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The liminal commons; theorising efficiency-induced complexity in socio-ecological systems

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Abstract

With heightened concerns for resource scarcity, growing interest in management performance, new emphases on green growth and improved understandings of the inter-linkages between resources (e.g. water and energy), the efficiency of resource utilisation come under increasing scrutiny. In such circumstances, the politics, science and outcomes of changes in the efficiencies of resource use and reuse become paramount if we are to conserve resources and boost productivity without creating unforeseen externalities, unwittingly raise total consumption or incur expenditure without benefit. This paper identifies an options space, termed the 'liminal commons', associated with efficiency and productivity, and the size, types and destinations of wastage and waste, which in turn influence how we sustainably govern certain types of commons. The uncertainties of this options space create significant management risks as well as differences between the political and scientific expectations of the benefits of raising efficiency and productivity of natural resources and their final outcomes. Thus the liminal commons frames efficiency-centred endeavours as 'in limbo' problematically located on the boundaries between beliefs regarding current use, future intended use (and directions of travel), and final outcomes. The Jevons Paradox – when efficiency gains in energy production fail to reduce aggregate consumption – is one expression of the liminal commons. The paper identifies four types of liminal commons for different resource conversions between inputs and outputs; a) ratio conversions (e.g. energy efficiency); b) multipath conversions between mainly quantitative forms of the resource (e.g. withdrawals for irrigation converted to crop evaporation); c) polymorphic conversions between mainly qualitatively different outcomes (e.g. carbon as forests and carbon as biodiversity) and; d) composite conversions involving linked resources (e.g. water and energy). The paper contrasts the liminal commons with the 'commons', and includes examples from irrigation systems, energy, ecosystem services, forests and carbon. It is proposed that liminality modifies the principle of subtractability applied to natural resources (that resources subtracted in one place are not available elsewhere) requiring revised thinking on property rights.

Key words: Commons, liminal, water, efficiency, irrigation, Jevons Paradox, productivity, complexity.

1. Introduction

The study of the commons continues to produce metaphors and labels to better convey understandings of resource governance. Updating Hardin's 'Tragedy of the Commons' (1968) examples include: 'commons and anticommons' where under or over regulation is tested (Heller 2008; Brede 2009); 'inverse commons' (Raymond, 1999) where greater consumption and sharing leads to greater good (as with open source software); 'new commons' (Hess, 2008) identified as those without developed rules and institutions; and the 'semi-commons' where overlapping ownership regimes in water exist (Smith, 2008). I use the term 'liminal commons' to capture emerging uncertainties and complexities associated with managing efficiency, waste and wastages applied to resource conservation and the search for sustainable consumption. These complexities arise from the high number of potential options and pathways that arise during efficiency-centred attempts to produce more goods, services and benefits from fewer environmental resources. I argue these potentials, moreover our conceptions of these potentials, and their often unexpected 'decomposition' into different outcomes, both guide and thwart resource sustainability and governance.

Thus, the liminal commons can be seen as a 'politics of expectancy' because they frames the uncertain differences between; a) the prefigurations of the promise of efficiency/ productivity[i] gains within a political-science realm and; b) the extant and often unforeseen material, productive and distributive outcomes for users and resources following attempts to make savings. These differences arise because efficiency-type conversions at different scales lead to numerous possible outcomes, especially when uncontrolled for in terms of setting clear boundaries, regulation, accounting methods and measurement, and because too often the science of efficiency improvements – either theoretically or in practice via technological or institutional interventions – is inadequate. Some of these ideas are captured within the literatures around the Jevons Paradox (Polemini et al, 2008) and agricultural water savings (Seckler, 1996; Crase and O'Keefe. 2009), but this paper provides a broader analysis of this phenomenon. While carbon, forests and energy are discussed briefly, I mostly choose irrigation to discuss the liminal commons because; the water wastage fraction is volumetrically large and valuable; irrigation water 'flows' via multiple pathways which in turn are difficult to measure; savings in irrigation are subject to competing legal claims, and; the sector witnesses uncertain applications of technologies to drive savings.

In a seven-billion plus world exploring the limits of resource availability and distribution, the science and politics of resource efficiency and performance dictate the extent to which living and environmental standards may be maintained, made

[i] On the whole, unless I make clear otherwise, the term efficiency includes productivity.

equitable and just. Sax (1990, page 258) wrote in reference to resource limits on "spaceship earth"; "It is not by accident that we are turning towards the control of waste and water marketing as ways to reallocate existing supplies and meet new demand. There is also increasing interest in reuse of existing water supplies and in technical means to achieve equal output with smaller inputs of water". These challenges have expressed themselves in a variety of efficiency-and productivity-centred ecologically minded thinking that has arisen in the last twenty years; eco-efficiency, industrial ecology, industrial metabolism and x-factor production (Reijnders, 1998; WBCSD, 2000; Anderberg (1998); ecological modernisation (Warner, 2010) and green growth (OECD, 2011).

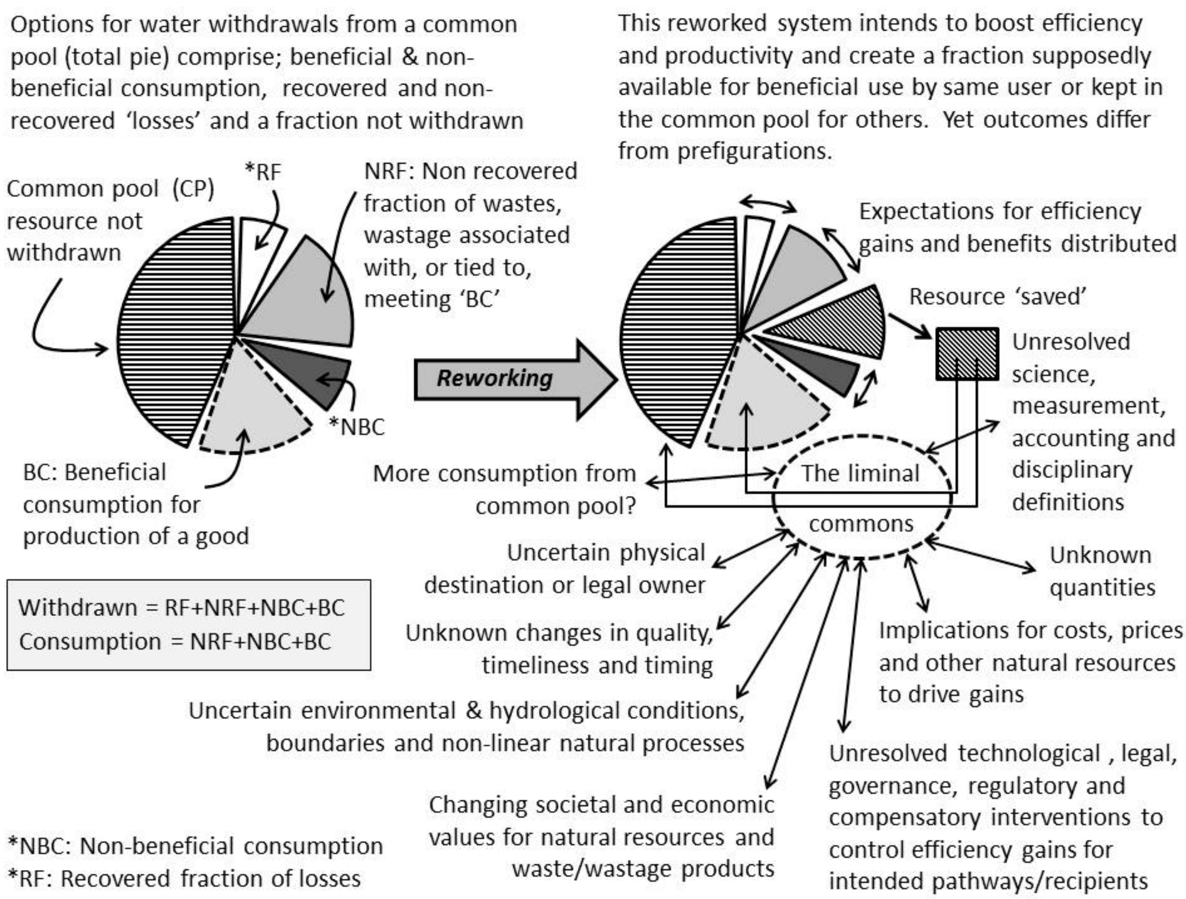
Increasing demand, scarcity, finance accountability and interconnections between input resources (such as land, energy, water and labour) establish new impetuses for management; to reduce consumption of natural resources while maintaining economic growth; to save money, labour and other inputs; to reuse and profit from waste products; and to reduce harmful pollution. Three interrelated responses arise – the first is that wastage and waste[ii] both as process (e.g. irrigation efficiency) and product (e.g. drainage effluent) come under increasing scrutiny and investigation. Second, attempts to manage natural resource 'commons' by reducing or reusing waste/wastage become more attractive; and third, monitoring waste and wastage becomes critical to knowing and adjusting the management of efficiency. However these are not straightforward; a range of conceptual and practical questions arise connected to how we perceive the role of efficiencies in resource management. Examples include the extent to which we discern and distinguish processes of recycling of waste/wastages and the selection of boundaries of systems under scrutiny. Scaling up to larger systems also is a challenge; it is one thing to decrease the total water consumption of one farmer's field; a very different matter to reduce the impact of an irrigation system on its hydrological environs; or at a larger scale, to improve the efficiency of a whole country's irrigation sector (As Spain attempted in the last 12 years with mixed results, see Lopez-Gunn et al, 2012). Further complications in efficiency science apply to the questionable claims (Larson and Richter, 2009) that water losses can be 'saved' in order to offset consumption elsewhere.

In this paper I argue that engaging with sustainability via 'efficiency' imbues socio-ecological systems with complexity and unpredictability. Thus commons liminality adds to other risks and complexities in resource science and governance where

[ii] Following dictionary definitions, 'wastes' are undesirable by-products and wastages are losses during conversion. For irrigation, saline drainage water is waste and open channel evaporation is wastage. Abundantly clear however is that this distinction rarely holds; waste takes place because of wastage, what is waste today becomes valuable in the future, and both can interchange and be recycled to provide useful benefits. These fluxes help define the essential uncertainties of the liminal commons (section .

outcomes either do not meet expectations, are unpredictable or difficult to manage. Other risks include random variation, measurement error, and non-linearity in the natural world[iii] (Clarke, 2006), dynamic equilibriums (Leach et al, 2010), non-stationarity and natural variability (Lundqvist, 2009) and inappropriate governance regimes ill-fitted to ecosystem types (Berge and Van Laerhoven, 2011). Figure 1 depicts the central role of waste/wastages and of efficiency/productivity in the science and politics of managing the commons, and of the contrasts between expectations of savings via efficiencies for eventual reductions in 'real savings' of natural capital. The exploded pie-chart on the right hand side of Figure 1 shows the doubts surrounding resources 'freed up' from savings from, and reductions of, waste/wastage fractions. The substantiating concerns informing and edified by the liminal commons are introduced below, with the paper providing exposition.

Figure 1. Introduction to the liminal commons



[iii] Nevertheless, the imprint of a dynamic natural world exacerbates the irresolution of complex efficiency conversion processes at the heart of the liminal commons concept.

1. At the heart of the liminal commons is a conversion process that relates resource inputs to outputs, and gives rise to waste/wastage and to an efficiency or productivity calculation.
2. In a scarce and increasingly ‘closed’ system world, previously valueless waste products are gaining in value. This in turn ratchets up resource cycling/cyclicality and the avoidance of waste. For example, carbon dioxide, once an externalised wastage of countless natural and human metabolic processes is now increasingly internalised, priced and ‘avoided’. In irrigation, volumes of ‘wasted’ water are arguably large and valuable enough to be the object of further re-use.
3. With reference to increasingly closed systems – for example planetary or river basin, (Falkenmark and Molden, 2008), scarcity and resource cyclicality combined with changing scales and boundaries impose new methods for accounting as we seek to understand the additional complexity of internalities of once linearly ejected externalities. This need for accurate accounting and terminology is behind the Jevons Paradox and debates on irrigation efficiency. Likewise, carbon dioxide now vested with value via carbon markets is the subject of budgeting and accounting debates to determine the theory and grounds for judging long-term sequestration (Law and Harmon, 2011).
4. The number of pathways that waste/wastage potentially take reveals the liminal commons. For example, in irrigation there are ten pathways that withdrawals of the gross volume of irrigation water may flow to[iv].
5. Society is increasingly interested in different forms, localities and qualities of wastes/wastages outcomes – exemplified by carbon as different kinds of forests and biodiversity. How these outcomes play out in terms of an equitable and just distribution of post-saving wastes/wastages is also of interest to social scientists.
6. Doubts about the technological, institutional and financial means of raising efficiency shape uncertain outcomes. In irrigation, it is not clear what interventions raise efficiency and crop productivity in a reliable, cost-effective manner while reducing hydrological impact. The inevitable political promises to deal with these options are part of the liminal commons.
7. Property claims over resources destined to be lost or saved from one user (for example seepage from canals) are subject to speculation. Liminality throws up vexed questions of ownership over the fraction of the resource not yet wasted, as well as the resource wasted, plus the resource subsequently ‘saved’ if an efficiency programme is implemented and veritably creates ‘real’ savings.
8. A range of ontological and epistemological concerns regarding system knowledge are illuminated by liminality; the information loss of efficiency

[iv] In their Figure 3, Law and Harmon (2011) identify 22 flows between atmosphere, biofuel stock, long-term products, forest C stocks, short-term products and landfill.

ratios; definitional differences between disciplines; scale and boundary choices for systems identification; and unpredictable emergent behaviour of systems undergoing efficiency-induced changes.

