Motueka Catchment futures, transdisciplinarity, a local sustainability *problématique* and the Achilles-heel of Western science

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Abstract

Model building is a process that attempts to capture some aspect of complex reality with the aid of simplifying assumptions. Research of this kind is an essential part of building disciplinary knowledge. However, the challenge of modelling progress towards sustainable futures introduces the dimension of perceptual complexity into the model building process, something that classical western scientific epistemology and system dynamics models are poorly position to deal with. This paper draws on comparative theories of epistemology to better understand the nature of this tension as seen in the aims, method and results of a futures modelling project in the Motueka catchment of New Zealand. What this evaluation shows is that even with the significant level of horizontal and transversal complexity integration involved in this futures model, it still falls short of satisfactorily addressing the local sustainability *problématique*. This comparative epistemological evaluation indicates that the elusive goal of sustainability lies beyond disciplinary-based research co-ordination. This conclusion implies that dependence upon a disciplinary-based prescription for sustainability may well turn out to be the Achilles-heel of Western science.

Key words

Dynamic accounting framework, catchment scale, multi-disciplinary, strong transdisciplinarity, elusive goal, sustainability

1. Introduction

The Motueka catchment futures model has been developed in an attempt to assist a diverse group of stakeholders to explore and work towards sustainable futures at catchment scale. This futures modelling research has drawn inspiration from a diverse array of leading international modelling projects (Carmichael et al., 2004; Voinov et al., 1998; Maxwell & Costanza, 2006; Lant et al., 2005) and as such may be considered as consistent with current theory and emerging practice in this area of research. However, the construction of the Motueka futures model has raised many questions related to exactly what type of modelling research will best achieve progress towards sustainability. It has gradually become evident that even though this modelling research is grounded in significant interdisciplinary co-ordination, the sustainability problem has proved to be more complex than a western scientific epistemology is capable of adequately addressing. Taking a fresh look at these problems through the eyes of an emerging transdisciplinary epistemology (Nicolescu, 2005; Max-Neef, 2004) has proved to be a highly insightful exercise. This evaluation suggests that despite its highly integrative qualities, the Motueka catchment futures model still represents a very small step towards a highly complex problem. What this paper indicates is that this sustainability *problématique* resists the modelling process of reduction in the same manner that macro-physical reality resists being reduced into quantum entities (Neane-Drummond et al., 1999). Thus, the "Achilles heel" of Western science in achieving sustainability may well turn out to be its inability to reduce the sustainability *problématique* to a single level or perception of reality as implied by the classical subject-object model. To theoretically ground this paper and provide a comparative basis upon which to *see the nature of this problem* it is necessary to review the historical development of theories of epistemology in the old and new world.

The remainder of this introduction provides a historic outline of the development of pre-science, classical Western science and transdisciplinary epistemology as a theoretical foundation for a re-think of sustainability research. Having outlined and surveyed this history from a historical perspective, we then seek to evaluate the Motueka catchment futures model using comparative classical Western and transdisciplinary epistemologies. Why use a comparative study of this kind? In experimental science we have learnt that it is not possible to test the explanatory power of a hypothesis (Mentis, 1988) in isolation from a competing theory (Platt, 1964). This is because the logical tests of explanatory power (i.e. conflict with back ground theory, parsimony, internal consistency and explanatory superiority) are comparative metrics. Without a comparative theoretical reference point of some kind it is not possible to say that an alternative explanation is better or worse.

1.1 The history of epistemology

The historical emergence of epistemologies in the old and new world provided an important impetus for the development of knowledge. A review of this history provides a useful context in which to outline the emergence of transdisciplinarity epistemology as an eventual outworking of inadequacies in disciplinary science that emerged during the time of the quantum revolution (Neane-Drummond et al., 1999).

1.1.1 A pre-science epistemology

The first stage in the human development of knowledge is postulated to have begun with the dawn of human consciousness. In this pre-science period of human history, knowledge development was probably linked more closely with the struggle for existence (Cole, 2006e) than any formal statement of axioms or method. Methods of knowledge development were typically dialogue-based, reflective and sustained by perfect oral transmission from one generation to the next (Royal, 1992). From the temples of the classical Greek states (Burckhardt, 1998; Giovanni, 1966) and the mysterious religious rituals of the Pacific islands (Flenley & Bahn, 2003) to the stunning gothic cathedrals of medieval Europe (Wylie, 1851; Oman, 1898), the development of knowledge was interwoven with the sacred or metaphysical dimension of the world (Figure 1). In classical western scientific terms, the pre-science worldview integrated subject and object as one indivisible whole with the sacred.

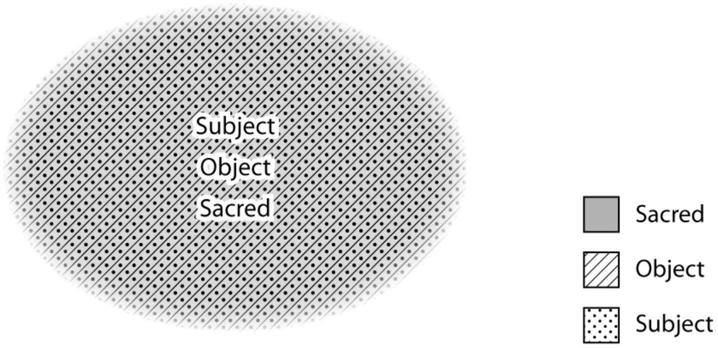

Figure 1 *The pre-science worldview in which the classical Western scientific entities of subject, object were thought to co-exist as one indivisible whole with the sacred*

1.1.2 Classical science

The foundations of modern science were already being laid during the pre-science period, in particular by the natural philosophers of the ancient Greek states, most notably Aristotle (Shand, 1994). This long period of relatively unhindered human knowledge development came to a close during the midst of the 5th Century AD under the ecclesiastical authority of the Roman Catholic Church. The Churches repressive influence on religious liberty and freedom of thought remained firm for ca. 1300 hundred years. In the wake of the protestant reformation (Merle D'Aubigne, 1885), the French revolution (Madelin, 1916), the conquests of Napoleon Bonaparte (Lockhart, 1833), the emergence of free though (Schouls, 1989) and the separation of church and state in the constitution of the New World (Kelly, 1963; McLaughlin, 1961) we find both the decline and end of ecclesiastical supremacy and the first beginnings of the classical age of science as we currently known it.

The Roman Catholic Church of the dark ages had claimed ultimate authority over (1) the state in both secular and religious matters and (2) the conscience. The protestant reformation undermined both of these foundations. The reformers (most notably in England (John Wycliffe (1330–1384), (Lewis, 1973) and William Tyndale (1492–1536)), (Campbell, 1949); in Bohemia (Jan Huss (1371–1414), (Petrz, 1966)) and in Germany (Martin Luther (1438–1546), (Steinmetz, 1980))) struck at the foundation of ecclesiastical supremacy by claiming that the word of God (the Bible) had authority over the Church and not the other way around. In matters of faith, therefore, the Bible not the Church should have authority over individual conscience (Ghosh, 1967). This therefore implied that individuals must have the freedom to study the bible for themselves and it was to this end John Wycliffe, William Tyndale and Martin Luther laboured to translate the Greek, Hebrew and Latin manuscripts of the Bible into the language of the common people.

In parallel to this revolution in theology, a revolution in natural philosophy was also unfolding. Contemporary to Martin Luther, Nicolaus Copernicus (1473–1543) was developing a heliocentric model of the universe that directly challenged the earth-centric model that was endorsed by the Church (Hoyle, 1973). Keenly aware of the risks of making his discoveries public, he shared his work only with trusted friends. His treatise was only published upon his death in 1543; a date is generally considered to constitute the beginning of the scientific revolution.

In reviewing this history it is interesting to note that while the Church of the dark-ages had repressed the unhindered expansion of human knowledge, this did not have the effect of fragmenting knowledge into disciplines. In keeping with the pre-science era of knowledge development, the dark ages was characterised by a similar worldview. Science and the sacred co-existed as one. This is clearly seen in the vocational interests of notable scholars of the time. For example, Nicolas Copernicus was a mathematician, astronomer, jurist, physician, classical scholar, Catholic cleric, governor, administrator, diplomat and economist. Amid these extensive responsibilities, astronomy served as no more than a interest (Hoyle, 1973). Yet his thesis that the sun (rather than the Earth) was at the centre of the solar system is considered as among one of the most important landmarks in the history of western science. Therefore, we can conclude that his intellectual breadth of understanding did not limit his ability to contribute in a powerful manner to knowledge development at the time.

Likewise, Johann Amos Comenius (1592–1670) was a Czech teacher, scientist, educator, philosopher and writer (Sadler, 1969). He was a Unity of the Brethren/Moravian Protestant bishop, a religious refugee, and one of the earliest champions of universal access to education, a concept eventually set forth in his book ‘Didactica Magna’ (Comenius, 1907). For his reforms in educational method of the day, Comenius earned the title of the father of modern education. Yet his life long ambition lay in a far more challenging purpose. Seeing that the moral depravity of medieval Europe (Comenius, 1672; Comenius, 1998; Comenius, 1971) resulted largely from inaccessibility to knowledge of the time that was the privileged lot of scholars, Comenius longed to write a Pansophy[1] – a systematic thesis of all knowledge (Comenius, 1957). Comenius is one of earliest transdisciplinary researchers known to the history of science.

