

Human Carrying Capacity

Stage 2: Application of Concept to Kāpiti Coast District



Human Carrying Capacity

Prepared for
Kāpiti Coast District Council

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Executive Summary

Kāpiti Coast District Council has expressed interest in whether the concept of human carrying capacity can be used in assessing sustainability in the District, and has commissioned this report as part of the District Plan review process. The Council has published discussion documents with clear and bold questions about the sustainability of the District, including questions about how the District might address peak oil and climate change.

One approach to assessing sustainability of society is the concept of human carrying capacity, which, generally speaking, is the population that can live sustainably in a given area. More specifically, human carrying capacity is defined in this report as:

the measure of a specified area's ability to support human activity sustainably given aggregate lifestyle and development choices and the means used to achieve these, and is expressed in terms of number of people.

Initial research in this project has found little evidence for the explicit use of the human carrying capacity concept in planning in New Zealand although it is likely some form of the concept is used implicitly in much planning regulation. Further work is therefore required to ascertain the feasibility and defensibility of using the concept explicitly in planning documents, which is planned as Stage 3 of this project.

In any assessment of whether society's activities are sustainable the question of limits arises. An activity may be sustainable up to a certain point, beyond which it is no longer sustainable. An example is abstraction of water from a river, where water cannot be withdrawn any faster than it is replenished. However, often these hard limits are not the limits we choose. In the case of river water, limits are generally set at much lower abstraction levels so that a minimum flow is maintained. This reflects other values associated with rivers, but also acknowledges the presence of uncertainty. Critically, if limits cannot be determined then sustainability cannot be assessed.

A core issue of human carrying capacity is that the relationship between population and limits can in many cases be modified by behavioural changes. For example, installation of rain tanks means that more people can live in urban areas without reaching reticulated water supply limits. As another example, if fewer trips in private vehicles are made per person then more people can live in the District at the same overall level of exposure to oil price volatility. Human carrying capacity therefore depends very strongly on how a community chooses to live.

In this report we present a framework for assessing indicators of human carrying capacity. The main steps in this framework are:

- Identify a list of potential indicators in consultation with the community;
- For each indicator assess across a range of criteria including existence and nature of limits, dependence on population, relationships to other indicators, and current and potential monitoring.

We expect that it will be possible to determine limits for some indicators, and therefore their absolute sustainability could be assessed, while for other indicators only relative sustainability will be assessable. Both methods of assessment are part of the framework and would provide valuable information to the District in its assessment of progress towards sustainability goals.

Human carrying capacity is a composite indicator. That is, it combines limits to a wide range of activities to result in a single number: the number of people that can be sustained when those activities are taking place. Because of the number and complexity of factors determining sustainability, it is likely that carrying capacity cannot be calculated directly as there is insufficient knowledge and information to undertake such a calculation. In addition, the 'number' shifts constantly, and can be both added to and detracted from by virtue of people's actions. For these, and other reasons, we recommend caution against the use of a composite indicator in this framework.

As part of this study, we demonstrate the framework by applying it to three example indicators: use of reticulated water, use of non-renewable energy, and nutrient content of freshwater bodies. The example of use of reticulated water showed that limits can change depending on available infrastructure capacity. The example of use of non-renewable energy highlighted the importance of clearly identifying the issues at hand (in this case price trends, price volatility, and intergenerational equity) and also the difficulty in setting a limit for a non-renewable resource. The third example, of nutrient content in freshwater bodies, demonstrated an indicator that can't be readily related to population, partly because of boundary issues.

Because of the complex issues highlighted by the three examples, it is unlikely that the criteria outlined above can be met for all indicators, and as such, HCC as we have defined it is unlikely to be able to be calculated. However, the framework outlined in this report allows much of the value of the concept of HCC to be retained instead of resorting to the use of relative sustainability for all indicators. It is noted that the framework would require significantly more effort than the standard relative sustainability analysis.

We believe the flexibility of this framework would allow Kāpiti Coast District Council to undertake a more comprehensive assessment of sustainability than current methodologies allow. We therefore would recommend that:

- the proposed third stage of this project proceed so that the practicality, feasibility and defensibility of using the concept explicitly in planning documents can be assessed.
- subject to the outcome of Stage 3, the Council adopt the framework to assess sustainability in the district, requiring community consultation and an assessment of selected indicators in the pattern outlined by the three examples given in this report.

1.0 Introduction

The Local Government Act 2002 refers to the role of local authorities in “promoting the social, economic, environmental, and cultural well-being of communities, taking a sustainable development approach.” The Kāpiti Coast District Council’s current District Plan was made operative in 1999, and the 10-yearly review was initiated in 2009 with endorsement from Councillors to explore a range of sustainability issues.

The Council aims to have a District Plan Review that:

- addresses the implications of significant global issues (including climate change);
- increases the ability of the community to deal with change, through resilience and innovation;
- reduces pressures on the natural environment and resources;
- increases the ability of people to work and live locally in a sustainable way;
- reduces pressure on people’s day-to-day lives (e.g. cost of travel, noise); and
- respects Kāpiti Coast culture.

As part of its Review process, Kāpiti Coast District Council is interested in the feasibility of incorporating the concept of human carrying capacity as a means of assessing sustainability. The concept implies some limit on human population in a given area, and this report explores those limits and the reasons for them.

The report begins by discussing the heritage of the concept of human carrying capacity (HCC), and its place in the discourse of sustainability, and continues by discussing the Kāpiti Coast District context, developing a list of desired attributes of a definition and framework, presenting a definition and framework that endeavour to meet these requirements, and working through three example indicators to demonstrate the use of the framework.

This report does not attempt to include Māori perspectives on human carrying capacity because these are being considered in a separate line of work undertaken by the Council and local iwi.

2.0 Historical Overview

The idea that humans might reach some population limit with respect to available resources has a very long history. Observers in ancient times wrote of disasters besetting humans because of overpopulation, often ascribed to the intervention of the gods (Cohen 1995a). While Malthus’ influential essay on population growth and resource limits, first published in 1798, is widely known, earlier thinkers in Europe had already written on the subject, and it may be that society was already ‘primed’ for the apparently convincing arguments put forth by Malthus in his essay (Seidl & Tisdell 1999).

While the concept of carrying capacity has been widely taught in ecology, ecologists recognise that the logistic equation, first posited by Verhulst (1838) after he had read Malthus’ *Essay*, applies only to greatly simplified situations, and most, if not all, real-world situations are far more complex (Price 1999). The interactions of environment, both biotic and abiotic, mean there is almost never a fixed carrying capacity for any population of a species in its home range. For example, both the influence of coevolution of predators and prey, and variations in weather cause populations to fluctuate, sometimes widely. For these reasons, the concept of carrying capacity has long been criticized by ecologists as unclear, imprecise, and seriously flawed (Price 1999).

When applied to humans, carrying capacity becomes even more complex because of our ability both to trade, and therefore postpone limits to local population growth by depleting resources in other regions, and also our ability to develop technology to eke more out of the environment, protect ourselves from environmental extremes, and develop medicines. The use of fossil fuels is an example of both these factors: fuels are exported by a small number of countries and shipped around the world, and they are made available by technology and in turn make further technology possible. By using fossil fuels humanity is making use of an historical, one-off subsidy, one that is non-renewable on relevant time scales. Oil has allowed rapid, reliable transportation across the globe, which has further increased our ability to source resources from a great distance; it has enabled mechanised agriculture, greatly decreasing labour requirements; and it has also led to the development of fertilisers and pesticides, two key ingredients of the green revolution that allowed an extraordinary increase in food production following the second world war.

In addition to our ability to trade, and use technology, the majority of humans also have a choice of how to live, and this can have a substantial effect on our carrying capacity. For example, in developed countries up to one third of all purchased food is wasted in the household (e.g., WRAP 2009). This lifestyle choice factor was captured by Ehrlich and Holdren (1971) as 'affluence' in their well known equation relating environmental impact with population, affluence, and technology ($I=P \times A \times T$). Cohen summarises the lifestyle choice aspect with some prosaic examples (Cohen 1995b, p. 343):

"How many people Earth can support depends in part on how many will wear cotton and how many polyester; on how many will eat meat and how many bean sprouts; on how many will want parks and how many will want parking lots. These choices will change in time and so will the number of people Earth can support".

Because of these significant differences between the standard ecological concept of carrying capacity and how it applies to humans, more recent scholars distinguish between biophysical human carrying capacity, the maximum population that could be sustained under a given set of technologies, and social (or cultural) carrying capacity, the maximum that could be sustained under a given set of social systems (Daily & Ehrlich 1992). However, for clarity we will retain the term human carrying capacity in this project.

Earth currently 'supports' about 6.9 billion people (US Census Bureau 2011), although there is wide debate about whether this number is potentially sustainable. The way the Earth currently supports this population is certainly not sustainable, given our reliance on many non-renewable resources and over-use of ecosystem services. Moreover, 'support' is probably not an appropriate term, given over 900 million are presently undernourished (i.e. protein and energy deficient) (FAO 2010).

At a sub-global level, HCC is even harder to define: communities can rely on resources (and other ecosystem services) from outside the community boundary. Such resources include food, water, electricity, fuels, medicines, and a large range of other goods and services.

3.0 Current Applications

Several existing methods attempt to estimate society's impact on the planet's supporting systems. Here we present a selection of these methods from which we can learn and extract useful features in our definition for the present project.

3.1 Ecological Footprint

The Ecological Footprint concept was developed in the early 1990s by William Rees and Mathis Wackernagel (Rees 1992; Wackernagel 1994) to create an aggregated measure of humanity's appropriation of total available carrying capacity. The Footprint includes land areas used by humans to produce food and fibre, urban areas, an equivalent area representing the marine fish harvest, and the area that would be required if all CO₂ emissions were to be absorbed by additional forests. All indicators are converted to an areal unit, the 'global hectare,' and then summed and compared to the Earth's biocapacity, defined as the area actually available to produce renewable resources and absorb CO₂. According to the most recent global estimate, in 2007 the Footprint exceeded the Earth's biocapacity by 50% (WWF 2010).

The Footprint methodology is applied by the Global Footprint Network (GFN) to all countries with populations over 1 million for which data are available. Studies have also been undertaken at finer scales, including districts, cities and organisations (Global Footprint Network 2011). According to GFN, New Zealand's Footprint was 4.9 gha/capita in 2007 compared with its biocapacity of 10.8 gha/capita, i.e. according to this measure New Zealand lives well within its means.¹ However, this does not indicate whether New Zealand's activities are sustainable: the Footprint methodology excludes any account of the use of non-renewable resources, in addition to a range of other environmental impacts such as water and air pollution. In addition, the Footprint's approach of aggregating indicators potentially allows individual indicators to be beyond thresholds while the aggregate is not.

3.2 Human Appropriation of Net Primary Production

Human appropriation of net primary production (HANPP) is a composite indicator that attempts to measure "the 'scale' of human activities compared to natural processes" (Haberl et al. 2010). As with the Ecological Footprint's

¹ A global hectare (gha) is a "productivity weighted area used to report both the biocapacity of the earth, and the demand on biocapacity (the Ecological Footprint)" (<http://www.footprintnetwork.org/en/index.php/GFN/page/glossary/>).

Biocapacity concept, HANPP attempts to use a single indicator to measure the proximity of human society's size to some limit. Net Primary Productivity (NPP) is the "net amount of biomass produced each year by plants; it is a major indicator for trophic energy flows in ecosystems" (Haberl et al. 2010). Global HANPP for the year 2000 was recently estimated to be 24% of potential NPP (Haberl et al. 2007), indicating significant interference with global natural ecosystems and suggesting caution should be used when considering our ability to continue growing, particularly with projected population and bio-energy growth.

3.3 Planetary Boundaries

Rockström and colleagues (Rockström et al. 2009a, b) present a framework for looking holistically at the level of stress humanity places on the Earth. Their framework consists of a set of boundaries, or limits, beyond which they say there may be abrupt and nonlinear consequences at a global level. They specify numerical values for these boundaries for seven planetary indicators: climate change, ozone depletion, ocean acidification, biodiversity, freshwater use, the global nitrogen and phosphorus cycles, and change in land use. In deriving/choosing numeric values for these boundaries, the authors attempt to account for the uncertainty associated with transition zones i.e. zones of rapid change.

4.0 Sustainability

Sustainability is a "necessary and sufficient condition for a population to be at or below any carrying capacity" (Daily & Ehrlich 1992). However, sustainability is a broad term that is often only vaguely defined. At its heart, sustainability describes whether an activity or group of activities can be sustained indefinitely. Thus it is not possible to say that an activity is unsustainable for a limited time, but it is possible to say that a society is currently unsustainable and may become sustainable if the activities of that society change.

