An illustrative application of the CRITINC framework to the UK

Journal Item

AN ILLUSTRATIVE APPLICATION OF THE CRITINC FRAMEWORK TO THE UK

An output of the CRITINC project funded by DGXII

MAKING SUSTAINABILITY OPERATIONAL: CRITICAL NATURAL CAPITAL AND THE IMPLICATIONS OF A STRONG SUSTAINABILITY CRITERION (CRITINC)

Project Number PL9702076
EU ENVIRONMENT AND CLIMATE RTD PROGRAMME – THEME 4:
HUMAN DIMENSIONS OF ENVIRONMENTAL CHANGE

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ABSTRACT

This paper sets out an illustrative application to the UK of a new framework for identifying critical natural capital (CNC). This involves classifying the characteristics of natural capital and the environmental functions to which it gives rise, and then defining standards of environmental sustainability for these functions. The framework then relates these functions to the economic system, through the input/output tables, in order to identify the pressures on the functions and hence the extent to which the functions are not being maintained at a sustainable level. The framework is worked though in some detail for water, with less detailed application of it to air, land and habitats. The methodology can be used to identify areas of environmental unsustainability and the processes to which this unsustainability is due, so that policies to more towards sustainability may be more easily identified.

1 THEORETICAL CONSIDERATIONS

1.1 INTRODUCTION

In Ekins et al., this issue, environmental sustainability was defined as the *maintenance of important environmental functions*, and hence the *maintenance of the capacity of the capital stock to provide those functions*. In other words the emphasis in this conception of environmental sustainability is on the *capacity* of the natural capital stock to perform important environmental functions, rather than on particular components of the stock themselves. This reflects a perception that, from a human point of view, what matters about the environment is not particular stocks of natural capital *per se*, but the ability of the capital stock as a whole to be able to continue to perform the environmental functions which make an important contribution to human welfare.

Clearly there is a close relationship between the capacity of natural capital to perform certain environmental functions and the particular components of the capital stock. But the relationship is complex, and is not one-to-one. It certainly cannot be assumed that certain environmental functions are uniquely performed by particular stocks of natural capital; and a particular component of natural capital may be involved in performing several, perhaps very different, environmental functions. Moreover, the environmental function may derive more from a natural process (for example, the carbon or water cycle) than any particular component of natural capital *per se*, and many different components may play a part in such processes.

While it may, therefore, be meaningful and useful to think of Critical Natural Capital (CNC) as that part of the natural capital stock which performs those environmental functions the maintenance of which is required for environmental sustainability, it is not possible to make a comprehensive inventory of CNC in these terms. In some cases it will be possible to identify particular components of natural capital as 'critical'. Obvious examples are rare species or ecosystems which are important for biodiversity and irreplaceable if lost. But generally CNC can only be identified in respect of particular *characteristics* of parts of the natural capital stock, which enable it, in combination with other characteristics of the same, or different, parts of the natural capital stock, to perform the environmental functions which are of concern. It is accordingly with an inventory of the *characteristics* of the natural capital stock that any attempt to classify, or make an inventory, of CNC must start.

1.2 DESCRIPTION OF NATURAL CAPITAL AND ITS CHARACTERISTICS

There are four basic types or categories of natural capital: air, water (fresh and marine), land (comprising the characteristics of soil, space and landscape) and habitats (including the ecosystems, flora and fauna which they both comprise and support)[1].

The four categories of natural capital have certain environmental characteristics, of which de Groot lists 53 (de Groot 1992, Table I.0-1, p.274), classified in nine groups as follows:

[1] There are different classifications of habitats, and different lists of habitats are appropriate for different countries. Annex 1 gives de Groot's classification for the world as a whole. In the UK, the UK Biodiversity Action Plan describes the main UK habitats as woodlands, grasslands, lowland heaths, uplands, wetlands (including bogs and fens), freshwater habitats (lakes and ponds, rivers and streams, canals and grazing marsh ditches), coastal areas (cliffs, estuaries, saltmarshes, sand dunes and shingle shorelines), marine habitats, and urban areas (UKG 1994, pp.31ff.), to which may be added peatlands, moorland and farmland.

1. Bedrock characteristics and geological processes
2. Atmospheric properties and climatological processes
3. Geomorphological processes and properties
4. Hydrological processes and properties (at the surface)
5. Soil processes and properties
6. Vegetation characteristics
7. Characteristics of the flora and fauna (species characteristics)
8. Life-community properties and food chain interactions
9. Ecosystem parameters

These characteristics, and their more detailed sub-characteristics (with de Groot's original order and wording slightly altered to suit the present purposes), can in fact be associated with one of the four basic types of natural capital, set out in Annex 2.

In addition to the characteristics of natural capital, there are characteristics of human-made capital (or mixed human-made and natural capital), which perform important environmental functions (for example, buildings or cultivated landscapes). These environmental functions, and the characteristics and capital from which they derive, may be important for the social and economic dimensions of sustainability, and may therefore be identified as critical capital. However, such capital is only considered in this paper where *natural* capital (including cultivated natural capital) is its principal component.

1.3 DESCRIPTION OF ENVIRONMENTAL FUNCTIONS

It is the characteristics of the natural capital set out in Annex 2 which constitute its capacity to perform *environmental functions*, which may be defined as the provision by natural capital's processes and components of goods and services that satisfy human needs (directly and/or indirectly). The 'goods' (e.g. resources) are usually provided by the components (plants, animals, minerals, ecosystems etc.); the 'services' (e.g. waste recycling) by the processes (biogeochemical cycling).

De Groot et al. (2000) have classified environmental functions into Regulation, Production, Habitat and Information functions (see also Ekins et al., this issue, and Chiesura & de Groot, this issue). Pearce & Turner (1990, pp.35ff.) have grouped environmental functions into Source, Sink and Service functions. Noel & O'Connor (1998, p.83) have divided the last of these categories of Scenery, Site and Life Support functions.

In line with the CRITINC Framework derived by Ekins et al., (this issue), environmental functions may be principally identified with one of the four basic types of natural capital, and divided into Source (So), Sink (Si), Life Support (LS) and Human Health and Welfare (HW) Functions, following the classification in Figure 6.1 in Ekins et al. (this issue). The environmental functions listed in de Groot 1992 (p.15), to which a few have been added, can then be grouped as in Annex 3.

Source functions refer to the provision of goods for human use and benefit, very often through the economy. Sink functions refer to the capacities of natural capital to dispose of the wastes generated by human activities. Human Health and Welfare (HW) functions refer to other services provided to humans by natural capital, very often of a non-economic kind, which maintain health and contribute to human well-being in a variety of ways. Source, Sink and HW functions all therefore provide goods and services directly *for* humans.

Life Support (LS) functions, in contrast, relate to the natural processes which maintain both ecosystems and the biosphere as a whole. These are the functions of and for the natural world overall, as opposed to functions specifically for people. Clearly these functions are of the utmost importance to humanity, because it is these functions which, in sum, make the Earth (uniquely among planets as far as science is so far aware) able to support life, including human life. Many of the Source, Sink and HW functions depend on the LS functions for their continuance. The LS functions are therefore the primary functions *of* the natural world, which establish the basic conditions for the other categories of functions to provide their benefits *for* people.

It must be stressed that although the functions have been allocated to one type of natural capital, in many cases they are actually the result of interactions between more than one type. Some of the more important examples of such interactions will be identified in the descriptions of functions, and their relation to natural capital, which follow. However, it can be said of relatively few of the functions that they are *exclusively* related to a single type of natural capital, and this should be borne in mind as impacts on the types of natural capital are being considered. Most obviously, activities which destroy or disrupt ecosystems may also affect functions which have been attributed to air/atmosphere, water or land, because of the continuous interactions and feedbacks between ecosystems and other types of natural capital.