9. Finally, how these uncertainties consequently (often counter-intuitively) determine eventual consumption of natural capital is the defining problem of the liminal commons. The liminal commons forms a heuristic test of the purposes of making 'savings', for example, either for a reduction of total abstraction and consumption, or for resource allocation to other users, or for reuse by the original owner, or as an implicit, even conspiratorial, actuator for increased resource use and consumption.

I have applied the terms 'liminal' and 'liminality' to the commons for the manner in which they capture the uncertainty and 'in-betweenness' of options arising when attempting to reach goals via efficiency/productivity changes. The term liminality arose through the social studies of Van Gennep (1909) who explored rites of passage in various societies. The term has also, amongst other applications, described the transitory period between stages of human experience (Buckingham, 2006), to change within communities (Lawrence, 1997) and to geographical histories of rapidly changing nation states 'being between positions' (Yanlk, 2011). In this literature it is the potential transition-in-waiting, rather than tangible outcomes and new states, that interests scholars.

In summary I argue that increasing scarcity, higher expectations of performance, stronger resource inter-connections and tighter checks on more valuable or costly waste/wastage raise the significance of the study of efficiency. I theorise that for some resources a threshold space arises out of, and recursively shapes, the theory, purpose, science and outcomes of resource efficiency and productivity. This space is where the potentials of size, location and destination of resources and their wastage fractions resolve themselves or, in other words, decompose into different outcomes. The contrast between (usually) optimistic expectations of resource savings/productivity gains set against (often disappointing) consumption and efficiency outcomes produces a political and scientific sphere in which efficiency-change interventions are problematically promised. It is this 'twixt and tween' that offers an opportunity to explore the liminal commons.

I do not aim to write comprehensively on efficiency or to argue that efficiency is exclusively at the heart of sustainability science – see also Jollands (2006). Instead I frame efficiency and productivity in a specific way. When savings and efficiency gains are chosen as strategies for reducing resource consumption, the presence and treatment of 'efficiency' casts doubts on and problematizes the prediction of the outcomes of resource management and sustainability – hence my selection of the term 'liminal commons' and examination of contrasts between it and the 'stock commons'[v]. Simply put, the liminal commons signals great ambiguity regarding how to deliver sustainability via efficiency savings. Recognising the early stages of the development of this idea, the paper is conceptual and explanatory in its conjecture, aiming to add new thinking to the evolving literature on the commons and natural resources sustainability.

1.2 Literature on resource efficiency

The treatment of efficiency-type conversions in the conservation of resources is problematic and far from complete. Despite early discussions of the links between conservation and efficiency[vi] (Hays, 1959) plus a robust debate on the Jevons Paradox on energy efficiency (see below) and emerging literatures on eco-efficiency and Factor X ideas, many mainstream natural resource, commons and ecosystem texts in the last twenty years have paid little attention to responses to conservation and resource sustainability via efficiency improvements. To mention a few, Leach et al (2010), Homer-Dixon (2001) and Adams (2008) treat conservation and distribution via the capping of total consumption to match supply. Whether and how consumption is reduced by managing waste/wastage or by treating withdrawal and consumption[vii] differently is rarely or insufficiently discussed. The result is that the building blocks and mechanisms of the consumption of natural capital – and the consequences of making savings – are poorly defined. This omission is paralleled perhaps more surprisingly in the irrigated agriculture literature, with the exception of specialist articles such as the recent Comprehensive Assessment of Water Management in Agriculture (CAWMA, 2007). Many mainstream texts on the management and conservation of water, including agricultural water, do not unpack efficiency and productivity (see for example: Falkenmark and Rockstrom, 2004; Pearce, 2007; Lenton and Muller, 2009; Rogers and Leal, 2010; Chartres and Varma, 2010; Matthews, et al 2011). This omission in this list is surprising if we note that globally irrigation systems are widely cited to be 40% efficient (see Lankford 2012, for a further discussion on this) thereby 'wasting' 60% of freshwater, in other words, the potential gains to be had for water allocation from even meagre 'savings' of water, are supposedly large[viii].

[v] Later in the paper I distinguish the two and explain my choice of word 'stock' to help contrast current commons theory with the ideas in this paper.

[vi] Although here the term 'efficiency' is of its era, aligned to interests in throughput and 'modernisation'. Thus although I re-engage with environmental productivity, I am not promoting environmental maximisation – see Schroeder, 2000.

[vii] In this paper, withdrawal and appropriation are synonymous but are different to consumption. Withdrawal means utilisation of natural capital which includes both the beneficial consumption to produce a good and additional wastes and wastages that may be required or generated in the process of production. Other terms are introduced and defined in the paper.

[viii] A calculation hints at the potential gains from raising irrigation efficiency – subject to the provisos in this paper. By assuming a global irrigated area of approximately 270 million ha, of which approximately 85% is gravity/surface fed, we could for the purposes of demonstration, accept a 10%

Furthermore technical (or physical) resource 'efficiency' can be confused with a 'political economy' sense of fitting an appropriate regulatory regime to a resource that in turn changes consumption and production – for this reason the implications of resource efficiency on policy and market efficiency/efficacy, and vice versa, are never far away (Leibenstein, 1966, both distinguished and linked the two). Daly (1992) refers to resource efficiency in allocative, fiscal and economic terms; in other words how society successfully bears down on an environmental or allocation problem by selecting the 'proper' tool (e.g. pricing), applying this at an appropriate scale and cost, and observing outcomes. In my discussion, while I exclude these 'governance' dimensions common to all questions of resource sustainability and instead focus on the uncertainties and promises of efficiency and productivity within resource management, I believe that the two are interlinked in ways that cloud, rather than resolve, the complexities suggested by the metaphor of the liminal commons. As I argue elsewhere, the uncertainties of resource efficiency management stem from poor terminology and definition. This might explain why in their essay, although arguing for clarification, Olschewski and Klein (2011) appear, confusingly, to mix their analyses of resource efficiency and economic efficiency, and why back in 1966, Wildavsky cautioned for a teasing out of the different constructions and purposes of efficiency.

Moreover the treatment of ramifications of efficiency improvements in the literature is highly sector- or discipline-specific, with one consequence being that an overall framework and agreed set of definitions has not been agreed despite efforts by scholars (Jollands, 2006). Outside of the debate in irrigation explored in this paper, perhaps best known is the Jevons Paradox, commonly found in the energy literature (Herring, 2006; Sorrell, 2009). Yet although the word 'paradox'[ix] echoes the uncertainties of the liminal commons, the Jevons Paradox is discussed in terms of how energy efficiency of the actual work or energy gained from a work or energy potential translates into 'efficiency-induced consumption of outputs' (Polimeni, 2008) by creating cheaper and more energy. However, as I make clear later, energy efficiency drives uncertainties in different ways to that of irrigation or carbon because the latter two resources have many material pathways that conversions can follow, whereas energy conversion produces heat, light, electricity, noise and vibration.

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relative reduction in total consumption (via non-beneficial consumption and non-recovered losses). Assuming a cautiously low gross annual consumption of 600 mm (building on Doll and Siebert's (2002) figure of approximately 420 mm net crop water requirement globally) this 10% saving in consumption gives a reduction of consumption down to 540 mm, releasing 60 mm depth equivalent. Spread over 270 million hectares, this is equivalent to 0.44 cubic kilometres water per day, the same volume as providing 7 billion people with approximately 63 litres per day of water per person; a sizeable proportion of an individual's daily water requirement.

[ix] The paradox arises because with improved throughput efficiency comes lower costs combined with an improved ability to consume – in other words efficiency savings leads to a 'rebound effect' of greater total consumption.

Ambiguities are often amplified if numerators and denominators of efficiency type ratios are taken for granted. In industry and commerce, ‘eco-efficiency’ views manufactured products or services as the numerator, with one or more ‘environmental pressures’ as the denominator WBCSD (2000; p 9), making eco-efficiency a measure of resource productivity, rather than a dimensionless efficiency indicator. This helps to explain the attraction of eco-efficiency in that the denominator is impact on natural capital, but introduces processual ambiguities if the *means* to raise efficiency and productivity and save resources are not unpacked (a point I level at the emphasis on irrigation productivity - see Lankford, 2006; 2012).

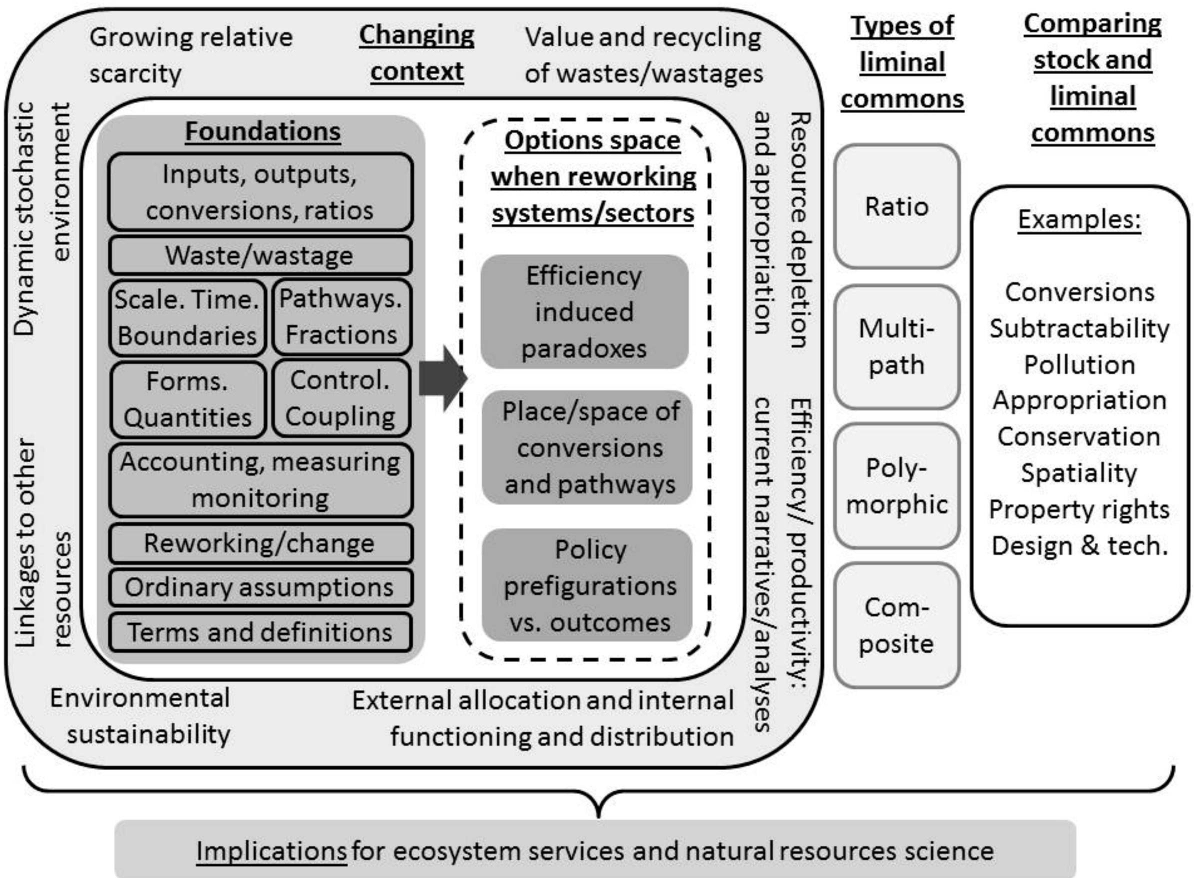
There is also the question of an appropriate scale or unit of interest for examining efficiency thinking. At the micro-scale, I believe, for example, the species-dictated metabolic efficiency of converting water into crop biomass, while of interest to irrigation scheduling within systems (Payero et al, 2009) has less relevance for determining the impacts of irrigation systems on the hydrology of catchments. At the larger scale, one also must be cautious. I surmise that measurement and accounting may never fully trace the complexities of an extended water commons, and here I refer to the ‘flows’ of water in and out of the landscape, rainfed agriculture, environment, urban systems and hydrosphere, soil water, the complexities of groundwater and the vagaries of rainfall (see Linton, 2008, for concerns regarding over-emphases on blue water accounting) and wastewater irrigation from human settlements (Qadir, et al, 2010). Although these systems will have elements of reuse and waste/wastage, to lump them together to create a ‘meta’ liminal commons may lose more than is gained.