The definition of sustainable development provided by the Brundtland Commission has gained some currency (WCED 1987):

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The details and consequences of this definition are often overlooked. What are the 'needs of the present'? The definition leaves open the question of how social choices determine the boundaries between 'needs' and 'wants'. What are the needs of the future? We do not know what the needs (or wants) of future generations will be.

The Brundtland Commission's definition was influential in developing a definition of 'sustainable management' for the Resource Management Act. The purpose of the Act is "to promote the sustainable management of natural and physical resources," where 'sustainable management' is defined as:

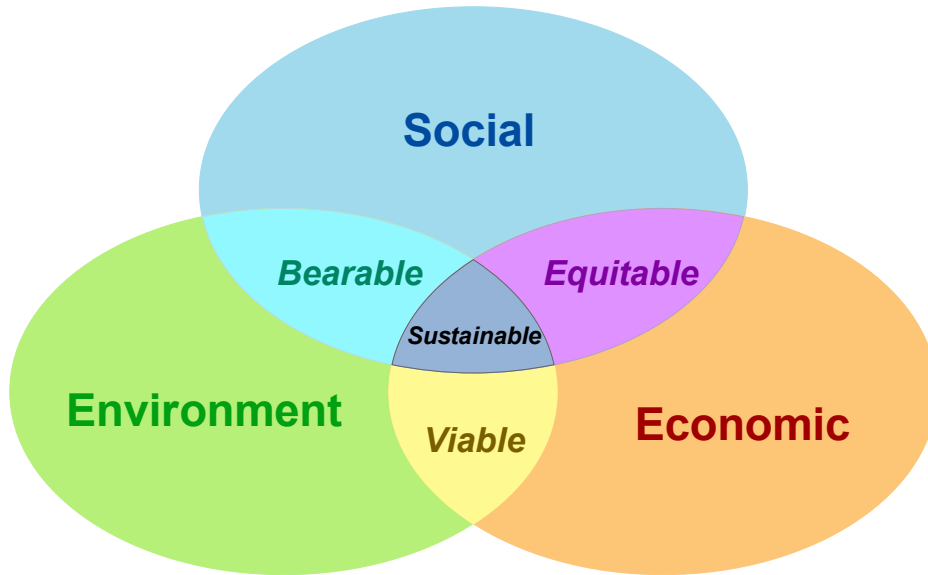
managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while—

- (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and*
- (b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and*
- (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

While these definitions are clearly anthropocentric, all practical definitions of sustainability are necessarily anthropocentric being defined according to human values. Deep ecology is a contrasting paradigm that views all species and ecosystems as having equal worth, with no pre-eminence of humanity. However, deep ecology is obviously very difficult to implement in policy.

The Brundtland definition is implicitly a statement of 'weak sustainability': that man-made capital be allowed to substitute for natural capital as the latter is depleted, based on the assumption that such man-made replacements will be found. The weak sustainability approach is often depicted as a trade off between the three (or four) pillars (Figure 1), indicating that the goal is balance.

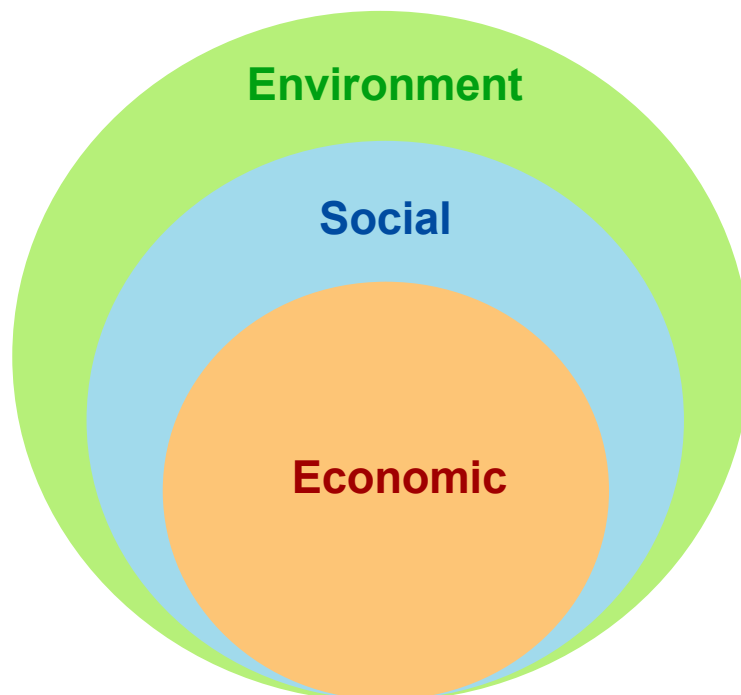
Figure 1 The intersecting-spheres depiction of sustainable development, where sustainability lies at the intersection of all three spheres (source: Johann Dréo, Wikimedia Commons).



In contrast, the ‘strong sustainability’ approach is commonly represented as having non-negotiable limits set by the environment taking priority over those of society, which in turn take priority over those of the economy (Figure 2). In this paradigm, balance is only considered after ensuring non-negotiable constraints are met. The use of the strong sustainability paradigm is one of the defining features of the field of Ecological Economics, delineating it clearly from Environmental Economics.

While a strong sustainability model is conceptually straightforward at a global level (e.g., the world’s real economy is constrained by the global environment), it becomes less so at a local level. For example, if the economy of Kāpiti Coast District were limited only by the District’s society and environment, then the District would be self-sufficient. However, the economy (and society) depends on factors outside of the District. Trade and travel complicate this picture, as do some environmental factors such as weather systems and air purification, and some social factors such as international treaties and protocols.

Figure 2 The strong sustainability view, representing the environment as being most critical, and society and the economy constrained within the environment



5.0 Kapiti Coast District Council

Kāpiti Coast District Council's Long-Term Council Community Plan (LTCCP) includes some bold and clear statements on sustainability, stating that the programme of activities 'is focused on delivering services across all wellbeing areas with a strong sustainable development approach' (KCDC 2009, p. 5). The document expands on this with a set of development principles (KCDC 2009, p. 24):

"These principles are consistent with the idea of 'strong sustainability' which seeks a readjustment of consumption patterns and systems and rejects the notion that resource depletion and degradation can be resolved through technological innovation alone (known as weak sustainability).... These principles imbue thinking on all Council activities".

Given the statement above defining strong sustainability, it is clear that the Kāpiti Coast District is currently not strongly sustainable. The use of non-renewable resources is contrary to the definition, and the District uses, for example, fossil fuels; many products derived from fossil fuels (e.g., plastics, fertilisers, pesticides, cosmetics); and mined minerals such as phosphates, coal, and limestone. While few would advocate immediate and total cessation of use of these non-renewable resources, the use of the term Strong Sustainability in the Plan is clearly as an aspirational goal.

One of the high level Community Outcomes also presented by the LTCCP is that 'the nature and rate of population growth is appropriate to community goals' reflecting the community's desire that population growth be managed to bring benefits rather than problems (KCDC 2009, p. 18).

As required by the Local Government Act, "Significant Issues" (major structural issues, external risks, and uncertainties) are identified in the LTCCP. These are: climate change, peak oil and the cost of energy, global conflict and disruption, narrow economic base, economic downturn, major swings in central government policies, local democratic structures and systems, and population structure (KCDC 2009, pp. 26–27).

The District Plan is currently under review, and KCDC have released a set of seven discussion documents relating to specific sustainability issues: global change, biodiversity, natural hazards, food and rural productivity, landscape, infrastructure, and urban form and transport. Carrying capacity is specifically mentioned in the Global Change discussion document (KCDC 2010, p. 15), which clearly establishes context for this current study:

"A carrying capacity assumes that it is possible to measure the ultimate population for the District based on the land available for particular uses such as food and energy production, housing and open space, taking into account the ecological and hazard constraints for the District. The District Plan review should explore carrying capacity as a concept and assess options against the theoretical carrying capacity for each resource".

Every community that has the good fortune to have more than sufficient resources to meet basic needs (food, safety, shelter) faces choices as to how to use 'surplus' resources. Communities might choose from a wide range of lifestyles, anywhere from subsistence, through comfortable, all the way to luxury. At any point on that subsistence–luxury spectrum choices can be made that will affect a community's impact on the environment, the economy, and on the society.

The Kāpiti Coast District currently relies on a wide range of goods and services (both economic and from the environment) and governance from outside the District. This follows from the concept of comparative advantage, whereby regions and nations that have a natural (or otherwise) comparative advantage in the production of a good or service can do so more cheaply, and thus greater system efficiency is obtained from making use of these advantages. On the other hand, reliance on others to produce critical goods and services reduces a society's resilience, so a trade-off is required. The following is a list of areas, albeit incomplete, where Kāpiti Coast is reliant on other areas:

- Foods not produced in the area;
- Manufactured goods including vehicles, fuels, medicines, fertilisers, pesticides;
- Clean air (via wind), ozone layer protection from UV radiation, climate regulation of the atmosphere;
- External regulation, national defence, disaster relief, culture;
- Seeds, breeding stock, etc. not occurring locally;
- Tourism revenue; and

- Financial and investment systems.

In the local context, the distinction between local and global issues becomes important. While specifically local issues, such as the availability of potable water in the District, are under the control of the District, the same cannot be said of global issues such as climate change; i.e. there is no set of actions the District can take to prevent climate change. However, the District does have control over its *contribution* to global issues, for example, through reducing its greenhouse gas emissions and planting trees to sequester CO₂. Both local and global issues are important in the assessment of sustainability.

6.0 Precedence for Application of HCC in Council Plans

A desktop search was undertaken to ascertain whether there is precedence for the application of the Carrying Capacity concept in New Zealand Council Planning documents.

It was found that the term “carrying capacity” was frequently applied in Council documents in terms of infrastructural carrying capacity, for example, roading networks. This usage has some relevance in that it relates to an infrastructural resource (roading) that has a carrying capacity limit in term of the number of vehicles that the roading resource can carry. However this example is not directly analogous in terms of the use of the concept of carrying capacity in this study, which is focussed on human carrying capacity.

The search indicated that some District Plans make reference to carrying capacity in a manner that has some similarity to its use in this study. Two examples are the Proposed (2006) Hauraki Gulf Islands Section of the Auckland City District Plan, and Plan Change 8 (Whitford Rural Area) to the Manukau City District Plan.

In the Proposed Hauraki Gulf Islands Plan, limited references are made to carrying capacity. For example, in reference to the Pakatoa Island Land Unit (Land Unit being an ecologically-based zoning method), the Plan states:

“Overall, the island provides for a mix of uses that support the potential for a small residential community combined with a tourist complex activity, while recognising limits to the physical and visual carrying capacity for a small island”.

While little further explicit mention is made of carrying capacity, the objectives, policies and rules are formulated to control development so that the limits of physical and visual carrying capacity are imposed. It is also understood that the concept of carrying capacity did provide some theoretical basis to the formation of the Plan, notwithstanding the only minor explicit reference in the final document.

This statement further underlines the varied application of the term “carrying capacity” in planning documents, in this case relating to both physical (biophysical) and visual aspects.

Plan Change 8 to the Manukau City District Plan sought to move away from a prescriptive approach (crude minimum lot sizes and performance standards) to a more nuanced and flexible planning approach to rural land use and subdivision, based on environmental qualities. Several general references were made in the Plan Change to the “carrying capacity” of the area, however the review indicated that the term was being used in the sense of landscape character.

Beyond these specific District Plan examples, which only touch on carrying capacity rather than using it as a central planning tenet, it is apparent that there is little evidence of the explicit use of carrying capacity in planning in New Zealand. However we consider that it is likely that some form of the concept of carrying capacity is implicitly utilised in much planning regulation. That is, planning regulation will be based on certain environmental and infrastructural constraints that dictate where, when and how much development occurs. Therefore, while prescriptive limits on human population are not necessarily imposed, approximate limits are effectively imposed by virtue of the yield of potential future development that a District Plan allows.

7.0 Desiderata for a Definition of HCC and the Assessment Framework

From the contextual discussion above, we distil the following list of desirable factors for a working definition of human carrying capacity and for the assessment framework in this project:

- Clear: should be generally understandable with minimal ambiguity;
- Covers the idea of allowing some things to be imported, with some reliance on non-renewables, i.e. some flexibility around the idea of strong sustainability, but such things are explicit and clearly reasoned;
- Make explicit the trade-off between population and some indicator of affluence (lifestyle, quality of life), and the way in which that lifestyle is achieved (i.e. technical efficiency), reflecting the relationship $I=P \times A \times T$;
- Precautionary principle: allowing a margin for uncertainty and resilience against extreme events;
- Will be a function of the community's choices, and reflect the range of social values and expectations within the community;
- Includes a range of indicators both separately and aggregated;
- Should be theoretically measurable and monitorable (but the practicalities will be examined in Phase III of this project);
- The Assessment Framework should be applicable at a range of scales; and
- The Assessment Framework should allow the conferment of benefit to areas where carrying capacity is maintained (or enhanced), or where certain technologies/methods are employed which are deemed to not detract from the carrying capacity of a particular area. Conversely, the framework could penalise development which is deemed to detract from carrying capacity.

