step, no date. What is the Natural Step Framework? http://www.naturalstep.org/about/whatis_framework.htm#systemconditions
Tyrrell, L. E. and T.R. Crow, 1994. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. *Ecology* 75(2): 370-386
UNEP, 2002. *Global Environmental Outlook 3*. Earthscan Publications, London.
UN Population Division, 2003. *World Population in 2300 (Draft)*. UN Department of Economic and Social Affairs Population Division. ESA/P/WP.187.
von Weisacker, E.U., A. Lovins, and L. Hunter Lovins, 1997. *Factor Four: Doubling Wealth, Halving Resource Use.* Earthscan Publications Ltd., London, U.K.
Wackernagel, M., Rees, W. E., 1996. *Our Ecological Foot-print: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, British Columbia, Canada.
Weaver, P., L. Jansen, G. Van Grootveld, E. Van Spiegel and Ph. Vergragt, 2000. *Sustainable Technology Development.* Greanleaf Publishing Limited. Sheffield.

White, A.L., M. Stoughton and L. Feng, 1999. Servicizing: The Quiet Transition to Extended Product Responsibility. Tellus Organisation, http://www.tellus.org/b&s/publications/servicizing.pdf

World Commission on Environment and Development, 1987. *Our Common Future*. Oxford University Press, Oxford, UK.