1.4 DEFINING STANDARDS OF ENVIRONMENTAL SUSTAINABILITY

With environmental sustainability defined as the maintenance of important environmental functions, Ekins et al. 1999 enumerated seven sustainability principles to give guidance as to which environmental functions should be maintained at what levels. The principles were derived from consideration of current environmental problems (symptoms of unsustainability) and insights from environmental science into the functioning of natural systems and their importance for human health and welfare.

Ekins et al. (this issue, Table 5.2)also listed the environmental themes and indicators which an expert survey had judged to be the most important. The themes may be grouped according to the types of natural capital as in Table 1.1.

AIR/ ATMOSPHERE	Air pollution, resulting in Climate change, Ozone depletion and Effects on ecosystems and human health
WATER	Availability of water resources Water pollution
LAND (inc. soil/space/landscape)	Loss of soil fertility/land degradation Depletion of non-renewable resources Land pollution/solid waste disposal Landscape degradation

HABITATS	Habitat and species loss Depletion of renewable resources (fish, forests)

Table 1.1: Principal Environmental Themes Identified by Expert Survey, (EUROSTAT 1998), grouped by type of natural capital

It is an easy matter to identify which of the environmental functions of Annex 3 are threatened by the environmental themes listed in Table 1. The threatened functions can in turn be related to the environmental characteristics, and thence to the components of natural capital, from which they derive. If the function is important for environmental sustainability, the natural capital thus identified may be identified as Critical Natural Capital in respect of that environmental function. It is in this sense that an inventory of CNC may be drawn up. The information for each of the main environmental media (Air, Water, Land/Soil and Habitats) may be ordered for ease of reference within the Critical Natural Capital (CRITINC) Framework presented in Ekins et al. (this issue). The next section illustrates the application of the Framework in some detail to Water, and the following section shows more generally how it may be applied to the other media.

2 APPLYING THE CRITINC FRAMEWORK TO WATER

Figure 2.1 (at end of paper) shows the Critical Natural Capital Framework for Water. In Level 1 are the Natural Characteristics for Water, taken from Annex 2. These characteristics give rise to the environmental functions (grouped as Source, Sink, Life Support and Human Health and Welfare functions) performed by water, which are given in Level 2 and are taken from Annex 3. Thus, for example, the characteristic 'Interactions with atmosphere' (2.4. in Level 1) influences the amount of precipitation observed. This, in turn, affects the overall reservoir *stock* (2.1. in Level 1). Precipitation also affects other parameters, such as the *flow* of rivers.

The stock and flow of water directly determine whether the various environmental functions can be provided or not. In particular, they constitute the main 'limiting factor' of water's Source functions, which are:

2.1So Water catchment and groundwater recharge
2.2So Water (for drinking, irrigation, industry etc.)
2.3So Medium for transport

Water stocks and flows also play a major and direct role in relation to the other environmental functions, which are:

Sink functions
2.4Si Regulation of the chemical composition of the oceans
2.5Si Dispersion and dilution of emissions to water

Life Support functions
2.6LS Fulfilment of habitat water requirements (quantity and quality)
2.7LS Regulation of runoff and flood protection (watershed protection)

Human Health and Welfare functions
2.8HW Purification of water for human consumption
2.9HW Provision and purification of water for recreation
2.10-2.13HW Aesthetic, spiritual and religious, historic, and scientific and educational information, and cultural and artistic inspiration

In the case of the Sink functions, the quantity and flow of water affects its capacity to abate pollution through dilution (2.5Si). With regard to the Life Support functions the water habitat (2.6LS) is dependent on water quantity and flow. Finally, the functions related to human health and welfare are also affected by water stocks and flows in that the quantity of water available for human consumption is critical for human health (2.8HW). Water levels also affect the enjoyment and recreation possibilities of a river (2.9-2.13HW). These interactions are shown figuratively in Figure 2.2.

Interactions with atmosphere
Precipitation
Reservoir stocks and flows
direct effects on:

Source Functions	Sink functions	Life Support functions	Human Health and Welfare functions
Quantity of water (irrigation, transport, catchment recharge)	Dilution	Habitats	Quantity, quality and appearance of water

Figure 2.2: The Effects of the Characteristic 'Interactions with Atmosphere' on the Environmental Functions of Water

The functions performed by the Natural Characteristics of water may be affected by economic activities. Possible interferences with the production functions include over-abstraction of water, runoff from impermeable surfaces, and alteration of the water flow. Over-abstraction may affect the ability of water ecosystems to dilute pollution and to support fish and other water-based foods and sea creatures, i.e. affect the Sink and Life Support functions, as well as the Source functions. In turn, if the habitat is altered, the production of species from these habitats can be reduced, a function which is listed in Annex 3 as a function of Habitats, but which is also clearly dependent on the adequate availability of water resources. Similarly, the effects of economic activities on the production functions of water also affect its human health and welfare functions.

These kinds of effects can be described in more detail with reference to the economic input-output tables, in Level 2 on the left of Figure 2.1, which enable the impacts of economic activities on environmental functions to be ascribed to the relevant economic sectors. Various sectors affect the Source functions, and therefore the other functions, of water through over-abstraction. In the UK about a third of water abstractions are related to the public and private water supply, with the rest being divided between power generation, industry and agriculture. Over-abstraction is having a significant effect on UK ecosystems, the most obvious effect being the drying out of water habitats. Thus, English Nature has identified a number of cases of river Sites of Special Scientific Interest (SSSIs) affected by over-abstractions aimed at meeting the needs of public and private demand for water. Impacts of water depletion on the Source functions of water are listed in Impact Matrix A. Impacts of water depletion on the other kinds of functions of water are listed in Impact Matrices B,C and D. The impacts are represented figuratively in Figure 2.3.

	Source (Production) functions	Sink functions	Life Support functions	Human Health and Welfare functions
Input-output table: economic activities. *Agriculture Industry Public and private water supply, etc.*	*Matrix A* **ABSTRACTIONS**	*Matrix B* Problems of dilution of pollution	*Matrix C* Change in habitats	*Matrix D* Lack of availability and problems of quality

Figure 2.3: The Impacts of Abstractions on the Environmental Functions of Water

The economic activities represented by the Input/Output Tables also produce emissions to water, which appear in the box below the I/O Tables on the left of Figure 2.1. These emissions feed across the Figure to affect water's environmental functions. For example, the agricultural sector contributes to UK eutrophication by discharging pollutants such as nitrates (between 165000 and 500000 tonnes in 1994) and phosphates (between 15000 and 25000 tonnes in 1994) into the water environment. It also pollutes water by contaminating it with pesticides (19 tonnes of mecoprop, and 17 tonnes of isoproturon discharged in water in 1994, for instance). Similarly, the energy sector pollutes the water environment with heavy metals (400 tonnes of zinc and 100 tonne of copper in 1994, for instance), while the industrial sector emitted 200 tonnes of lead into water in 1994 (Vaze, 1998). The pollution of water affects its Source functions, especially the provision of drinking water and water-based foods. These impacts are listed in Impact Matrix A'. It also affects the Sink functions, most obviously the ability of water to disperse and dilute emissions. These impacts are listed in Impact Matrix B'. This leads to concentrations of water pollutants which have unsustainable impacts on water's Life Support functions. These impacts appear in Impact Matrix C'. The combination of the impacts matrices C and C' may result in elevated concentrations emitted to water that might lead, in turn, to unsustainable impacts on ecosystem health (Royal Commission on Environmental Pollution, 1992).