8.0 Definition of HCC

We have used the following definition of human carrying capacity in this project:

The Human Carrying Capacity (HCC) is the measure of a specified area's ability to support human activity sustainably given aggregate lifestyle and development choices and the means used to achieve these, and is expressed in terms of number of people.

Notes on the definition:

- Because of the number and complexity of factors determining sustainability, it is likely that carrying capacity cannot be calculated directly: there is insufficient knowledge and information to undertake such a calculation and the 'number' shifts constantly, and can be both added to and detracted from by virtue of people's actions. Rather, we expect that at least qualitative changes in carrying capacity may be observed via a set of indicators;
- Sustainability implies the ongoing maintenance (and potentially improvement) of environmental, social, and economic indicators;
- The degree of sustainability of each indicator will be both determined by the community and specific to the Kāpiti Coast District, such that sustainability is strong for one set of indicators, weak for a second set, and flexible for remaining indicators;
 - Strong sustainability views the stock of natural capital as irreplaceable, while weak sustainability views natural capital as substitutable with man-made capital;
 - We define flexible sustainability as the explicit decision that some indicators will be neither strongly nor weakly sustained, but will rather be traded off against other indicators. This recognises priorities of the community that the requirement of some indicators to be either strongly or weakly sustained is not negotiable, while remaining indicators are desirable but negotiable;
 - The definition implies that some indicators may be limiting factors in the number of people the district can support. Strong and weak sustainability of individual indicators implies there is a limit (perhaps unknown or highly uncertain) that cannot be breached. If one additional person in the district would

breach a single limit for a single strongly or weakly sustained indicator then the carrying capacity would have been surpassed. In contrast, flexibly sustained indicators cannot be limiting factors;

- While the definition allows some factors to be weakly sustainable and others not, the reality is that most inputs into human life support and lifestyle are interdependent. For example, if oil is not included as at least a weakly sustainable factor, then, strictly speaking, all other factors that depend on oil (i.e. that are transported using existing modes) cannot be sustainable; and
- Indicators will also be clearly identified as locally or globally sustainable. An indicator that is at a locally sustainable level is one that is sustainable without dependence on other areas. This implies specific self-sufficiency. For example, potable water is likely to be locally sustainable for the District as a whole (ignoring growth), although in many places within the District it is not locally sustainable because of reliance on reticulation from other areas. In contrast, an indicator that is globally sustained is one that is sustained in net across a larger area through use of offsets, trade, etc. For example, use of medicines by an area is potentially above any capacity of that area to produce medicines, but well within global capacity;
- Being dependent on 'aggregate lifestyle and development choices', the Carrying Capacity of the Kapiti Coast District can be directly influenced by the actions of individuals and organisations in the District. Indeed, as discussed earlier, actions taken outside of the District can also affect the Carrying Capacity of the District;
- Recognising that data and limits are uncertain, the definition in effect requires a 'safety margin' or buffer.

9.0 Limits and Thresholds

The human carrying capacity of an area depends on the resources available, the activities that occur in that area and the ability of the environment to absorb and process the results of human activities, among other things. There are some clear limits on the number of people that can be supported by an area, such as the areal extent, the amount of food available, the supply of drinking water, etc. However, some of these 'clear' limits are beyond a level that many would deem acceptable. For example, the hard limit of an area is really only directly limiting when no more people can be physically squeezed in (and then consider high-rise apartments), while the hard limit of food is some minimal level of calorific intake that would only barely sustain life. Therefore, rather than using such hard, theoretical limits, limits are often defined based on some level of acceptability by society, but even then that acceptability varies by individual. Perhaps one segment of society would choose a minimum area per person of 50 m², while another segment might choose 500 m². One group of people might choose a minimum calorific intake that allows them to perform a range of energetic activities, while another chooses a minimum that satisfies an emotional connection to food.

These difficulties are even greater for environment limits: what is an unacceptable level of nitrate in a stream? Some in society might believe that water pollution has no impact on their well-being and therefore there should be no limit on pollution levels in streams, while at the other extreme some might believe in the intrinsic value of the waterways and see any level of pollution as a diminution of the water's spirit. The science around water pollution clarifies but does not necessarily resolve the problem because there will be different limits on pollution depending on what goal society would like to achieve: is the goal water clarity and attractiveness, safety for recreation, suitability for irrigation, protection of native fish species, protection of introduced fish species, protection of microinvertebrates, or minimising potential for algal growth? Each value-derived goal, while interlinked, can result in a different limit being defined. Moreover, the nature and complexity of environmental interactions means that there is significant uncertainty in the science around the interactions of levels of pollutants and outcomes in the stream.

Beyond the challenges in determining limits, it is necessary to define a functional relationship between the number of people and the pressure in question. That is, it is necessary to be able to ask the question: how much closer to or further away from the limit do we get if we add one person to this area? As a simple example, consider a village of ten people who currently produce all their own food and have sufficient surplus to sell half their food to a neighbouring village. One among several possibilities is that if this village doubles its population, they would then use all their food and be at their limit, implying a linear response curve (see section 9.2). However, other factors may influence the relationship between the village's population and the amount of food it requires.

As a more relevant example, consider the limits of reticulated water supply: how many more people could live in Waikanae before a new reservoir is required? These examples sound linear, but only in the absence of interactions with other effects. For example, as the number of people in Waikanae increases and the limit of current water supplies is approached, the Council's efforts to encourage water efficiency could increase. Further,

the probability of reaching the water use limit depends on the weather, and to manage this uncertainty engineers plan for a chosen drought return period, effectively accepting a specific level of risk that water demand will not be met.

Therefore limits are often difficult to define and determine, and the relationship between the indicator used to describe a limit and the number of people is not always straightforward. Further still, the impact of exceeding limits can vary widely. Based on an extensive review of the limits literature, Haines-Young et al. (2006) distinguish between limits and thresholds by defining a threshold as a limit that, once crossed, is likely to be irreversible. That is, reducing the pressure either does not return the indicator to the previous state or requires a larger reduction than the increase that caused the threshold to be exceeded. Examples of threshold effects include eutrophication, where substantially reduced levels of nutrient inflows are required before a water body will return to an un-eutrophic state; and a drop in GDP that may result in loss of confidence and withdrawal of capital, compounding the problem.

The setting and enforcement of limits can force society to adjust if those limits are not already met. In these cases there are sometimes adjustment costs, and it is up to policy makers and community processes to establish where these costs are borne. However, in some cases these costs can lead to innovation such that the costs create new revenues. The nitrogen limit placed on pastoral farmers in the Lake Taupō catchment has driven this kind of innovation. For instance, some farming operations have been streamlined and made more efficient to meet the limits with trees planted in areas with greater nitrogen losses, some are exploring lower nitrogen leaching activities such as blueberries or capitalising on the carbon benefits from planting trees for the sale of carbon credits, some are participating in the nitrogen market to purchase additional allowances to meet the limits while others are experimenting with new technologies to reduce nitrogen losses.

9.1 What is a Sustainable Level of Erosion?

As an example of the complexity of determining limits, consider the following question: “What is a sustainable level of erosion?” It might seem obvious that the ‘sustainable’ level of erosion is no erosion at all, but in fact the picture is more complicated. Land erosion is a set of processes redistributing soil and rock, and these processes occur in the absence of humans, just as they occur in the presence of humans. In the absence of human intervention, some ‘background level’ of erosion occurs, gradually (although sometimes catastrophically) wearing down hills and mountains, and redistributing silt onto floodplains and shingle into riverbeds. This redistribution maintains fertility of lowland soils and structure of rivers. Research has shown that approximately half of all erosion in New Zealand derives from the conservation estate, largely from the Southern Alps (Dymond 2010).

Humans modify erosion processes such that erosion is increased in some areas and reduced in others. Clearance of hill forests leads to increased loss of soil and increased risk of massive slips. Stopbanking of rivers prevents flooding, and this prevention helps maintain year-round agricultural production, but also prevents redistribution of fertile sediment in major rain events.

The ‘sustainable’ level of erosion is not necessarily no erosion at all, but rather the cumulative effect of many inter-related processes operating across a range of scales that determines net erosion in a given place. Indeed, the sustainable level is not necessarily the level that would occur in the absence of humans. By definition a ‘sustainable’ level is one that can be sustained *ad infinitum*, but a range of constraints must be understood to home in on this level. These constraints include the presently available resource of material that could be eroded, the rate of generation of new material (uplift, pedogenesis), the effects of erosion and the methods available for ameliorating these (e.g., addition of fertiliser, manual scouring of river beds), the rate of use of materials by society (e.g., nutrient extraction via food production, aggregate use for construction), among others.

9.2 Relationships between Population and Indicators

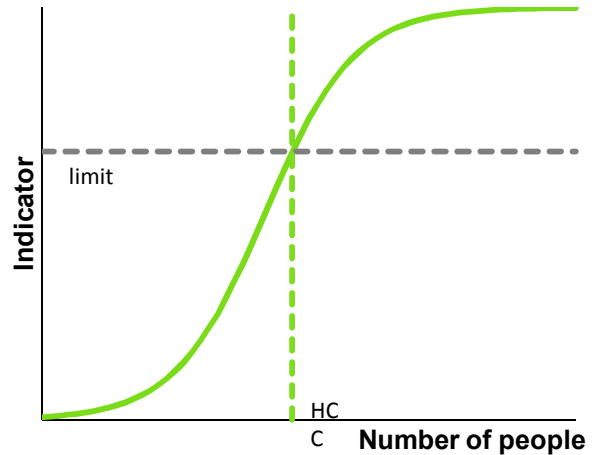
For many indicators, all other things being held constant, increasing the number of people in an area is likely to move an indicator closer to the specified limits. Figure 3 and Figure 4 show two types of generic relationships between number of people and an indicator. An example of the linear response curve shown in Figure 3 might be nitrate leaching from livestock agriculture, assuming a constant rate of meat consumption per person and all meat produced locally such that increasing the number of people leads directly to increased livestock numbers in a constant area, which in turn leads to increased nitrate leaching in an approximately linear fashion. Figure 4 typifies a situation with a zone of rapid transition, where the indicator responds more steeply to increased numbers of people, accelerating beyond some point. An example of this functional relationship is soil erosion, where, all else equal, increased farming occurs on more erodible land and hence erosion increases. In each case,

the human carrying capacity is the number of people at which the indicator's limit is reached. Various other general shapes are possible for these response curves, including those that acknowledge gains in efficiency with greater production.

Figure 3 Response curve showing a linear relationship between number of people and an indicator, with human carrying capacity with respect to the indicator determined by a limit.

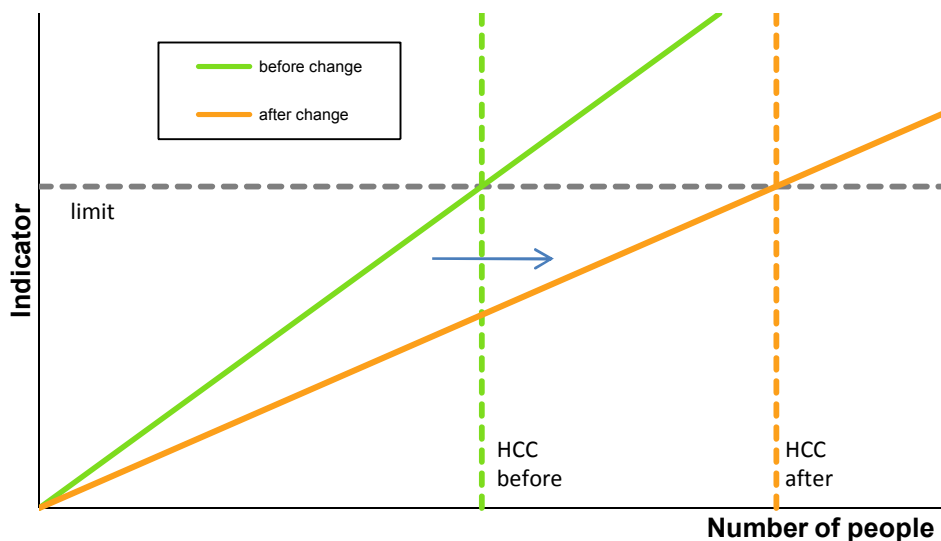


Figure 4 Response curve showing a sigmoidal relationship between number of people and an indicator, with human carrying capacity with respect to the indicator determined by a limit.