Similarly, when assessing combinations of resources such as energy and water, analyses will have to proceed carefully if combined numerators of benefits, and combined denominators of consumed resources, are to retain informational utility for decision-making. Although analytical tools incorporating exergy and emergy (Odum, 1996) help convert different resources to fewer metrics for efficiency and productivity type analyses, these remain thermodynamically (kilojoule) based – a conversion step that might involve loss of information regarding how the resource itself is managed. In the case of irrigation in the paper by Chen et al 2011, unexplained assumptions regarding how water was saved enabled their research to conclude it was ‘water savings’ from efficiencies of 45% increasing to 70% afterwards that resulted in improvements from project interventions. It is my belief that their paper’s failure to explain in detail how these efficiencies were arrived at that undermines the validity of their conclusions – but precisely signals the risks associated with simplified efficiency assumptions applied to resources that have their own rich ‘efficiency theory’ discourse (CAWMA, 2007; Perry, 2007; Lankford 2012; Halsema and Vincent 2012).

2. The liminal commons explained

To explain the liminal commons I use the conceptual framework given in Figure 2. The zones in this Figure labelled 'changing context', 'foundations, 'options space' and 'types' are explained in this Section. The contrasts between liminal and stock commons are given in Section 3, and implications of this theory for three other topics in natural resource governance are explored in Section 4. To save space, terms are selectively defined in the course of the discussion.

Figure 2. Conceptual framework for the liminal commons



2.1 Changing context

A number of contextual factors feed and validate the significance of efficiency type conversions in the search for economic sustainability and environmental protection. Some of these have already been discussed, such as increasing relative scarcity (for example the closure of river basins; the capping of appropriation in order to protect the depletion of ecological systems or to allocate resources to other users; the search for green growth and environmental sustainability; the increasing value of, and ability to recycle, wastes and wastages; current narratives regarding inefficiency combined with normative intentions to raise efficiency and productivity; linkages between resources such as land, energy and water, and; the location of efficiency in responding to natural variability and dynamics such as drought and flooding. Importantly, rapidly changing physical and political contexts feed into further uncertainties around the rationale and interpretation of efficiency improvements – yet paradoxically efficiency knowledge benefits sometimes by being in, and contributing towards, a dynamic environment of contraction and expansion (for example dryness and wetness, winter and summer, and economic boom and recession) than by being placed in a static environment. This is because in the former, as discussed below, we gain experience to judge efficiency measures from relative change rather than from absolute measures.

2.2 Foundations

It is my argument that the more a resource is defined by the presence of losses and efficiencies characterised by quantity, economic value, the geographic scale(s) over which efficiencies take place, and a multiplicity of inputs, conversions and pathway options, the greater the complexity of the resource. With this complexity comes a greater likelihood of incomplete understanding, inadequate monitoring, erroneous accounting of resource flows and mistaken interventions designed to reduce consumption or change distributions via efficiency and productivity. And with these risks comes amplified differences between hopes, potentialities and eventualities of policy interventions – the hallmarks of a liminal commons. In examining how the liminal commons is created, I have identified ten sources or 'foundations' of uncertainties, described below. Mindful of space constraints, I have purposively drawn attention to the technical 'resource' foundations of the liminal commons rather than include additional human, social and institutional complexities related to governance models of managing the commons and commons transitions (Berge and Van Laerhoven, 2011; Geels, 2010) .

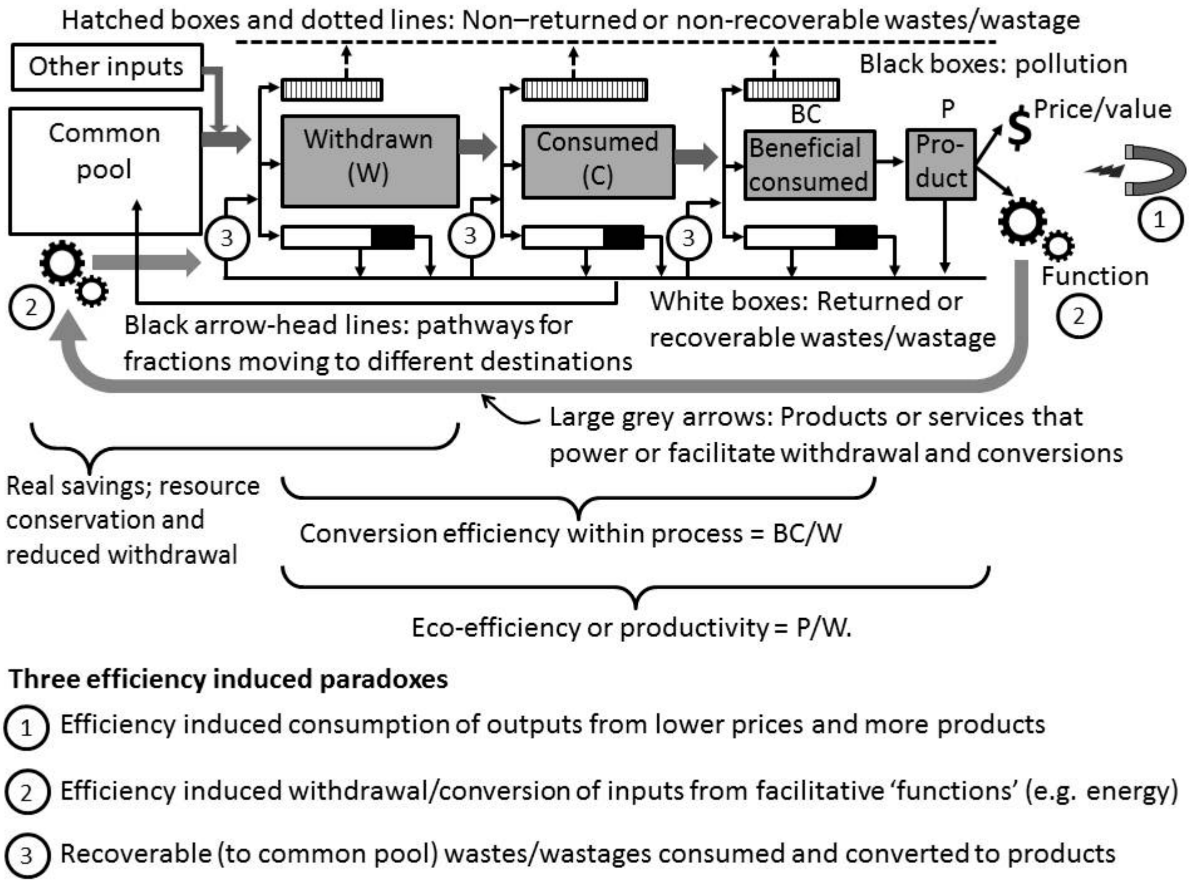
2.2.1. Inputs, outputs, conversions and ratios

The liminal commons is predicated on the insertion of efficiency between what is withdrawn from natural capital and what is produced for society. This requires the conversion of inputs to outputs which, set against each other, allows their ratio to be calculated. Figure 3 depicts a flow from left to right, moving from natural capital to the production of a good. Central to the efficiency ratio is the conversion of inputs to outputs with some degree of loss of waste or wastage. Within this flow one or more conversion steps may take place – Figure 3 gives three steps offering three stages of utilisation; withdrawal, consumption and beneficial consumption[x]. At each stage,

[x] For example, withdrawals into an irrigation system account for net consumption by crops (transpiration) plus all recoverable and non-recoverable fractions, plus non-beneficial consumption (non-crop evaporation). Consumption adds together beneficial and non-beneficial consumption and

unrecoverable wastes/wastages are produced (light grey boxes) and recoverable wastes/wastages (black arrows and boxes).

Figure 3. The efficiency conversion process and three efficiency-induced paradoxes



Resource management may be seen as a chain of practical activities and resources coordinated to appropriate, grow, harvest, store, process and therefore convert various natural capitals such as land and water into products. Examples of activities include scheduling water, selecting varieties, adding fertiliser, ploughing soil and so on. These inputs influence, and are subject to, conversion processes, which if biological (rather than, say, chemical or industrial), turn nutrients, water, sunlight and atmospheric gases into living things. Derived from these inputs and conversions are intermediate outputs such as rice grown, timber felled, wild plants collected and fish caught. And from these, following further conversions of storing, refining, processing, and cleaning are final products such as hulled rice, wood products, packaged wild products and fish ready for sale.

beneficial consumption leaves only crop transpiration remaining. If re-drawn specifically for irrigation (rather than generically as it is now) Figure 3 would have some boxes and arrows removed to depict these differences.

Recording, analysing and comparing performances of resource management means defining the inputs, outputs and ratios while recognising these are fraught with implicit assumptions about the distillation of complex and multiple processes (think of all the biological, natural and human systems creating a tonne of rice) into simple indices – such as tonnes, area, cubic metres of water, labour-days, dollars, and so on. These indices are utilised to create technical performance ratios of outputs to inputs of two types; as dimensionless 'efficiency' ratios or percentages (e.g. the irrigation efficiency of smallholder irrigation system) or as 'resource productivity' with dimensions (e.g. tonnes rice produced per hectare). Easily forgotten are animate/inanimate related timing aspects of efficiency if the conversion process depends on timing to keep things alive and growing – for example crops on irrigation schemes (Lankford, 2006). Thus at the heart of these performance ratios, indeed embodied as the viniculum between numerator and denominator, exist relationships that bind (but also importantly blind) the conversion of inputs to outputs.

2.2.2 Wastes and wastages

An earlier footnote hints at how wastes (physical or chemical material and often seen as polluting though recoverable) and wastages (often intangible such as gas, heat, noise, vibration) might interchange but also become less or more valuable over time. Although the 'form' of wastes and wastages is the subject of sub-section 2.2.5, the flux between waste and wastage is dependent on shifting societal values ascribed to waste/wastage and our technical and market ingenuity. Carbon dioxide is instructive because it is ostensibly a wastage product yet vested with value via carbon markets – in some senses becoming a recoverable 'waste' and turning upside down the nature of the 'commons' (if carbon dioxide is the 'commons' and carbon in timber becomes the conversion). The future legal and technical uncertainties of what wastes and wastages may be valued and recovered feeds the uncertainties of the liminal commons.

2.2.3 Scale, time and boundaries

Knowing inputs, outputs and ratios allows for the step of defining total production and total consumption by controlling for boundaries such as time and area. (For example, 18,000 kg of rice is annually produced from a three hectare farm producing 3000 kg/ha with two seasons per year). As well as area, scale also plays an important role in terms of nesting of systems. Irrigation nested within a larger catchment creates accounting difficulties because local recoverable losses are returned to the hydrological basin. Therefore, knowing the total amount of water consumed (rather than withdrawn) allows for the impact of a particular irrigation system on the host catchment's water balance to be calculated. Similarly, energy savings at the household (micro) level may in turn lead to rebound for the broader (macro) economy (Sorrell, 2009). Controlling for time and timing also offers another uncertainty element of the liminal commons because changes in efficiency may trade-off against timing which in turn may alter production internally (as takes place with irrigation efficiency, Lankford 2006; 2012) or externally via increased demand from time saving (Hertwich, 2005; Ruzzenenti and Basosi, 2008).

Understanding scales, time and boundaries is central to determining how well we manage natural resources and ecosystems, simultaneously knowing how transparently we control for externalities such as pollution that may harm natural systems and long-term productive ability. Boundary control is significant when humans expediently seek to flex and change or obfuscate boundaries (for example by extending time, neglecting sinks, or by borrowing) for the purposes of demonstrating higher performance than otherwise possible without better coordination of inputs. Boundary determination is also important for adjudicating decisions on water rights (Skaggs et al, 2011) and to derive a more complete picture of resource accounting in order to judge performance more holistically – given as society generally attempts to correct free-riders seeking to more cheaply export pollution to nature or marginalised members of society. These two points further appositely inform the performance debate given that in a globalising and more inclusive view of an interconnected planetary commons, obfuscating boundaries is increasingly less tenable or acceptable, and that wastes are either becoming valuable in themselves or are seen more as eroding the ecological resource base.

2.2.4 Fractions and pathways

Exemplified by irrigation, the conversion of natural capital resources into products and various types of wastes/wastages creates 'fractions' (Perry, 2007) of the original resource. Table 1 gives the Perry (2007) taxonomy for physical fractions defined by where water physically ends up and whether it is ready or not to fulfil further work. Taking one example, water losses may end up as non-beneficial consumption if water evaporates from a nearby salt pan situated at the end of an irrigation system. By defining fractions, resource flows are then subject to a debate on water accounting (e.g. Perry, 2011; Molden, 2006; Foster and Perry, 2010)[xi].

Table 1. Water accounting for water withdrawals (Perry 2007)

Consumed Fraction	Beneficial Consumption: Water evaporated or transpired for the intended purpose - for example evaporation from a cooling tower, transpiration from an irrigated crop.
	Non-beneficial Consumption: Water evaporated or transpired for purposes other than the intended use - for example evaporation from water surfaces, riparian vegetation, waterlogged land.
Non-Consumed Fraction	Recoverable Fraction: water that can be captured and re-used - for example flows to drains that return to the river system and percolation from irrigated fields to aquifers; return flows from sewage systems.
	Non-Recoverable Fraction: water that is lost to further use - for example flows to saline groundwater sinks, deep aquifers that are not economically exploitable, or flows to the sea.

[xi] With regards to carbon sequestration pathways an example may be found in Law and Harmon, 2011.