The elevated concentrations of pollutants in water may also damage water's Human Health and Welfare functions. It is now very clear that a series of health problems are directly created by water pollution. The impacts of water pollution on these functions are listed in the Impact Matrix D'. Figure 2.4 shows figuratively how water pollution from economic activities can directly affect the different kinds of environmental function. The weakened Sink functions that are the results have a further indirect effect on the other kinds of function.

	Source (Production) functions	Sink functions	Life Support functions	Human Health and welfare functions
Water pollution emissions by sector Directly affect *Agriculture* *Energy sector* *Industrial sec.* *Domestic sec.*	*Matrix A'*	*Matrix B'* Nitrates Phosphates Pesticides Heavy metals Lead Chemicals	*Matrix C'*	*Matrix D'*
	Matrix A'	**weakened Sink functions** *Indirectly affect*	*Matrix C'*	*Matrix D'*

Figure 2.4: The Impacts of Water Pollution on the Environmental Functions of Water

Sustainability standards may be applied to each of the types of affected environmental functions, as shown in Level 3 of Figure 2.1. With regard to Human Health and Welfare functions, this may be the level of concentration of the pollutant in water that should not be exceeded if human health is to be protected. Such sustainability standards also exist in the case of ecosystem health, and may or may not be the same as for human health. For example, nitrates, in the quantities normally found in food or feed, become toxic under conditions in which they are or become nitrites. Under other conditions, at reasonable concentration levels, nitrates are rapidly eliminated through urine. The reaction of nitrites with haemoglobin can be hazardous in infants under 3 months of age. There are also serious risks of poisoning in infants, and potential risk of methemoglobinemia at various ages. The World Health Organisation (WHO, 1995) has set the standard of 10 mg/l nitrate nitrogen (N) for domestic water supplies to safeguard human health. Various ecosystem species react differently. So, for instance, it seems that levels of nitrate nitrogen (N) at or below 90 mg/l would have no adverse effects on warm water fish, and that nitrite nitrogen at or below 5 mg/l might even be protective of most warm fish. In the UK, it has been identified that there is an 0.9% exceedance of the drinking water standards in England and Wales, 3.7% exceedance of standards for pesticides in water, and 0.6% exceedance for nitrate standards, amongst samples analysed.

There are also standards for bathing water, to the effect that at least 95% of samples taken must not exceed the mandatory limit values set down in the European Bathing Waters Directive for total and faecal coliforms, which is considered to be the most reliable indicator of sewage contamination. In 1996, 90% of UK Bathing Waters were complying with the Directive.

It is therefore clear that, for water, sustainability standards relating to the concentrations of pollutants in water, may be derived to protect both human health and ecosystem species health. There also exist some sustainability standards concerning the quantity of water, as English Nature has shown in 'Water level requirements of selected plants and animals' (EN, 1997). Generally, there are also some 'Minimum acceptable flows', that would correspond to sustainability standards for the provision of the Source functions of water. Figure 2.5 shows in general terms that, for each of the different kinds of environmental functions, there are sustainability standards relating to both the depletion and pollution of water.

	Source (Production) functions	Sink functions	Life Support functions	Human Health and welfare functions
Input-output tables QUANTITIES	*	*	*	*
Water pollutants emissions QUALITY	*	*	*	*
Sustainability standards	Minimum requirements for catchment recharge Safe water availability	Minimum requirements for dilution Other requirements for pollution abatement	Minimum requirements for habitats Ecosystem health standards	Minimum quantity necessary Human health and recreation standards

Figure 5: Sustainability Standards for Depletion and Pollution for the Different Environmental Functions of Water

The distance between current concentrations and emissions for a given pollutant, and those identified as environmentally sustainable, is termed the physical 'sustainability gap' for that pollutant. The monetary sustainability gap (M-SGAP) may be derived from this by calculating the costs associated with abating or avoiding emissions, or restoring environmental functions, such that the sustainability standards are met.

This framework permits the identification of sustainability gaps and the prioritisation of the conservation actions which may restore the water environment and eliminate effects on human health. The framework shows which economic activities are primarily responsible for damage to the functions of water, and also which other species or habitats are being affected, which enables a set of restoration strategies to be established and implemented in a holistic way.

Water as Critical Natural Capital

Completion of the Impact Matrices A, A', B, B', C, C', D, D' and their comparison with the sustainability standards of Level 3 in Figure 2.1 would be likely to show that effects from human activities are having a serious impact on the capacity of water to perform its environmental functions as listed under 2.1-2.14. In some cases, the effects may be reversible (e.g. much water pollution). Some effects, however, are irreversible, including those from climate change, some ecosystem change as a result of water abstraction or drainage, some effects on human health (most obviously where people die from water pollution, as many do especially in developing countries) and some effects on the human cultural heritage (e.g. from the diversion of rivers or flooding due to large dams). Perhaps the best known example of unsustainability with regard to water has been the shrinking of the Aral Sea.

Environmental sustainability is therefore not being achieved in many instances with regard to water. Water is often not being maintained in its role as Critical Natural Capital. Derivation of the SGAPs in Figure 2.1 would allow a quantitative assessment of the extent to which this was the case and, if remedial action was undertaken, would further be able to show when sustainable use of water was being achieved. Irreversible changes might mean that the level of the environmental functions performed by water was different to what it would have been had it not been affected by human activities in the first place.

3 APPLYING THE FRAMEWORK TO OTHER ENVIRONMENTAL MEDIA

3.1 AIR/ATMOSPHERE

The only source function of air/atmosphere is the production of gases that are indispensable for human life (mainly oxygen). Immediately an interaction between the air/atmosphere and habitats (ecosystems) may be noted in the performance of this function. This Source function is not (currently) threatened by human activities, so that depletion is not an issue.

The polluting effects of human economic activities have a strong impact on air and the atmosphere, and affect its Sink, Life Support and Human Health and Welfare functions (see Annex 3), with consequent effects on the health of the ecosystems and on human health.

This may be illustrated for the UK by considering emissions of sulphur dioxide (SO_2). These would constitute a significant entry in the table for 'Air emissions per sector' for the electricity generation sector: power stations are the largest source of SO_2 emissions in the UK, emitting 1588 thousand tonnes (kt), 67% of total SO_2 emissions, in 1995 (DETR, 1997). The next most important sources of SO_2 emissions are other industrial sectors, through their combustion of fossil fuels.

If emissions are allocated to end users of energy, then industries become the main SO_2 emitters (843 kt in 1995: 36% of total emissions) followed by the domestic sector (641 kt in 1995: 27% of total emissions) (DETR, 1997). Use of the framework of Figure 2.1 over time would reveal the evolution of SO_2 emissions both in terms of quantities and in terms of which sector pollutes. For the first half of the century, SO_2 emissions were generated by the combustion of coal, both in the domestic sector, and in commercial and industrial premises and in power stations, which were located predominantly in towns. The Clean Air Act of 1956, in response to the dense smogs of the 1950s, mandated the replacement of domestic coal with cleaner fuels, and power generation began to be located outside urban areas, using larger power stations with high chimneys which dispersed SO_2 emissions over large areas. Although national emissions of SO_2 have decreased by almost 60% since 1970, and by 45% since 1980 (DETR, 1997), emissions remain high, and impacts on ecosystems and on humans are still observed. There has, for example, been much research which shows how air pollution can affect some of the characteristics of the atmosphere (for example, chemical composition of the atmosphere, concentration of atmosphere dust, etc.), with consequent effects on ecosystems through its interference with the atmosphere's Life Support functions.