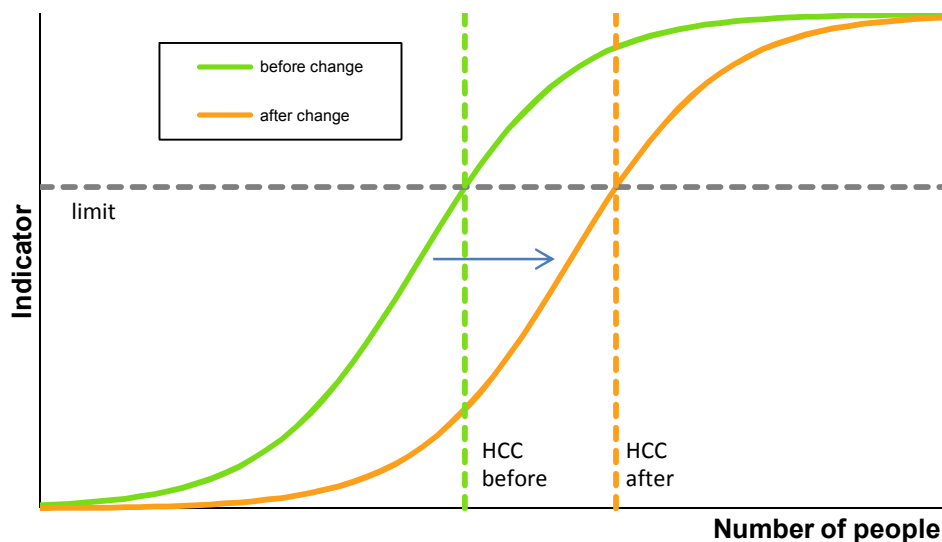
While these theoretical relationships hold with 'all else equal', that is assuming a certain set of behaviours and technologies remain constant, often all else is not equal, whether by design or otherwise. Any number of things can cause the response curve to shift, thereby changing HCC without changing the indicator's limit. For example, if the indicator is emissions from transportation, and people in the area change their driving behaviour, change to public transport, use more efficient vehicles, or reduce travel, then the response curve shifts, resulting in a change in HCC. Figure 5 shows a linear example, which could be transport emissions, where some change, for example a drop in the average distance travelled in private motor vehicles, results in a shift of the curve and an increase in the number of people that the area can accommodate before the limit is reached.

Figure 5 Linear response curves showing a change in human carrying capacity (HCC) resulting from a change in some related factors (examples provided in text).



Similarly, Figure 6 shows a sigmoidal example, which might be soil erosion, where some change, for example widespread improvement in soil conservation measures, results in a shift of the entire curve. Another example of the behaviour in Figure 6 is stormwater causing discharge of untreated sewage, where the shift in the curve might result from increased uptake and installation of domestic raintanks.

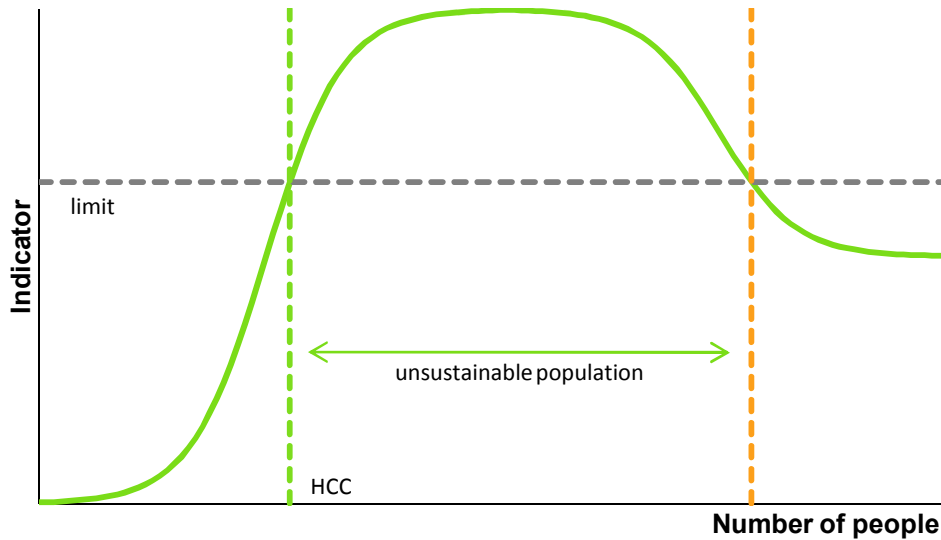
Figure 6 Sigmoidal response curves showing a change in human carrying capacity (HCC) resulting from a change in some related factors (examples provided in text).



While for clarity we present all example indicators here as increasing with increasing population, clearly this depends on the definition of the indicator, and there is no reason not to have an indicator that decreases with increasing population. An example of the latter is services such as public transportation and waste collection that depend on population density, which tends to increase with higher populations. In their work in Ireland on sustainable settlement sizes, Moles et al. (2002, p. 4) found that “some indicators signal that larger settlements are more sustainable, while others suggest that smaller settlements are more sustainable.”

In addition, all examples shown here are monotonically increasing, i.e. they consistently increase as the number of people increases. Some indicators may be non-monotonic, where an increase in population may result in an increase in the indicator up to a point, after which the indicator decreases. For example, as population grows, so too does use of private transport, but as population continues to grow sufficient funding becomes available to provide public transportation. At even higher populations it may become more difficult and expensive to use private transport. This type of situation – which potentially results in a range of population over which its activities are unsustainable – is depicted in Figure 7. There is considerable debate in the literature as to the existence of this phenomenon in relation to environmental damage as a function of economic scale. An example of the argument for the presence of this phenomenon is that as a population grows it is able to invest in more costly, less environmentally damaging infrastructure. The counter-argument is that along with this population growth come other environmental damages that outweigh any gains.

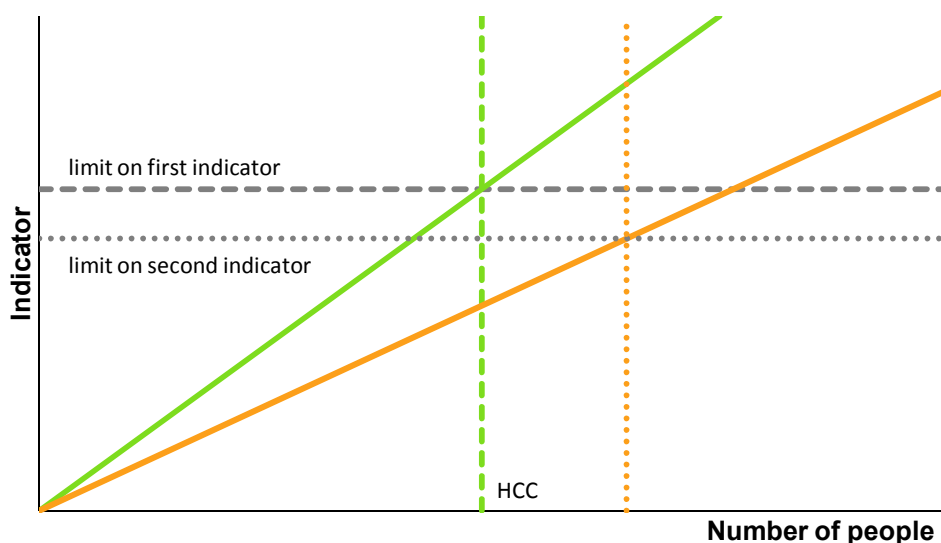
Figure 7 Non-monotonic response curve demonstrating an indicator that drops below the limit again when a high enough population is reached (example provided in text).



Limits imposed on different indicators are most likely to result in different human carrying capacities with respect to those indicators. In theory the human carrying capacity with respect to all indicators would be the lowest of these different carrying capacities (see Figure 8). For example, a limit imposed on area of productive agricultural land might result in a lower human carrying capacity than that from a limit on use of non-renewable energy. In this case the area of productive agricultural land might be said to be a determining or limiting factor on human carrying capacity.

Lastly, many indicators may not be sensitive to local population, and therefore limits on these indicators will not determine a sustainable population. Obvious examples are any indicators that are measured in per capita terms, but another clear example is the impacts of exporting sectors, where the level of activity is not a function of local population.

Figure 8 Response curves for two indicators, each with a limit, where human carrying capacity is determined by the limit that is reached first (examples provided in text).



10.0 Selection of Indicators

Multiple indicators are used to assess sustainability because of the wide variety of impacts human activities have on the economy, society and the environment, and the complexity of interactions between these different impacts. No single measurable factor can explain this range of impacts.

There is a very wide range of potential indicators that could be used to assess human carrying capacity, reflecting the complexity of human society. The process of selection of indicators for sustainable development has been undertaken many times in New Zealand. For example, Statistics New Zealand produced a list of 85 indicators as part of its Sustainable Development monitoring programme (Statistics NZ 2009), while the Choosing Futures Waikato project selected 75 indicators from an initial list of about 200 (Choosing Futures Waikato 2006a). These indicators are listed in Appendices 1 and 2, respectively. In both of these examples, however, indicators are monitored but not compared with any limits to determine sustainability. That is, they provide measures of relative sustainability.

It is important that the set of indicators cover a range of social, environmental, and economic themes to cover sustainability in the broadest sense. The Choosing Futures Waikato project provides a good example of the process of indicator selection, where an initial, large set of indicators was established with stakeholder input and then a smaller set was distilled according to a clear set of criteria (Choosing Futures Waikato 2006a). The transparency of the selection process is important to understanding the robustness of the indicators used in any reporting.

Statistics New Zealand used the following criteria in the selection of indicators of sustainable development (Statistics NZ 2009, p. 145):

- adequately and consistently reflects the phenomenon that it is intended to measure;
- responds rapidly and reflects changes in the phenomenon;
- is unambiguous with regard to evaluation (not applicable to context indicators);
- is derived from high-quality, methodologically sound data;
- is relevant to the New Zealand context;
- can be directly related to at least one of the defining principles; and
- is easily understood and provides information useful for decision making.

The monitoring and reporting community outcomes (MARCO) team of the Choosing Futures Waikato programme developed an initial list of over 200 indicators. This list was refined using the following general criteria (Choosing Futures Waikato 2006b):

- only outcome indicators were included, as opposed to output indicators
- regional relevance as determined by a workshop
- local relevance as determined by survey of all local authorities in the region
- a technical evaluation assessing measurability, cost effectiveness, and understandability.

These criteria were used to rank indicators, and the number used was reduced by taking the top 50 indicators and adding others where an outcome group was not represented in this top 50, bringing the final total to 75 (see Appendix B).

In addition to these two lists, we have identified at least 166 potential indicators in the District's community outcomes document (KCDC 2009), and these are listed in Appendix C along with the outcome to which they relate.

We recommend that Kāpiti Coast District Council use these lists as starting points for a list of indicators suitable for the District. However, with the different goal of human carrying capacity, as discussed above, a different selection process is required to determine suitability of indicators in this work. Section 11.0 discusses that process in the context of the full framework.

10.1 Aggregation: A Composite Index of Human Carrying Capacity?

Composite indicators may be formed by combining a set of separate indicators. Where separate indicators provide useful, detailed information, a composite indicator potentially provides a concise summary that is more easily understood. On the face of it, a composite indicator also allows trade-offs to be made more readily. However, there are also some distinct disadvantages with the production and use of composite indicators, and these will be elaborated in the following discussion.

Production of a composite indicator requires components expressed in different units to be 'normalised' so that they may be combined. For example, the Ecological Footprint allows carbon emissions to be added to land used for food production by converting emissions to the area of forest that would be required to remove that carbon from the atmosphere.

In the absence of clear relationships between different components, normalisation requires some subjective input to establish a fixed means to bring all components to a common unit. In Life Cycle Assessment (LCA) this process is separated into three distinct steps: characterisation, normalisation, and weighting (Baumann & Tillman 2004, pp. 140–142). Each of these three steps used in LCA is subjective and requires assumptions and value judgements. Characterisation makes commensurate² separate effects that have a similar impact by using an equivalency factor (e.g., the use of 100-year global warming potential to combine the warming impacts of different greenhouse gases into a 'CO₂-equivalent'). Characterisation can be based on empirical or theoretical knowledge of the relative impacts of a range of actions, but there is a danger that once this common impact is counted other impacts of the actions are not counted. For example, emissions of nitrous oxide have impacts on both global warming and human health through local air pollution. In the case of global warming potential, the choice of warming horizon (usually 100 years) is critical to relative effects of each greenhouse gas.