Drawing on Table 1 for the liminal commons theory, I interpret 'fractions' as an exercise in defining where water ends up in a physical place as well as taxonomic fashion (e.g. beneficially, non-beneficially, within the irrigation system or within the basin, and so on). However, ending up in different 'places' is not the same as the potential pathways available. The presence of a 'options space of potential pathways' to redirect resources between fractions is a defining component of the liminal commons. By taking water in irrigation as an example, it is possible to discern ten different pathways that resources, wastes and wastages may fall to (Figure 4 and Table 2 – the numbers in brackets relate to the circled numbers in the Figure). This topic is picked up in detail in section 2.3.2.

Figure 4. Pathways and fractions of the liminal commons (irrigation)

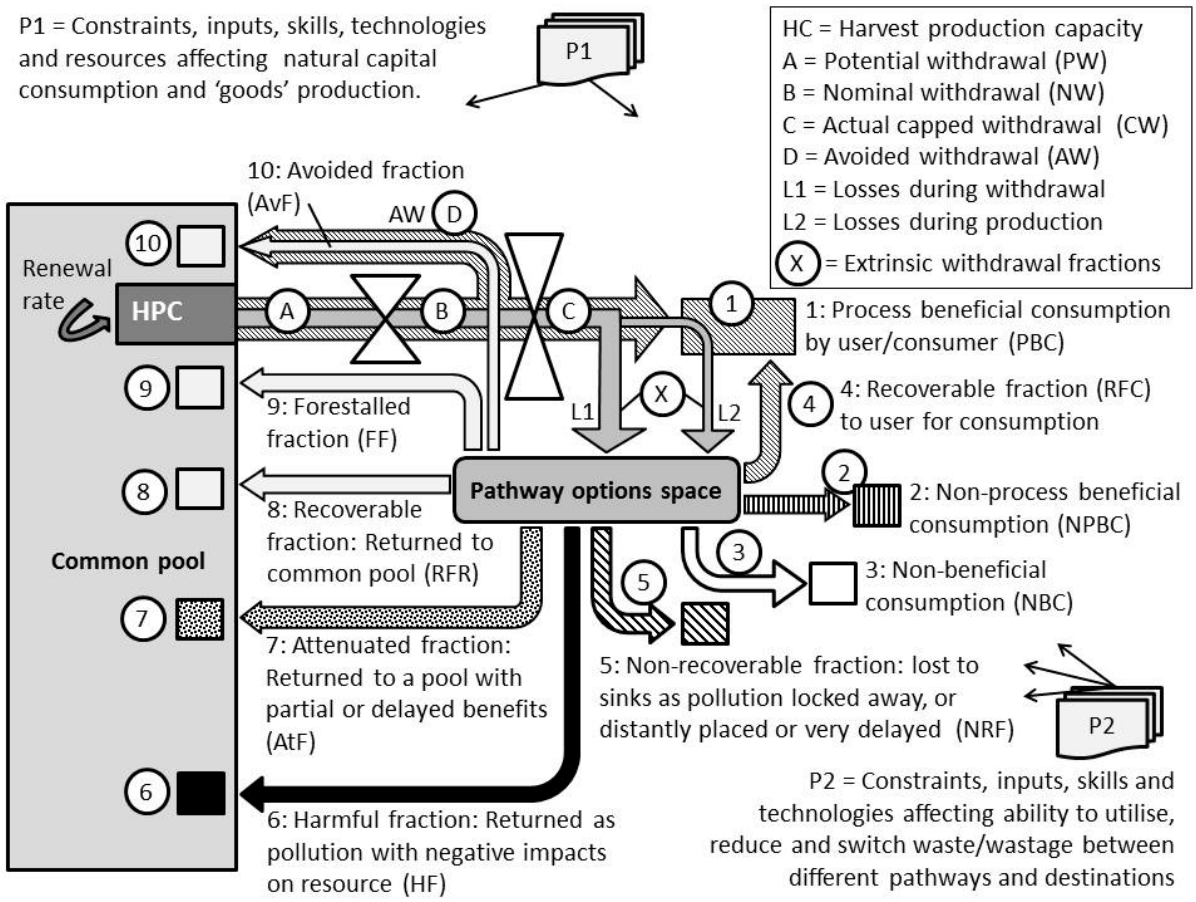


Table 2. Pathways of resource flows when irrigation systems are reworked

Main type	Sub-types
Natural capital withdrawal	Potential withdrawal (PW) [A]. This is the amount of resource that possibly could be harvested or withdrawal. It can exceed a water right or otherwise agreed amount. If exceeds the harvest production capacity of a renewable resource then 'mining' is taking place.
	Nominal withdrawal (NW) [B]. This is the fraction *intended* to be appropriated from the common pool that includes intrinsic and extrinsic fractions. It is normally defined by an established right or officially sanctioned technological constraint.
	Actual capped withdrawal (CW) [C]. This is the water that is withdrawn at any given time, averaged over time. In some instances the capped withdrawal will be greater than the nominal withdrawal but below or equal to the potential withdrawal. At other times, CW will be less than NW, for example via reductions to the water right, or by pricing or a drought.
	Avoided withdrawal (AW) [D]. This is the term applied to the difference between NW and CW when CW<NW, and will equate to a volume of water subsequently not abstracted. As it includes both intrinsic and extrinsic fractions, avoided withdrawal can reduce losses (see 'Avoided fraction' below).
	All of the above includes intrinsic and extrinsic withdrawal fractions Intrinsic withdrawal fraction (IWF) [1]. Synonymous with process beneficial consumption – see below. | Extrinsic withdrawal fraction (EWF) [X]. This includes fractions numbered (2, 3, 4, 5, 6, 7, 8, 9, 10)
Consumed fraction	Process beneficial consumption (PBC) [1]. This is the intrinsic resource consumed and/or converted to the intended principal product. An example is sugarcane transpiration.
	Non-process beneficial consumption (NPBC) [2]. This is used beneficially but not in the production of the principal product. An example might be trees lining a canal.
	Non-beneficial consumption (NBC) [3]. This is one of nine extrinsic fractions and leads to consumption that has no beneficial or harmful impact on users or the common pool.
	Recoverable fraction; reused and consumed (RFC) [4]. This fraction is returned to by original owner, sector or user for consumption.
Non-consumed fraction	Non-recovered/able fraction (NRF) [5]. These are losses that pass to sinks such as deep aquifers or the sea and represents water lost to further use
	Harmful fraction (HF) [6]. These are wastes that pollute and degrade users or the common pool. They may offer some sustenance for specialised ecologies.
	Attenuated fraction (AF) [7]. This is water that returns to the common pool but is mildly polluted or delayed in timing, as commonly happens in irrigation systems.
	Recovered/able fraction; return flow (RFR) [8]. Water returned to natural capital pool once has travelled through the system – with relatively little timing delay or quality loss.
	Forestalled fraction (FF) [9]. These are wastes/wastages deemed to be 'reducible' within the system that can be identified, acted upon and therefore retained in the common pool. This is different to avoided withdrawal.
	Avoided fraction (AF) [10]. These are the losses locked (coupled) into avoided withdrawal and can be cut only by reducing intrinsic withdrawal.

Note: process and non-process consumption has been distinguished by IWMI, see Molden and Sakthivadivel, (2006)

2.2.5 Quantities and forms of waste/wastage

In section 2.4, four classes or types of liminal commons are outlined; ratio, multipath and polymorphic and composite. The first three of these are dependent on the emphasis given to quantities or forms within the conversion-and-loss process. Exemplifying quantity (and therefore ratio and multipath types), in irrigation, depending on the accounting theory used, potentially millions of cubic metres of water annually and globally are 'wasted' to be reused by farmers or retained within the environment. On the other hand, in polymorphic liminality, carbon can manifest itself as multiple forms with different benefits and functions for a variety of interest groups; for example as soil fertility via organic matter content; as timber via forest products; or as avoided deforestation valued by carbon markets.

2.2.6 Control and coupling

Sitting between physical resource inflows and outflows to produced goods and wastages/ wastes lies a socio-ecological/technological system – often imbued with 'black box' lack of detailed knowledge of cause and effect. Thus although scientists and resource users might observe where resources begin (abstracted river water) and 'end up' (e.g. a flow in a drain), the means and ability to control the multiple human and technical activities on an irrigation system that switch and direct the resource towards chosen end-points is by no means simple and transparent. Furthermore I argue Lankford (2006, 2012) that fractions are coupled. This means they can move in lock-step with each other – for example reducing the beneficial consumption of crop transpiration allows non-beneficial consumption to be reduced. Thus while not subscribing to a black box where we genuinely do not know the technologies involved or how to control them, I recognise rather a 'grey box'. This is where specific changes to technologies and activities to adjust the switching of fractions do not predictably give us the precise outcomes we seek. While there is not the space to fully explain this, Appendix A gives more information.

2.2.7 Accounting, measuring and monitoring

With regards to the reform and application of new institutional arrangements of common pool resources, an 'effectiveness' gap exists. This may be summarised in the question – do new technologies, devolved institutions or markets result in water being used more efficiently, equitably and productively? This information gap appears throughout CPR research and implementation, and was alluded to by Dolšak et al 2003, in their concluding section on 'developing new methods'. In my review (Lankford 2008) of the Warner 2007 book on multi-stakeholder platforms in water, I was clear of differences between principles of CPR (Ostrom, 1990; McCay, 1996) and of monitoring the outcomes of rules on resource patterns and productivities[xii].

Thus closely connected to the previous five sub-sections is the question of an appropriate theory and practice of accounting, measurement and monitoring. In

[xii] In an unpublished systematic review of the water allocation literature for the UK's Department for International Development, in which the author has been involved, a search of approximately 30,000 publications has revealed that less than five contain accurately derived and analysed data showing the physical and hydrological outcomes of policy reforms.

terms of accounting, irrigation exemplifies because classical efficiency and effective efficiency respectively include and exclude recoverable losses in the denominator. This difference means that effective efficiencies values are higher than classical calculations, and that the former can be used for basin accounting (Keller et al, 1996, Haie and Keller, 2008), the latter for evaluating irrigation schemes (Lankford, 2012). Once the accounting frame has been selected (though in irrigation this is the subject of an intense debate; Gleick et al 2011), it does not then follow that methods to measure the quantities and dimensions of the different fractions are agreed by all parties or easily determined. For example, I believe that an erroneous emphasis is put on sampling canal losses in irrigation which fails to record the myriad and micro ways in which water is reused over a season within an irrigation system (Lankford, 2012).

The uncertainty at the heart of the liminal commons is to a great extent derived from the relative failure to embed appropriate schemes for measuring and monitoring resource use. This task should not be underestimated; the fugitive nature of water and carbon moving through society, landscapes, atmosphere, soils and geology in different quantities and forms means the flows and fractions of different components of resource withdrawals are unexpectedly difficult to trace and apportion. This difficulty and associated error undermines the reliability of efficiency and productivity computations in addressing natural resource management and sustainability. The answer as, Skaggs et al (2011) cogently argue on precisely this issue is to determine actual not the modelled use of resources.

2.2.8 Reworking and change

Significant for a liminal commons framing are the changing expectations surrounding the manipulations of the inputs and conversions that intend to produce more and consume less, resulting in additional benefit, financial saving or gain. Central to ideas of intentions and manipulations are three fundamental and highly interrelated subjects; a) the unsystematic reworking of systems; b) dynamic change, and c) assumptions; – the first two are discussed below, and the latter is discussed in section 2.2.9.

On the first, I take as axiomatic that resource users, service providers (e.g. engineers) and policy-makers regularly alter micro-scale practices and the behaviour of whole systems in order to maintain or improve efficiency and productivity, and I term this the ‘reworking’ of systems or parts of systems. However the reasons for improving efficiency need to be carefully explored because the lack of a systematic approach to reworking sets up the likelihood for expectations to be dashed or for methodical experimentation to be thwarted – key dimensions of the liminal commons. In Lankford (2012), I make clear that efficiency adjustments to improve the internal scheduling of irrigation are very different from a water allocation rationale for raising efficiency, a distinction rarely made in other literatures on irrigation efficiency and productivity. Also, how farmers perceive the purpose for 'saving' water depends on myriad signals such as food prices, input prices (e.g. labour scarcity) set within a wider context of drought, capping of water rights, the availability of new technologies and ideational changes to cultural norms (e.g. that rivers should not run dry). Identifying particular drivers and associated subsets of responses for efficiency reworking (who is making what changes for what reasons) helps to reduce these uncertainties.

Furthermore, reworking is a nested endeavour; technologies may be simple for a smallholder's field with only rainfed maize, no fertiliser and a hand-hoe to till with. Scaled up to a large 3000 hectare irrigation system sitting within a 1000 square kilometre catchment, and the nature and size of expectations of what is, and what could be, grows substantially. The insight for the liminal commons is that while at the micro-scale, resource users and their support/service agencies intend to 'do better' on a daily or weekly basis assisted by relatively clear feedback signals, at the larger environmental, system and societal scales over longer time periods, emergent and unpredictable feedbacks and fudging of boundaries result in disagreements and unforeseen results. The reworking of systems that are invariably nested implies that, in the absence of a thoroughly comprehensive overview, the raising of efficiencies of whole systems and sectors is characterised by uncertainty and unpredictability.

