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SUSTAINABILITY OF COASTAL AND WATER RESOURCE ENGINEERING

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ABSTRACT

In following both the precepts of the Resource Management Act, and the burgeoning exhortations of "sustainers", sustainability of coastal and water resource engineering requires more than just environmental adequacy. This paper examines the sustainable aspects of both coastal and water resource projects and includes a range of projects, some of which have been recognised for environmental excellence, and others that have won recognition for the quality of their engineering. Consideration of sustainability introduces the role of kaitiakitanga or stewardship and the integration of a range of options considering time as well as resource use.

INTRODUCTION

Sustainable development is *"development which meets the needs of the present without compromising the ability of future generations to meet their own needs"(MfE, 2003).* How can we judge and ideally ensure the sustainability of coastal and water resource projects and how realistic are such goals?

The purpose of the RMAct (1991) is to promote the sustainable management of natural and physical resources. In this Act, sustainable management is defined as *'managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural wellbeing and for their health and safety while sustaining the potential of natural and physical resources to meet the reasonably foreseeable needs of future generations; and safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and avoiding, remedying, or mitigating any adverse effects of activities on the environment'.* This definition creates a healthy tension with regard to rights and expectations of both individuals and existing communities and those of future generations, and the protection of existing natural and physical resources.

In this paper we endeavour to examine the issue of effective sustainability of a number of coastal and water resource projects. Developing and maintaining sustainable coastal engineering projects entails particular recognition of climatic and marine parameters, not least the reality of sea level change, historical, current and future. We take an inevitably selective view of some coastal and water resource projects in which we have been involved, notwithstanding that they have been recognised as environmentally or socially beneficial and we ponder on their sustainability, or lack of it.

Some thoughts are offered on how such projects, if not those specifically described, might be improved or whether it will be practicable for their function to be replaced.

It is argued, perhaps contentiously, that the goal of achieving true individual project sustainability may be an idealistic dream and that the crux of the challenge may well be in recognising this upfront and requiring early consideration of long-term replacement. Such an approach could both accord more closely with the Resource Management Act requirements and the notion of "kaitiakitanga" or stewardship, to be applied to engineering designs, providing for future generations.

COASTAL DEVELOPMENT

Globally, the coastline is an area that has always attracted intensive and valuable development. Worldwide over 20% of the world's population lives near a coastline, and this proportion is expected to rise rapidly (IPCC, 2001). In the USA 66% of the south east coast of the US is developed and 85% is eroding. There is US$3 Trillion of insured infrastructure within these hazard areas and US$1 billion worth of damage occurs every hurricane. Miami Beach attracts more tourists than the top 3 National Parks in the US and beach tourism brings more money into the economy than the US receives in exports. New Zealand has about 18,000 km of coastline, indented by some 350 estuaries, harbours, inlets, bays or fiords. The majority of our populations are firmly established in close proximity to the coast and there is extensive infrastructure development, including roads, rail track, ports and utility structures. Initial estimates suggest that up to 25% of our coast is rapidly eroding, while a further 56% was static to slightly erosional (Gibb, 1984).

Nowhere else are the complex issues associated with sustainable development, private and community rights and protection of the natural environment more visible than on these coastal margins. We, as New Zealanders have a long-term love affair and affinity with the coast. There are few pristine beaches in Auckland and those that exist are fragile and threatened. However, in a recent Forsyth Research survey, Aucklanders rated "beaches/coast" as the key contributor to the quality of life in their region. The desire of being close to the coast has driven prices of coastal property up around the country and there is huge demand in almost all areas of existing and new development.

COASTAL HAZARD ASSESSMENTS

Prior to, and during the 1970s, there were no national standards for coastal hazard risk assessment in New Zealand. Controls on coastal subdivision and development were largely based on the judgement of the local Catchment Board or Territorial Authority (ARC, 2000). The modification and sub-division of the Mangatawhiri Sandspit at Omaha Beach, north of Auckland, the subsequent failure of constructed protection works threatening the recently constructed beach front lots, and the extensive physical works required to improve the stability of the dune tip is still probably the most famous New Zealand example of inadequate consideration of coastal hazards when determining the location of coastal development and the expenditure of public funds to provide property protection (Figure 1). An Act of Parliament was passed for the emergency remedial work

Figure 1: Erosion at Omaha North (Photo: TM Hume, NIWA)

Unfortunately, Omaha is not the only example of development set-up too close to the coast. There are many coastal communities developed closed to the coastal margin that experience significant erosion resulting in a wide range of protection works.