A serious phenomenon deriving from SO_2 pollution is acidification, due to the fact that SO_2 dissolves in water to give an acidic solution which is readily oxidised to sulphuric acid. Further interactions between SO_2 emissions and characteristics of the atmosphere are due to the pollutant being transported by winds (parameter 1.8), and dissolved by water (precipitation: parameter 1.7), with effects on the life support function 1.4LS (fulfilment of habitat air requirements, see Annex 3). Forest decline, the disappearance of fish from lakes, and increased susceptibility of plants to parasites, pathogens and insect damage have all been attributed to acidification in which SO_2 emissions play a part.

In the UK, a computer system developed for mapping the Forestry Commission's records of forest conditions has shown that between 1989 and 1992, a general decline in the conditions of all species, except Sitka spruce, was observed (Mather et al., 1995). In particular, it was noted that the Norway spruce was being badly affected by sulphur deposition. The phenomenon of forest decline would show up elsewhere in the CRITINC sustainability framework, under the Source functions of Habitats, since the forest habitat provides a variety of trees. This illustrates again the close interdependency between the four natural capital media, air/atmosphere, water, land/soil and ecosystems/habitats.

The elevated concentrations of air pollutants, or the effects to which they give rise (including climate change and ozone depletion), may also damage the Human Health and Welfare functions of the atmosphere and have unsustainable effects on human health. As an example again, SO_2 is an irritant when it is inhaled, because of its acidic nature, and high concentrations may cause breathing difficulties in people exposed to it. Recent studies have shown that people with asthma may be especially susceptible to the adverse effects of SO_2 and that, within the range of concentrations that occur in pollution episodes, it may provoke attacks of asthma (DoE, 1996b).

Sustainability standards may be set to avoid or resolve these problems of adverse effects on the three relevant types of air's environmental functions. The relevant standards are those which maintain climate stability, ozone shielding, ecosystem function and human health. For climate stability, there is a maximum atmospheric concentration of greenhouse gases (GGs), from which emission limits of GGs may be derived. Similarly, maximum atmospheric concentrations of ozone-depleting substances (ODSs) may be specified, to protect the ozone layer, from which emission limits of ODSs may be derived. Critical loads for threatened ecosystems may be determined, from which emission limits for pollutants which exceed the critical loads may be derived. With regard to human health, maximum concentrations of air pollutants may be set, from which emission limits may be derived for those pollutants which exceed these concentrations.

In the case of sulphur dioxide, until relatively recently, air quality guidelines and standards were expressed in conjunction with values for black smoke or other particles (80/779/EEC directive and WHO 1987 guidelines). More recent research has addressed the effects of SO_2 acting alone, and exposures of the order of minutes have been shown to exhibit adverse effects on human health. This has led the Expert Panel on Air Quality Standards (EPAQS) to recommend an air quality standard for SO_2 of 110 ppb (parts per billion), measured over a minute averaging period. More recently, the Air Quality Strategy (AQS) for the UK has set a standard of 100 ppb measured as a 15 minute mean, with a provisional objective to meet this standard at the 99.9th percentile level by 2005 (DoE, 1996b). In parallel, the WHO guidelines set a figure for a shorter averaging period of

175 ppb for a 10 minute mean concentration. The UK Department of the Environment, Transport and the Regions (DETR, 1997) published figures illustrating the details of places where these standards are being exceeded. Thus, for instance, in 1995, the AQS standard was most exceeded in Belfast (the number of periods when the 15 minutes concentrations over 100 ppb were recorded amounted to nearly 900).

Table 2 gives a selection of sustainability standards and policy targets concerning SO_2 emissions.

Guideline set by	***Description***	***Criteria based on***	***Value, ppb ($\mu g\ m^{-3}$)***
Department of the Environment	Very good Good Poor Very poor	Peak hourly average concentration in a 24 hour period	< 60 (160) 60-124 (160-330) 125-399 (330-1050) ≥ 400 (1050)
European Union 80/779/EEC	Limit value	Annual (median of daily values over one year)	30 (80) if smoke >34 45 (120) if smoke ≤34
	Limit value	Winter (median of daily values over October-March)	49 (130) if smoke > 51 68 (180) if smoke ≤51
	Limit value	Annual (98th %ile of daily values)	94 (250) if smoke >128 131 (350) if smoke ≤128
	Guide value	Annual (mean of daily values)	15-23 (40-60)
	Guide value	24 hours (daily mean value)	38-56 (100-150)
WHO	Health guideline	10 minute mean	175 (500)
	Health guideline	1 hour mean	12 (350)
	Vegetation guideline	Daily mean	48 (125)
	Vegetation guideline	Annual mean	10 (30)
UNECE	Vegetation guideline	Daily mean	26 (70)
	Vegetation guideline	Annual mean	8 (20)

Table 2: Selected Standards for SO_2
Source: Colls, J. (1997)

Much research has also been carried out concerning critical loads for acid depositions, sometimes through ecological modelling (CLAG 1995). Critical loads have been defined as the highest depositions of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function. They have been estimated using chemical criteria, in the UK, for soils and fresh waters, and maps have been produced, showing places where the critical loads have been exceeded, depending on the chemical composition of soils, for instance. In the case of water, the critical load is exceeded when the first change in the aquatic ecosystem that can be related to acid deposition occurs. Target loads may be set according to the need to protect any selected individual or groups of species. Dynamic modelling shows that it is not possible to calculate a critical load for surface water without due consideration of the future land use policy within a catchment.

The advantage of specifying the impacts of the same air emissions on each of the different environmental functions is that it enables sustainability standards to be derived separately for each of the functions. The standards may differ, for instance the standard for a particular pollutant may be more stringent with respect to human health than with respect to ecosystems, or vice versa. The more stringent standard is the binding one as far as sustainability is concerned.

For SO_2 in the UK, the emission reduction required to close the sustainability gap has been estimated as an 80 to 90% reduction from the 1980 level of 4903kt. The monetary sustainability gap (M-SGAP) may be derived from this by calculating the costs associated with abating or avoiding emissions, or restoring environmental functions, such that the sustainability standards are met. Various practical measures have been suggested (e.g. by Halkos, 1993) to reduce SO_2 emissions. For instance, an 80-90% desulphurisation of heavy fuel oil would involve a capital cost of $150/tonne (1985$) and an operating cost of $35/tonne (1985$).

3.2 LAND (inc. SOIL/SPACE/LANDSCAPE)

The Natural Capital Characteristics for Land, from which its environmental functions derive, are shown in Annex 2. For example, 3.13 concerns the concentration of organic matter in soil. Organic matter is important for the development of soil structure and contributes to soil stability. Its absorption properties help to regulate the movements of pollutants and contaminants in soil. It also plays an important role in the cycling and storage of plant nutrients, which are vital for food production, and low organic matter concentration can increase the risk of erosion. In 1995, in the UK, concentrations of organic matters exceeding 7% of dry weight were encountered in only 11% of the soils sampled, reduced from 22% in 1978-1981 (DoE 1996). This confirms the fact that some agricultural practices have reduced organic matter concentrations in some soils in recent years.