Normalisation compares each characterised component to some fixed level and transforms the component to a fraction. Definition of this fixed level commonly involves some value judgement. For example, a community might decide to aim for a limit in fossil fuel consumption of 1 GJ, so normalisation would divide actual consumption by this limit to derive a fraction.

Weighting allows normalised components to be compared and combined by assigning each a weighting factor that indicates relative importance. Typically this involves expert judgement or community involvement, and clearly weights are subject to changing evidence and values. Contradictory positions cannot be represented easily in this process unless a sensitivity analysis is used, i.e. more than one set of weights is used and more than one composite indicator is produced, but this becomes difficult to manage. Extreme examples of weighting are (i) where potential components are omitted entirely from a composite indicator, whether intentionally and explicitly or otherwise, effectively reflecting a zero weighting; and (ii) where all components are weighted equally, indicating no differentiation of importance.

Cost-benefit analysis (CBA) is an example of the production of a composite indicator since it involves the use of commensuration and aggregation to facilitate decision-making. In CBA relevant factors are enumerated and monetary values are assigned to them such that a net (present) value may be obtained. Implicit in this process is that only factors to which a monetary value can be assigned can be included, and that there are sometimes many ways to assign monetary values to non-market factors, such as human life, well-being, and the environment. However, the formality of the approach and the absence of alternatives lend CBA an air of robustness and credibility and lead to its wide acceptance.

Reflecting the subjectivity in the production of a composite indicator, and also the potential for opaque development such that assumptions are hidden, Saisana and Tarantola (2002, pp. 13–14) list some disadvantages of using composite indicators:

- May send misleading policy messages if poorly constructed or misinterpreted
- May invite simplistic policy conclusions
- May be misused, e.g. to support a desired policy, if the construction process is not transparent and/or lacks sound statistical or conceptual principles
- The selection of indicators and weights could be the subject of political dispute
- May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action, if the construction process is not transparent

² i.e., brings together to an equivalent measure.

- May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored

In addition, composite indicators may not be enforceable under the RMA or LGA. This will be investigated fully in the final stage of this project.

According to Saisana and Tarantola (2002, pp. 13–14), “composite indicators are much like mathematical or computational models. As such, their construction owes more to the craftsmanship of the modeller than to universally accepted scientific rules for encoding.” Saltelli (2007, p. 68) remarks that “the use of composite indicators is very much the subject of controversy, pitting aggregators against non-aggregators.”

In the case of Human Carrying Capacity, we would ideally be able to aggregate indicators to a single number in each area: the number of people that can be sustainably supported given aggregate lifestyle and development choices. This would allow all activities that affect HCC to be compared such that a detrimental activity could potentially be offset by an improving activity. To be able to produce this composite indicator, the following conditions must be met:

- All indicators selected in the consultation process are included. Exclusion of indicators must be based on a decision not to treat that indicator as a requirement for sustainability.
- A limit can be determined for each indicator: if limits are unknown then absolute sustainability cannot be determined.
- Each indicator can be related to population. That is, the approximate response of an indicator to a change in population is known, estimated or assumed.

If any one of these conditions is not met then a composite indicator of human carrying capacity should not or cannot be formed. If this were the case, what alternatives would be available for assessing human carrying capacity?

10.2 Using Non-aggregated Indicators to Assess Sustainability

For each indicator for which a limit has been established, sustainability *with respect to that indicator* can be assessed. While sustainability of one indicator does not imply that a society is sustainable as a whole, it does provide some support for such an argument. On the other hand, if society is found to be unsustainable against any one indicator then this does show that society is unsustainable as a whole.³ Such an approach still provides significant value in highlighting unsustainable activities.

In addition to testing whether human carrying capacity has been exceeded or not, those indicators for which limits and functional relationships with population are known (i.e. whether it is linear, sigmoidal, or other; see section 9.2) provide information about proximity to limits of carrying capacity. If the indicator is below the limit, there is potential either to increase population or to relax per capita constraints (e.g., accept higher per capita imports or private transportation). Conversely, if the indicator is over the limit then this information can be used to direct policy initiatives.

It is critical, however, to maintain vigilance over indicators that have been selected but for which limits and/or relationships to population have not been or cannot be established. In general, setting a non-empirical limit such as current levels allows at least *relative sustainability* to be assessed.

Floridi et al. (2011, p. 5) note:

[in many cases] we lack reliable objective reference points; benchmarking to actual performances becomes then the only available route, even if there is no guarantee that those held as good performances belong to sustainable paths. In this case ... indicators allow for comparisons ..., that is, they map relative sustainability....

Relative sustainability measures whether a community is more or less sustainable than it was previously or compared with other communities. However, it doesn't measure whether a community *is* sustainable.

³ Consider, for example, a society that is otherwise sustainable but is harvesting wood for heating and construction at a rate faster than the forest can regrow. If such a society has no plans in place to replace wood for the multiple activities that depend on its use, then that society is not sustainable, or rather the *current activities of that society* are unsustainable.

11.0 Framework for Assessing Indicators of Human Carrying Capacity

In this section we develop a framework for the assessment of indicators of human carrying capacity, based on the developments of previous sections. This framework is effectively a structured process by which Council may explore selected indicators and assess them against a range of criteria to establish to what extent they can inform the concept of human carrying capacity.

The steps of this process are as follows:

- In consultation with the community, establish a list of values that are important for sustainability;⁴
- Establish a list of indicators that could provide information about the state of these values;
- For each indicator, perform an assessment of the following:
 - Carefully explore the resilience and sustainability issues the indicator represents and the links to society's values, including links to the District's Community Outcomes;
 - Determine the importance of the indicator to the community, the degree to which it should be sustained (strongly, weakly, or flexibly), and the reasons behind these;
 - Discuss links to other indicators and the nature of such inter-relationships;
 - Determine whether the indicator is currently monitored. If so, document the data source, frequency, spatial aspects, and quality aspects of such monitoring;
 - If the indicator is not currently monitored, explore the potential for monitoring. Document requirements, costs, and related regulatory issues;
 - Determine whether regulatory limits are already in place for the indicator. Explore these limits and determine whether they meet the sustainability requirements of the community, i.e. whether the limits are sufficiently or overly stringent;
 - Determine what limits should be in place in light of the chosen level of sustainability of the indicator. Absolute limits (e.g., a hard limit based on empirical research) should be used in preference, but in all cases, including where there is insufficient information or where value judgements are involved, rationale for choice of limits must be clearly stated. Consideration should be given to the precautionary principle in this process;
- When this process has been completed for all indicators, determine whether all indicators meet the requirements for the creation of a composite indicator of human carrying capacity (section 10.1). Whether or not these criteria are met, indicators should be reported separately.

To demonstrate the framework we will apply it to a small selection of indicators in the next section.

⁴ We note the Council has already undertaken this step as part of the Choosing Futures work.

12.0 Framework in Action: Application to Three Example Indicators

To demonstrate the framework we apply it to three indicators: use of reticulated water, use of non-renewable energy, and level of nutrients in freshwater bodies. These three indicators were chosen to allow exploration of a range of different factors associated with sustainability and human carrying capacity.

12.1 Example 1: Use of Reticulated Water

The availability of potable water to society is a core requirement of survival, and in urban areas responsibility for its supply is usually taken by local authorities, recognising the substantial efficiencies gained from reticulated distribution. However, as urban populations grow the demands on reticulated water supply systems grow with them, requiring ever greater infrastructure for collection, storage, treatment, and distribution. Moreover, supply capacity must be designed to account for the likelihood and severity of potential disruptions, such as return period and magnitude of droughts.

Potable water reticulation is complicated in New Zealand and many other countries by its dual use for consumptive and non-consumptive (e.g., gardens) purposes. A high standard of water supply, both quality for health reasons and consistent provision, is therefore required for a much larger quantity of water than would otherwise be necessary. One advantage of this approach is that the 'over'-supply effectively forms a buffer than can mitigate the impacts of drought years: it is extremely unlikely that urban reticulated supplies would not provide sufficient water for life support needs given typical levels of non-essential uses.

Control over use of reticulated water is further complicated by the lack, in most New Zealand urban areas, of variable charging, which would encourage efficiency among residents. Other methods used by the Kāpiti Coast District Council to influence efficiency include education and regulation (for example, mandatory installation of rain tanks). The Council recently announced it plans to include the provision for the installation and use of water meters in the draft Annual Plan for 2011/12 (KCDC 2011). This is still subject to further investigation and consultation as part of the 2012 LTCCP process.

The use of reticulated water relates to Community Outcome 4: 'The District's resources are used wisely.'

12.1.1 Defining a Limit

There are several approaches to determining a limit for the use of reticulated water. Clearly climate and hydrology together set an upper limit on the total volume of water available to the district. Below that upper limit many other important factors limit potable water availability such as land use in collection areas, which affects water quality; regulatory limits imposed by other governing bodies; installed infrastructure; and the economics of future options.

Importantly, the limit imposed by existing infrastructure for supply of reticulated water is not fixed: as a community approaches an existing limit it makes choices about how to address the constraint and either introduces measures to reduce consumption or increases available supply by, for example, installing new infrastructure. However, each subsequent limit that is approached is harder to overcome because usually the easiest and lowest cost efficiency gains and infrastructure options have been implemented. At some point a community reaches a point where no further efficiency gains are available and the cost of supplying additional reticulated water is too high, and population will be constrained.⁵

Because both demand and supply vary by year according to weather, the proximity to any limit can also show significant variation. The nature of water supply planning is to account for such variation using return periods, effectively choosing an acceptable level of risk.

Given Regional Council standards for minimum flows in the District's rivers, and knowledge of climate and hydrology, an upper limit on abstraction for reticulated supply from both surface and ground water can be determined based on historical data. With some allowance for non-residential use, this could then be combined with an upper limit already set on per capita use by the Council to derive a human carrying capacity with respect to this indicator. Indeed, this is effectively the reverse of how water supply infrastructure is designed: infrastructure is designed based on expected population, hydrology, weather variation, per capita consumption, and engineering margins.

⁵ Some communities continue to push limits by implementing costly measures such as building desalination plants or importing water from other regions.

Limits can be defined as annual totals (or, equivalently, daily averages) or peak daily figures. Use of an annual total reflects the longer term stability of average annual rainfall, where daily and monthly volatility often evens out over a year, such that inter-annual volatility is lower. Use of peak daily figures reflects the capacity of infrastructure including the shorter timeframe of storage and pumping.

12.1.2 Existing Limits

In 2003 Kāpiti Coast District Council adopted a sustainable water use strategy ('Water Matters'), including setting a target for district-wide, residential peak water use of 400 litres/person/day (KCDC 2002). This approach effectively takes projected population in place of human carrying capacity and works backwards to determine the limit on the indicator.

For example, the Council is using a peak of 400 litres/person/day in conjunction with the 2060 population forecast on medium growth to design the size of water supply needed for the central area (Waikanae, Paraparaumu and Raumati).

12.1.3 Links to Other Indicators

Because use of reticulated water is linked to other indicators, such as land use, economic capacity, and food production from home gardens, it is possible that limits established for those other indicators will be the determining factor in limiting use of reticulated water (see discussion of Figure 8 earlier in this report).

Land-use patterns partly determine future options for water supply catchments. Although land use can and does change, the higher the value of the land use, the less likely that it will change. Areas of residential and commercial development (e.g., the CBD) are the most unlikely to change. In its report to Council presenting options for water supply to the central area (Waikanae, Paraparaumu and Raumati) of Kāpiti Coast, CH2M Beca advised Council to purchase land behind Nikau Valley to ensure that the option of construction of a dam would be possible in future (CH2M Beca 2010). A prerequisite to purchase of the land would be negotiation of modification of a covenant placed on part of the land to protect ecological values (CH2M Beca 2010, p. 215).

Use of water for reticulated town supply is linked to the amount available for other uses, such as agriculture and industry, given that the same constraints on minimum flow may be imposed by regional councils.

12.1.4 Monitoring

Because reticulated water is distributed from specific locations, the quantity supplied can be and is very closely monitored. However, until meters are installed the Council relies on residents reporting leaks,⁶ and has limited spatial consumption data beyond zone meters (major valve points), so it is difficult to influence change and changes can only be monitored at a gross level.

Use of reticulated water is measured in both litres per year and peak litres per day, reflecting different types of constraints on the supply system.

12.1.5 Other Aspects of the Framework

The Council has a range of measures in place to encourage water-use efficiency, but their effects will be substantially improved if the installation of water meters proceeds as planned because metering will quantify the effectiveness of existing water-use efficiency measures and help target the most effective ones.

While water meters for all connections to the reticulated water supply would provide fully spatial use data, it may not be appropriate to define carrying capacity limits specific to individual properties. Limits for entire supply areas are more realistic and reasonable. However, a property-level progressive charging system might be appropriate, e.g., not charging for a given amount of water per property and charging a moderate amount above that level.