Subsequent consideration of the restoration works at Omaha concluded that a cautious approach to consideration of future uses of coastal land be applied, even taken into account coastal engineering works already constructed (Kirk, 1981). This precautionary approach was taken into the New Zealand Coastal Policy Statement (1991) that forms the policy direction for Regional Coastal Plans and District Plans.

Since the late 1970s the concept of coastal hazard management began to gain acceptance, particularly for beach fronted shorelines. Generally coastal hazard assessments are required to evaluate potential land at risk from sea erosion, sea inundation and tsunami. This requires consideration of the coastal morphology and geology, the physical processes acting on the area, observed trends to establish the existing risks, then a prediction on likely changes over the next (typically) 100 years, including any potential climate change effect such as sea level rise.

While the 100 year period provides an end date for any extrapolation of trend, the potential for ongoing erosion trends or worsening climate change trends beyond 2100 needs to be recognised when determining appropriate land use and planning regimes (Figure 2).

Figure 2 shows relative sea-level trend for Auckland since 1899 (Hannah, 1990), the annual variability in mean sea level (Bell et al., 2001) and the predicted IPCC (2001) projections in "global" sea-level rise. The middle "most likely" zone spans the range of average estimates produced by a range of climate-ocean models.

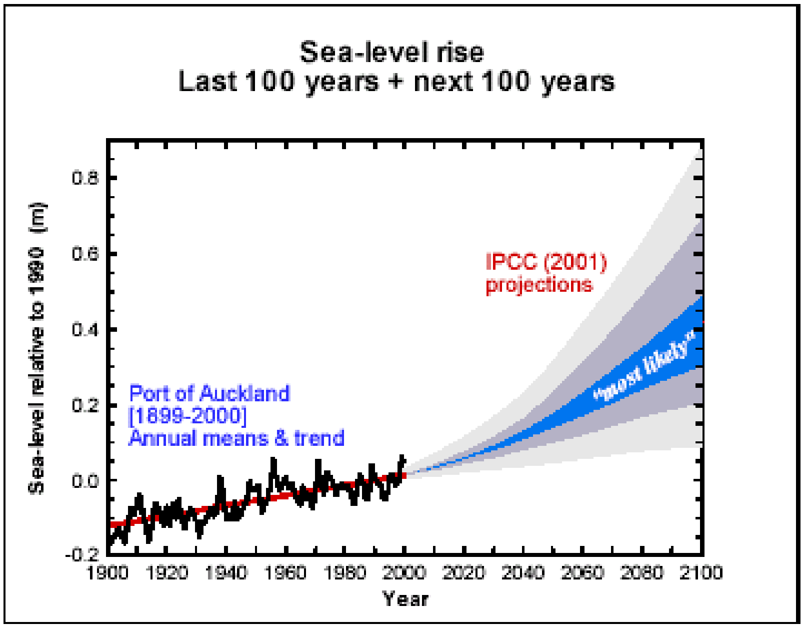

Figure 2: *Sea level rise from 1900 to 2100 (MfE, 2001).*

While various different approaches currently exist, the results are the development of coastal hazard areas or zones in recognition of the local processes and hazards that exist (Figure 3). The development of these hazard areas enables a focus on appropriate development and use of that land.

Figure 3*: Predicted coastal hazard erosion zones along Hawke Bay shoreline (Tonkin & Taylor 2003)*

Ongoing use of the coastal hazard mapping principle should result in the majority of future development being located further away from known hazard. However, the greatest problem that currently exists is the areas of existing development in areas where there are significant coastal hazards. Significant effort is required in these areas to balance the existing rights and needs of the present community with the needs of future generations.

MANAGEMENT OPTIONS FOR EXISTING DEVELOPMENT

The statutory documents set out a range of potential mitigation options, from planning responses (avoid), relocation (remedy) through to protection options (mitigation). However, our experience is that the majority of beachfront property owners prefer hard structures to be installed, such as seawalls, in order to protect their investment.

Often Councils are requested to pay for the structures both as part of their service to the property owners and as their obligation, having originally allowed development to occur or potentially adding to or exacerbating the erosion problem. Similar issues are starting to be raised with regard to erosion of cliffs.

As properly designed coastal protection structures are typically expensive, a plethora of lower cost options tend to be constructed, often with low effectiveness, adverse effects on physical processes and considerable visual and amenity impact.