Depletion is most obviously an issue with the Source functions of Land (including soil/space/landscape), one of which is the formation of topsoil and maintenance of soil fertility (3.1So in Annex 3). Soil is obviously required for the provision of biomass, a Source function which is listed under Habitats and ecosystems, and this is another example of the joint performance of an environmental function by different types of natural capital. Economic activities may cause soil erosion or otherwise reduce soil fertility, and result in the depletion of mineral resources and fossil fuels. The activities that have a direct effect on the source functions are numerous. Extraction of minerals and fossil fuels, the use of land for urban and other types of development, and the impact of modern agriculture not only on space but also directly on the soil, are only a few examples of effects on the Source functions of the land. In the UK in 1995 the major power producers consumed 58 million tonnes of coal, 2.2 million tonnes of fuel oil, and 145.8 million tonnes of natural gas, while 13.5 million tonnes of gas oil were used in road transport. In 1994, 225 million tonnes of minerals were extracted. The land used for agricultural activities in 1995 covered 18,406 thousand hectares in 1995, corresponding to 75% of the total land cover, while 15% of the land was used for urban developments (DoE 1996). The use of modern machinery in agriculture also affects the top soil, compacting it and thereby causing it to react differently to infiltrations, filtering and nutrients.

The fertility of soil is determined by factors such as nutrient contents and acidity levels. Maintaining an adequate supply of nutrients is important to obtain an optimum crop performance. However, the amount of these nutrients should not be excessive, in order to avoid polluting effects (eutrophication, etc.). With regard to soil acidity, pH-6 - pH-7 is the optimum range of acidity for arable soils. If soils become more acidic than pH6, the yields of some arable crops may be reduced. The proportion of relatively acidic fields in the UK has increased since 1969.

The depletion of minerals, for example through quarrying, can create voids for waste disposal, so that in such cases not only can the same space perform Source and Sink functions in sequence, but the Source activity actually improves the Sink potential (for discussion of the sustainability of which see below).

The mechanisation of agriculture mentioned above also affects the capacity of the soil to decompose, disperse and dilute the emissions to land because of the change of structure of the soil. So agriculture affects the Sink function in a ‘physical/ structural’ way. It also affects this function through the polluting substances it emits to the soil, hence contributing to some forms of soil contamination.

The winning of mineral resources, through mining or quarrying, often conflicts with the Life Support functions of land in respect of habitats and ecosystems The use of land for various economic activities restricts the space available for natural habitats.

Finally, the degradation of soil, or the extraction of mineral resources and fossil fuels, can have an impact on the Human Health and Welfare (HW) functions of land, especially by changing land use and landscapes. The impacts that are most often observed in relation to this fourth type of environmental function relate to the availability of space for recreation and leisure, which is especially important for urban communities. Urban developments that do not put enough emphasis on green space may have a serious effect on human health and welfare.

All material derived from the Earth’s crust through the performance of the Source functions of land will ultimately be returned to the environment, much of it as emissions to land from different sectors of economic activity. Through land contamination these emissions can reduce soil fertility or render space unusable for other activities, thereby impacting on land’s Source functions; they can overwhelm the Sink functions of soil and space; they can displace or pollute habitats and ecosystems; and they can impair the HW functions of enabling recreation and the enjoyment of landscapes.

Some work has been done to map the concentrations of some of the most important heavy metals in agricultural top soils in England and Wales. These maps (DETR, 1996) show that the range of values for each metal can be large, with the upper values above those recommended for the control of soil pollution. Elevated concentrations are mainly found in areas of heavy past or present industrial activities.

The eventual impacts of emissions to land well illustrate the interactions between environmental media and between different types of environmental function (DETR, 1997). Examples of the former include the leaching of wastes from landfill sites (when they were emissions to land) into water courses (when they become emissions to water), and the decomposition of wastes in landfill sites to produce methane, a greenhouse gas, which can also be used as an energy source (when an emission to land produces emissions to air, or evolves a new Source function). Similarly, emissions to land can enter the food chain and have a negative impact on the way habitats and ecosystems can fulfil their Source functions.

Application of sustainability standards to each of the types of affected environmental functions, shown in Level 3 of Figure 2.1, leads various constraints.

To maintain the Source functions at a sustainable level, top soil should not be lost faster than it is created, and it should exceed minimum standards for soil structure and organic content. The Royal Commission on Environmental Pollution advised that the minimum rate of application of organic compounds must be stated as to provide no less than 500 grammes organic matter (dry weight) per m^2 of ground. There are also some limits for nutrients loads, such as total nitrogen ($8g/m^2$), total phosphate ($6g/m^2$) or total potash ($12\ g/m^2$). These are closely related to the fertility of the soil (Royal Commission on Environmental Pollution, 1996). Non-renewable sub-soil resources should be used such that a minimum life expectancy of the resource is maintained, and renewable substitutes for the resource are developed.

To maintain the Sink functions of land, there should be maximum rates of disposal to land, consistent with constraints of space, and the leaching of wastes from landfill sites should be minimised or avoided altogether. Methane from landfill sites should be used as an energy source. Some detailed work has been carried out on the disposal of wastes and limits to the quantity of certain types of wastes that a landfill will be able to 'deal with' before infiltrations of pollutants pass through the soil and perhaps pollute groundwater, depending on the nature of the soil, the nature of the wastes, the interaction between pollutants, etc. More general studies indicate a necessary reduction of 80-90% of the annual amount of wastes disposal, and such figures are sometimes cited as a 'sustainability target' (Department of the Environment and the Welsh Office, 1995; Ekins and Simon, 1999). Policy targets which have been adopted include the reduction in the proportion of wastes going to landfill from 70% to 60% by 2005, and the recovery of 40% of municipal wastes by 2005. While they may push waste management in the right direction, such targets do not relate explicitly to sustainability standards. One way of deriving sustainability standards for wastes would be through a reconceptualisation of wastes as by-products, all of which could be used as an input for other production processes.

There are also some sustainability standards related to Land's Sink functions that are expressed in terms of thresholds of concentrations of pollutants that contaminate the soil. Thus, for example, no product may contain amounts of the following elements in concentration greater than the following values, measured in terms of dry weight (mg/kg): zinc: 300; copper: 75; nickel: 50; lead: 140, etc. (DoE 1996). Some critical loads for acidity of soils have also been calculated. Similarly, there are some standards for eutrophying substances, based on the principle that the land should not be supplied with more nutrients than the agricultural crop can absorb.

To maintain Land's Life Support functions, occupation of space, whether for mining and quarrying, or for disposal of wastes to land, should not be allowed to degrade soil. Important ecosystems should receive statutory protection from displacement by other activities. Standards of protection might be defined in terms of the space needed for certain habitats and ecosystems. Clearly such standards would need to relate very closely to the different kinds of ecosystems to which they refer.

The performance of Land's Human Health and Welfare functions requires that toxic wastes disposed of to land must not be allowed to enter the food chain; access to land for recreation should be safeguarded; and important areas of landscape should be protected.

The physical 'sustainability gap' for land may be expressed by a number of indicators: excessive loss of topsoil; lack of organic content in soil; unsustainable use of non-renewable resources; excessive disposal of wastes to landfill; excessive leaching of landfill wastes into the environment; continuing loss, or inadequate restoration, of important ecosystems; pollution of ecosystems from contaminated land; damage to human health from contaminated land or from wastes disposed of to land; continuing loss, or failure to protect, important landscapes. The monetary sustainability gap (M-SGAP) may be derived from these indicators by calculating in each case the costs associated with restoring environmental functions, such that the sustainability standards are met.