Council adopted a plan change in 2008 requiring all new homes to be equipped with either a 10,000 litre rainwater tank or a smaller tank combined with a greywater system. The Council has also been considering introducing interest-free loans for installation of raintanks and greywater systems into existing homes.

12.1.6 Summary

While Council has set a target for use of reticulated water of 400 litres/person/day, this target is effectively chosen by using the projected population as the metric for the human carrying capacity.

⁶ According to the Council, they respond to 'hundreds of calls to fix leaks and other problems' with the water reticulation system every year (<http://www.kapiticoast.govt.nz/Your-Council/A---Z-Council-Services-and-Facilities/Water-Services/>).

The freshwater resource is limited, but renewable. Extraction can continue indefinitely but at a limited rate that varies depending on inputs of rainfall and surface water flows.

Use of reticulated water is a function of population, so a limit on use implies a limit on population, all else being equal.

Council can enforce limits on use through the use of bylaws (e.g., summer restrictions) but can also encourage reduced use through education and pricing (which requires meters).

While environmental limits can be set, e.g., limits on total abstraction from a river, actual limits on reticulated supply depend on existing and planned infrastructure and available options.

Use of rain tanks and greywater systems by property owners increases HCC because they make more efficient use of available water supply.

Table 1 Summary of assessment of use of reticulated water in the proposed framework

Indicator	Potentially within control of Council?	Options for measuring	Spatial application	Limit	Source for limit data
Use of Reticulated Water	Yes	Metered water use	Yes, once meters are installed	Per capita limit	Best practice (based on research)
				Total district limit	Based on min environmental stream flows and groundwater levels

12.2 Example 2: Use of Non-renewable Energy

In this example we discuss the sustainability of the use of non-renewable energy, by which we specifically mean oil and its derivative products (diesel, petrol, etc.), natural gas, and coal. While the combustion of these energy carriers generates other social and environmental effects, not least of which is contribution to global warming, here we will deal with the non-renewability aspect as distinct from other effects. Other effects should be dealt with separately: for example, limits might be established for greenhouse gas emissions in the district. We take this approach to demonstrate clearly the links between indicators and the range of issues that must be addressed within this framework.

The Council has signalled that use of non-renewable energy is an important issue for the District Plan review process by discussing peak oil in the Global Change Issues district plan review document (KCDC 2010). Any limit determined for use of non-renewable energy above zero is a reflection either of a weak sustainability paradigm, where plans exist for replacement, or a lack of sustainability. Strong sustainability is only achieved by no use of non-renewable resources.

The use of any non-renewable resource is by definition not strongly sustainable, and energy sources such as coal, oil, and natural gas are no exception. However, the weak sustainability paradigm permits the use of non-renewable resources as long as substitutable resources are discovered at some point in the future before resource exhaustion.⁷ In the case of oil, for example, weak sustainability assumes or requires that a substitute form of energy will be developed to power private motor vehicles and all other forms of transport that rely on oil.

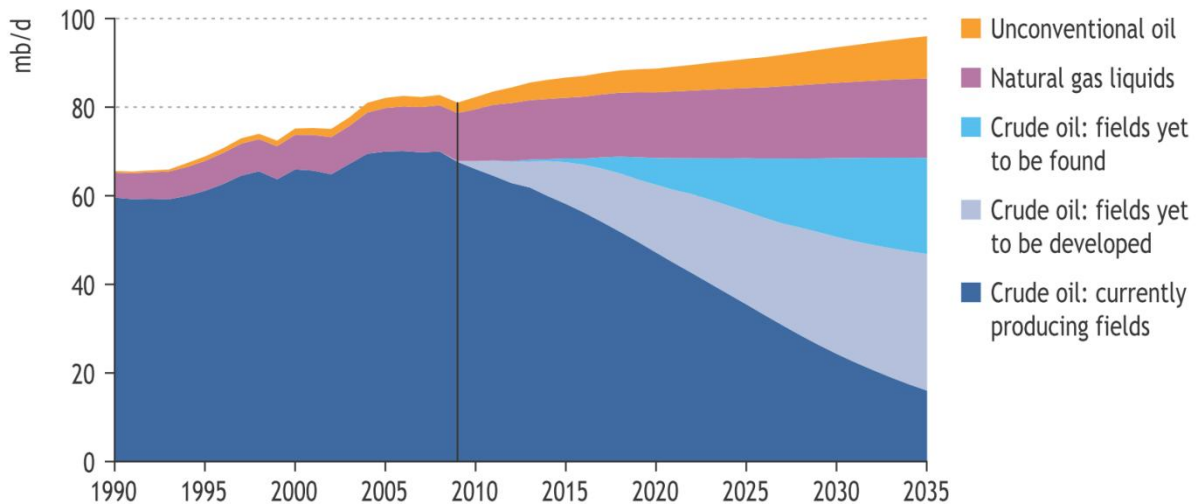
Another way to assess the sustainability of non-renewable energy is to assess the activity that requires such energy. That is, rather than focussing on the use of oil products, the focus could instead be on private transportation for multiple purposes. Is this activity sustainable, and are other possibilities available? That is, rather than considering an alternative source of energy to sustain the same activity, the activity itself might be questioned and alternatives to the activity might be sought. While this idea is certainly worth attention when considering community resilience we will not develop it further here.

The International Energy Agency (IEA) has recently indicated that peak production of conventional crude oil occurred in 2006 (at approx 70M barrels/day) in their chosen forecast scenario (IEA 2010). This 'peak' is a

⁷ Neumayer (2003) argues that the use of resources not used by environment can be classed as strong sustainability where they might normally be classed as weak sustainability, i.e., where plans exist to substitute the resource before exhaustion. However, as with many other countries, New Zealand has no such explicit plans, instead expecting market forces to provide a substitute.

reflection of forecast supply and demand, in a scenario that explicitly assumes measures by world governments to reduce greenhouse gas emissions.⁸ The IEA still projects an increase in total oil production and a marked increase in natural gas production at least as far as 2035 (Figure 9). Critically, the projections indicate a steep rise in energy prices, with oil reaching a 'stable' price of \$US113/barrel in 2035 from 2009's \$US60/barrel (IEA 2010, p. 69).⁹

Figure 9 International Energy Agency projections for production of all types of oil in their New Policies Scenario, in millions of barrels per day, to 2035 (IEA 2010, p. 122)



The view of many economists is that the depletion of oil reserves in combination with rising demand will naturally lead to an increase in the price of oil, which will encourage further exploration and exploitation of unconventional sources, which we've already witnessed with Canadian oil sands. As the price of oil continues to climb, the incentive for private industry to develop alternatives continues to increase, so that a smooth transition is expected where oil never actually runs out, but is gradually replaced by another technology. Allied with this 'laissez-faire' approach is the view that any non-market (i.e., without monetary value and not traded) environmental or social problems that may result from resource depletion and transition is best solved by assigning prices to these problems (e.g., a carbon tax).

Given this particular view, that a transition will happen gradually, and setting aside the very important global warming issue, then why should a limit be imposed on the use of non-renewable energy? There are three reasons:

- Because this view of a gradual transition could be wrong – the transition might be painful. That is, costs could rise very high before substitutes are available, and costs for energy may never be as low again as they are now. The assumption of market-based solutions does not guarantee equity: that is, the market will find alternatives to non-renewable energy, but those alternatives may not be available to as wide a portion of society. Oil may be a one-off cheap endowment provided by the planet for human society. Markets have proved fallible in the past, and belief that they will solve problems in future must be seen as a matter of (perhaps misplaced) optimism;
- The price of non-renewable energy is hugely volatile because it's a limited resource, because it's critical to the world economy, because there's significant uncertainty about future levels of supply, and because its supply is subject to such a wide range of global events (wars, natural disasters, economic growth of developing countries), and a resilient community needs to reduce exposure to such volatility; and
- One view is that by being profligate now with these resources is that we are depriving future generations, and that this therefore is an issue of intergenerational equity that economics is (intentionally) blind to.

⁸ That is, the timing of the peak of production ('peak oil') depends on what happens in future. If developed countries do not address climate change by reducing use of fossil fuels, then exploration, development, and production of conventional crude oil reserves may increase.

⁹ At time of writing, the Brent crude price was about \$US115/barrel, but this is considered to be a result of short-term volatility.

12.2.1 Defining a Limit

With no clear physical limit, how might a limit on the use of non-renewable energy be determined? There are a number of ways depending on a range of factors. The first approach is to set limits by choosing a level of acceptable impact of price volatility to society. Transport fuels form a significant component of a household's budget and also of the expenses of business. Just as engineers design infrastructure against a defined return-period (e.g., a 100-yr flood or a 50-yr drought), based on some estimate of the variability of important parameters, so potentially could a limit be defined for use of non-renewable energy sources based on expectation of the pattern of volatility. Much of the time the price of oil may be stable, but occasionally it exhibits very significant swings,¹⁰ and the ability of society to adjust is partly determined by the speed of the upward swings. By reducing the importance of oil (and other price-volatile commodities) in the economy, the effects of volatility are reduced.

More specifically, a limit might be implemented by shifting mean expenditure on oil so that the likelihood of volatility causing expenditure to exceed a chosen level is at or below some chosen probability. For example, if it were decided that oil expenditure should not exceed 15% of an economy's expenditure more than 1% of the time, then, based on known patterns of oil price volatility, the mean oil expenditure should be shifted so that the 99th percentile of the oil expenditure distribution sits at the dollar value equivalent to 15% of total expenditure.¹¹

A second approach to defining a limit would be to focus on reducing exposure to systemic price increases. That is, because supply of non-renewable energy carriers is not expected to keep pace with growing demand, prices are expected to increase.¹² As noted above, the IEA forecasts the price of oil to approximately double by 2035. The implication is that a limit on use of non-renewable energy carriers might decrease over time, perhaps at the same rate as the price is forecast to increase.

A third approach is to have the community to determine the limit. A community-determined limit can include additional factors such as perceived moral obligation, aspiration, and voluntary efforts. A limit might also be set with reference to current best practice, derived from a review of overseas experience. A community-determined limit is likely to be either a per capita limit or set relative to existing levels (e.g., the limit might be set to 20% below current district-wide level).

In addition to the different approaches to establishing a limit, there is also a range of system boundaries that can be used. These include energy used by residents, energy used in the district (whether by residents or not), energy used by residents while they are in the district, households only or households and businesses, or energy embodied in goods and services. Then the limit may be set on a per-capita basis, a per-household basis, or by area, each having different implications. The only readily apparent reasons for varying the limit by area is to allow trials to take place or to account for varying community enthusiasm, scope of reductions, and reliance on non-renewable energy.

12.2.2 Implications of Different Types of Limits

As with all other indicators, if a limit on the use of non-renewable energy is set on a fixed per capita basis then this imposes no limit on population. That is, the population could increase with no change in proximity to any limit, and therefore would not be a determinant of human carrying capacity. However, per capita limits provide a different set of options for enforcement and incentivisation, which may be sufficient to warrant their use.

An alternative approach might be to set a district-wide (or other area) limit, and then derive a per capita limit from this. If the district-wide limit is constant then the per capita limit would decrease as population increases.

As suggested above, an area limit (e.g., district-wide) could change over time, recognising that a level determined to be sustainable (in the sense of conferring resilience) at one time might be too high at a later time, or reflecting a phased-in approach to ease transition towards a target. An area limit does impose a human carrying capacity constraint.

12.2.3 Links to Other Indicators

Because non-renewable energy is linked to other indicators, such as greenhouse gas emissions, air pollution, use of renewable energy, and imports, it is possible that limits established for those other indicators will be the determining factor in reducing use of non-renewable energy (see discussion of Figure 8 earlier in this report).

Greenhouse gas emissions are clearly linked to use of non-renewable energy, and there are well known and stable factors to determine emissions from combustion of oil, coal, and gas. However, greenhouse gas emissions

¹⁰ The price of oil dropped by about 70% in the latter half of 2008 from a peak that took about three years to reach.

¹¹ This approach relies on the relative inelasticity of oil consumption because of its critical place in the economy.

¹² This is analogous to the contrast between sea-level rise (long-term trend) and storm surges (shorter-term volatility).

also included emissions from other sources, such as waste treatment, industrial processes, agriculture, and land use change. In addition, the rationale for a limit on emissions would be different to those for a limit on use of non-renewable energy. We would therefore argue that a separate indicator is required for greenhouse gas emissions.

Use of non-renewable energy is also linked to quantity and value of imports. All oil, coal, and gas are imported into the District. However, while oil is largely imported from overseas, natural gas and most coal are imported from other parts of New Zealand, such that different market forces act on each type of energy carrier. Indeed, this may be an argument for an indicator specifically for use of oil products rather than the more general non-renewable energy.