Once structures are installed the coastal erosion problem is often viewed as being mitigated. Property values increase and there is an associated intensification of development, resulting in an increase of the value of properties at risk and therefore an increase in the overall risk (risk = likelihood x consequence). The increase in both development and value does not take into account the increase in risk as more valuable assets are located within a hazard area and the potential of increased hazard due to climate change effects. It is therefore arguable whether solely providing erosion or inundation protection structures provides a sustainable solution to coastal hazards.

While there will always be the need to provide protection works in certain areas, alternative solutions are likely to be more appropriate for many areas where recreational and natural character values are dominant features. Options such as beach nourishment may provide protection as well as improved public amenity. However, a commitment is likely to be required for ongoing nourishment.

Whatever protection options are initially used, the ongoing planning response to reduce assets at risk and to move development away from the most hazard prone areas should be considered to provide for future generations.

Determining who pays is always a significant issue when considering the management of coastal hazards. Historically for public works, costs have been distributed across the region. This approach is sometimes seen as being unfair for the majority of property owners who do not directly benefit from protection works and may be adversely affected by the presence of the structure on the foreshore. Recently more direct targeting has been considered, with beachfront property owners agreeing to pay up to 80% of the costs for the Waihi Beach seawall rehabilitation.

Alternative funding options include applying a levy or proportion of the rates of all development within the designated hazard area. These funds could be specifically targeted for coastal management, including property purchase, relocation, compensation, beach nourishment and the design of coastal structures.

We believe the focus for sustainable coastal engineering should be to provide the best assessment of potential risks to enable appropriate consideration of potential strategies taking into account the extent of the hazard, local context and long-term vision, incorporating the full range of available tools, including the statutory, planning and works based solutions.

INFORMATION AND KNOWLEDGE

Coastal engineering is still a relatively new science. There are significant gaps both in existing information to assess the past and in the knowledge of how physical processes operate. Given these constraints, extrapolation of existing data to predict extreme events has inherent uncertainties and can lead to a false sense of reliability. Sea level rise is a classic example, with significant debate within the scientific community not just on "how much" but also on "if". The prudent approach is to use the best guess as predicted by the IPCC, but note the potential for higher or lower trends. Once sea level rise is defined the next issue is what effect it has on coastal processes. A commonly used method for assessing shoreline retreat due to sea level rise is the Bruun rule (1988). This method is subject to significant criticism and debate, but remains a useful tool to quantify a potential effect. Ongoing research is needed both to acquire data on existing processes and to understand and quantify ongoing changes and potential effects.

CASE STUDIES

Two case studies are provided below. Both case studies highlight the use of engineering works in providing solutions for particular time periods. However, over a longer time period other measures may need to be considered.

Sewer Protection for North Shore City at Brett Avenue, Takapuna

A trunk sewer trenched into basalt rock was threatened by progressive erosion of the volcanic tuff underlying the basalt. A medium term and environmentally acceptable solution involved rock bolting of the basalt and limited protection of the erodible tuff. The project received an Arthur Mead award for application of environmental awareness to the solution of an engineering problem. However, combating future erosion of the substrata may require unacceptably extensive engineering works in a coastal conservation zone and North Shore City recognises that an alternative sewerage system facility will be required in the future.

Inundation Protection for Moanataiari Subdivision, Thames

The low-lying Moanataiari subdivision on the Thames foreshore has already suffered from storm-water drainage problems. The lowest area was also completely inundated by coastal flooding (high tides combined with a storm surge) in July 1995 and January 1997, with damage to over 30 properties. Given the increased frequency of future sea-flooding events and the withdrawal of insurance cover for property damage, the Thames Coromandel District Council, after a cost-benefit analysis, took action to address the issues and mitigate potential health hazards.

The Moanataiari reclamation was formed progressively from the 1900's, initially by dumping mine tailings and mullock over intertidal flats. Dumping dredgings from the port further reclaimed the area, which was then capped with a raft of weathered rock and clay from the hills under more controlled conditions in the mid to late 1960s. Housing construction was generally underway in the 1970s (Figure 4).

Moanataiari' s existence was threatened by the elements from the start as it lies near the mouth of a large river where floods and storm surges in the Firth of Thames cause coastal flooding of low-lying land. The steep catchment behind the subdivision also delivered stream flood waters during heavy rainfall, besides the acute vulnerability to sea flooding.