Second, I observe the effects of dynamic change in efficiency; by this I mean that both external and internal sources of change are pervasively expressing themselves, creating a co-emergence of context driving new efficiency practices, and efficiency practices driving wider sectoral, societal change and environmental distributions of resources. Thus efficiency gains meaning by being 'relational' (Geels, 2010) both compared to itself (in a trajectory of attempts to improve systems) and to wider contextual change. Irrigation efficiency taken as an absolute measure is arguably meaningless especially when there are opportunities to define measures in relation to previous or to neighbouring conditions (Lankford, 2006; Solomon and Burt, 1999)

2.2.9 Changing assumptions of 'ordinary' waste/wastage

Closely connected to the expectation of gain from changing practices discussed in the previous section, are ordinary assumptions about waste and wastages. To explain this, I first wish to convey the sense that for resource users within a dominating political economy, interests in wastes or by-products are changing, practically, theoretically or politically, from a position of little interest to one where interest and value is increasing. This results in resources having a *current* waste/wastage fraction destined to be 'wasted' and claimed by nobody *yet in the near future* could be, if valuable or necessary, the subject of intense interest and managed accordingly - for example not appropriated from the natural world (in other words 'avoided'), consumed beneficially or captured then returned to the natural world. But this change from current assumptions to new interests is not a smooth process. The tension that arises between current custom towards what *is deemed* to be uninteresting waste[xiii] and the dawning realisation of new waste values in a fast-moving and increasingly scarce world, is perhaps one of most subtle, even psychological, aspects of the liminal commons. This tension expresses itself among irrigators in different ways with some quickly adopting efficient technologies while others do nothing and yet others remain with inefficient practices influenced by the assuredness of water rights and possibilities for further rent-seeking (Dellapenna, 2002).

In addition to changing assumptions amongst resource users, scientists and policy-makers also hold assumptions. These assumptions – often simplified (Crase and O'Keefe, 2009) – shape policy designed to drive resource users to adopt new practices. For example in irrigation, it is often assumed that 60% of water goes to waste, whereas that fraction may be much less. Thus, the common pool resource, in this case water, is treated for forthcoming losses which do not reduce total withdrawal – leading ineffective spending of development aid[xiv]. Therefore actions taken on mistaken belief that losses are greater than they really are, relate more to the liminal commons, less the stock commons.

2.2.10 Terms and definitions

A lack of definitional precision incorporating user perspective (what is gross demand from an irrigation system equates to net withdrawals from the river), scale (e.g. differences between household efficiency and wider efficiency in the economy apply, see Sorrell and Dimitropoulos, 2008) and subject- or disciplinary-specific use of the English language offers multiple interpretations and definitions in this subject area. Until agreement over definitions is achieved (not the purpose of this paper), talking at cross purposes most likely will be a signature of negotiations over the liminal commons (see also Neuman, 1996, for the role that vague definitions play in negotiating new water rights on the basis of water conservation). Terms as ‘loss, saving, wastes’ are used throughout in the irrigation and other literatures ill-advisedly, either carelessly by rote or wilfully for gain. Drawing on definition problems in irrigation efficiency and productivity, and for the purpose of introducing the liminal commons theory, I am selective in using precise and vernacular terms. I ask critical readers to know that for example ‘saving a water loss’ is useful in a vernacular, introductory sense but limited in a precise sense (because

[xiii] Furthermore the basis of how this is measured and accounted will be central to this claim and counter-claim.

[xiv] Either refer to Lopez Gunn (2012), Crase et al, (2009), or government policies behind drip irrigation subsidies in Syria and India to name two.

water saved may not have been lost in the first place if water losses are recaptured downstream).

2.3 Three types of options space

Discussed above are the 'uncertainty' ingredients or building blocks of the liminal commons. These cumulatively produce an 'in-betweenness' between, on the one hand, intentions and potentials and the other hand results and outcomes. This 'in-betweenness' in turn comprises three sub-types of 'options spaces'; 1) efficiency-induced paradoxes 2) place/space conversions and 3) policy prefiguration. In Figure 2, they are found within the dotted rectangle and are discussed in order below. The difference between them is that the first describes difficult-to-predict and paradoxical consequences for aggregate demand or production (either at a given level or whole system/sector level), the second principally describes pathway options within a particular abstraction-and-conversion system (e.g. irrigation scheme) and the third applies to the political and material expectations of policy that aims to rework the whole sector to a higher level of performance. All three combine as if one, although for different types of resources, emphases may differ.

2.3.1 Three efficiency induced paradoxes

Relevant to the defining uncertainties of the liminal commons, there are three properties of Figure 3 that explain uncertain consequences at raising efficiencies. In keeping with the literature on the Jevons Paradox, I have retained the term 'paradox' for all three given that the consequences for consumption (the left hand of Figure 3) and production (right hand of Figure 3) cannot be imputed solely from the efficiency ratio (Ruzzenenti and Basosi, 2008). These are 'paradoxical' because greater efficiency results in greater appropriation (rebound) which is counter to the notion that efficiency depends on the denominator staying the same or decreasing. The first type arises because final products are more numerous and cheaper, reducing price and raising the consumer attraction and purchasing power. Polemeni et al (2008) introduce this as efficiency-induced consumption of outputs, and Sorrell and Dimitropoulos (2008) term this 'direct rebound' (for specific produced goods) and 'indirect rebound' (for other general goods). Second, the output may have facilitative or power function (e.g. electrification, communication, transportation, miniaturisation) for accessing more natural resources. This is discussed as a powering of an 'economy-wide rebound' (Ruzzenenti and Basosi, 2008; Sorrell and Dimitropoulos, 2008). Third via the pathways listed in the previous section recovered losses may recycle not back to natural capital pool but to its consuming 'owner' or to other users leading to consumption (see Ward and Pulido-Velázquez, 2008).

2.3.2 Place/space of conversions and pathways

Continuing the discussion in section 2.2.4, liminality applies to resources with potentially different resolutions for how wastes/wastages manifest themselves and switch between the pathways available. In the case of irrigation, the ten pathways given in Table 1 and Figure 3 indicate how potentially abstractable freshwater 'decomposes' into different destinations by switching between a very large number of combinations available. While the liminal commons describes the main canal water, crop transpiration and drainage water as real flows with real destinations (in other words as 'places'); it also describes the relationship between them, with the irrigation system and its management forming the threshold between options to adjust where the canal water flows to or is saved. At this point, the concept of an 'options space' can be introduced because, with reference to Table 2, Figure 3 and Appendix A, conserving water in the common pool can now take place through three different choices;); a recoverable fraction returning to the river (no. 8); losses saved and forestalled (no 9) and losses foregone by avoiding initial withdrawal (no 10)[xv].

Revisiting the 'intentions and assumptions' discussions in sections 2.2.8 and 2.2.9, the sense of future parallel alternatives juxtaposed against current habits is important because the resulting drain water is either a resource for its 'owner' (in other words the farmer that allowed the drainage to take place in the first place), or for other claimants such as neighbouring irrigators, or the nation state if water is vested with meeting state interests such as maintaining ecological flows. Therefore the threat or intention to switch resources between pathways can, via recycling or waste foregone, become associated with claim and counter-claim over ownership. These claims arise out *expectations* of the potential changes in distribution (as a result of intended re-using/ economising/ avoiding) from competing resource users who themselves are expecting certain pathways and volumes of resource flow to be adhered to on the basis of current and accustomed water distribution.

2.3.3 Policy prefiguration

Formal attempts to raise the efficiency of a large system or sector are of particular interest to the concept of the liminal commons – principally because of the accelerating level of complexity as we move from small individual conversion units such as fields and plots (or indeed light bulbs) to agglomerations and collectives such as irrigation systems or whole irrigation (or energy) sectors. This turns efficiency from being a relatively simple and controllable endeavour in the first instance to, in the second instance, a measure of policy formulation that recognises and accommodates the foundational factors referred to in section 2.2 such as scale, boundaries, nestedness, pathways and accounting theory, to name but a few. A comprehension lag or error might arise from a policy-maker's mistaken inference

[xv] Although Perry identifies recovered flows he does not separate pathways that take water back to the hydrological cycle or to further re-use. Similarly, no options for avoiding or forestalling 'losses' are given.

that large systems are simply bigger versions of smaller systems, rather than allowing for emerging behaviours that come with larger systems.

Therefore in terms of policy while the concept of the liminal commons describes natural resource systems with prospects that could fall to different resolutions, it is not merely the 'before and after' of an intervention applied to a natural resource. Rather the liminal commons pertains to the differences between the 'expected before' and 'expected after'. The 'expected before' arises because of current inadequate measurement, knowledge of current resource inputs, outputs and ratios and the excessive dominance of outmoded efficiency narratives and solutions. The 'expected after' arises out prefigurations of the benefits of future efficiency/productivity changes and their effect on total resource depletion rates and distributions. The liminal common occurs because both are uncertain. Furthermore liminality should not be applied to, say, changes within a large stock commons such as a sea fisheries because these do not witness parallel, valuable and sizeable waste streams and complex mechanisms and pathways for reworking, avoidance or offsetting. Moreover, at the very centre of these uncertainties lies the artefact and phenomenon of an efficiency calculation of resource conversions with an inherent propensity to obfuscate the nature of those conversions.

2.4 Four types of liminal commons

From the above discussion, I distinguish four types of liminal commons. Figure 5 reveals the additional layers of complexity moving from the first to the fourth.

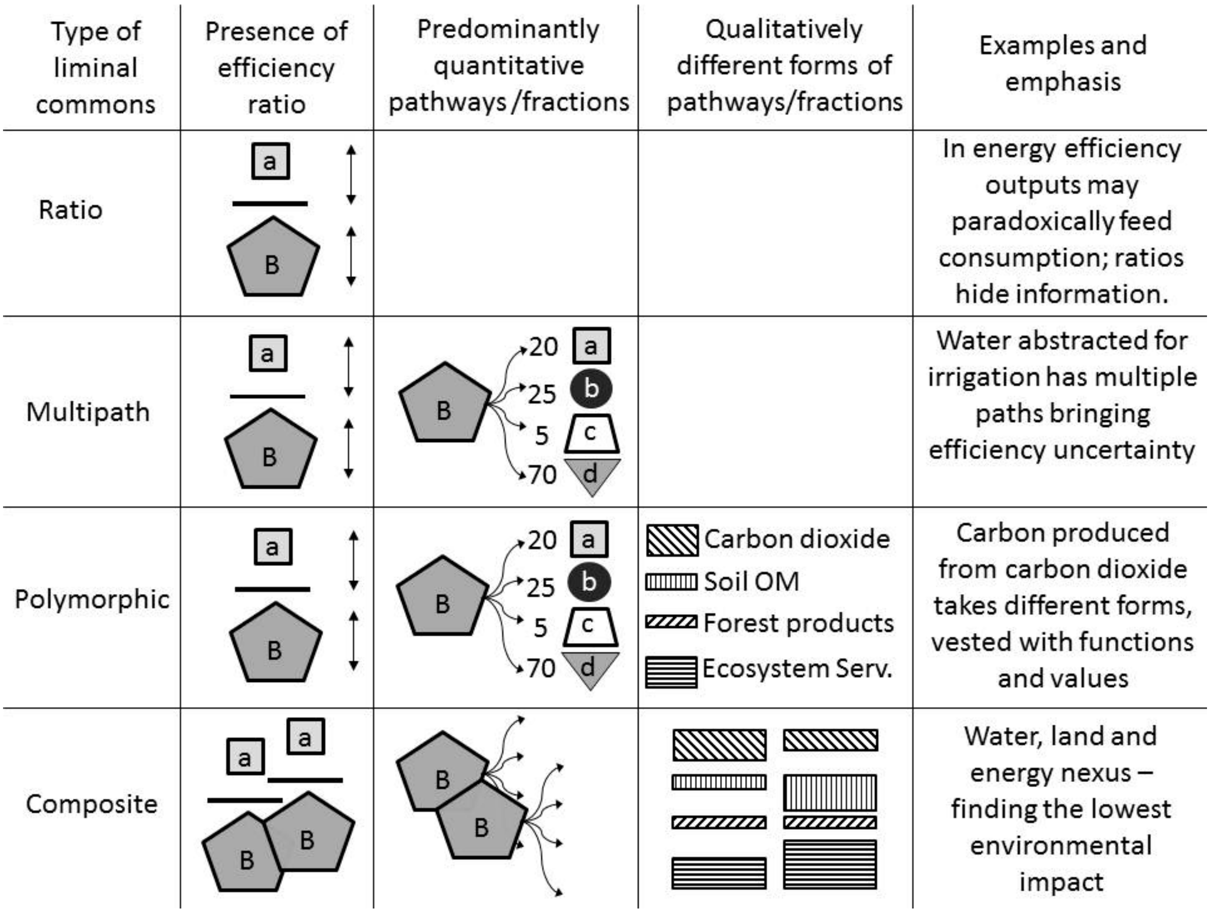
2.4.1 Ratio liminal commons

This type of liminal commons applies to relatively elementary conversion processes, and is probably best exemplified by the conversion of hydrocarbons such as coal or oil to useful energy output in kilowatt hours, as takes place in electricity generating stations and delivered to substations. A longer 'chain' of the conversion process might see the final product as electricity consumed in the household, allowing for demand side efficiencies to be analysed. The uncertainties that arise are principally from the first two Jevons-type paradoxes described in 2.3.1.