Both Copernicus and Comenius were typical scholars of this period, however their approach to knowledge development was about to be interrupted. In building upon the scientific lineage that began with Aristotle’s natural philosophy and system of axiomatic logic, the astronomers and natural philosophers of the 16th century boldly departed from conventional wisdom and began to develop a systematic approach to studying the natural world. In addition to greatly expanding upon the heliocentric model of Copernicus, Galileo Galilei in his *Dialogue on the great world systems* (Galileo, 1957) developed the revolutionary assumption that the human observer can be entirely separated from the external physical reality to be studied and in so doing, became the first to formally articulate a scientific methodology that may be articulated by the following three axioms.

1. There are universal laws of a mathematical character,
2. These laws can be discovered by scientific experiment,
3. Such experiments can be perfectly replicated.

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[1] The term Pansophy appears to have been only used by Comenius and probably derives interpretation from its Latin roots; “pan” meaning all and “sophy” to study. Hence, “Pansophy” literally means the study of all things and may therefore be interpreted as an early precursor for transdisciplinarity.

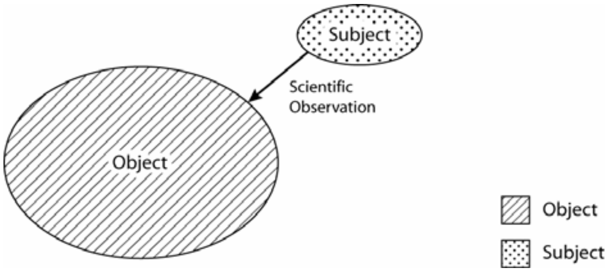

Figure 2 *The separation of subject and object in the classical model of scientific method as first articulated by Galileo Galilei in his "Dialogue on the great world systems"*

Galileo Galilei pioneered the use of quantitative experiments whose results could be replicated and analyzed with mathematical precision, an approach that is now believed to have been lacking in Europe at the time. Galileo is perhaps the first to clearly state that the laws of nature are mathematical, writing that "the language of God is mathematics." His mathematical analyses are a further development of a tradition employed by late scholastic natural philosophers which Galileo learned when he studied philosophy (Wallace, 1984).

Reliance upon mathematical quantification could only be successfully achieved by also embracing accepting the Aristotelian system of categorical logic. Bertrand Russell later formalized 3 "Laws of Thought" as more or less "self evident" or "a priori" in the sense of Aristotle (Nakhnikian, 1974; Earnes, 1969; Dorward, 1951):

The law of identity:	'Whatever is, is.'
The law of contradiction:	'Nothing can both be and not be.'
The law of excluded middle:	'Everything must either be or not be.'

While he tried to remain loyal to the Catholic Church, Galileo's adherence to deductive reasoning contributed to the rejection of a prevailing unquestioning allegiance to authority; both philosophical and religious, in matters of science. This helped lead to the separation of science from both philosophy and religion, a major justification for his description as the "father of science".

> Modern science was born of a violent break with the ancient vision of the world. It was founded on the idea – surprising and revolutionary for that era – of a total separation between the knowing subject and reality, which was assumed to be completely independent from the subject who observed it. This break allowed science to develop independently of theology, philosophy and culture. It was a positive act of freedom. But today, the extreme consequences of this break, incarnated by the ideology of scientism become a potential danger of self-destruction of our species. (Nicolescu, page 4, 2005)

There is a point in the above quote from Nicolescu that perhaps requires elaboration for the sake of clarity. "The break (i.e. the separation of object and object) allowed science to develop independently of theology, philosophy and culture." The continued co-existence of subject, object and the sacred as one (Figure 1), implied that these 3 entities were inseparably interconnected and interdependent. Evaluating this history we can deduce that if this model was correct, it would be extremely difficult to isolate cause and effects relationships because of the complexity involved, especially in the metaphysical or sacred domain of reality.

Secondly, the Church considered itself to be custodian of knowledge related to the sacred domain that just happened to be interrelated with everything else. This second issue was extremely problematic as it was becoming increasingly clear that the Church, as custodian of all truth, and defender of the faith held to ideas that contradicted reality (e.g. the earth centric model of the universe) and followed policies in defence of the faith that contradicted sound reason as well as civil and religious liberty. Therefore, it is important to note that classical scientific method was as much a break with Christianity as it was a break with the pre-science system of knowledge development.

1.1.3 Beginnings of the third era of knowledge development

The unexpected beginnings of the third era of development in human knowledge came about in the early 20th century with a group of physicists including Max Planck, Niels Bohr, Erwin Schrödinger, Albert Einstein and Werner Heisenberg. The impact of the developments in physics since this time can be summarised into 4 key areas: (i) the rediscovery of time through relativity theory, (ii) the rediscovery of the observer through quantum theory, (iii) the Big bang theory and finally (iv) the empirical rediscovery of complexity through chaos theory (Neane-Drummond et al., 1999). Below, we concentrate on the implications of emerging quantum theory and the revolution in thinking this lead too.

Emerging quantum theory seemed to place limits on ability of Western scientific method to observe nature at the atomic scale because it implied that the act of observation disturbed that which was being observed. This dilemma did not overthrow classical scientific method, but led many to question its absolute supremacy as expressed in Werner Heisenberg's famous "uncertainty principle" (Price & Chissick, 1977). In 1927 Heisenberg argued that key physical quantities (e.g. position and momentum) are paired in quantum theory. As a result, they cannot be measured simultaneously to any desired degree of accuracy. Attempts to increase the precision of one measurement therefore result in less precise quantification of the other member of the pair (Heisenberg, 1959; Heisenberg, 1930).

This dilemma is often illustrated using experiments designed to determine the position of an electron using electromagnetic radiation. Because electrons are so small, radiation of very short wavelength is necessary to locate it accurately. However, shorter wavelengths contain more energy. The higher the energy of radiation used in a sub-atomic experiment, the more the momentum of the electron is altered. Thus any attempt to determine electron location accurately will change the velocity. Conversely, techniques for accurately measuring the velocity of the electron tended to result in uncertainty about its precise location. Thus, quantum physics began to depart from classical scientific assumptions (Neane-Drummond et al., 1999).

First, determinism gave way to an emphasis on probability theory and implied that we simply do not have access to enough information to make deterministic predictions. Furthermore, it has since become increasingly apparent that probabilistic behaviour is an inherent feature of the micro and macro-physical (DeAngelis & Waterhouse, 1987; DeAngelis et al., 1985) world rather than just being an observational limitation.

Secondly, reductionism has given way to a more holistic approach to physical systems. For example, there is now a greater emphasis on describing quantum systems as a whole, something that runs contrary to 'bottom-up' organisational theories of reality. Classical physicists tended to assume that systems were collections of separate entities, and this therefore lead them to try and reduce macro-physical complexity to the individual properties of the simplest possible components. From the quantum revolution emerged the realisation that the simplest entities we currently know of (i.e. sub-atomic system) seem to resist this process of reduction.

> For an outsider it might seem paradoxical that it is from the very core of exact sciences that we arrive at the idea of limits of disciplinary knowledge. But from the inside, it provides evidence of the fact that after a long period, disciplinary knowledge has reached its own limitations with far reaching consequences not only for science, but also for culture and social life. (Nicolescu, page 4, 2005).
>
> The quantum revolution radically changed this situation. The new scientific and philosophical notions it introduced … led the founders of quantum mechanics to rethink the problem of the complete object / subject separation. (Nicolescu, page 5, 2005).

Heisenberg in particular focused on the object/subject relationship (Heisenberg, 1959; Heisenberg, 1930). It was now clearer to him that the notions of objective and subjective reality were extremes of a continuum of human perceptional possibilities of the same reality.

> However, we would make a very crude simplification if we want to divide the world into one objective reality and one subjective reality. Many rigidities of the philosophy of the last centuries are born of this black and white view of the world. (Heisenberg, page 269, 1989).
>
> The too strong insistence on the difference between scientific knowledge and artistic knowledge comes from the wrong idea that concepts describe perfectly the "real things" … All true philosophy is situation on the threshold between science and poetry (Heisenberg, pages 363-364, 1989).

One way of overcoming the perceptual and reductionist limitations imposed on the existence of a single disciplinary subject as implied by the classical model of science was to co-ordinate knowledge development across and between disciplines (Max-Neef, 2004). Over the decades following the emergence of quantum theory a number of variations on this basic theme were tried. Multidisciplinary research involved the study of a research topic across several disciplines at the same time with the aim of coordinating knowledge development from the exclusive disciplinary, perceptual vantage point of a single home discipline. For the Motueka integrated catchment management research programme[3] of which this futures modelling research is a part, this home or parent discipline would be hydrology (Davie et al., 2004). The supporting disciplines are diverse and include: resource economics, GIS, human dimensions research, marine ecology, organisational learning, trans-cultural research and ecological economics.

However, all of these supporting disciplines seek to assist hydrological researchers in more fully exploring their paradigmatic view which assumes that in research and management, water is the basic organising variable of catchment scale systems. In interdisciplinary research coordination, the sharing of knowledge across discipline boundaries with a parent or home discipline is enriched by the transfer of methods from one discipline to another. With inter and multidisciplinary research coordination, western science had begun the early stages of exploring transdisciplinarity which currently represents an important emerging theoretical, ontological and methodological frontier of western science (Nicolescu, 2005).