Engineers were engaged to rectify the problems of sea flooding and rainfall ponding to a 1 in 50-year design for non-coincident events (Duder *et al.,* 1999). The old seawall was reconstructed, made impermeable, its elevation raised, and a timber parapet added for further protection against wave run-up of the sea over the crest. A pump system was installed to pump catchment rainfall or seawater from the subdivision when it exceeds the capacity of the gravity drainage system. The back-beach 'dune' at the beach immediately north of the subdivision was built up to improve its capacity to absorb the main wave uprush. Swale drainage behind this beach and behind the subdivision was constructed to channel storm water from the upland catchment around the subdivision. The construction works alone cost $1.08 million, for the benefit of about 100 households in the subdivision.

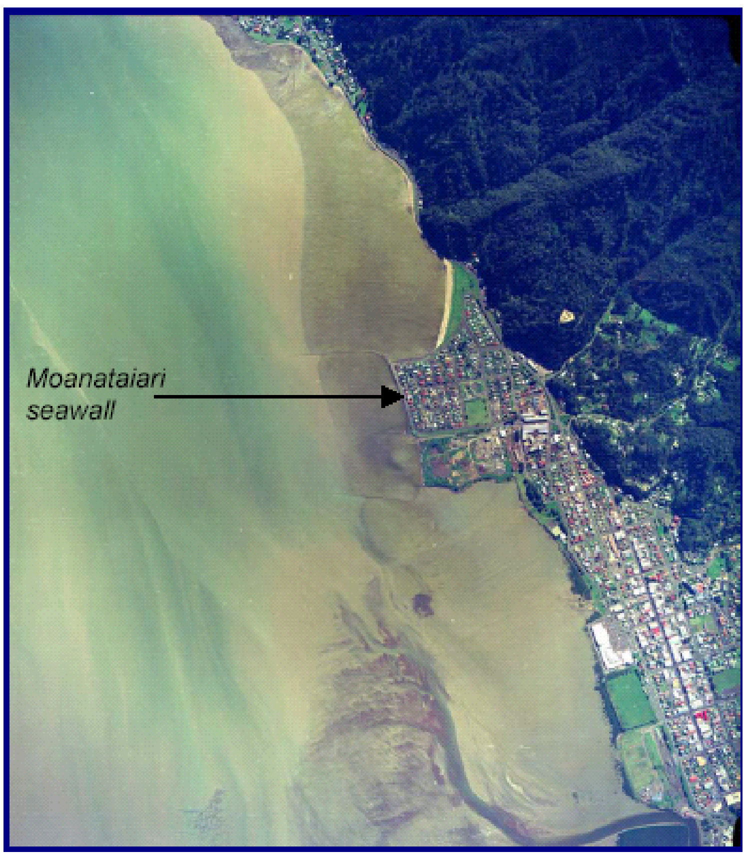

Figure 4: *Moanataiari subdivision at the north end of Thames.*

This development received the Arthur Mead award and was a finalist in the IPENZ supreme award for engineering excellence in infrastructure. However, the subdivision is experiencing continuous compression of the underlying marine sediments and its sustainability will depend on the outcome of ongoing monitoring of marine and geotechnical parameters, and may eventually lead to retreat after all feasible engineering measures have been implemented.

SUSTAINABLE MANAGEMENT OF WATER RESOURCES

A key element in sustainable management of water resources is the extent to which we work with rather than interfere with the runoff phase of the natural hydrological cycle. The IPENZ report on the president's task committee on sustainability. IPENZ 2004 includes suggested checklists for general sustainable engineering and a sustainable water checklist with specific tasks for water resource engineers, copies of which are attached.

We have taken a range of projects which are essentially management of surface water and have considered them against the elements of that checklist. In such projects there is an inherent limitation in the design standards which will typically include recognition of drought or flood conditions. In some cases the sustainability of such projects may depend on their capability to cater for extreme events, tempered by the realisation of what would have happened naturally.

Requirement for guaranteed downstream residual flows may not be a reasonable requirement if the river would one day dry up naturally. Flood control works will inevitably have a finite design limit in terms of the peak flood flow that can be accommodated. Provision must be made for dealing with overland flows in extreme events and should include emphasis on the control rather than the protection function. Flood control schemes on natural floodplains which may be continuing to aggrade may require a difficult balance between stopbanking and gravel extraction and will raise a question of the sustainability of the assets for which protection is being provided and may lead to the solution of retreat, leaving the river to behave naturally. The following case histories indicate a degree of sustainability or otherwise in a range of water resource projects in New Zealand and overseas.

