Foodshed Vancouver:
Envisioning a Sustainable Foodshed for Greater Vancouver

by

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Abstract

This study explored assessment methods for sustainable foodshed design. A sustainable foodshed was defined as a regional form that *meets local food needs*, is *energetically productive*, and is *ecologically and socially resilient*. Food system energy inputs were measured through a life-cycle assessment of production, distribution, processing, and nutrient cycling inputs to determine the food system energy balance for Greater Vancouver's hypothetical foodshed. The model accounted for embedded variables such as dietary habits, circulation allotments and distribution chains, ultimately requiring the integration of qualitative and quantitative indicators at a regional, municipal and farm scale.

Findings suggest that Canadians purchase roughly 710 kg of food per year, demanding 0.68ha of farmland per capita. If all proximal Agricultural Land Reserve areas were fully utilized to support Greater Vancouver's 2006 population, it would require 3.5 joules of energy to produce, distribute, prepare and cycle nutrients for every joule of energy contained in the food Vancouverites eat. It may require a radical transformation of dietary habits and processing methods, and a renewed dependency on human-powered agriculture to sustainably feed the population of Greater Vancouver.

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1 Introduction

Foodshed design is a problem of both *size* and *shape*. Size describes the amount of land and energy required to support a food system, while shape is defined by the relative placement of farmlands and people at a provincial, regional and neighbourhood scale. This study explored both qualities and will propose methods to envision a sustainable foodshed for Greater Vancouver.

In 1974, British Columbia enacted legislation to protect some of the provinces richest agricultural land. Since then various studies have reported on the degree to which Vancouver can meet its food needs within the region but none have proposed objective methods for appropriately placing foodshed boundaries. Accordingly, though the total area of land protected remains roughly the same (at 4.7 million ha), the location and quality of British Columbia's Agriculture Land Reserve (ALR) land has shifted responding to development pressure from British Columbia's major urban centres (Smart Growth BC, 2004). ALR land in Greater Vancouver and the Fraser Valley has been reduced by 9% and 6% respectively since 1974 (ALC, 2009) and will likely continue to erode without objective justification for its protection.

Objectives of a Sustainable Foodshed

The United Nations defines food security as a condition when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food" (UN FAO, 2009). From a biophysical perspective, this requires all members of the population to have access at least the minimum energy requirements of 1,800kcal day^{-1}. (Ibid). *Food sovereignty* is an iteration of food security with a focus on providing communities the *capacity* to meet their own food needs (Forum for Food Sovereignty, 2007). As it is impossible to design food security and *guarantee* access to food, this study focused on the biophysical qualities of a foodshed that has the *capacity* to meet the food needs of Greater Vancouver. *Meeting food needs* is the first imperative of a sustainable foodshed. This should go with out saying, though too often foodshed planning seems able to compromise by meeting some food needs - implying that parts of the population will go without. Robins (2006, p1) for example suggested that British Columbia is roughly 48% food self-sufficient - a finding that should be met with great concern and an outpouring of research to identify the other 52%. Complete foodshed planning will undoubtedly force planners and designers to expand system boundaries to a national and even global scale, however it is the only option if this work is to be done in a moral and comprehensive way.

A Tale of Two Foodsheds

Early hunter-gatherer societies were small, usually less than 500 people, and spent much of their energy securing food or building shelter (Pimentel and Pimentel, 1996, p2). The introduction of agriculture enabled societies to dedicate more time to non-food gathering activities such as security and leadership (Ibid, p4) a movement of specialization which eventually supported the modern city. In British Columbia,

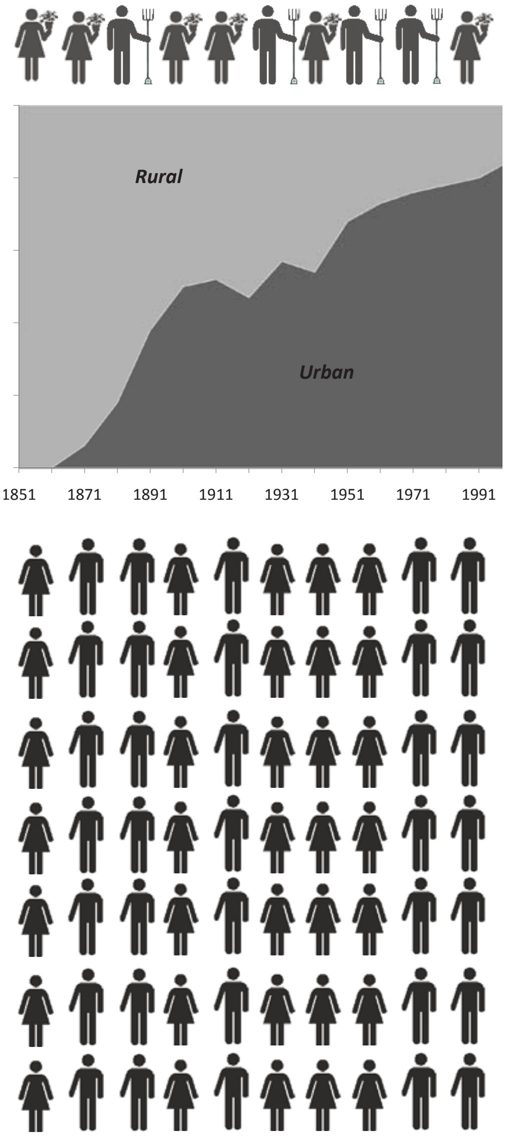
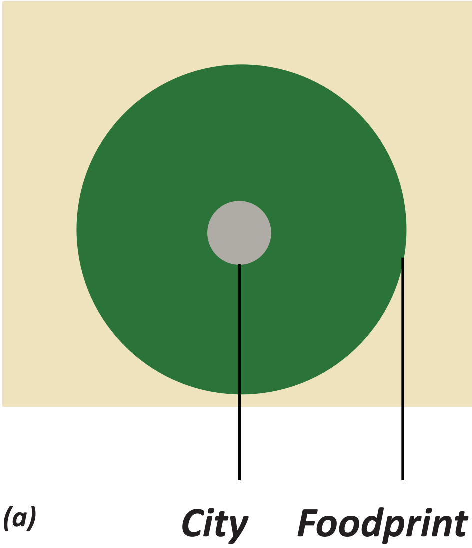