2.4.2 Multipath liminality

Multipath liminality describes resources with mainly quantitative apportionments between the natural capital and its various products and waste pathways (see section 2.3.2). Irrigation offers a good example of this type because the resource is quantitatively transferring between ten different pathways leading to five different destinations (beneficial consumption, natural capital freshwater, non-beneficial consumption, harmful pollution and non-recoverable bodies of water) and although these destinations might take different forms (vapour, liquid, moderately saline, heavily polluted) the essential nature is one of calculable mass balances of water.

Figure 5. The four types of liminal commons compared



2.4.3 Polymorphic liminality

Figure 6 captures the third type – arising from expectations of resources converting between multiple forms and providing multiple services, best exemplified by carbon and carbon dioxide in forests, soils and the atmosphere. I argue this is polymorphic problem because carbon takes up multiple forms – it is found as carbon dioxide, charcoal (biochar), soil organic matter, forests and agro-forestry products such as timber. Furthermore carbon also produces multiple benefits when, as forests, animals, vegetation and soil organic matter, it generates multiple ecosystem benefits such as different biodiversities and runoff regimes. Adding further complexity, carbon in forests is offset against fossil fuel carbon. Law and Harmon (2011) explain these benefits in their paper, as do other papers surround REDD+ (Thompson et al, 2011). The liminal performance/efficiency problem therefore is; 'how might the carbon dioxide 'commons' be managed through forests to *more productively* achieve multiple gains of long-term carbon sequestered, forest biodiversity enhanced, forest goods increased and hydrological runoff improved?'

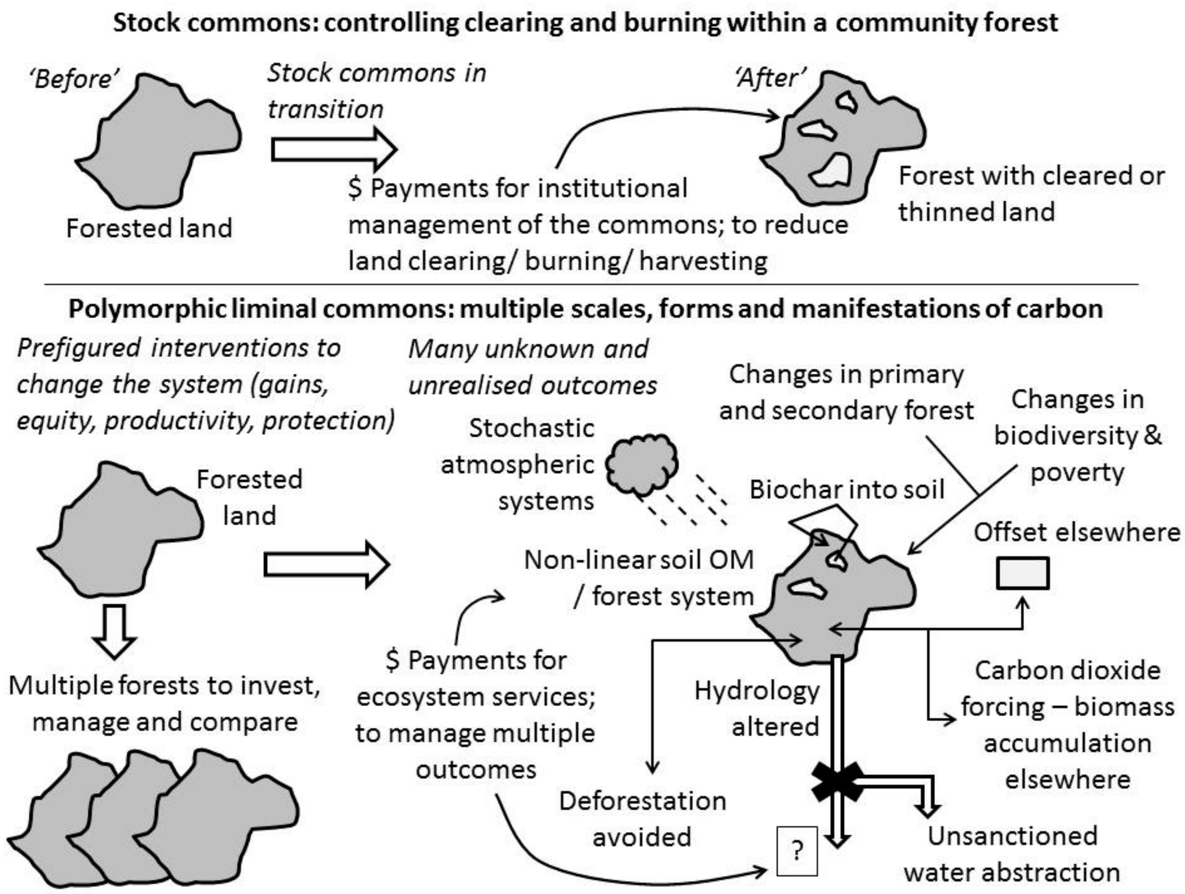
By asking this question, I note three important possibly contentious issues. First, I have inverted the productivity process; I take carbon dioxide as the common pool and long-term 'net biome production' (Law and Harmon, 2011) as the produced good. Thus wastage is returned carbon dioxide that covers all the managed activities that fail to convert carbon dioxide into fully sequestered carbon. Second, the liminal conversion process of carbon dioxide to long-term sequestered carbon is 'stretched' through multiple stages and made problematic via wider boundaries and longer time spans - Law and Harmon (*ibid*) also draw attention to time and scale frames in carbon accounting. Third, Figure 6 contrasts a conventional stock and liminal commons framing. In the former, forest communities are concerned with the renewable and renewing biology of 'their' forest reserve, mostly likely on a seasonal to two or three year time horizon. The productivity problem is 'simply' one of matching harvest rates with biological production of forest and forest products. In the liminal commons, forest communities now have to consider the trade-offs between their forest density and size; long term carbon sequestration – beyond 50-100 years; offsets for other carbon dioxide sources; consequences for the global atmospheric commons and impacts on biodiversity and downstream river flows. Although there is no room to explore this topic further, the twixt-and-tween liminality operating here tells us that endeavours to create these more equitable, beneficial and productive versions of the erstwhile forest stock commons will be immeasurably subject to greater degrees of freedom and nth dimensional options spaces suggesting outcomes differ very greatly from expectations.

2.4.4 Composite liminality

The fourth type arises from increasing inter-linkages between resources within a highly contested world facing limits of consumption. Within the 'composite liminal commons' where numerous resources interact and spillover, the premise for saving or re-using one resource (e.g. water) by the application of another resource (e.g. energy for introducing drip irrigation – or additional land at the tail-end of irrigation systems) comes under even more doubt as outcomes for all resources and their efficiencies play out in unintended ways. In this case, water may not be truly saved depending on water's final destination, carbon externalities may be excessive; the extra time required to maintain complex drip systems may be deemed 'wasted' by farmers; and the water recaptured by tail-end land insufficient to produce a viable crop. Saving water in agriculture by switching from gravity/canal irrigation to pressurised/drip irrigation becomes problematic in multiple ways (because water may not have been 'lost' in the previous system) because the extra carbon generated in energy consumption for pumped and filtered irrigation may be an unwelcome addition to global carbon. Rothausen and Conway who omitted the efficiencies in irrigation water and energy in their 2011 Nature publication are exploring this in the next stage of their work[xvi].

[xvi] Law and Harmon (2011) on page 74 link irrigation and forestry when thinking about boosting carbon sequestration.

Figure 6. Stock commons and polymorphic liminal commons (forestry and carbon)



3. Distinctions between the stock and liminal commons

The liminal commons can be distinguished from the 'stock commons' (Table 3). The stock commons are those that the CPR literature are concerned with and exhibit problems of 'non-excludability' (difficult to exclude users); and 'subtractability' (or 'rivalry', where in joint use, one user is able to subtract welfare from another). Although distinctions in ecological or economic systems between stocks and flows can be made (see Millennium Ecosystems Services and related literature (MEA, 2005; Mooney, 2009)) where a stock of a resource gives rise to portions of that stock that can be harvested as a flow, I combine both stocks and flows as constitutive features of the 'stock commons'. Thus both the body of water in a dam and the dam's exit flow comprise 'a stock commons'. Another 'stock commons' example includes the adult fish in a fishery plus the fish eggs and fry. The following sub-sections discuss eight of these key differences.

Table 3. Distinguishing the stock and liminal commons

Dimension	Stock commons	Liminal commons
Efficiency and performance ratios	Given brief, incomplete or summary treatment	Defining feature of the liminal commons.
Pollution, wastes and wastage	Summary treatment or seen as pollution subject to removal and treatment	Materials seen as desirable and subject to competition and recovery
Conversion process	Resource replenishment, recovery, regrowth. Sustainable harvest attempts to match this	Multiple conversion concepts: E.g. Resource to wastage (harmful, recovered, not withdrawn, averted, non-recovered).
Subtractability	Subtractability. A resource consumed in one place cannot be consumed elsewhere.	Modified subtractability. A resource consumed in one place leads to products or resources captured/reused elsewhere
Non-excludability or rivalry	Defining feature of the stock commons. Difficult to exclude others accounting for geographical and spatial factors	Excluding others from accessing the waste fraction is one option; or not if recycling/reuse by others deemed normal
Appropriation or harvest	Appropriation	Intrinsic appropriation and extrinsic appropriation (wastage/wastes elements)
Conservation	Reduction of abstraction / appropriation	Reduction of waste fraction (reducing extrinsic appropriation)
Spatiality-conferred ownership claims and competition	In parallel (all users acting simultaneously); or in geographical sequence with users in longitudinal, vertical or lateral sequence	In extrinsic-appropriation sequence: likely to be a complex intricate and unique maps of resource and wastage flows.
Cross-resource connections	Efforts to economise one resource relays linearly to another related resource usually in gross quanta terms	Explicitly recognises uncertain trade-offs and outcomes related to net, gross and tare fractions.
Design and technology	Technology related to harvest and appropriation capacity	Technology related to raising efficiency – though often unpredictably so.
Property rights questions	What goods require what property regimes? Who owns the commons? How might rights be transferred?	Who owns the waste and recycled resources, and future waste saved and averted? How is ownership of reducible ('tare') portion transferred?
Regulatory questions	How to regulate demand – markets/price, licenses and CPR modes?	How to govern wastage or the commons with a significant proportion of salvageable wastage? What technologies and prices?
Space/Place	Place	Place/space

3.1 The defining conversion process

The nature of the conversion process at the heart of managing the sustainable harvest and protection of natural capital defines the two types of commons. Taking fisheries as an example, the conversion process at the centre of managing the stock commons is that of a natural biological process; viable adult fish spawning eggs and fry. To sustainably manage fisheries is to set harvest rates against the rate of reproduction to protect fish stocks so that they may replenish themselves[xvii]. In the forestry stock commons, the conversion is one of trees seeding new trees. From this balance stems the problems of entitlement to harvest associated with the commons. However, in the liminal commons, the conversion process adds elements of managing losses in

[xvii] A characterisation for essentialising the stock commons problematic – see Finley 2009 for example on a more nuanced examination of fish harvest rates.

the chain of husbandry, harvesting, processing, storage and refinement. Not only does this introduce another component (losses) to balance natural supply with societal demand, the conversion process increases in complexity and distance, requiring multiple measures to judge performance, specifying how scale and different pathways are accounted for.

3.2 Subtractability and rivalry

The liminal commons features 'modified subtractability', where a wastage/waste fraction is part available for other users. This fraction is subject to a variety of reuse and recycling claims, and thus for example, is not as 'subtractable' as fish stocks are where discards at sea benefit only the marine foodchain. By taking this view, I question the purity of the concept 'subtractability' as a defining feature of the 'stock commons'. Subtractability is explained in a discussion on resource units by Ostrom (1990) page 31 "*Resource units are not subject to joint use*' (her italics) and repeated by Dolšak and Ostrom (2003); "The tons of fish or acre-feet of water withdrawn from a particular water resources by one user are no longer available to others using the same resource" (p 7). In the stock commons, a unit consumed by one user is no longer available for another. In the liminal commons however a portion of a unit withdrawn by one user is available for other users including the original withdrawer by the different pathways mentioned in section 2.3.2). However, this re-usable portion is commonly modified by location, quality, quantity and timing – influencing the manner in which ownership claims are then raised, pursued and countered.