In some cases, as with many of the effects on the atmosphere and on water, unsustainable effects on Land may be reversible (e.g. much land contamination) at a cost. Some effects, however, are irreversible, including, especially, the loss of ecosystems and their associated species as a result of changes in land use, and the loss of valued landscapes. Also irreversible is the depletion of fossil fuels, and it is still not clear that substitutes for these are being developed at an adequate rate to avoid economic disruption from energy shortages.

3.3 HABITATS (inc. ECOSYSTEMS, FLORA & FAUNA, BIOMASS)

It may immediately be noted from Annex 2 that there are many more natural capital characteristics for this type of natural capital than for other types, because of the relative complexity of ecosystems and habitats, compared with air, water and land. To take an example, characteristic 4.8 gives information on the population and diversity of fish species. With regard to one UK species, haddock, after 1968 there was a dramatic collapse in the stock, which has continued to decline. Stocks fell from 6000 thousand tonnes in 1968 to just above 2000 thousand tonnes in 1969, while in 1995 the overall stock of haddock in the North Sea was just below 1000 thousand tonnes. The North Sea herring population was also seriously affected by over-fishing in the 1970s and the fishery was closed between 1978 and 1982, allowing stocks to recover. Herring stocks have declined again since their peak in the mid-1980s. Emergency measures were taken in 1996 to prevent closure of the fishery. An important fact is that trends vary considerably between species, due to different economic impacts and also to differing ecosystem reactions.

The natural capital characteristics of Habitats give rise to their environmental functions, grouped as usual into Source, Sink, Life Support and Human Health and Welfare functions, and listed in Annex 3.

A characteristic of the Source functions is that they are potentially renewable, that is, their use below some maximum sustainable level does not deplete the resource. However, current usage rates of many renewable resources (e.g. fish, tropical timber) are substantially higher than the maximum sustainable levels, so that the stocks of these resources are being rapidly depleted. Where deforestation, for example, involves laying soil bare, especially on steep inclines, soil erosion will reduce the ability of land to produce biomass. The loss of primary productive potential, through soil erosion and the loss of vegetation and other stocks of biomass, is one of the most alarming aspects of current global environmental change.

One of the characteristics of (non-human) natural systems and cycles is that there is little room for the concept of waste. The outputs of one part of the system or cycle become the inputs of another, with the ecosystem performing any necessary transformation for this to be able to take place. Ecosystems such as forests can perform this Sink function to some extent with wastes from human activities, but excessive emissions, as well as over-harvesting of biomass, and the resulting soil erosion, reduces their ability to carry it out.

Biomass stocks can be reduced (or made 'non usable') through pollution as well as through excessive harvesting. Thus, with regard to the contamination of fish by metals and pesticides, in the UK in 1994 cod had an average of 3.8 mg/kg wet weight of zinc, 2.3 mg/kg wet weight of

PCBs, and 0.1 mg/ kg wet weight of dieldrin (DETR 1997). Reduced growth or die-back in trees is another effect of pollution on the Source function of Habitats.

The Life Support capabilities and functions of habitats are obviously their most important attributes. Again, the excessive harvesting and depletion of renewable resources interferes greatly with these functions, not least through the reduction of biological and genetic diversity. The economic activities impacting upon these functions include agriculture and urban development, since they alter the habitat structure. For instance, agriculture affects the medium-scale habitat by changing the land use, replacing existing ecosystems with agricultural fields. It also affects the ecosystem/ habitat within the soil (fertility, decomposition mechanisms, transfers of nutrients, etc.). In the UK in 1995, 75% of the country was agricultural land, with forest and urban use accounting for the remaining 10% and 15% respectively. Almost half of the 46 species found on farmland have declined in numbers over the last twenty years.

Finally, the depletion of renewable resources can have a direct impact on the Human Health and Welfare (HW) functions of habitats and ecosystems, as once biodiverse, varied and fertile landscapes are converted to large areas of monoculture or even degraded land that can produce little biomass of any kind.

All biomass used by human activity through the performance of Habitats' Source function 4.4So will ultimately be returned to the environment as wastes, and may be related to different sectors of economic activity. Unlike materials from the Earth's crust, or synthetic, human-made materials, these wastes are normally degraded fairly easily through natural processes. However, if in excess, the wastes still have considerable potential to disrupt ecosystems and affect all their different types of functions.

The eventual impacts of biomass wastes, as with emissions to land, also well illustrate the interactions between environmental media and between different types of environmental function. When biomass is burnt it contributes to air pollution. Wastes from livestock start off as emissions to land, but can cause serious pollution of water courses.

For the sustainable performance of Habitats' Source functions, soil cover should be maintained to limit soil erosion. Biomass stocks should be maintained at biologically acceptable levels and the harvesting of all renewable resources should be carried out at sustainable levels. For fish the Minimum Biological Acceptable Level (MBAL) corresponds to the level below which there is an increasing risk that the reproductive potential of the stock will collapse. The percentage of stocks fished by the UK fishing fleets and other international fleets which was above the MBAL reached a peak of 63% in 1993 and decreased to 42% in 1994 (DoE 1996). A more recent UK Government publication (DETR 1999, p.207) noted that the mix of species used by the International Council for the Exploration of the Sea (ICES) to calculate the MBAL is not consistent from stock to stock or from year to year. As a consequence, the MBAL measures are now not used by the UK Government, being replaced by the categorisation of stocks as being within or outside the safe biological limits based on the spawning stock size and the fishing rate. DETR (1999) reports on the basis of this indicator that, in 1997, 49% of fish stocks had spawning levels which were insufficient to guarantee stock replenishment. Other criteria such as the *minimum critical ecosystem size*, which may also be used as a sustainability standard, might also be adopted for certain species.

To maintain Habitats' Sink functions, biomass wastes should be disposed of such that they are able to be reabsorbed into natural cycles. Methane from landfill sites should be used as an energy source. The maintenance of Habitats' Life Support functions require that emissions of biomass wastes must be limited such that critical loads for eco-system disruption are not exceeded. The richness and diversity of species in ecosystems must be maintained, as well as ecosystems' structure, function and resilience. Similarly the continuing performance of Habitats' Human Health and Welfare functions requires that species, habitats and ecosystems that are important for recreation and inspiration should be protected

The physical 'sustainability gap' for habitats and ecosystems may be expressed by a number of indicators: the extent to which biomass stocks have fallen below minimum biologically acceptable levels (MBAL), and harvests are above (conservatively estimated) maximum sustainable yields; loss of species richness or diversity, or disappearnace of certain habitats; excess of biomass wastes over critical loads; excess concentration of such wastes in ecosystems (e.g. excessive biological oxygen demand in freshwater ecosystems); continuing loss, or failure to protect, ecosystems with important aesthetic or recreational functions. The monetary sustainability gap (M-SGAP) may be derived from these indicators by calculating in each case the costs associated with restoring environmental functions, such that the sustainability standards are met. However, in many cases habitats, with their associated ecosystems and species, cannot be recreated or restored. The extinction of species is also irreversible.

4 CONCLUSION

This paper has presented an integrated framework, the CRITINC framework, for accounting for and analysing the interactions between the economy and the environment, with the purpose of identifying the extent to which current uses of the environment are unsustainable and the activities which are responsible for such uses.

Unsustainable uses are those which reduce, or threaten to reduce, the ability of the environment to carry out its Source, Sink, Life Support and Human Health and Welfare functions. These functions derive from the Natural Capital Characteristics of the four environmental media: Air/atmosphere; Water; Land (including soil/space/landscape); and Habitats/Ecosystems. By presenting the functions and characteristics in the same Figure as the economic activities which have impacts on them, it is possible to track these impacts and discover to what extent the impacts need to be reduced, and/or various characteristics of the environment need to be restored, in order for standards of sustainable use of the environmental functions to be achieved. This information is of considerable importance to those seeking to formulate environmental policy.