1.1.4 Transdisciplinarity: an emerging frontier

We begin an analysis of the word transdisciplinarity by breaking it into its constituent parts. The Latin prefix “trans” means “across”, “between” and “beyond”. The word “discipline” in this context means a branch of knowledge that is formally taught, either at university or some other related institution. It follows that “transdisciplinary” implies that which is simultaneously between, across and beyond the disciplines. Research approaches that cross conventional mono-disciplinary boundaries have been widely advocated for and pursued in light of the complexity of social-economic-ecological problems (Norgaard, 1989; Klein et al., 2001; McGregor, 2005). However, a survey of the published journal literature using the keywords “transdisciplinary” or “transdisciplinarity” quickly indicates that most researchers currently associate transdisciplinarity with that which is “between” and “across” the disciplines. This is essentially what Max-Neef (2005) classifies as weak transdisciplinarity because it is primarily concerned with complexity – one of the three pillars of a strong transdisciplinary approach. In this system of classification, inter and multidisciplinary research co-ordination would fall into the category of weak transdisciplinarity as they are principally concerned with that which is across and between the disciplines.

By contrast, strong transdisciplinarity is simultaneously concerned with that which is “across”, “between” and “beyond” the disciplines (Nicolescu, 2005). Thus, it potentially opens the door to rich domains of knowledge not explored by any other academic

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[3] http://icm.landcareresearch.co.nz/

approach. However, it is important to note that transdisciplinarity does not diminish the importance of disciplinarity or its taxonomy of collaboration (i.e. interdisciplinary, multi-disciplinary, supra-disciplinary, etc.) in academic research, as “there is no transdisciplinarity without disciplinarity” (Nicolescu, 2005) and therefore “discipline and transdiscipline must be understood as complementary” (Max-Neef, 2004).

Drawing from his background as a theoretical quantum physicist, Basarab Nicolescu proposes three fundamental pillars or axioms for transdisciplinarity, which are listed below and then briefly outlined:

(i) The ontological axiom: there are in nature and in our knowledge of nature, different levels of reality and correspondingly, different levels of perception.

(ii) The logical axiom: the passage from one level of reality to another is insured by the logic of the included middle.

(iii) The complexity axiom: the structure of the totality of levels of reality or perception is a complex structure: every level is what it is because all the levels exist at the same time. (Nicolescu, page 9, 2005)

Ontology – the ontological axiom

Around the turn of the last century, Werner Heisenberg put forward the notion of levels of reality in response to the contradictions that arose between quantum physics and the theories of Einstein (Heisenberg, 1989). However, these ideas remained buried from most English language speakers in German text (Heisenberg, 1942). More recently Basarab Nicolescu (2000) also acknowledged the existence of levels of reality in physics, suggesting that the laws governing the behaviour of quantum entities differ from those governing entities in the macro-physical world.

> Two different levels of reality are different if, while passing from one to the other, there is a break in the laws and a break in fundamental concepts like, for example, causality (Nicolescu, page 11, 2000).

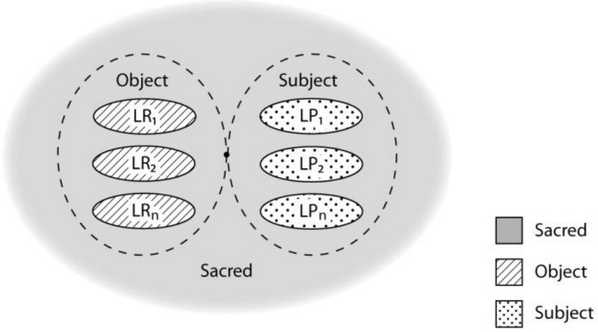

Figure 3 *Different levels of reality (LR_n) and perception (LP_n) and their relationship to the classical model of scientific object (reality) and subject (observer).*

Nicolescu (2000) has proposed that between different levels of reality there exists a region of discontinuity in which the organisational laws and logic of one level of reality merges into another. While quantum theory points to the existence of levels of reality, human beings are not aware of the existence of regions of discontinuity. The parts (e.g., atomic particles and macro-physical entities) appear as a whole. Nicolescu has proposed that the region between levels of reality corresponds to the sacred (Figure 3), that which resists our knowing or attempts at quantification.

Furthermore, the different *levels of reality* are:

> "… accessible to human knowledge through the existence of different *levels of perception* which stand in a one-to-one correspondence with levels of reality (Max-Neef, page 13, 2004).

The ability of the human subject, as defined in the classical model of science to perceive *levels of reality* is related to our sensory and intellectual capabilities. This implied interdependence of levels of perception and reality poses a challenge to the classical model of science, which assumed a separation (Figure 2) between scientific subject and the object (Nicolescu, 2005). However, the correspondence between levels of reality and perception implies that the study of human perception, consciousness and the acquirement of knowledge must form an integral part of our consideration of the observation of levels of reality. Transdisciplinarity not only acknowledges complexity in the natural world around the observer (i.e. the object), it also acknowledges that the observer's power of perception, current knowledge, systems of belief and values are constituent parts of this complexity.

Quantum theory thus far acknowledges the existence of three organisational levels of the reality: the sub-atomic, macro-physical and metaphysical realms (Forrest, 1988). Hence the use of the term "levels" is perhaps justifiable in this context. However, both the term "level" and this limited organisational classification is confusing when we step into the social realm. The sub-atomic, macro-physical and meta-physical characterisation of reality exists at the objective rationality end of the Heisenberg continuum (Heisenberg, 1989). In other words, this perception of reality is empirically grounded within a single discipline which relies heavily on objective rationality.

The existence of levels of reality may also be of direct relevance to the social sciences (Loisel, 2005), thus completely satisfying the full continuum of possibilities between objective rationality and subjectivity articulated by the Heisenberg continuum. It is more difficult in the social context to see the relevance of Nicolescu's use of the term "levels" of reality because a social organisational structure is not immediately obvious. To explore this idea further in the social realm it is first necessary to distinguish between the words "real" and "reality".

> “Real” designates that which is, while “reality” is connected to resistance in our human experience. The “real”, is by definition veiled forever, while “reality” is accessible to our knowledge. (Nicolescu, page 11, 2005).

If reality is accessible to our knowledge, how many social realities are there? Clearly, the answer to this question requires a better understanding of the central of human intelligence in perceiving individual realities. Howard Gardner’s theory of multiple intelligences (Gardner, 1993b) is highly compatible with Nicolescu’s levels of perception. Early educational psychologists considered that the subject of intelligence was well understood, rested principally upon linguistic and logical/mathematical ability and could be accurately measured using standardised IQ tests that produced a normal “bell-shaped” statistical distribution (Murray & Hermstein, 1996). The weakness of this theory includes: (i) the reduction of human cognitive abilities to one or two levels of perception (i.e. linguistics and logical/mathematical) and (ii) the classification of students into one of two principle categories – the haves and those who have not. With his theory of multiple intelligences, Gardner challenged conventional thinking and this body of theory represents an important starting point for exploring the interdependencies between between human perception and that which we may apprehend of reality.

Gardner (1993b) proposed that there were not just two, but at least eight clearly distinguishable forms of human intelligence: (i) linguistic, (ii) logical/mathematical, (iii) musical, (iv) spatial, (v) bodily-kinaesthetic, (vi) intra-personal, (vii) inter-personal and (viii) naturalist. In *Frames of Mind* he also mentions the likely existence of religious and existential intelligence, both far more difficult to quantify (Gardner, 1983). Each form of intelligence employs different sensory and cognitive capabilities that combine to provide a range of tools for perceiving reality. Gardner points out that some aspects of learning may depend on the creation of multiple representations of reality (Gardner, 1999) through the use of multiple intelligences. Gardner’s theory of multiple intelligences provides a theoretical basis for postulating the existence of what Nicolescu calls “levels of reality” in the social sciences. We return to this body of theory later latter in this paper was a basis for mapping and evaluating different stakeholder perceptions of reality. However, it has been adequately explained at this stage to highlight the fact that human perceptions of reality may be just as effectively structured around intelligence as levels of organisational scale. In the social domain, reality may appear to look different as viewed from the reference point of different combinations of intelligence.

Logic – the logical axiom

Despite the limitations of classical, binary logic that have been laid bare by modern physics, contemporary scientific and western cultural thinking is still dominated by the Aristotelian tradition of exclusive categorical logic, which is based on three fundamental axioms:

1. The axiom of identity:	A is A
2. The axiom of non-contradiction:	A is not non-A
3. The axiom of the ***excluded middle***:	There exists no third term T, that is simultaneously A and non-A.

Borrowing from developments in the field of quantum logic, Nicolescu has proposed a transdisciplinary epistemology must acknowledge the existence of levels of reality, a constraint which implies a change to the third axiom of classical logic:

3. The axiom of the *included middle*: There exists a third term T, that is simultaneously A and non-A.

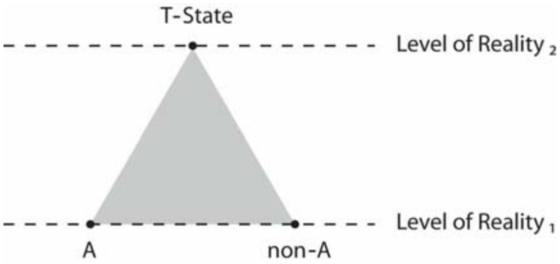

Figure 4 *A graphic representation of transdisciplinary logic*

That which in the same level of reality would appear as contradictory and antagonistic (A and non-A), ceases to be so when a third element, the T state (Figure 3), is introduced from another level of reality (Max-Neef, 2004). We can expect that the reconciliation of the apparent contradiction between A and non-A will be a temporary phenomenon. The new T state will eventually collapse into a new pair of contradictory phenomena, A' and non-A', and their reconciliation through the discovery of a new state T'. The emergence of a new T state achieves more than a compromise between the contradictory terms A and non-A, it provides new insights and perceptions that can only be perceived from a new vantage point. Transdisciplinary logic is thus the theoretical and operational basis for the discovery and convergence of knowledge about the real world as revealed through different perceptions of reality.