3.3 Pollution in common pool resources

As wastes are the central focus of the liminal commons, the treatment of pollution in common pool literature is relevant. Cole's (2002) analysis is instructive in so much while he refers to pollution as a defining feature of stock commons – that pollution is largely an unwanted by-product of the absence, or inappropriate mix, of property rights and control mechanisms with attendant excludability, informational and transactional failures. While I have no argument with this per se, this analysis applies toxicity or nuisance values to pollution in keeping with Hardin's view that the gains of resource use fall to one but costs of pollution fall to all. This is the same starting point for (in)justices analysed by Low and Gleeson (1998) that albeit resource and waste distribution is treated in their book as amongst the factors that determine distribution of justices, waste is seen as without value or with negative harmful properties, and otherwise an injustice. Despite Dolšak and Ostrom (2003) on page 15 drawing our attention to the problems of devising rules for a sink-type commons (where air soaks up gases or particulate pollution), this analysis does not draw attention to potential routing pathways over a transitive options space, and their respective characteristics, costs and benefits. It is when pollution or wastes become valuable we have the option of new property rights overlapping or of one resource leveraging another. In other words, the commons literature does not explicitly frame pollution as a desirable common resource.

3.4 Appropriation

I define two types of 'appropriation' – intrinsic and extrinsic. The stock commons witnesses water abstraction as appropriation with little or zero recognition of an extraneous waste/wastage – or that losses can be reduced (Ostrom, 1990). In other words, all abstraction and harvest is deemed to be intrinsic to the user's needs and therefore intrinsic appropriation is an artefact of the subtractability of the stock commons. In the liminal commons, both intrinsic and extrinsic appropriation exists. The intrinsic element is the beneficial and consumed fraction while the extrinsic element is the additional fraction abstracted that meets expected recoverable and non-recoverable 'losses'. For example, a sizeable extrinsic fraction may be normatively argued and engineered to be part of the intrinsic net crop water needs, as observed in irrigation (see discussion in Section 3.8). Yet intrinsic but especially extrinsic appropriations are not tightly and objectively defined, thereby creating political or scientific space for claims of excess and access in the face of competition (see Section 3.7).

3.5 Resource conservation in CPR

Conservation in the stock commons takes place via the reduction of aggregate appropriation. Although efficiency within CPR literature is discussed, this is largely related to the provenance of conservation thinking in ecology and preservation of renewal in biological populations (e.g. fishstocks, see McCay, 1996). The attention afforded to a comprehensive view of resource efficiency – and the technical mechanisms to improve efficiency – tends to be neglected or at best underwhelming. For example Ostrom et al (1999) and Dietz et al., (2003) omit the complexities of governing the commons arising from resource inefficiencies. The liminal commons arises because of the number of choices that can be made to conserve a resource and political interests levied against the 'yet to be wasted' principal resource that form the basis for conservation programmes and expenditure. In other words, the liminal commons offers conservation via a reduction in both extrinsic and intrinsic appropriation.

3.6 Spatiality-conferred claims and competition

The losses associated with extrinsic appropriation place an additional layer of spatiality. The spatially determined access of the 'normal' stock commons such as fish and wildlife are influenced by population distributions or physical location of the abstractor (with additional difficulties mediated by power relations, controlling regulation and excluding access). In some senses, boundaries have relevance here (for example Acheson and Brewer, 2003, discuss physical territorial boundaries). Furthermore, surface water, in its ‘stock’ form cascades through the landscape longitudinally, vertically and laterally, accentuating social power relations, exemplified by top-to-tail-enders in irrigation systems and river catchments. However, additional to these intrinsic patterns, the liminal commons contains another spatiality – that of a sequence of abstraction-consumption-wastage-recovery, or ‘extrinsic-appropriation sequential use’. Here, the spatiality of wastages to be recovered and salvaged is particular to each system and context where the location of fields, canals, pipes, drains, owners, neighbours, licences and rights create a mosaic of waste/wastage sources and legal and illegal recovery. Reworking of a resource to raise efficiency influences the physical pathways that water then follows, and this takes place either quantitatively, for example where low-salinity drainage water is reused) or qualitatively (partially saline drainage water recaptured). Yet recall, this ‘before and after’ is also mediated by *expectations* of what will happen to the *potential forms and pathways* that wastage might follow (or are foregone into different fractions) before they physically flow to different destinations within the landscape, sectors and user-groups, thereby decomposing back into the stock commons.

3.7 Revising water legislation for water conservation

Recent changes in water legislation in the dry parts of the United States of America and Australia (Crase et al, 2009) exemplify the problem of accommodating the revised destinations and ownerships of the volumes of water made available through water conservation (Skaggs et al, 2011). In so doing these accommodations reveal the uncertainties of the liminal commons and current structures to deal with recoverable or avoidable fractions. Bell (2007) describes attempts in four US states to remove disincentives to water conservation which existed under a previous prior appropriation doctrine. The previous doctrine forbade the spreading of the freed up or salvaged water to new lands belonging to the water right holder as this effectively expanded their water right expressed in consumptive terms. The four examples variously show who then had claims to the ‘freed up’ water including the original user, other users/sectors, the State for further allocation, and freshwater ecology. Identifying uncertainties for the programmes, Bell notes that a lack of take up in Oregon can be related to the high costs of conservation to meet aims, and identifies the differences between expectations of benefits and ensuing reality, writing on page 3:

> *While Montana's salvage statute provides the opportunity to better use limited water resources, determining whether the conservation measures implemented actually save water can be difficult and complex. These difficulties have limited the success of Montana's program. The Department of Natural Resources and Conservation has noted that*

> *permitting an applicant to enlarge their irrigated acreage based on the water saved when switching from flood irrigation to a sprinkler system may diminish return flows, thereby injuring junior appropriators or other third parties.*

Neuman (1998) and Shupe (1982) provide further analysis of the manner in which entrenched water abstraction law (and water markets) in western USA "has revealed itself to be woefully inadequate at eliminating waste and encouraging efficiency. Beneficial use affirmatively protects inefficient water use customs and practices" (Neuman, 1998: 996). Included in the wider structures of legislative change are compensations arising over 'takings' where the state on behalf of itself or other parties elicit public property rights by taking up existing private property rights. Agreeing with Cole that 'takings' are a boundary issue (2002, p 166), in the case of conservation, the liminal commons, with its multiple pathways, inexactitudes and opportunity for claim-making, constitutes a thicker form of boundary. As we witness new levels of resource competition, connections and fragmentation, we necessarily require new regimes for legislating for the intrinsic and extrinsic components of resource consumption separately and for meeting the transaction costs of doing so.

3.8 Technology and design

The design of irrigation systems illustrates the manner in which 'potentialities of wastage' are artificially or axiomatically created, and by which a liminal threshold arises. It does this through the contrast made between assumptions applied to irrigation efficiency and the ensuing physical, extant realities.

The highly standardised procedure (FAO, 1977; 1999) to establish the dimensions of irrigation headworks as abstraction points on rivers and the canals that feed irrigated fields includes five variables; crop water requirements ; a dependability measure (usually to meet four in five years of rainfall); command area; supply time (usually 24 hours); and a measure of irrigation efficiency. This procedure is well established throughout the world as the normative concept for drawing up water demands for irrigation systems where trained engineers become involved. While a number of uncertainties exist with each component (for example modelling crop water requirements), the officialised procedure offers opportunities for accessing excessive water thereby depleting downstream users of their water (Lankford, 2004) and for poorly accommodating a flexible transparent approach to differences between design and construction assumptions and eventual outcomes. It does this in five interconnected ways:

First, in this procedure irrigation efficiency is rarely measured. This is because irrigation efficiency is extremely difficult to assess but also engineers habitually look up or estimate figures rather insist on measurements. Related and second, the assumed efficiencies commonly results in design efficiencies that are too low. For example, in Tanzania the rice water duty is accepted by government engineers to be 2.0 litres/second/hectare (l/sec/ha) largely via the low efficiencies applied to system design. This contrasts with a measurable demand of about 1.0 l/sec/ha or less (Machibya, 2003). This can establish physical systems established that abstract more water than if a smaller design parameter had been used. Third, designers and regulators incorrectly assume that water wastage will be returned to drains despite commonplace evidence that farmers rarely care for their drainage water and that other consumptive uses often evolve around such spillages (be they opportunistic farmers or wetlands). Fourth, current design procedures prioritise the irrigation system rather than split water between irrigation and downstream (Lankford, 2004). Simply put, the design standard procedure has no formal step for taking downstream demand into account when adjusting for improvements in operational or design efficiency and often tend towards designs that are non-proportional in their division between irrigation flows and river flows. Finally, the differences between design and final reality are then subsequently rarely revisited in the light of errors un-covered. While farmers might make adjustments either via negotiated or conflictual means (e.g. vandalism), often these tend to be ad hoc (replacing steel with wooden gates or adding sandbags), rather than substantive (replacing an undershot orifice gate with a proportional gate or installing a larger or smaller discharge orifice).

The procedural 'regularities' for irrigation design therefore establish options for resource capture irregularities. The consequences for water consumption and allocation following improvements in irrigation efficiency are profound because the design and its operation biases the system and its farmers to utilise those 'savings' within the irrigation system rather than cascade them up to the headworks for downstream users (withdrawal avoided or forestalled fraction). A smarter procedure for irrigation design involving careful selection of efficiency parameters might show why efficiency gain expectations and outcomes differ from each other and therefore underpin future success in water allocation. Even in the latest monographs on irrigation design (Bos, et al. 2009) the above flaws are poorly covered.

4. Significances and applications

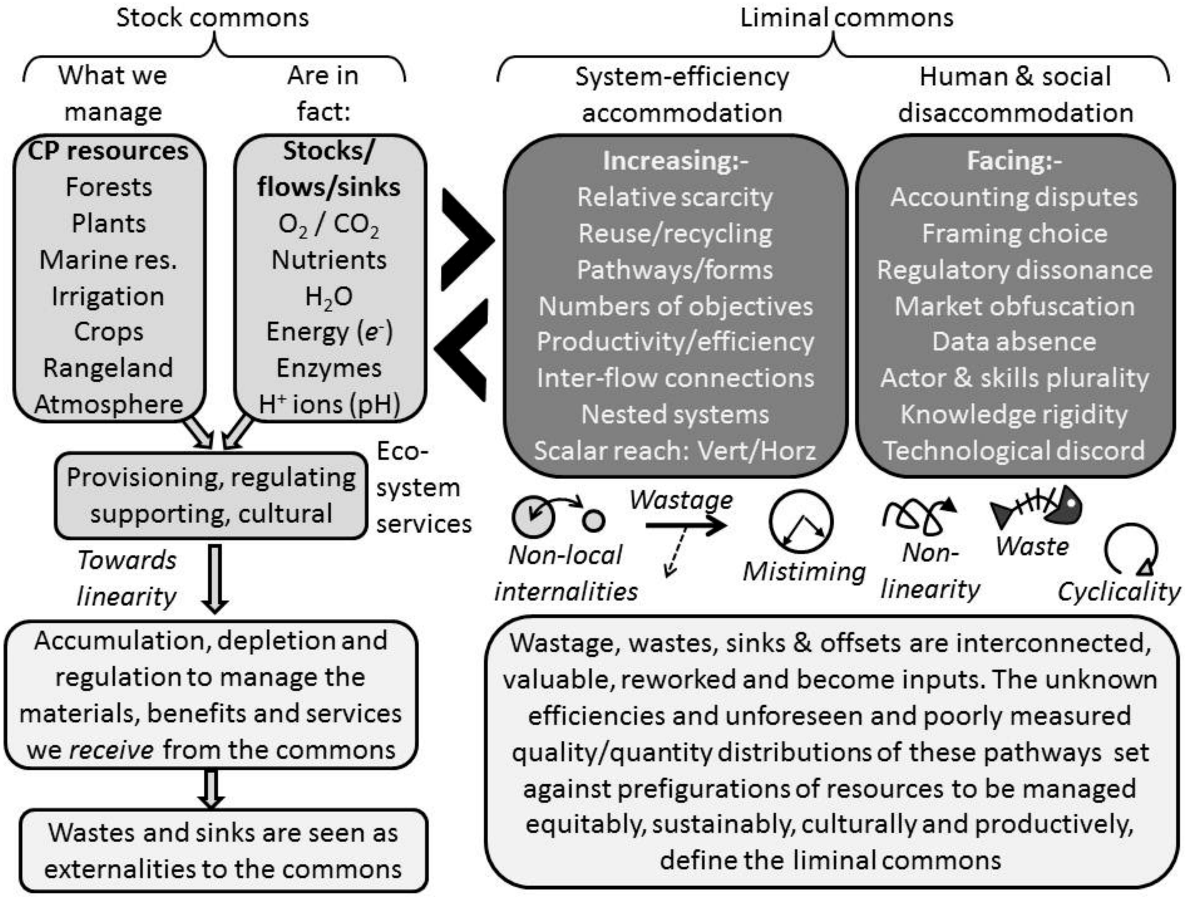
4.1. Linear and cyclical ecosystem services

In Figure 7, I align ecosystem services (ES) with the stock commons, both characterised by linear pathway from a source of production to the destination of use (despite the deployment of complex diagrams of services, the most reproduced one being from the Millienium Ecosystem (see MEA 2005; Figures A and B). In an increasingly scarce and populous world, resources are or will be used recursively and cyclically – yet the ecosystem services approach despite alluding to complexity (Norgaard, 2010) does not speak to the reciprocity between realms of supply, demand, technologies, conversions and societal distribution. This is one danger, yet there is another. The second risk refers to manner in which we utilise only one instrument to address multiform benefits of nature – the key proponent of which is payment for ecosystems services (PES) to alter, in a non-linear dynamic world, the benefits of carbon sequestration, biodiversity and catchment hydrology. In other words, I cannot see how ES and PES by firmly planting us in 'ecosystems-as-providers' gives us more productive and efficient eco-agro-industrial-urban systems. The venture does little to solve the metabolic rift between nature and society (Clark and York, 2005).