If total energy requirements are fixed then any reduction in the use of non-renewable energy would result in an increase in the use of renewable energy. However, because it is likely that energy efficiency would be one of the means by which non-renewable energy use would be reduced, acting to reduce total energy use, the two types of energy are not perfectly correlated.

12.2.4 Monitoring

The use of non-renewable energy is not currently monitored in the district. However, as part of the Ōtaki Future Energy project, which has as a goal to develop Greater Ōtaki as a net exporter of energy, the Council plans to monitor energy use in the Greater Ōtaki area. This is in very early stages, and sources of data are being investigated.

For transport fuels, traffic count data could be combined with other datasets to estimate usage, and with further assumptions this could be disaggregated spatially but with higher uncertainty.

Electricity use in the district is monitored by the network operator, but these data may be commercially sensitive and otherwise difficult to estimate.

Most likely use of non-renewable energy should be measured in energy units (e.g., GJ), but should probably also be measured in monetary terms if the rationale for the limit is based on price increases or volatility.

12.2.5 Other Aspects of the Framework

If the Council chooses to accept strong sustainability in the case of non-renewable energy then the only possible limit is no use at all. We therefore assume that Council is more likely to adopt some weak sustainability approach to non-renewable energy, for which there is no clear existing limit. Therefore, this indicator cannot yet be used to assess whether the District exceeds human carrying capacity. However, as with all indicators, it could be used to assess relative sustainability.

The Council has limited influence over the use of non-renewable energy by residents and businesses. Potentially Council could impose energy efficiency conditions on new developments, but is unlikely to have any control over the use of transport fuels within the District. For this reason, it might be appropriate to subdivide the indicator into different uses of non-renewable energy, such as home heating.

12.2.6 Summary

- Issues associated with use of non-renewable energy are expected price increases, price volatility, and intergenerational equity (whether future generations have access to these non-renewable resources).
- Use of non-renewable energy does not meet the criteria for strong sustainability.
- Limits can be determined based on some acceptable level of exposure of price increases and volatility and/or some response to the equity issue.
- Per capita limits could be based on best practice (established by further research)
- Limits are not generally enforceable by Council, particularly use of transport fuels.
- While there is currently no monitoring of non-renewable energy in the district, some monitoring is intended in the Ōtaki Future Energy project.

Table 2 presents a summary of some key features of the assessment of use of non-renewable energy.+

Table 2 Summary of assessment of use of non-renewable energy in the proposed framework

Indicator	Indicator Subset	Potentially within control of Council?	Options for measuring	Spatial Application	Limit	Source for Limit data
Non-Renewable (NR) Energy Use	Stationary NR Energy	Yes – to be discussed in Stage 3 of project	Electricity use for the region, multiplied by grid average emissions factor. Metered natural gas use.	No spatial data readily available	Per capita limit	Best practice (based on research)
					Total district limit	Aspirational reduction target from BAU
	Transport NR Energy	Limited to indirect policies of land use and public transport policy	Traffic count, or fuel sales	Limited potential for spatial disaggregation	Per capita limit	Best practice (based on research)
					Total district limit	Aspirational reduction target from BAU

12.3 Example 3: Nutrient Content of Fresh Water Bodies

Society values fresh water in a wide range of ways, including as a source of drinking water, recreation, removal of wastes, cultural, electricity generation, and provision of habitat for aquatic fauna (NZ Government 2011). The addition of nutrients – particularly nitrogen and phosphorus – to freshwater bodies can reduce these values. Nitrogen, in the form of nitrates and ammonia, can be toxic for aquatic fauna, while a combination of nitrogen and phosphorus can lead to growth of noxious aquatic weeds such as periphyton.

There are a range of other indicators of water quality, including ammonia, turbidity, BOD, macroinvertebrate index, and trout numbers. We have selected nutrient content for this example, but this should not be taken as implying that we consider it more important than these other indicators of water quality.

The nutrient content of fresh water bodies relates to Community Outcome 1: 'The district has healthy natural systems which people can enjoy.'

12.3.1 Defining Limits

Because there are so many values associated with freshwater bodies, there are also a large number of approaches to determining limits to nutrient levels. For example, with respect to recreational values, limits might be determined with reference to potential health impacts, whereas when considering electricity generation limits might be determined with reference to the fluidity of the water (e.g., absence of algae that grow because of high nutrient levels).

It is generally the consequences of excessive nutrient content in freshwater bodies that determine any limit imposed. A possible exception to this is the Māori concept of mauri, where the nutrient content of the stream per se may be important, as distinct from consequences.¹³

Limits to nutrient content are defined primarily by limits to direct toxicity (high levels of nitrates are toxic to aquatic fauna and livestock) and periphyton growth, from which other consequences derive. Both toxicity and periphyton growth are partly determined by the size of the water body and the rate of flow, while periphyton growth is also strongly determined by the timing of freshes (high-flow events following rainfall, usually specified as three times median flow).

¹³ Indicators often monitor impacts that are not themselves directly the issue of concern. For example, compaction of soils leads to loss of future production and the need for remedial actions, while depletion of resources leads to difficulty making products that depend on those resources and in performing activities that depend on those products.

If many waterways currently have higher than what are deemed acceptable levels of nutrients, limits can be set in relation to 'best practice', in this case determined by the levels in the best water bodies.

There is no straightforward relationship between population and nutrient content of freshwater bodies. Assuming consumption patterns continue unchanged, a higher population will consume more agricultural and horticultural produce, and these additional foods may come from within the area or from outside. If they come from within the area then water quality may be affected, although that relationship also relies on assumptions. If additional food is sourced from outside the area then water quality within the area is unaffected by population changes.

These are tenuous links. However, if we were instead considering water quality anywhere, whether in the district or not, then increasing population is likely to result in reduced water quality, all else being equal (that is, with same consumption and production patterns). This brings us back to the discussion in sections 3.0 and 4.0 where sustainability was a function not only of impacts within the area but also of impacts outside the area. From a sustainability perspective, the consumption of foods whose production pollutes waterways cannot be sustained regardless of whether those waterways are in the district or not.

12.3.2 Existing Limits

There are no national surface water quality standards, and the Wellington Region does not yet have its own specific guidelines or limits (Olivier Ausseil, pers. comm., May 2011). The Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (commonly known as the 'ANZECC guidelines') define acceptable baselines for surface water quality based on data from the National Rivers Water Quality Network (NRWQN). However, these guidelines are not effects-based and therefore do not meet the requirements of the RMA.

Greater Wellington Regional Council is currently developing a new freshwater plan (Olivier Ausseil, pers. comm., May 2011). Horizons Regional Council is currently in the latter stages of taking its One Plan through the planning process, and the proposed plan is the first in the country to include region-wide standards (limits) for nutrient content of all surface water bodies. These limits – proposed by Ausseil and Clark (2007b) – were derived with reference to a set of 24 different freshwater values defined by Ausseil and Clark (2007a). Seven of the 23 values presented by Ausseil and Clark (2007a) were translated into quantitative standards, with two further values being translated into qualitative standards. The remaining values were considered better protected by standards applied to other values, or by other policies (Ausseil & Clark 2007b).

A recent report by NIWA for Environment Canterbury advised new, lower guidelines for nitrates in freshwater to prevent toxicity to aquatic fauna (Hickey & Martin 2009).

A new National Policy Statement on Freshwater Management (NZ Government 2011) was released in May 2011, and, under the RMA, this Policy Statement must be reflected in all regional plans. The Statement takes effect from July 2011, but allowance is made for gradual introduction of standards according to each region's specific circumstances. Importantly, the Policy Statement provides for regulating based on over allocation of both quantity and quality, thereby using the existing construct applied to water quantity of level of allocation. The Policy Statement directs regional councils to set enforceable limits and dates by which those limits will be met, based on a set of freshwater values, including both use values and intrinsic values.

12.3.3 Links to Other Indicators

Because the nutrient content of freshwater bodies is linked to other indicators, such as other water quality parameters, recreational opportunities, land use, and cultural values, it is possible that limits established for those other indicators will be the determining factor in reducing nutrient content of fresh water bodies (see discussion of Figure 8 earlier in this report).

Other potential water quality indicators include ammonia, turbidity, BOD, macroinvertebrate index, and trout numbers, and these are all linked to the nutrient content of freshwater bodies. Some other water quality indicators are driven to some extent by nutrient content, but not vice versa. For example, nitrates are toxic to macroinvertebrates, which in turn are consumed by trout. In contrast, ammonia levels are not determined by nutrient levels, but are determined by some of the same processes as nutrient levels.

Nutrient content of freshwater bodies is linked to land use, with the main drivers of nutrient content being leaching and runoff from agriculture and horticulture. Therefore, many of the indicators that could be used to monitor land use and land-using sectors are linked to nutrient content of freshwater bodies.

Recreational opportunities and cultural values are also indirectly affected by the nutrient content of freshwater bodies, via growth of periphyton and other algal species that flourish with higher nutrient levels.

In general it is these other indicators that will be used to set limits on nutrient content, because it is these derived effects that expose nuisance rather than nutrient content per se.

12.3.4 Monitoring

In New Zealand river water quality is monitored by several different organisations. NIWA monitors quality at 77 sites on 35 rivers in the NRWQN, and this network is important for long-term trends, with monitoring having been carried out for over 20 years (NIWA 2011). However, none of the network's monitoring sites network are in the Kāpiti Coast District. Regional Councils monitor surface water quality as part of their requirements under the RMA, and there are 56 sites monitored in the Wellington Region (Olivier Ausseil, pers. comm., May 2011). Most Regional Councils monitor monthly, while some monitor quarterly. Few Territorial Local Authorities monitor water quality, but exceptions include the Christchurch and Palmerston North City Councils, which both have significant monitoring programmes.

Units of nutrient content of water are generally mg/litre or parts per billion.

12.3.5 Other Aspects of the Framework

Regional councils have more influence over water quality issues than district councils, with the power to prosecute specific breaches. However, currently most regional councils do not have the power to prosecute for excessive nutrient levels in runoff or groundwater that ends up in freshwater bodies. One exception to this is "Variation 5," Waikato Regional Council's policy aimed at reducing nitrogen levels in Lake Taupō, under which the Council is establishing nitrogen leaching limits for farms within the Taupō catchment (Waikato Regional Council 2011).

12.3.6 Summary

- Higher levels of nutrients in fresh water lead to periphyton growth, toxicity to aquatic fauna and livestock, reduced recreational values, among others;
- Ideally, both fresh water nutrient content (as a causal factor), and the other indicators as described above should be considered in this framework;
- The nutrient content of freshwater bodies is primarily limited by the specific hydrological regime of the water body, i.e. the ability of the water body to remove the nutrients or to deal with the consequences of the nutrients (e.g., scouring periphyton during a fresh);
- There are currently no regulated limits on freshwater nutrient levels outside of the Taupō catchment, although Horizons and Wellington Regional Councils, Environment Bay of Plenty and Environment Canterbury are considering implementing nutrient limits;
- There are no direct links between nutrient content of freshwater bodies and population, largely because much of agricultural production is exported from the area. In general, higher populations with a given diet are likely to result in more nutrient problems in waterways, but those waterways may not be in the area in which the population live;
- Nutrient content of freshwater bodies is monitored both by NIWA as part of the National Rivers Water Quality Network and by regional councils as part of their obligations under the RMA; and
- There is no clear link between nutrient content of local freshwater bodies and local population, and as such HCC is not directly constrained by this indicator. That is, if population goes up, then this indicator doesn't necessarily go up.

Table 3 Summary of assessment of nutrient content in freshwater bodies in the proposed framework

Indicator	Potentially within control of Council?	Options for measuring	Limit	Source for limit data	Spatial application
Nutrient content of freshwater bodies	Only indirectly, via land use policy	Data provided by NIWA and GWRC	Limit per freshwater body	Regional Council	Specific to freshwater body

13.0 Conclusions

One approach to assessing sustainability of society is the concept of human carrying capacity, which as part of this project, we have defined as:

the measure of a specified area's ability to support human activity sustainably given aggregate lifestyle and development choices and the means used to achieve these, and is expressed in terms of number of people.

Indicators are used to assess sustainability because of the large number of things that society relies upon for its continued functioning and because of the complexity of relationships between those things. This report has developed a framework to construct indicators of human carrying capacity. As part of the framework we set out three criteria that should be met when considering whether to aggregate indicators to create a composite indicator of human carrying capacity:

- All indicators selected in the consultation process are included. Exclusion of indicators must be based on a decision not to treat that indicator as a requirement for sustainability.
- A limit can be determined for each indicator: if limits are unknown then absolute sustainability cannot be determined.
- Each indicator can be related to population. That is, the approximate response of an indicator to a change in population is known, estimated or assumed.