> The logic of the included middle is not a metaphor. It is, in fact, a logic of transdisciplinarity and complexity, since it allows, through an iterative process, to cross different areas of knowledge in a coherent manner, and generating a new simplicity (or simplexity). It does not exclude the logic of the excluded middle; it just limits its boundaries and range of influence. Both logics are complementary." (Max-Neef, page 13, 2004)

It is important to note that transdisciplinarity logic does not imply the need to discard a logic of exclusion. It's not that a logic of exclusion is wrong, but by itself rather incomplete. We need the methodological freedom to be able to move our point of observational reference back and forth between exclusion and inclusion; the parts and the whole.

Complexity – the complexity axiom

While a strong transdisciplinary typology of complexity acknowledges the existence of levels of organisational complexity, it also acknowledges the existence of perceptual complexity (Nicolescu, 1996).

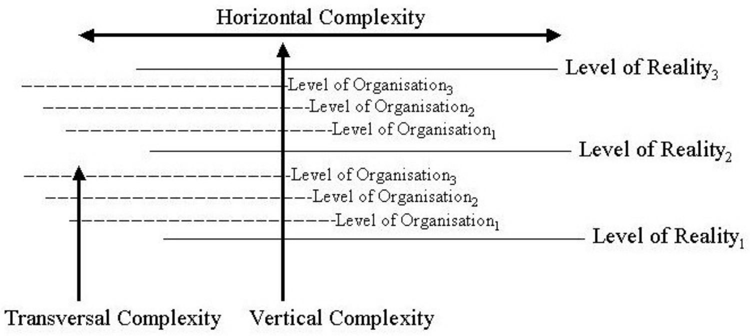

Figure 5 *Three types of complexity: (i) vertical across multiple level of reality, (ii) transversal across multiple levels of complexity, and (iii) horizontal with a given level of reality*

The existence of levels of reality means it is important to differentiate between (i) horizontal complexity which refers to collections of complex phenomena within a single level of reality (e.g. the macro-physical realm) (ii) transversal complexity (i.e. levels of organisation within a level of reality), and (iii) vertical (or human perceptual) complexity which includes multiple levels of reality, (Figure 5), (Nicolescu, 2005).

> From a transdisciplinary point of view, complexity is a modern form of the very ancient principle of universal interdependence (Nicolescu, page 22, 2005).

Complex reality resists our knowing because the approach to levels of reality involves passage across zones of non-resistance (Nicolescu, 2005). As used in the context of quantum physics, non-resistance implies the existence of a medium that does not respond to normal methods of experimental quantification and thereby resists our knowing. In the social realm a zone of non-resistance may correspond to the transition-zone between one perception of reality and another. The transition zone resists our knowing because it involves a breakdown in the laws and logic that hold in the subject's perception of reality, but do not necessarily hold in the perception of reality we are approaching (i.e. the object). According to Nicolescu, this zone of non-resistance or discontinuity may correspond to the sacred;

> to that which does not submit to any rationalisation (Nicolescu, page 12, 2005).

Through the disciplinary assumption of a single level of reality we effectively eliminate zones of non-resistance (the sacred). What has become increasingly clear in the Motueka catchment futures modelling research project is that the challenge of movement towards a sustainable future involves many transition-zones of discontinuity between the various stakeholder perceptions of reality. Hence, this local sustainability *problématique* involves a degree of complexity that is beyond the capability of a multi-disciplinary futures model; even one that constitutes a point of theoretical and methodological integration for numerous individual disciplines.

1.3 A summary of the history of epistemology

This narrative on the history of epistemology has been summarized in Table 1 which provides a basis for comparison of 3 different epistemologies of science based on distinguishing attributes. What is of interest in this summary Table and the evaluation that follows is that Western science, after a violent break or bifurcation with a pre-scientific epistemology is now re-converging on what Nicolescu (2005) has called an epistemology of universal interdependence. The attributes of Table 1 are used in the remainder of this paper to provide a comparative evaluation of the Motueka catchment futures model.

2. Aim and research context

The aim of this evaluation is to conceptually quantify how much of the local sustainability *problématique* the Motueka catchment futures model is capable of addressing. The Motueka catchment futures modelling research project is a component of a larger integrated catchment management research programme located in the Motueka catchment of the Tasman region of New Zealand. The research programme has 6 years of government research funding and as of June 2006 has successfully completed its 3rd year of development. An aim of this research programme is to explore the application of a participatory approach to democracy at catchment scale (Costanza & Folke, 1997). The researchers involved in this multidisciplinary science programme seek to work as far as possible in an action research mode with a diverse range of stakeholders including: local catchment communities, iwi, planners, policy makers and business managers. The participatory democracy dimension involves collective effort to ensure that the catchment is utilized and managed in a manner consistent with local stakeholder aims.

The futures modelling dimension of this research programme was initially connected with a similar regional-scale modelling programme involving both the local Nelson and Tasman regions (Cole, 2006a; Cole, 2006b; Cole et al., 2003). Funding for this regional scale modelling research has been discontinued. Therefore, the catchment-scale futures modelling is currently all that remains of this initially larger project.

In addition to seeking to measure how effectively the Motueka futures model addresses the local sustainability *problématique* there are a number of secondary aims including: (i) addressing methodological challenges associated with participatory modelling of this kind, (ii) bridging the gap between theory and practice in applying scientific tools to real world problem solving. In summary, every effort possible has been made to connect the futures modelling work with real world issues and processes.

Table 1 *Characteristics of pre-science, science and transdisciplinary epistemologies*

Time period	**Subject/ object interrelation**	**Method of knowledge development**	**Reality**	**Theories of logic**	**Complexity**	**Sacred**	**Method of knowledge management**	**Principles forms of intelligence**
Pre-science	Co-exist and are inter-dependent	Indigenous trans-disciplinarity	Multiple realities	Multiple co-existing	Holistic	Explicit	Oral histories	Multiple
Scientific revolution	Separate and independent	Objective rationality	Disciplinarity	Exclusive logic	Reductionist	None	Mathematics	Logical /mathematical
Post - quantum revolution	Co-exist and are inter-dependent	Context dependent	Levels of reality	Multiple co-existing	Vertical, horizontal, transversal	Implicit	All forms of intelligence	Multiple intelligences

3. Method used in futures model development

There are four aspects of the futures model that need to be considered to explain how and why the model was developed. First, we outline and explain a stepwise process of the key model development and participatory stages involved. Second, we theoretically position the modelling framework and look at the various bodies of theory that are involved in the participatory process. Third, we seek to classify the model mathematically and identify the various bodies of theory underpinning the model structure. Fourth, emerging complexity theory suggests that model structure may be interdependently related to organisation scale. This problem is briefly outlined along with the initial strategy designed to explore this problem.

Finally, a strategy for evaluating the model from the vantage point of alternative epistemologies is outlined.

3.1 Stepwise model building process

The futures model has been developed according to the stepwise process outlined in Figure 6 and explained as follows. The layout of the stepwise process depicted in Figure 6 has 3 key components. First, steps 1, 2, 3, 5, and 6 are all connected to the box to the left called “stakeholder participation and validation”. This interconnection is intended to diagrammatically represent the fact that steps 1, 2, 3, 5, and 6 all involved direct stakeholder participation and validation. This does not imply that all stakeholder groups were equally represented in each of these 5 steps. Instead, stakeholder groups were chosen or formed based on the context of the task at hand. The details of this selection process are noted below. On the right hand side of Figure 6 is a recursive loop which indicates that these final steps are to be repeated again and again as: (i) the model datasets are improved with datasets gathered by annual monitoring (step 10) and (ii) the futures model is used in an adaptive management mode to explore future options as they unfold.

Step 1 – involved the use of a stakeholder/scientist participatory process to develop and evaluate an influence matrix. A detailed account of the underpinning theory (Cole A.O. et al., 2006), process (Cole et al., 2006), mathematical methodology (Cole, 2006f) and results of this participatory model building stage are outlined in a range of reports and published papers. The aim of this step was to trial the use of a participatory process in the identification of goals and whole-of-system values for the future management and use of the catchment. The participatory dimension of this model building research was undertaken by the Motueka community reference group (CRG). This group of stakeholders composed of local catchment residents, planning and policy staff and research scientists involved in the research programme was especially formed to act as a touch-stone for scientists involved in the research programme. The results of this participatory process were never intended to be representative of the collective stakeholder community. However, they were widely reported at various community forums associated with the research project that involved a diverse cross section of stakeholder interests. Time and resources permitting, much more research would have been required to obtain broad community consensus. This is clearly a limitation of this method and a question to be grappled with is how to define the term “representative”.

The results of the influence matrix suggested the need for model development that made it possible to look at the broader social, ecological and cultural implications of economic growth scenarios for catchment, with the overarching goal of this futures research being to achieve future sustainability and social fairness outcomes.