4.2. Performance monitoring

Figure 7 also draws attention to gaps in accounting theory and lack of data. The stock and liminal commons are connected to performance monitoring in three ways. Both arise from the failure to properly audit the performance of natural resources management, pre- and post-institutional and technical reform. My first point is that this gap arguably has led to the 'commons' largely being seen as a stock type with first order features of rivalry and subtractability. Second, although some researchers work on productivity (see IWMI's work e.g. CAWMA, 2007), on the whole water is rarely analysed by operators and users as benefits to cubic metres depleted or in terms of related resources in ratio (water depleted per kilowatt hour consumed or net tonnes carbon emitted). Yet where such figures are given, they must be intensely scrutinised because of the logistical and methodological challenges to be resolved. My third point is that setting aside the current absence of monitoring (as one explanation of current commons practice and theory) a future field of theory and practice, characterised by increased competition over resources and tools required to deal with competition, will necessitate a more numerate approach to resource management. This will have legal ramifications because I argue that the currently inadequate assignment of property rights to water resources in relation to who owns the consequences of changes in productivity and efficiency can be traced to poor monitoring and evaluation (see Skaggs, et al 2011).

Figure 7. Liminal and stock commons directionality



4.3. Natural resources science; disaccommodating widening complexity?

I complete this section by reflecting on the current mismatch between increasingly complex and widening framing of different types of resources, boundaries and benefits, and our inadequate responses to those complexities (Ruth et al, 2011). Figure 7 captures these efficiency-related tensions in the two boxes on the right hand side of the diagram. The liminal commons arise because 'gains' achieved by one user at one scale need to be validated by reference to gains and losses for other users or other resources at other scales. This increases the number of variables in play. Yet these problems are further magnified if as managers we fail to grow and accommodate them accordingly, and therefore maintain and update appropriate measuring and accounting systems, theories, skills, incentives and technologies. The liminal commons points to significant problems arising from disciplines and users failing to resolve theories and management of resources with pronounced efficiency dynamics. A widening accommodation of resource complexity not accommodated by society and science offers further room for chasms to develop between what we hope will transpire and what does transpire.

5. Conclusions

This paper has explored the legal, physical, economic and managerial dimensions and significances of waste/wastage and efficiencies associated with the appropriation of natural resources for human consumption. In considering the fate of these fractions, an options space termed the liminal commons has been posited. This options space contains *potential and multiple* pathways and paradoxes lying between the expectations and outcomes of intentions to recapture, redirect and economise wastage. The liminal commons describes a space of potentiality prior to the destinations that resources decompose into once used, consumed, avoided, forestalled or reused. In this space the liminal commons includes all the manifold backwards and forwards connections between the pre- and post-liminal resources, savings enacted, and associated institutions and processes, influencing the location and availability of not only the post-liminal resource, but also the location and availability of the pre-liminal condition. The liminal commons offers a pause between overly optimistic (or pessimistic) prefigurations of resource management and ensuing savings and consumptive outcomes. In the case of water, the liminal commons is given significance because of the size, number and value of fractions that constitute waste and wastage that in turn give rise to uncertain distortions of costs and benefits in attempts to improve management. The liminal commons includes the institutions, agreements and technologies that shape the direction, magnitude and quality of the reworked resources resulting from passage through this space.

Four types of liminal commons were explored, 'ratio', 'multipath', 'polymorphic' and composite', each representing different elements of the liminal commons. The ratio liminal commons is best exemplified by hydrocarbon fuel efficiency. Multipath liminality describes water and irrigation within river catchments. Polymorphic liminality captures the complex flows and transformations of carbon and carbon dioxide held in, and fluxing between, atmosphere, forests, other biomass and soil, and their impacts on other hydro-ecological outcomes. The composite liminal commons explore the efficiency uncertainties emanating from linkages between resources such as water, land, labour and energy. The paper also contrasted the stock commons (e.g. fisheries) with the liminal commons.

The significance of the liminal commons is correlated to the magnitude of the scarcity value and the complexity of the wastage fraction associated with the principal resource. Thus with irrigation the liminal commons is 'made real' because the wastage fraction is significant and valuable. And because of the complexity of water, the liminal boundary also lies between the state and irrigator in the form of takings of wastage fractions; it sits between the disciplines and languages of politics, law, economics and irrigation engineering in how they frame and discuss water consumption and efficiency; it helps define performance judgments of 'best, good, optimal, poor' resource management, and; it is at the heart of technological and regulatory reform designed to conserve water. The liminal commons of water would surely be somewhere in a future articulation of Linton's 'socioecological nature of water' (2008; 646) or 'hydrosocial cycle' (Budds, 2009), both analyses currently omitting productivity and efficiency.

Pursuing the latter point, the liminal commons throws light on a critical revisiting of the modernisation of nature started by Hays in 1959 and continued by Clark and York (2005) and others; that one of the great aims of environmental governance is to protect and sustain nature while meeting the economic needs for the growing human population of the planet. There is much that can be said here in terms on the politically problematic mechanisms for achieving this, such as green capitalism. However, by placing efficiency and productivity within this modernisation trajectory, the liminal commons points to profound and multiple sources of 'systems uncertainty'. In contrast to the (in my view conventional) framing of nature-serving-society as through an ecosystem services prism, it is possible to see that resource and waste/wastage flows create a complicated nested and recursive embedding of social-ecological-technological-systems. In these systems, ranges of resources and fractions flow, cascade and interact; are attractive to some and neutral or harmful to others; and reveal quantities and qualities that change over time and space. These 'agro-eco-built-systems' vary in type, from the engineered 'end' of resource use, distributing water via canal systems, arguably containing freshwater away from 'nature', to forestry, watersheds and carbon sequestration that shift questions of productivity and efficiencies to 'within nature'[xviii] in (albeit where technologies of forestry husbandry and harvesting exist).

Summarising, the liminal commons stems from differences between policy expectations and physical outcomes arising from the complexity of 'flows' of resources and their wastage fractions where the latter are deemed valuable for users or other sectors. In responding to this policy uncertainty, the liminal commons corrals and meets five sets of concerns about resource governance and management.

- First, is the observation that regulatory instruments (legal, market or customary) for the ownership and regulation of recycling and losses are being outstripped by fast-moving events driven by scarcity, necessity and technical ingenuity. If not regularly updated and reformed, our normative procedures for managing water also sitting within silos such as irrigation engineering and water law, will fail to advance productivity gains while attending to environmental, community and sustainability criteria.

[xviii] Ecologists might argue that nature cannot be inefficient given that all energy, light, enzymatic flows cascade through ecology to produce myriad species, interactions and services. Yet efforts at REDD+ and payments for ecosystem services signal that our credo is restore degraded or sub-performing environments by managing the performance and products of natural conversions.

- Second is the expectation that the physical parameters (quantitative and qualitative) of natural resources need to be better quantified, understood and measured. Tracking of water in river basins and irrigation is an omission in CPR and co-management research. Another example of measurement omission is in the emerging claims of water offsetting, neutrality and virtual water transfers. It is my belief that much of this work remains dependent on modelled assumptions. Yet even with much better monitoring, cautions apply. The liminal commons framing suggests that research of causality between efficiency interventions and outcomes may not be possible (see also Sorrell and Dimitropoulos, 2008)
- Third, because resources such as water, carbon and energy inter-connect their wastage fractions require heightened scrutiny so that externalities and impacts of the consumption of one resource on another are educed.
- Fourth, and connected to the first three concerns, is the expectation that the frames of resource governance and common pool theory will have to enlarge and deepen if we are to incorporate the post-liminal products (including those economised and forestalled) of primary resource consumption – and their implications for other resources. The evidence from irrigation is that the liminal commons not only determines access to the derived, salvaged resources, but that these feed ‘backwards’ into mechanisms that determine the scheduling and distribution (and therefore performance) of the original principal resource. In this way, with increasing scarcity and inter-connectivity, ‘losses’ and ‘wastage’ ordinarily seen as at the margins of resource systems move towards the centre ground.
- Fifth, this analysis asks what comprises ‘the commons’? In a closing-system world where wastes/wastages are increasingly recycled and vested with virtue and value, wastes/wastages and natural capital resources invert and swop places, if not in quantitative terms then possibly in interest terms. The carbon dioxide ‘commons’ converted to timber and eco-system services is one example of this phenomenon, and irrigation losses as the sole remaining source of water in a closed river basin is another.

This paper will leave to others to discern the implications of the liminal commons for other subjects such as climate change adaptation, sustainability and societal resilience. In the light of this purposive omission, it has not specified a comprehensive, cross-disciplinary approach to managing the liminal commons and the politics of efficiency within resources conservation. Nevertheless, it does strongly agree with Neuman’s (1996) recommendation for a more systematic approach to improving efficiency and performance, and placing this challenge at the heart of sustainable productive and equitable/just resource management. Given that issues of scarcity, recycling, aggregate withdrawal and linkages between resources are increasing, commons liminality seems set to rise in prevalence. The concomitant response is to create efficiency-cognisant epistemic communities of scientists, users and service providers capable of addressing efficiency-induced complexity, thereby shrinking the ‘thickness’ of liminal uncertainty.

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Appendix A.

Table A1. Place/space framework of liminal commons accounting

<table>
<tr><td rowspan="2">Starting point and fractions in withdrawal
A</td><td rowspan="2">Vernacular terms and ‘visibility’ of irrigation losses (examples)
B</td><td colspan="2">Liminal space for reworking</td><td rowspan="2">Final place outcome (each with properties of quantity, location, water quality, time and timing)
E</td></tr>
<tr><td>Water management inputs (selected examples)
C</td><td>Switches between potential pathway options
D</td></tr>
<tr><td>Process beneficial consumed fraction (PBC)
Intrinsic withdrawal fraction (IWF) [1]</td><td>· Crop transpiration</td><td rowspan="7">· Headworks regulation
· Canal system management
· Canal system seepage/leakage
· Canal de-weeding
· Canal density
· Canal flow control technology
· Field and in-field design, e.g. gradient, basin or furrow morphology
· Irrigation deficit scheduling
· Crop season length
· Field pre-watering
· Crop selection
· Cropping patterns
· Micro-control technology</td><td rowspan="7">Main pathways and switches:
IWF → PBC (1→1)
EWF → PBC (X→1)
EWF → NPBC (X→2)
EWF → NBC (X→3)
EWF → RF (X→4,8)
EWF → NBC (X→5)
EWF → HF (X→6)
EWF → AtF (X→7)
EWF → FF (X→9)
EWF → AvF (X→10)

Other examples of switches:
NRF reduced→ BC increased (5→1)
NRF reduced→ NBC increased (5→3)
NRF reduced→ FF increased (5→9)
NBC reduced→ BC increased (3→1)
NBC reduced→ RF increased (3→4, 8)
HF reduced→ AtF increased (6→7)</td><td>Process beneficial consumption fraction (PBC): Water evaporated or transpired for the intended purpose [1]. Could also include non-process beneficial consumption [2]</td></tr>
<tr><td rowspan="6">All other extrinsic withdrawal fractions (EWF) [X]</td><td rowspan="6">· Seepage
· Spillage and leakage
· Bare soil evaporation
· Canal evaporation
· End of field drainage
· Sub-soil drainage
· Weeds transpiration
· Excessive water depth (rice)
· End of session draining of canals</td><td>Non-beneficial consumption (NBC): Water evaporated or transpired for purposes other than intended use [3]</td></tr>
<tr><td>Non-recoverable fraction (NRF): Water that is lost to further use [5]</td></tr>
<tr><td>Harmful fraction (HF): Heavily polluted water degrades common pool [6]</td></tr>
<tr><td>Attenuated fraction (AtF) [7] is reduced</td></tr>
<tr><td>Recoverable Fraction (RF): Water is re-used [4] or returned to the river [8]</td></tr>
<tr><td>Forestalled fractions (FF) [9] and avoided fraction (AvF) economised is then not withdrawn [10]</td></tr>
</table>

(Note: Acronyms, letters and numbers correspond to Figure 3)

The left and right hand columns (A and E) of Table A1 give the inflows and outflows of fractions of water of a multipath liminal commons exemplified by irrigation. Column A dissects the inflow into intrinsic and extrinsic fractions – the latter comprising ‘losses’ listed in Column B and as fractions numbered 2 to 10 listed in Column E. The central two columns suggest how technical options in Column C give rise switching options in D, resulting in changes in flows to the right hand column, E, of outflows. Yet as discussed in section 2.2.6 of this paper, it is extremely difficult to discern, control for and predict how alterations listed in column C (which are responses to reduce tangible visible problems listed in column B) define and adjust the less-tangible/visible switches listed in column D (of which only a small selection are given). Thus attempts to improve irrigation efficiency suffer from informational discontinuities between the columns and from coupling between fractions as well as other issues identified in the paper such as ill-defined terms and definitions, and a lack of a theory and practice of measurement.