If these criteria are not met the indicators should still be reported, but only separately, without creation of a composite indicator.

All three examples with which we have demonstrated the framework highlight the complexity of the concept of human carrying capacity. The example of use of reticulated water showed that limits can change depending on available infrastructure capacity. The example of use of non-renewable energy highlighted the importance of clearly identifying the issues at hand (in this case price trends, price volatility, and intergenerational equity) and also the difficulty in setting a limit for a non-renewable resource. The third example, of nutrient content in freshwater bodies, demonstrated an indicator that can't be readily related to population, partly because of boundary issues.

Because of the complex issues highlighted by the three examples, it is unlikely that the criteria outlined above can be met for all indicators, and as such, HCC as we have defined it is unlikely to be able to be calculated. However, the framework outlined in this report allows much of the value of the concept of HCC to be retained instead of resorting to the use of relative sustainability for all indicators. It is noted that the framework would require significantly more effort than the standard relative sustainability analysis.

We believe the flexibility of this framework would allow Kāpiti Coast District Council to undertake a more comprehensive assessment of sustainability than current methodologies allow. We recommend that the proposed third stage of this project proceed so that the practicality, feasibility and defensibility of using these concepts explicitly in planning documents can be assessed. Subject to the outcome of Stage 3, we would recommend that Council adopt the framework to assess sustainability in the district, requiring community consultation and an assessment of selected indicators in the pattern outlined by the three examples given in this report.

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Appendix A

Indicators Used in Statistics New Zealand's Sustainable Development Approach

Appendix A Indicators Used in Statistics New Zealand's Sustainable Development Approach

- Population size and growth	- Real household consumption expenditure
- Fertility rate	- Research and development expenditure as a proportion of GDP
- Dependency ratio	- Research and development expenditure by purpose
- Ethnic diversity	- Personnel involved in research and development
- Regional population change	- Rate of innovation by type
- Number of threatened species	- Labour force participation rate
- Distribution of selected native species	- Unemployment rate
- Area of native land cover	- Pay equality by ethnicity
- Proportion of assessed fish below targets	- Labour productivity
- Distribution of selected pest animal and weed species	- Educational attainment of the adult population
- Net greenhouse gas emissions	- Participation in tertiary education
- Greenhouse gas emissions by sector	- Literacy skills
- Annual surface temperature	- Access to early childhood education, by ethnicity
- Greenhouse gas intensity of the economy	- Real net of total assets per person
- Stratospheric ozone	- Real net of infrastructure per person
- Air pollution	- Real investment in fixed capital per person
- Population with drinking water meeting standards	- Ratio of debt services to export earnings
- Nitrogen in rivers and streams	- Diversity of exports
- Biological health of rivers and streams	- Government debt
- Lake water quality	- Real gross national disposable income per person
- Groundwater quality	- Real household consumption expenditure per person
- Bacterial pollution at coastal swimming spots, rivers, and lakes	- Income inequality
- Water allocation compared with total water resource	- Population with low incomes
- Area of land used for farming	- Housing affordability
- Soil health	- Household satisfaction with material standard of living
- Nitrogen and phosphorus content in soil	- Health expectancy at birth
- Contaminated soil sites	- Prevalence of healthy lifestyles
- Versatile soil extinction	- Childhood immunisation coverage

- Hill country erosion	- Prevalence of psychological distress
- Total primary energy supply per person	- Suicide rate
- Energy intensity of the economy	- Avoidable hospital admissions
- Percentage of electricity generation from renewable resources	- Cancer-survival probabilities
- Household expenditure on energy used in the home, by income group	- Formal unpaid work outside the home
- Energy dependency	- Rate of death from assault
- Energy-related greenhouse gas emissions	- Impact of fear of crime on quality of life
- Vehicle-kilometres travelled by road, by vehicle type	- Voter turnout at general and local elections
- Road freight transport intensity of the economy	- Representation of women in Parliament and local government
- Total public transport boardings per person	- Trust in government institutions
- Number of international flights per week	- Speakers of te reo Māori
- Proportion of population in employment walking or cycling to work	- Children attending Māori language immersion schools
- Solid waste disposed to landfill	- Number of historic places
- Proportion of population with access to kerbside recycling	- Local content on New Zealand television
- Proportion of packaging waste recycled	-

(Source: Statistics NZ 2009, pp. 146–149)

Appendix B

'Core Set' of Indicators Used in Choosing Futures Waikato Programme

Appendix B 'Core Set' of Indicators Used in Choosing Futures Waikato Programme

Theme / #	Indicator
<i>Sustainable environment</i>	
1	River water quality for ecological health
2	River water quality for recreation
3	Lakes water quality for ecological health
4	Lakes water quality for contact recreation
5	Land use
6	Air quality (particulate matter, PM 10)
7	Groundwater availability and use
8	Surface water availability and use
9	Protection of natural heritage and landscapes
10	Extent of native vegetation (forest, wetland,coastal)
11	Protected native vegetation areas
12	People's environmental attitudes
13	People's personal environmental actions
14	Coastal water quality for recreation
15	Public access (or Coastline ownership)
16	Rural subdivision
17	Stock density
18	Total energy consumption
19	Greenhouse gas emissions
20	Energy efficiency (or Energy use relative to economic growth)
21	Waste to landfills
22	Proportion of recycling
<i>Quality of life</i>	
23	Life expectancy at birth
24	Social deprivation index (*)
25	Avoidable mortality and hospitalisation rates (*)
26	Overall quality of life
27	Barriers to accessing general health practitioners
28	School leavers with no formal qualification
29	Educational attainment of the adult population
30	Participation in early childhood education
31	Adult and community education
32	Work opportunities matching skills
33	Rent to income ratio
34	Housing affordability
35	Home ownership rate
36	Household crowding
37	Proximity to work, study, recreation
38	Criminal victimisation rates (or reported criminal offences and resolution rates)
39	Perceptions of safety
40	Road traffic injury rates
41	Unpaid work
42	Participation in sport and active leisure
43	Participation in social networks and groups
44	Contact between young people and their parents
45	Youth and older people's engagement in decision-making
<i>Sustainable economy</i>	
46	Genuine progress indicator (or ecological footprint)
47	Regional GDP
48	Unemployment rate
49	Median weekly income
50	Number if businesses and employees by industry
51	Building consents
52	Drinking water quality
53	Road traffic crashes and casualties
54	Resident's confidence in councils' decision making
55	Resident's confidence in councils' approach to planning and and providing services
56	Regional GDP contributed by primary industries
57	Nights in commercial accommodation
58	Income from tourism (international and domestic)

59	Employment in the tourism industry
60	Total research funding
61	Enrolments at tertiary education institutes (by type of study)
<i>Culture and identity</i>	
62	Resident's rating of their sense of pride in the way their city/town looks and feels
63	Proportion of Maori speakers (in Maori and in total population)
64	Proportion of population that speak the 'first language' of their ethnic group
65	Number of buildings and places listed on Historic Places Trust register
66	Number and proportion of heritage buildings demolished or removed from heritage records
67	Design of new developments (survey)
68	Resident's satisfaction with cultural facilities provided
69	Participation in cultural and arts activities
70	Proportion of council's spending on cultural activities and events
71	People employed in the cultural sector
<i>Participation and equity</i>	
72	Percentage of voter turnout at local and general elections
73	Degree of representation by tangata whenua and minority groups on governance and decision-making bodies
74	Residents satisfaction with council's provision of opportunities for community involvement in decisions
75	Percentage of residents perceiving that cultural diversity makes their region/city/town a better place to live

(Source: Choosing Futures Waikato 2006a)

Appendix C

Potential Indicators Identified in the Community Plan

Appendix C Potential Indicators Identified in the Community Plan

Group	Indicator	Outcome
LAND COVER		
	New development	3
	Location of new development	3
	# of Dwellings	3
	Residential lots created	3
	Residential infill	3
	Medium density/apartments	3
	Proportion 1 and 2 bedroom houses	6
	Emergency Housing	6
	Pastoral – dairy	5
	Pastoral – non-dairy	5
	Cycleways	1
	Walkways	1
	House insulated	4
	Rainwater tanks installed	4
	Greywater systems installed	4
	Stormwater network	4
LAND USE		
	Residential – Existing	4
	Residential – Zoned	4
	Open Space – Existing	4
	Open Space – Zoned	4
	Rural – Existing	4
	Rural – Zoned	4
	Commercial/Retail – existing	4
	Commercial/Retail – Zoned	4
	Industrial - Existing	4
	Residential lots created	3
	Residential infill	3
	Rural lots created	4
SOILS		
	Soil compaction	1
	Soil fertility	1
WATER		
	Surface water N loading	1
	Surface water P loading	1
	Surface water E coli	1
	Surface water dissolved oxygen	1
	Macroinvertebrates	1
	Groundwater N loading	1
	Groundwater P loading	1
	Wastewater treatment	4
	Highest daily water use	4
ENERGY		
	Petrol consumption	4
	Diesel consumption	4
	Electricity consumption	4
	Natural Gas Consumption	4

SOLID WASTE	
Plastics	4
Organic waste	4
Paper	4
Glass	4
Aluminum	4
Tin	4
Other metals	4
Landfill capacity	4
RECYCLING	
Plastics	4
Organic waste	4
Paper	4
Glass	4
Aluminum	4
Tin	4
Other metals	4
GREENHOUSE GASES	
CO2	4
GHG from transport	4
COMMUNITY & WELL-BEING	
Active conservation groups	1
Rail travel	4
Participation in sports	6
% of high school students undertaking 30 minutes or more of physical activity per day	6
Junior club membership	6
Suicides for persons aged 15–24	6
Proportion live births to teenage mothers	6
Proportion of police apprehensions of persons aged 14–16	6
Proportion of police apprehensions of persons aged 17–20	6
Proportion of police apprehensions of persons aged 21–30	6
Youth engagement	6
Treaty relationships	7
Speakers or Maori	7
Voter turnout- Kapiti Coast District elections	7
Voter turnout- General Elections	7
Volunteering	7
Recreation Facilities	7
Groups using community facilities	7
Events	7
Applications for Contestable Council Event Funding	7
Library usage	7
BIODIVERSITY	
Abundance of native plants	1
Identification of significant vegetation	1
Representativeness	1
Covenanting of significant natural vegetation	1
Native planting	1

BIOSECURITY	
Weed control	1
ECONOMICS	
GDP	5
GDP Growth	5
# Business	5
Business growth	5
Employment	5
Unemployment	5
Labour – non-dairying pastoral	5
Labour – horticulture	5
Labour – forestry	5
Access to landline	5
Access to mobile phone	5
Access to internet	5
Broadband uptake	5
Building consents	5
Cost of renting – 1 bedroom flat	6
Cost of renting – 2 bedroom flat	7
Cost of renting – 2 bedroom apartment	7
Cost of renting – 2 bedroom house	7
Cost of renting – 3 bedroom house	7
Average hourly earnings	7
Average annual personal income	7
People receiving income support	7
People receiving accommodation supplement	7
Deprivation Index	7
Median sale price for sections	7
Median sale price for dwellings	7
LOCAL CHARACTER	
Quality of planning mechanism	2
Development of local outcome statements	2
District Plan Changes	2
Non-regulatory mechanisms	2
Council projects	2
Effectiveness of planning mechanisms	2
Range of council-initiated projects	2
Quality of council-initiated projects	2
Level of improved interconnectivity achieved	2
POPULATION	
Population	3
Population Distribution by Age	3
Population Distribution by Sex	3
Population Density	3
Population change	3
Population aged 0–9	6
Population aged 10–24	6
Population aged 25–29	6
School leavers with higher qualifications	6

School leaver with no qualifications	6
Truancy	6
Stand-downs	6
Suspensions	6
MANAGEMENT	
Active management	3
Culver inspections	4
Open drain inspections	4
Stormwater neutrality	4
Management of after-ball parties attended by young people	6
HEALTH & SAFETY	
Life expectancy	7
Suicide rate	7
Attempted suicide	7
Cigarette smoking	7
Physical activity – brisk walking	7
Physical activity – time spent brisk walking	7
Physical activity – moderate	7
Physical activity – time spent in moderate activity	7
Physical activity – vigorous	7
Physical activity – time spent in vigorous activity	7
GP Access	7
Perception of safety	7
Offences (crimes)	7
Offences (crimes)	7
Types of offences	7
Family violence	7
Injuries and accidents	7
Deaths by accidents	7
Road casualties - Minor	7
Road casualties - Serious	7
Road casualties – Fatal	7
Home ownership	7
Vacation homes	7
Social housing	7
House crowding	7
Housing insulation	7