The framework has been presented and discussed with the environment being conceived in terms of natural capital. There is much logic in this, for much of the environment functions as a stock of physical things which give rise to flows of matter and energy which are the source of the various environmental functions. However, just as important as the physical things themselves in the performance of environmental functions are the relationships and interactions between them. It is only comparatively rarely possible to identify particular functions with particular physical stocks. More often the functions come about as a result of interactions and processes between many different physical elements, which may also be considerably spread out over space and time. Thus Critical Natural Capital, those elements of the environment which are essential for environmental sustainability, should be considered in terms of physical environmental 'assets' *plus* a whole host of sometimes very complex interactions between them. This makes it more difficult to be sure which physical elements of the environment need to be conserved for environmental sustainability. It also counsels caution with regard to the possible loss of some of these elements, for although they may not seem important in themselves, they may be necessary for wider interactions that are obviously important. Doubtless over time environmental science will clarify some of these areas of uncertainty. But it seems likely that it will not be reduced to an insignificant level for a considerable period to come. The CRITINC framework itself can cast light on these uncertainties and show how policy makers need to modify economic activities if undesirable risks to society are to be avoided.

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ANNEX 1

List of major ecosystems of the world and their surface covering (approximate situation in 1970-1990)

De Groot (1992, Table II-1, p.305) has classified the world's ecosystems, and their surface coverage, as follows:

TYPE OF ECOSYSTEM	AREA Million hectares
TERRESTRIAL ECOSYSTEMS	**14,400-14,796**
Evergreen forests	2,704
Deciduous forests	1,213
Evergreen woodland	687
Deciduous woodland	624
Shrubland/thicket	1,207
Grassland	2,691
Arctic/alpine tundra	743
Desert	1,555
Ice/glaciers	1,640
Cultivated land (agriculture/pastures)	1,400
Human occupied area (settlements, infrastructure)	332
AQUATIC ECOSYSTEMS	**530**
Wetlands (bogs, swamp, marsh)	330
Lakes and streams	200
MARINE ECOSYSTEMS	**36,100-36,236**
Estuaries (excl. marsh)	1,400
Algal beds and reefs	600
Continental shelf	2,660
Upwelling zones	40
Open ocean	33,200
TOTAL SURFACE AREA EARTH	**51,000**

ANNEX 2

Natural Capital and its Characteristics

Source: after de Groot 1992, Table I.0-1, p.274

1. AIR Atmospheric properties and climatological processes

1.1 Chemical composition of the atmosphere
1.2 Solar radiation input
1.3 Temperature
1.4 Concentration of atmospheric dust
1.5 Concentration of water vapour/air humidity
1.6 Clouds
1.7 Precipitation/drought
1.8 Winds
1.9 Occurrence of lightning/fire

2. WATER Hydrological processes and properties (considering both coastal and fresh, surface and underground waters)

2.1 Water reservoirs/availability
2.2 Groundwater table/aquifers
2.3 Water quality/biological oxygen demand
2.4 Interactions with atmosphere
2.5 Runoff and river discharge
2.6 Tides and ocean currents

3. LAND (inc. soil/space/landscape)
Bedrock characteristics and geological processes

3.1 Bedrock properties/lithology
3.2 Occurrence of distinct geological formations
3.3 Volcanoes/volcanic activity
3.4 Geotectonics/geophysical features

Geomorphological processes and properties

3.5 Topography (slope/relief/altitude)
3.6 Distinct landforms
3.7 Type/structure of surface (see also 4.4)
3.8 Albedo
3.9 Weathering/erosion
3.10 Sedimentation/fossilisation

Soil processes and properties

3.11 Soil depth
3.12 Texture/structure (physical characteristics)
3.13 Organic matter
3.14 Mineral content (fertility)
3.15 Soil moisture/humidity/drainage
3.16 Chemical characteristics/chelation
3.17 Biological characteristics (see also 4.19)

4. HABITATS

Vegetation characteristics

4.1 Height, structure, density and roughness
4.2 Succession stage/age/maturity
4.3 Standing biomass/chlorophyll (see also 4.14)
4.4 Surface covering/leaf area index (LAI)
4.5 (Evapo)transpiration/water use efficiency
4.6 Litter production
4.7 Root system and nutrient uptake/recycling

Species properties (characteristics of flora and fauna)

4.8 Species composition and diversity
4.9 Population size (rarity) and distribution (endemism)
4.10 Population viability/vulnerability (genetic diversity)
4.11 Population dynamics (increase, decrease, etc.)
4.12 Dispersal and migration
4.13 Special functional properties

- edibility/nutritious value
- useful genetic and biochemical properties
- role in biogeochemical cycles
- indicator value
- other (e.g. aesthetic value)

Life-community properties and food-chain interactions

4.14 Biomass production/photosynthesis (see also 4.3)
4.15 Consumption and respiration
4.16 Decomposition
4.17 Food-chain interactions
4.18 Deposition of calcareous material
4.19 Bioturbation/activity of soil communities (see also 3.17)

Ecosystem parameters

4.20 Naturalness/integrity/heritage value
4.21 Uniqueness/distinctiveness
4.22 Diversity/richness
4.23 Minimum critical ecosystem size
4.24 Ecological fragility (carrying capacity)
4.25 Replaceability/renewability
4.26 Information value

- amenity value/aesthetic qualities
- historic/cultural value
- inspirational/spiritual value
- scientific and education value