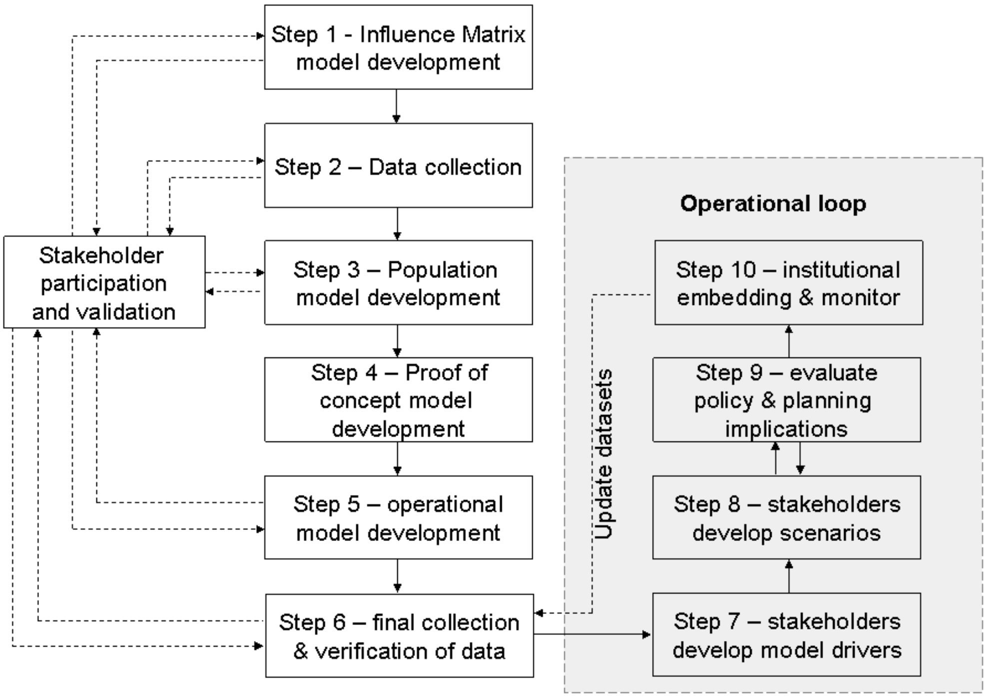

Figure 6 *An illustration showing the various steps involved in the development of the Motueka catchment futures model*

Step 2 – involved the collection of initial datasets needed to build a proof-of-concept model. This included: (i) the development of an economic input-output model at 48 sector ANZSIC[4] disaggregation, (ii) the development of various biophysical and energy accounts by sector based on the rapid assessment methods used in the Nelson Tasman regional study (Cole et al., 2003) and (iii) the collection of male and female, 5 year age cohort population data. The base year chosen for the model was 2001. Where possible every effort was to be made to collect historic data so as to back cast the final model as a form of calibration test. The development of the energy and economic input output model was sub-contracted to an economic consultancy firm in Auckland, New Zealand (Market Economics Limited). All other biophysical accounts were developed by drawing on datasets, reports and expertise knowledge within the local regional Council (Tasman District Council, TDC)[5].

Step 3 – The population data was used as a basis for building a dynamic, age specific, component cohort population model (Cole, 2006c). This model building process involved a quite comprehensive and lengthy mediated modelling process (Cole & Maxwell, 2005) supported by policy staff from the local regional councils and included the development of population models at both regional (Cole, 2006a; Cole, 2006b) and catchment scale (Cole, 2006c). The mediated modelling process involved the use of Vensim (Ventana Systems, 2002) system dynamics software that we

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[4] Australia and New Zealand Standard Industry Classification

[5] A forthcoming publication will provide a detailed account of the various data sources used in the construction of the biophysical and social accounts

planned to use for the development of the final futures model. This cross scale model development process[6] was designed in order to provide a form of independent validation of the final catchment scale population model against regional scale model behaviour. The population model structure was designed to achieve a number of aims. First, it provided an opportunity to experiment with a mediated modelling process in a local context to test the suitability of this approach in steps 7-10 of the futures model building process. Second, it provided a method of grounding the population model-building research stage in local knowledge. Third, it provided a very useful experience in exploring how to connect a theory-rich modelling process with real-world planning and policy practice (Cole, 2006d).

Step 4 – involved the development of a proof of concept model that was undertaken in virtual isolation from stakeholder participation and built on theory and method developed in earlier research (Cole, 2001). The reason for isolating this step was because it involved quite technical and mathematical experimentation. The final proof of concept model was presented to an open stakeholder meeting that provided an opportunity for feedback, questions and comments on the type of model structure that was emerging, as implied by the prototype. The prototype model was scripted in MatLab (The Math Works Inc., 1984) which is a command-line programming language based on matrix algebra. This type of modelling language is ideal as a prototyping tool, but limited as a participatory modelling tool. Output graphics from the proof of concept model were prepared in Microsoft Excel.

Step 5 – the various components of the futures model were brought together into one fully operational futures model built on the mathematical structure defined in the earlier proof of concept models (Cole, 2001; Cole, 2000). The dynamic population model was designed to be integrated into the fully operational futures model in this stage of development along with other modules that had to be custom built during this stage. The relationship between the various subcomponent modules of the futures model are shown in Figure 7. The development of the labour market and dynamic driver modules was based around a restricted mediated modelling approach that built on lessons learnt (Cole & Maxwell, 2005) in facilitating a process of this kind from the population modelling (step 3). The labour market module development was linked with an existing labour market research programme being run by the Nelson Economic Development Agency. Staff at the agency both informed and conceptually guided the construction of this module. The dynamic, sector driver module was developed in participation with a range of local agencies able to represent the primary sectors of the Motueka catchment (horticulture and fruit growing, livestock and cropping, livestock and cropping, dairy cattle farming, other farming, forestry, fishing and quarrying and mining). The same process was repeated for secondary and tertiary economic sectors of the economic model. After completion of this step, the futures model was constructed, validation tested and ready for projection testing. However, as of the writing of this paper, further datasets are still be added (step 6) along with refinements to the dynamic driver module (step 7).

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[6] Involving both regional and catchment scale model building research

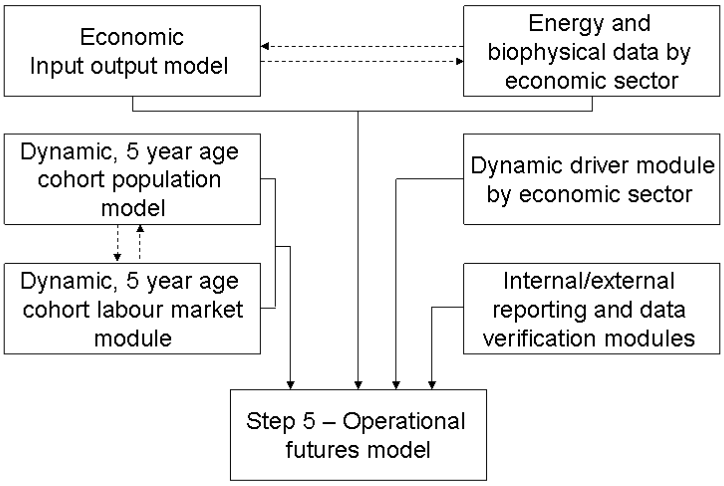

Figure 7 *The various sub-components of the fully operational futures model are depicted in a manner which shows how they related to each other.*

Steps 6-10 – As of the writing of this paper steps 6-10 and beyond are still to be completed. Step6 involves the collection of addition ecological, social and cultural data that can be clipped into the existing structure of the model in a manner that broadens the scope and power of the model. Step 7 is a repeat run of step 5 that involves the development of a dynamic driver module. This driver module needs a process of much broader participation and validation that will ground this part of the model in a combination of empirical data, current theory and local knowledge.

In step 8, a representative stakeholder group will work together with the model builder and appropriate facilitators to map out a series of developmental scenarios for the use of the futures model. These scenarios will be run and adjusted in a group participation mode. In step 9, the results of the scenario runs will be evaluated and written up in a series of reports that inter-relate the various growth scenarios of the catchment with what the model is able to tell us about likely ecological, social and cultural costs and benefits. An effort will be made at this stage similar to step 3 to ensure that the model results connect with and inform current planning and policy process.

In step 10, the model will be institutionally embedded, a process that implies: (i) agreement on the nature and scope of future use of the model, (ii) the development of a suitable user interface and (iii) training of support staff to provide future data management, data monitoring, updating of the model datasets and facilitation of its use by local interest groups. Step 10 re-links with steps 6-10 in an ongoing operational loop that is intended to provide for the on-going use of the model as an adaptive management support tool.

3.2 Theoretical scope

The futures model is grounded and based in 5 main bodies of theory which are individually outlined below.

3.2.1 Ecological economic theory – the over arching theory base for this futures modelling research is drawn from the ecological economic literature (Costanza, 1989) that provides a critique of conventional economics (Costanza, 1991; Costanza, 1996;

Daly, 1973a; Daly, 1973b; Daly, 1968; O'Riordan, 1993) and a theoretical and methodological frontier for the development of tools to address these problems. Within this broad field of research and theory, the model specifically integrates across (i) current thinking on the use of system dynamics modelling software (Costanza & Gottlieb, 1998; Costanza & Voinov, 2001; Costanza, 1987) in the development of (ii) whole-of-system modelling tools (Costanza & Folke, 1997), (iii) developed in a participatory (Maxwell & Costanza, 2006; van den Belt, 2004) open context that links (iv) economic processes (Bockstael et al., 1995) with (v) ecological processes (Costanza, 1994) to (vi) explore sustainable futures (O'Riordan, 1993) with an emphasis on (vii) connecting theory and practice (Costanza et al., 2002).

The development of ecological datasets for the model is grounded in ecosystem services theory (Daily, 1997; Goulder & Kennedy, 1997). The ability to integrate economic, social, ecological cultural datasets together in one single model draws on the ecological economics theories of value (Ulanowicz, 1991; Patterson, 1998; Costanza, 1980) literature.