Aniwhenua Hydroelectric Station, Bay of Plenty, New Zealand

The 25 MW project is a typical run-of-river hydroelectric station with a low concrete barrage with gated spillway diverting water through a concrete lined canal to a powerstation below the Aniwhenua waterfall on the Rangitaiki River. The barrage impounds a relatively shallow lake which provides storage for daily regulation of power generation. The reservoir also traps sediment of the order of 100,000 cu m per annum with a mixture of sedimentary gravels and pumiceous sands. These sediment deposits are beginning to impact on the volume of live storage and on the upstream parts of the reservoir with the potential for effects on the adjacent farmlands.

This issue is a smaller version of the significant impact of gravels impounded in the Roxburgh reservoir in the South Island, affecting the township of Alexandra, partly caused by a delay in implementing in flushing procedures during floods and the attendant inflow of bedload.

At Aniwhenua, a modest drawdown of the reservoir in floods is assisting in flushing sediment into dead storage. While the ultimate fate of the shallow reservoir is to fill with sediment, the project can be considered sustainable in terms of a true run-of-river station without the ability to meet daily peaks by drawing on reservoir storage except by flushing of sediments deposited near the barrage through its full height gates and other more pro-active works such as dredging or river training which are currently under economic evaluation.

Tongariro Power Development, North Island, New Zealand
Some of the rivers flowing south from the central volcanoes are intercepted and passed through a series of tunnels into the Waikato River system to enhance generation through a chain of two new powerstations and eight existing stations. Those on the Waikato River can be considered as a good example of sustainable hydroelectric generation as they draw effectively clean water from Lake Taupo and not experiencing significant rates of sediment accumulation.

However, the diversion systems and the two new powerstations are most vulnerable to volcanic activity such as ash showers which had a significant effect on waterways and one powerstation in the 1995-1996 eruptions from Mt Ruapehu, and the potential impact of lahars on major intake structures. It can be argued that the ongoing diversion of headwaters from other rivers is an unsustainable practice. However, this issue has been addressed by the granting of consents for such diversions, notwithstanding appeals to the contrary and at least in the medium term it can be argued that the Tongariro power development is a sustainable use of a major water resource.

Tongariro River
The river itself is part of and to a degree affected by the above power scheme. However, the predominant factor in river management is the effect of major floods on the lower reaches of the river, passing through the township of Turangi and flowing into Lake Taupo. As witnessed in the 29 February 2004 flood with a return period of approximately of 100 years, the river can deposit several 10,000 cubic metres of gravels on its floodplain. Progressive river management works have focussed on protection against bank erosion and construction of stopbanks to about 1/100 year design height.

However, it is recognised that these engineering approaches have to be balanced with management of gravel deposits ideally as a commercial resource but in any event by gravel removal coupled with river training, to avoid "a dog chasing its tail" situation of ever-increasing stopbank heights to address gravel accumulations and achieve a sustainable relationship between the river and township.

Tauranga-Taupo River.
A short distance to the north and draining a similar catchment into Lake Taupo, this river is highly dynamic with a constantly changing and aggrading river pattern across its littoral floodplain. At issue is the control of floods to afford a measure of protection, nominally to a 1/50 year standard, to the townships of Oruatua and Te Rangiita. Current management methods include formal spillways for diversion of flood peaks into storage areas or directly to the lake as well as stopbanking on both sides of the river.

In the 40 years since major floods (1958 and 1964) which significantly affected both the Tauranga-Taupo and Tongariro Rivers there has been a period of relatively low flood peaks. However, over the past six years several significant floods have focussed concerns on both river bank erosion and flood controls and in particular on the allowances that should be made in dealing with exceptional floods in excess of the design standard, including allowance for auxiliary floodways to minimise risk and damage to prime assets.