ANNEX 3

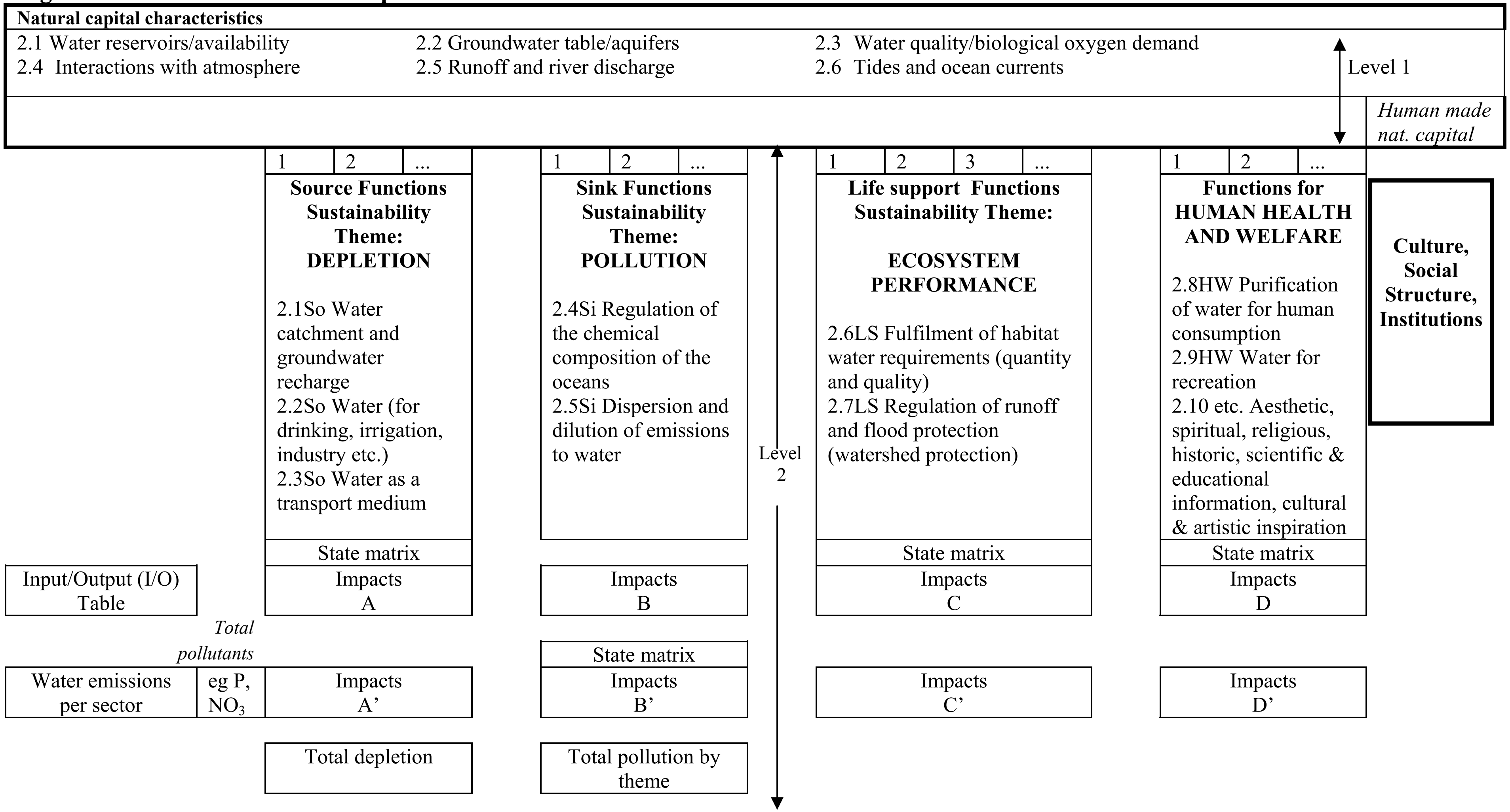
Classification of Environmental Functions by Type of Natural Capital

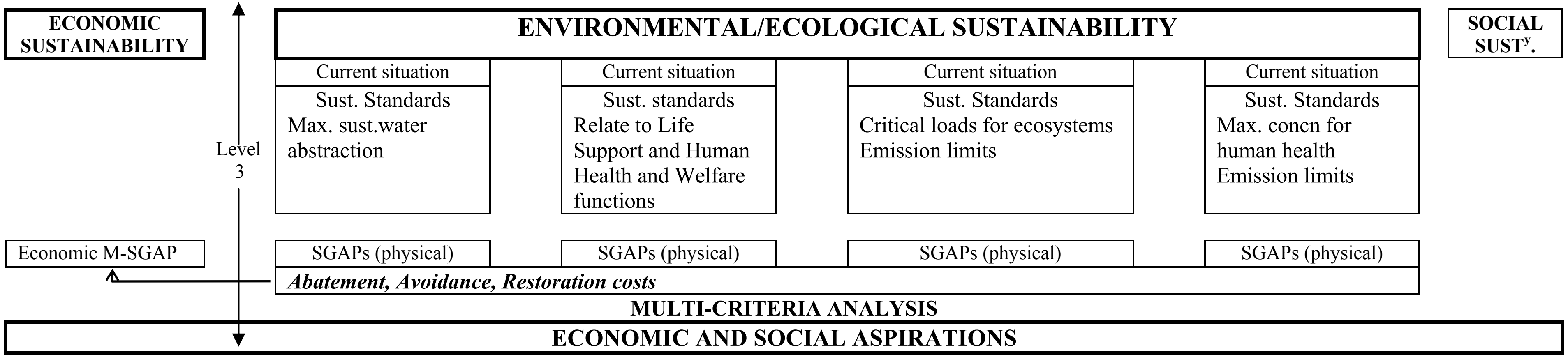
Source: de Groot 1992, p.15, and own classification

	SOURCE	SINK	LIFE SUPPORT	HUMAN HEALTH AND WELFARE
AIR (includes atmosphere, outer space)	1.1So Oxygen	1.2Si Regulation of the chemical composition of the atmosphere 1.3Si Dispersion and dilution of air emissions	1.4LS Fulfilment of habitat air requirements (quantity and quality) 1.5LS Protection against harmful cosmic influence 1.6LS Regulation of the local and global energy balances 1.7LS Regulation of the local and global climate (inc. the hydrological cycle)	1.8HW Air for respiration 1.9HW Aesthetic information 1.10HW Spiritual and religious information 1.11HW Historic information (heritage value) 1.12HW Scientific and educational information 1.13HW Cultural and artistic inspiration
WATER (includes fresh and sea water)	2.1So Water catchment and groundwater recharge 2.2So Water (for drinking, irrigation, industry etc.) 2.3So Medium for transport	2.4Si Regulation of the chemical composition of the oceans 2.5Si Dispersion and dilution of emissions to water	2.6LS Fulfilment of habitat water requirements (quantity and quality) 2.7LS Regulation of runoff and flood protection (watershed protection)	2.8HW Purification of water for human consumption 2.9HW Provision and purification of water for recreation 2.10-2.14HW Aesthetic, spiritual, religious, historic (heritage value), scientific and educational information, cultural and artistic inspiration
LAND (inc. soil, space, landscape)	3.1So Formation of topsoil and maintenance of soil fertility 3.2So Mineral resources for construction, industrial, commercial and ornamental use 3.3So Fossil fuels 3.4So Providing space for human habitation, transport, agriculture, other economic activities	3.5Si Containment of emissions to land 3.6Si Decomposition, dispersion, and dilution of emissions to land	3.7LS Providing fertility for habitats and ecosystems 3.8LS Providing space for habitats and ecosystems	3.9HW Providing space for recreation 3.10-3.14HW Aesthetic, spiritual, religious, historic (heritage value), scientific and educational information, cultural and artistic inspiration

HABITATS (including ecosystems, flora and fauna, biomass)	4.1So Prevention of soil erosion and sediment control 4.2So Fixation of solar energy and biomass production 4.3So Energy conversion 4.4So Biomass for terrestrial or marine foods and drinks, genetic and medicinal resources, biochemicals, fuel, fodder, fertiliser, construction, clothing and household fabrics, and ornaments	4.5Si Storage and recycling of human wastes	4.6LS Storage and recycling of organic matter 4.7LS Storage and recycling of nutrients 4.8LS Regulation of biological control mechanisms 4.9LS Maintenance of migration and nursery habitats 4.10LS Maintenance of biological and genetic diversity	4.11HW Nature protection 4.12-4.15HW Aesthetic, spiritual, religious, scientific and educational information, cultural and artistic inspiration

Figure 2.1: Critical Natural Capital Framework for WATER




ECONOMIC SUSTAINABILITY
ENVIRONMENTAL/ECOLOGICAL SUSTAINABILITY
SOCIAL SUST^{y}.
Level 3
Current situation
Sust. Standards
Max. sust.water abstraction
Current situation
Sust. standards
Relate to Life Support and Human Health and Welfare functions
Current situation
Sust. Standards
Critical loads for ecosystems
Emission limits
Current situation
Sust. Standards
Max. concn for human health
Emission limits
Economic M-SGAP
SGAPs (physical)
SGAPs (physical)
SGAPs (physical)
SGAPs (physical)
Abatement, Avoidance, Restoration costs
MULTI-CRITERIA ANALYSIS
ECONOMIC AND SOCIAL ASPIRATIONS