3.2.2 Economic theory - the structural foundation of the futures model is a static economic input output model that provides a stationary, data-rich portrayal of annual economic transactions by sector for a given local economy (Leontieff, 1941; Kurz & Salvadori, 1998). The input output table has been constructed by utilizing national-level input output and employment data in association with a GRIT method adapted to catchment scale (West et al., 1980). The input output table is yet to be locally verified using standard econometric survey techniques.

The futures model draws on labour market (Spoonley et al., 2004; Shirley et al., 1998) and demographic theory (Pool, 2002; Zodgekar & Khawaja, 2002; Newell, 2002) in the development of the linked component cohort population model and labour market module. The dynamic drivers for the futures model are grounded in macro-economic theory (Honda, 1998; Dalziel & Lattimore, 1991) which provides a near-equilibrium theoretical basis for linking the various interactions between the global (Clark & Williams, 1995), national (Lane, 1983) and regional economies.

At a micro-economic scale, the development of the economic drivers requires an acquaintance with the drivers (Hansen & King, 2004; Chatterjee, 1988) and historic behaviour of individual economic sectors (Easton, 1997; Callander, 1998; Callander, 1992; Easton, 1982) including their relationship to the New Zealand labour market (Shirley et al., 1998). The dynamic, biophysical input output model at the heart of the futures model builds on leading input-output theory and practice as a basis for integrating economic and biophysical data (Daly, 1968; Isard, 1968; Leontief, 1970; Victor, 1972b).

3.2.3 Mathematical theory

The futures model is mathematically based on the use of coupled systems of finite difference equations as employed in system dynamics modelling software (Ventana Systems, 2002). The input output model and data entity is based in matrix algebra (Leontieff, 1941; Victor, 1972a; Victor, 1972b). The demographic module of the futures model is based on component cohort population model theory (Pittenger, 1980; Pittenger, 1977; Pittenger, 1976; Klosterman et al., 1993) and an understanding of curve fitting techniques (Kuo & Fox, 1992) needed to re-construct incomplete historic datasets. The development of a dynamic driver module for the future model builds of the theoretical foundations of cross-impact matrix analysis (Gordon & Hayward, 1968; Cole A.O. et al., 2006) and influence theory (Vester, 2004; Vester & Hesler, 1982; Cole, 2006f). The overall structure of the model is built by using the modelling principles and theory provided in the system dynamics literature which provides guidelines for the mathematical treatment of: (i) time, (ii) space, (iii) scale and (iv) cross-boundary interdependencies (van den Belt, 2004; Keys, 1990; Morecroft, 1987). Rapid assessment techniques (McDonald & Patterson, 1998b; McDonald & Patterson, 1998a; McDonald & Patterson, 1999; Cole et al., 2003) for the development of datasets from incomplete knowledge about the relationship between mass and energy flows through the catchment economy and annual economic activity by sector.

3.2.4 System context

One of the greatest challenges of this modelling research project lies in bridging the gap between the theoretical scope of the futures model and real-world practice (Bingham et al., 1995; Costanza & Cornwell, 1992; Costanza et al., 1992), especially in New Zealand's current planning and policy context. This dimension of model development combines theory in the areas of: (i) organisational learning (Senge et al., 2005; Senge et al., 2004; Kim & Senge, 1994), (ii) educational psychology (Gardner, 1999; Gardner, 1993b; Gardner, 1993a; Gardner, 1983; Sharma et al., 2006; Carmichael et al., 2004), and (iii) transdisciplinarity (McGregor, 2005; Nicolescu, 2005; Nicolescu, 2002; Nicolescu, 2000; Nicolescu, 1996; Max-Neef, 2004) with knowledge of and experience in New Zealand's legislative and local body context.

3.3 Model classification

The Motueka futures model is a multiple goal, aspatial, discrete time, system dynamics futures model based on multiple units of account. The model assumes that economic growth results from both endogenous and exogenous drivers which are influenced by partial price functions, biophysical change in the system and time-delayed feedback from the final demand end of the economy.

3.4 Modelling rationale

The Motueka futures model is designed to produce projections of system behaviour into the future rather than exact predictions. The focus of projections is on the identification of upper and lower bounds of likely behaviour (Costanza et al., 1992). The combination of model structure and the user interface provided by the Vensim software provides scope for the evaluation of the model based on fundamental system properties such as feedback regulation, thresholds and the impact of time delays. The model structure is designed around the cross-matching of biophysical, social, ecological and cultural datasets at sector scale which provides significant scope for data-rich analysis of model scenarios and projections. Model validation is undertaken on a component-by-component basis in participation with local expert knowledge. Where ever possible, historical data has been collected to make back casting of the model possible. Where ever possible, model relationships have been empirically based and in the absence of data we have relied upon expert knowledge and theory.

3.5 Modelling rationale: key model assumptions

Below, we comment on those key assumptions needed to uphold the modelling rationale outlined above. The Motueka catchment futures model assumes that feedback regulated economic growth linked with indicators of ecological, social and cultural change provides a suitable basis for achieving sustainability across the quadruple bottom line. The futures model further assumes that the most effective way of identifying preferred developmental pathways that minimise negative ecological, economic and social impacts lies in: (i) a participatory process in which (ii) the futures model facilitates dialogue around (iii) key trade-offs to be made in achieving multiple system goals as quantified in the model.

In terms of system dynamics, we assume that the model system stays near-equilibrium and can be usefully projected over a time horizon of 1-10 years (i.e. a time horizon that does not include the need to represent significant structural change in the model). Finally, we assume that economic, demographic, ecological, social and cultural system structures can be adequately represented within the confines of the system dynamics stocks and flows modelling paradigm based on the discrete (annual) treatment of time.

3.6 Epistemology

The method section outlined above has been provided in order to more fully document the complex theoretical and empirical nature of the Motueka futures model. The futures model is a product of serious theoretical integration across a diverse range of academic disciplines grounded in mathematical rigor and extensive participatory process. The question may now be asked, "after this extensive research effort that has taken 3 years (plus) and that still falls short of what might have been done, how much closer are we towards achieving a sustainable future"? In the results section of this paper we seek to answer this question. We show that what has thus far been accomplished in building a futures model; by seeking to co-ordinate theory, data and methods in a kind of multidisciplinary synthesis; still falls well short of addressing the actual nature and character of the local sustainability *problématique*.

4. Results

Having articulated the strengths and potentials of the Motueka futures model (above), we document some of its more obvious weaknesses when measured against the goal of achieving locally owned sustainability outcomes.

Observed weaknesses in our modelling strategy and participatory modelling approach, include: (i) the existence of differing worldviews within the stakeholder community (ii) the inadequacy of consensus-building, (iii) the choice of an appropriate model structure and drivers, (iv) the existence of both scientific subject and object complexity and (v) the challenge of integrating indigenous knowledge. These challenges may all be thought of as barriers to achieving sustainability outcomes.

4.1 Differing worldviews

The stakeholders have a sum total of worldviews[7], interests and agendas that are often contradictory in nature (Table 2) and this clearly has implications for the ability of a model to adequately represent reality. How do we decide, *a priori*, which stakeholder worldviews should form the basis of model development that will have turned out to have been helpful in achieving a future sustainable state?

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[7] A detailed treatment of divergent worldviews among the stakeholder group is documented in Cole and Maxwell (2005)

Table 2 *Contradictory entities associated with divergent worldviews held by differing stakeholder groups within the catchment.*

1	Economic Growth	No Economic Growth
2	Simple Qualitative Models	Complex Empirical Models
3	Spatial Models	Aspatial Models
4	Real-world	Own-world
5	Macro-physical	Meta-physical
6	Precautionary	Pragmatic
7	Land Use	Land Preservation
8	Strong Sustainability	No Sustainability
9	Ethically strong	Ethically weak

4.2 The adequacy of consensus building

In light of the divergent perspectives shown in Tables 2 and 3, which theory of choice (e.g. democracy, consensus building, deliberation, dialogical democracy, autocracy, socialistic) should be used to make decisions *a priori* that will have turned out in the end to have assisted progress towards a preferred sustainable state?

4.3 Model structure and drivers

There is no model that we can build that can be all things to all people. How do we determine *a priori* which model structure or assumptions will have turned out to have been useful in terms of assisting progress towards future sustainable state? In building the Motueka futures model we have assumed *a priori* that we can achieve sustainability outcomes by adapting conventional economic growth models to track environmental, cultural and social externalities. This approach is based on the assumption of economic growth as a foundation for sustainability. However, sustainability, in theory at least, implies a global-scale re-orientation away from quantitative economic growth towards qualitative growth (WCED, 1987). It's unlikely that the structure and drivers of an economic growth model will help to achieve the efficiency and structural changes implied by a qualitative growth goal.

4.4 The existence of both subject and object complexity

The Motueka futures model is primarily concerned with the depiction and representation of horizontal and transversal complexity (Figure 8). Of the total available transversal complexity within the catchment system[8], the model focuses on: (i) economic sectors, (ii) ecological processes at ecosystem and landscape scale, (iii) social processes at community scale and (iv) cultural processes at iwi scale (the region of transversal organisational scale shaded in grey in Figure 8). In its current state, the Motueka futures model fails to acknowledge the existence of: (i) vertical complexity (levels of reality) that clearly exists (Table 2) outside of the multi-disciplinary, perceptual reference point that the model represents, (ii) much of the transversal complexity that also clearly exists (Figure 8) but has not been integrated into the model structure, and (iii) the horizontal complexity not represented or inadequately represented by the quadruple bottom line system of classification (e.g. the climate system, marine ecosystems, biogeochemical processes). Points ii and iii outlined above represent a classic example of the model builder's trade-off or boundary

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[8] Which due to space limitations is not fully represented within this illustration

problem (Weisberg, 2003) as viewed from a classical Western scientific epistemology. Points i, ii and iii represent the scope of a model building problem as viewed from a transdisciplinary epistemology.