Dujiang Dykes, China
Among the classic examples of ancient water resource projects spanning millennia which could fairly be considered sustainable is the irrigation system near Chengdu. For over 2000 years, a system of seasonal diversion weirs, training banks and sediment sluices has diverted relatively clean water for irrigation. For each flood season, the diversion structure of timber trestles and gravel filled bamboo baskets was demolished, and then rebuilt. Flow through the dry season diversion channel was divided by floating skimmers into cleaner surface water for irrigation, and sediment laden bottom water returned to the river. After an abortive Russian attempt to control the river with a dam and power plant, the principle features have been reinstated with modern equivalents, while still following the basic precepts of the visionary engineer Li Bing whose principles are engraved on the cliff above the irrigation intake "Keep the weirs low and the sluices deep". Such advice is as relevant today as 2000 years ago; and Li Bing's masterpiece clearly demonstrates that water management projects can be truly sustainable if nature is worked with rather than against.

CONCLUSION

We have endeavoured to cast a critical eye over a selection of coastal and water engineering projects to examine whether, despite engineering or environmental success, they are potentially sustainable. We conclude that full appreciation of all physical, social and environmental parameters covering both the life of the project and into the future, is essential for aiming at sustainability.

Engineering design can therefore provide a fit-for-purpose solution. However, over the longer term, consideration of other non-engineering solutions may be required for true sustainability.

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7. Sustainable Water Checklist

General Responsibilities for Water Resource Engineers:

1. Do you understand the concept of sustainability, the holistic-thinking it requires and what it means in the field of water resource management? ☐

2. Do you actively seek out more efficient and sustainable technologies, and, more importantly, find ways to make them competitive with conventional approaches? ☐

3. Do you realise that sustainability must be addressed at multiple levels and by many disciplines, and we need to change how we work accordingly? ☐

4. Do you keep up to date with the changing aspects of sustainability by reading widely and being aware of trends and current arguments for and against increasing efforts to make the world sustainable, particularly in the field of water resource engineering? ☐

Specific Tasks for Water Resource Engineers:

1. Have you carefully accounted for water use throughout the entire design process? ☐

2. Have you ensured that water sources (including groundwater) are protected from contamination and given careful consideration to efficiency techniques at every step? ☐

3. Can potable water only being used for life-sustaining functions? ☐

4. Is water from aquifers, rainwater, surface run-off water, greywater, and any water use for sewage transport or processing systems all being considered within a cyclical concept? ☐

5. Have you ensured that wastewater is returned to the earth in a beneficial manner, and in particular considered organic treatment systems? ☐

6. In your designs have you minimised impermeable ground cover? ☐

7. Have you considered rainwater and surface run-off water as a possible water resource for use in infrastructure systems and processes? ☐

8. Can 'greywater' be treated and applied to practical or natural purposes suitable to its characteristics? ☐

9. Can water use in any process-related activity be put back into circulation, and contamination minimized? ☐

10. Has water used for sewage treatment or transportation been restored to appropriate water quality standards prior to distribution or reuse? ☐

4. General Sustainable Engineering and Technology Checklist

1. Have you thoroughly considered any project or plan that will have a significant impact on the life support functions upon which human well-being depends? ☐
2. Have you ensured that the true cost of resource depletion is included in all your feasibility studies and estimates? ☐
3. Have you minimised the absolute use of resources on a life cycle basis, and used renewable energy as much as possible? ☐
4. Have you maximised the use of renewable resources within sustainable extraction or harvest rates and taken account of environmental damage? ☐
5. Can you minimise waste products, particularly hazardous ones, from the total life cycle of engineered products, processes or systems, as near to the source as practicable? ☐
6. Does the project, product or process improve the overall quality of life for humans and other life forms, without large increases in the consumption of resources and energy, or at the expense of the environment? ☐
7. Has resource use been considered over a sufficiently long time scale so that present and future generations are not disadvantaged by excessive and unnecessary consumption? ☐
8. Does the project, product or process decrease comparative gaps in health, security, social recognition, political influence between groups of people as much as it could? ☐
9. Have those likely to be affected by the project been consulted if practicable, and will any relevant opinions be considered and where practical incorporated into final planning? ☐
10. If outcomes cannot be accurately foreseen, is your planning based on risk reduction and the precautionary principle? ☐
11. Have you taken an integrated systems, overall holistic approach including all stakeholders and the environment in your proposed solution? ☐
12. Is your project, product or process based on human needs rather than just finding a use for some newly available technology? ☐
13. Does the project, product or process involve past hazardous practices, and if so can these be eliminated and cleaned up in a cost effective way and time frame? ☐
14. Does the project, product or process contribute towards reducing non-sustainable practices to zero over a relatively short time frame? ☐
15. Can social and economic accounting methods be used at the planning stages to disclose, identify and quantify previous or developing environmental problems? ☐

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