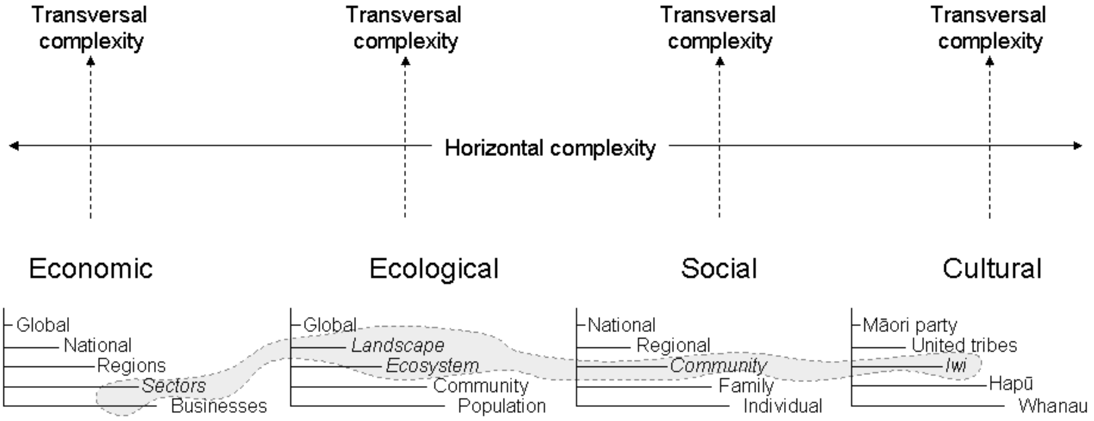

Figure 8 *Graphical portrayal of the existence of horizontal and transversal complexity in the structure of the Motueka catchment futures model.*

4.5 Integrating indigeneity

How do we meaningfully integrate the language and approach to science (Cole, 2006e) of the Maori people into a mediated modelling process grounded entirely in a Western European scientific epistemology? Furthermore, in the economic domain of complexity, how do we integrate: (i) a kaupapa Māori approach to economic organisation and (ii) assumptions about human behaviour based on reciprocal generosity[9] into a conventional economic framework (Cole, 2006)?

4.6 Getting sustainability right by accident

Given the complexity of both the scientific subject and object components of our futures modelling project (outlined above), can we safely assume that: (i) a consensus-building approach based on, (ii) neo-classical economic growth models and drivers, (iii) which ignore the existence of logical contradictions, and (iv) exclude indigenous knowledge from decision-making will lead to sustainable futures? It is possible that a sustainable outcome might be accomplished by accident when using this type of approach? Given the complexity of the problem, this outcome seems highly unlikely.

The above section has focused on outlining the challenges that have emerged in the course of our futures modelling research project. What is readily apparent from this brief evaluation is that the problem of sustainability falls with the solution-space of a strong transdisciplinary epistemology that is capable of (i) integrating levels of reality (sub-sections 4.1, 4.3, 4.5), (ii) finding a T-state when confronted with contradictory logic (sub-section 4.2) and (iii) accounting for the existence of vertical complexity (sub-section 4.4). Our current model structure is limited within the confines of a cross-disciplinary perspective of the world. This conclusion can be more strongly supported by depicting the preferences of the different worldviews outlined in sub-section 4.1, 4.3 and 4.5 above and Table 2 in a model that graphically includes the missing dimension of vertical complexity.

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[9] As opposed to self-interest

4.7 Adding the vertical complexity dimension

As a basis for depicting vertical complexity it is first necessary to ensure the adequate depiction of horizontal and transversal complexity (Figure 8). In order to simplify the following illustration, Figure 8 has been collapsed into the simplified system of horizontal and transversal complexity shown in Figure 9.

Figure 9 *A simplified representation of horizontal and transversal complexity as depicted in Figure 8*

In Figure 10, the horizontal and transversal complexity dimensions depicted in Figures 8 and 9 forms the foundation of a model that includes vertical complexity. Above the horizontal and transversal foundation is depicted various model attributes that can be represented by a series of categories that forms of type of attribute continuum (when reading from left to right). The various attribute continuums are outlined and explained below.

Preferred model type – is a continuum that grades from spatial complexity at one extreme to model simplicity at the other and contains 6 possible categories or approaches to futures model development.

Preferred model aim – is a continuum that grades from the development of conceptual models developed with the explicit aim of communicating ideas, to the use of theoretical models for the express purpose of encoding and testing theory. There are 4 categories of feasible model aims represented in this continuum.

Preferred scenario type - is a continuum that grades from a metaphysical-based model scenario that might be of interest to an indigenous culture to a purely pragmatic scenario type involving a high degree of abstraction and a low level of realism. There are 5 possible scenario types in this attribute continuum.

Ethical preference – contains 3 possible categories for giving expression to preferred ethical preferences in a futures model. The continuum grades from ethically weak to strong with moderate being the middle position.

Economic orientation - is a continuum that grades from growth through no-growth to qualitative growth. This continuum acknowledges the fact that there are at least 3 possible type of economic model that could be developed.

Preferred model scale - is a continuum that grades from national to sub-catchment and thus gives opportunity to express preference for the desired levels of organisational scale to be represented in a model.

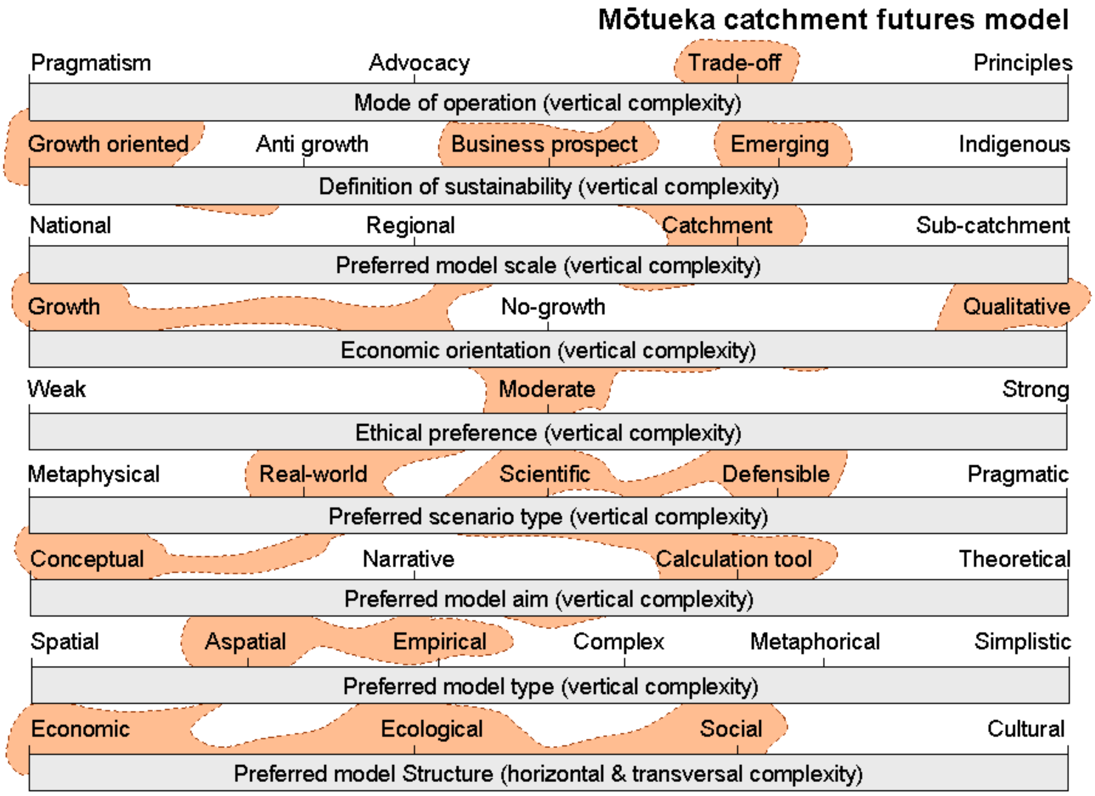

Figure 10 *The inclusion of vertical complexity and mapping of the Motueka catchment futures model solution space (shaded in orange).*

Definition of sustainability - is a continuum that grades from growth oriented to indigenous. There are 5 categories in this continuum that provide opportunity for economic growth oriented, anti-growth, business prospect, emerging and indigenous perspectives on sustainability to be expressed as preferences in a Future model.

Mode of operation – this continuum acknowledges that sustainability outcomes from a model can be achieved by utilizing different facilitation methods (pragmatism, advocacy, building trade-offs and following guiding principles (e.g. guiding kaupapa)). In total there are 4 possible categories in this continuum.

A second feature of Figure 10 is that the various attributes of the existing Motueka futures model have been mapped in terms of the categories covered by this model (shaded in orange). This map is coloured orange and represents the total potential solution space of the current Motueka futures model in terms of its ability to achieve sustainability outcomes. By contrast, in Figure 11 we have mapped the total solution space required to include all of the various stakeholder worldviews and preferences outlined in sub-sections 4.1, 4.3, 4.5 and Table 2 above.

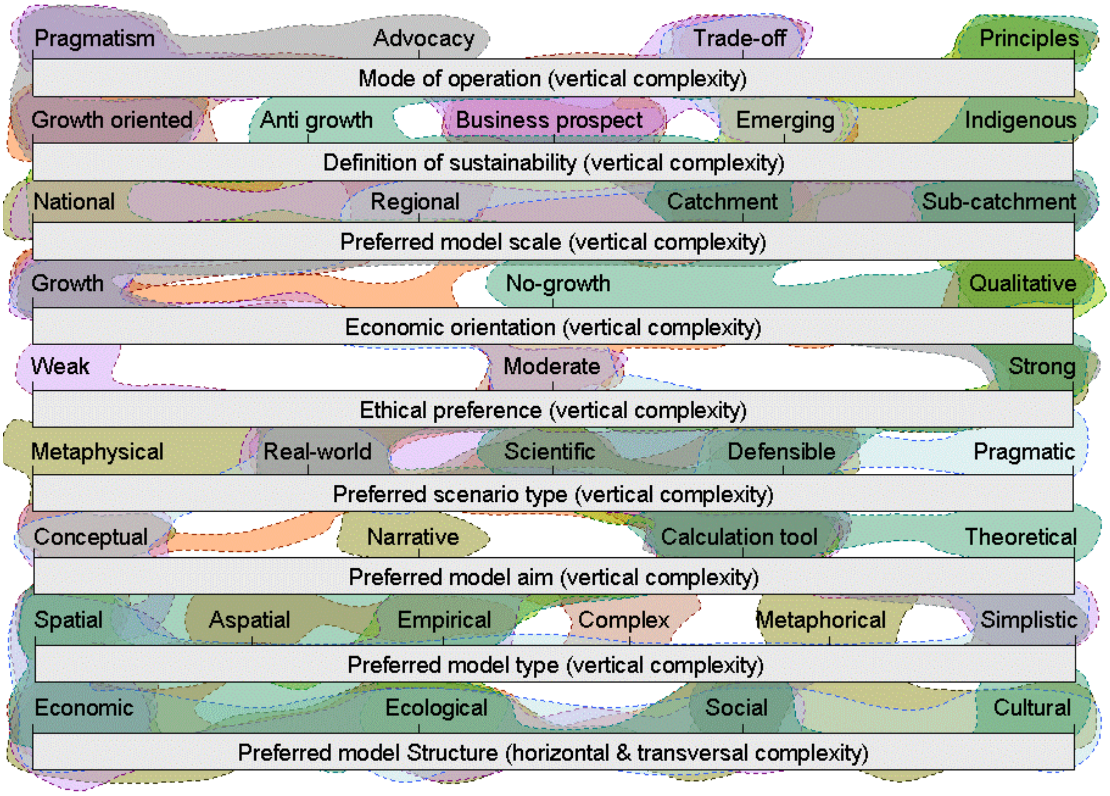

Figure 11 *A composite map of all Motueka catchment stakeholder worldviews and preferences in terms of preferred model structure and approach for achieving sustainability outcomes*

5. Discussion

The illustration shown in Figure 11 reveals a number of interesting points. First, the addition of all stakeholder worldviews and preferences in composite map form produces a very complex and rich vertical complexity structure. Second, the total solution space mapped in the various shaded colours of Figure 11 represents an approximation of the actual scope of the sustainability *problématique* in this local context. By including all known dimensions (vertical complexity) it is easier to see that disciplinarity and weak transdisciplinarity (Max-Neef, 2004) research co-ordination as used in the Motueka futures model cannot solve the sustainability *problématique* for everyone. Third, by comparing Figures 10 and 11 we can see that this local sustainability *problématique* resists reduction into component parts in the same way that macro-physical reality resists reduction into quantum reality (Neane-Drummond et al., 1999). By mapping the various complexity dimensions we can begin to more clearly see the limitations of a disciplinary approach to the sustainability *problématique*.

First, classical scientific method implies the existence of a single, level of reality in the subject/object model, as a preferred reference point for knowledge development. Currently, there exists some 8000 academic disciplinary reference points (Nicolescu, 2005). The Motueka futures model has involved a significant effort to co-ordinate disciplinary-based theory, data and methods across a range of disciplines. However, this effort still falls short of adequately addressing the complexity associated with this local sustainability *problématique* for everyone involved. A multidisciplinary futures model of this kind can at best only represent a very small percentage (ca. < 0.25%[10]) of the knowledge potential that exists within all academic disciplines alone (i.e. assuming we can exclude the constituent complexity associated with a diverse range of stakeholder worldviews (Table 2)). Is this enough to achieve sustainability outcomes?

Second, the current state of our disciplinary-based modelling paradigms is inadequate to deal with the level of complexity shown in Figure 11. As indicated in Table 2, many of the individual stakeholder maps portrayed in Figure 11 represent a statement of logical contradictory positions. For example, we have one stakeholder group who are strong advocates for economic growth and other groups who are equally strong advocates for no growth options. Each of these perceptions (growth, no-growth and qualitative growth) is based on its own internally consistent logic and system of rational/subjective validation.

No individual perception of reality is non-essential because there is no single perceptual reference point from which it is possible to apprehend all reality (Nicolescu, 2005) and it is in this way that this local sustainability *problématique* resists reduction. Resistance to reduction is a problem for classical scientific method because the logic of the excluded middle (Nakhnikian, 1974; Earnes, 1969; Dorward, 1951) is intolerant of inclusion (Brenner, 2005). Based on exclusive logic, the only way to reduce this problem is to exclude parts (Figure 10) and disciplinarity is the basis upon which this filtering process is usually undertaken. However, by using this approach, "exclusion" becomes the default logic of sustainability with the direction of movement towards a sustainable future indirectly dictated by the disciplinary orientation (the filter). The Motueka futures model was an attempt to address this problem by seriously integrating across disciplines, however even multi-disciplinary co-ordination still operates from exclusive logic. Hence, the effect is to change the filter rather than remove it. Research co-ordination across and between different disciplines cannot solve the irreducibility problem because it is an epistemological problem, *not a complexity problem.*

Third, given the problem of resistance to reduction outlined above, it should come as no surprise that even a superficial survey of the published literature on sustainability reveals that attempts to define sustainability are typically disciplinary based (Pezzoli, 1997b; Pezzoli, 1997a[11]).

Fourth, interdisciplinary and multidisciplinary research is currently called for by government funding agencies because of an assumption that the achievement of sustainability is a complex problem. This assumption is only partly correct if our conception of complexity has been limited by a Western scientific epistemological orientation. As this paper has endeavoured to show, while the Motueka futures model has achieved a significant degree of horizontal and transversal complexity integration, this still represents a considerable abstraction of the actual complex reality implied by this local sustainability *problématique*, let alone a sustainability goal of global scale! The Motueka futures model has failed to deal with the problem of vertical complexity

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[10] The estimate of less than 0.25% assumes the development of a multidisciplinary model by successfully integrating knowledge and methods across 20 academic disciplines.

[11] These two papers by Pezzoli have attempted to gather together the many disciplinary definition of sustainability so as to make them easily available for transdisciplinary synthesis.

which arguably is the most difficult and most important dimension of the sustainability *problématique*.

Fifth, the central role played by objective rationality as defined by the logical/mathematical intelligences limits Western scientific method to a fraction of its potential perceptive power as defined by the full range of multiple intelligences. As implied by the Heisenberg rationality – subjectivity continuum (Heisenberg, 1942), we should not reject (or exclude) a perception of reality for no other reason than it is encoded in a form of intelligence that we don't share. This point implies that the inclusion of vertical complexity in the sustainability equation creates a highly complex irreducible problem. The existence of different perceptions of reality implies the existence and use of different combinations and permutations of sensory capabilities. Because of this fact, we cannot assume that superiority in the logical/mathematical intelligence prepares Western science for trying to communicate in a stakeholder language or logic defined by other combinations of intelligence (Cole & Maxwell, 2005).

In summary, the sustainability *problématique* involves complexity that resists reduction. Futures models based on Western scientific method and its typology of co-ordination across and between the disciplines seek to solve the irreducibility problem by: (i) excluding complexity, (ii) with the aid of disciplinary filters while (iii) relying upon logical/mathematical intelligence (iv) as a basis for knowledge capture.

A strong transdisciplinary approach to the sustainability *problématique* attempts to deal with the irreducibility problem by: (i) acknowledging the existence and validity of multiple levels/perceptions of reality, (ii) providing for the reconciliation of contradictions through the logic of the included middle, (iii) working with a typology of complexity that includes horizontal, transversal and vertical dimensions and (iv) acknowledging the existence of both object and subject complexity. This last point satisfies the requirement for inclusion of both objective and subjective perceptions of reality in the Heisenberg continuum.

6. Conclusions

This paper has attempted to show that individual academic disciplines make an essential, but incomplete contribution to sustainability science. Furthermore, recourse to interdisciplinary and multidisciplinary co-ordination of research is not a satisfactory solution to the local sustainability *problématique* because it fails to deal with the problem of vertical complexity and the limitations imposed by objective, logical/mathematical rationality. This comparative epistemological evaluation indicates that the elusive goal of sustainability lies beyond disciplinary research co-ordination and model building. Furthermore, attempts to address a local sustainability *problématique* through reliance on disciplinary filters of reality, system reduction and dependence on objective logic may well turn out to be the Achilles-heel of Western science.

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