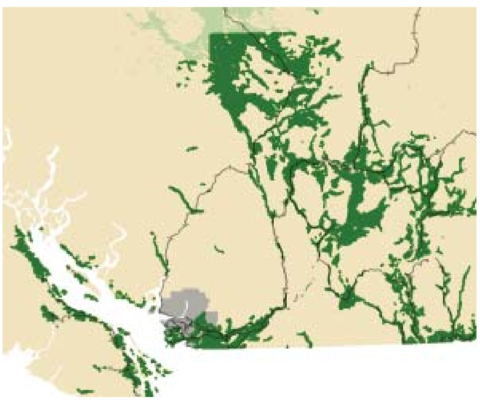
Figure (1.1). Rural Urban Population Split in BC, 1851 - 2001

urban populations did not even register on the census until the 1860s, but soon reached par with their rural counterparts in 1901 (Statistics Canada, 2006). Since then, rural populations have rapidly declined and now represent only 15% of the total population of BC (Ibid) (figure 1.1). The last decade has seen an increase in the average farm size and decrease in the number of people engaged in agriculture in a rapid departure from the traditional family farm. In 2006, farms in BC averaged 353 acres in size, 23% larger than in 1996 (Statistics Canada, 2008). During this same time, the population of farm operators decreased 10% while the population of BC increased by 11%. (Ibid)

The modern city is made possible by technological advances that enable the cultivation and harvest of large areas with little labour inputs, availability of cheap energy, and access to productive food plant cultivars (Davis, 1955). Slave labour facilitated large urban populations in ancient Egypt (Pimentel, 1996, Cottrell, 1955) while cheap energy in the form of fossil fuels drives the current industrial agricultural model and modern mega-city. The availability of cheap energy today contributes to the undervaluing of food and the farmland that produces it. After the United States, Hong Kong and Barbados, Canadians spend less of their expendable income on food than any other country in the world (USDA, 1996)[1.1]. Those that have cultivated a small patch of Earth to produce a head of lettuce will agree that there is simply no way to produce food for the prices charged in grocery stores. Profit margins are so small for some foods that it is difficult to grow food without losing money. Several of the foods sold at conventional market prices will only yield a negative contribution margin. That is, the more the farmers grow, the more money they lose. Small-scale beef, for example, costs more to produce and process than can be earned in sales assuming average yields and pricing (BCMAL, 2008). The only way to produce within this framework is to induce hidden costs, endured by future generations, or by people in “other places”. Without regulatory protection, the steady state of landscapes that are “valued” in this way is for use in housing. The rise in applications to remove prime agricultural land from the ALR for urban development (Smart Growth BC, 2004) suggests that even this external regulatory body is insufficient to counter economic pressure. The system that attributes value to land is broken and must be rebuilt in order to properly preserve agricultural land and the food it produces.



(a)



(b)

Figure (1.2). Defining a *Foodprint* (a), and *Foodshed* (b).

Measuring the Footprint of Food

A *foodprint* or *foodshed* is a spatial manifestation of the ecological footprint concept developed by Wackernagel and Rees (1996). For the purpose of this study, a *foodprint* is defined as the absolute area required by a community to meet its food needs (figure 1.2a). When constrained to land available for agriculture a city's *foodprint* is contextualized as a *foodshed* (figure 1.2b). This area may be local or at some distance from where the food is consumed, and is more often the latter in the Canadian context. The amount of land required depends on the dietary habits of the population where a vegetarian diet demands a much smaller land foodprint than a meat-based diet. Whether a community's foodshed is local or global, the concept alone can help planners and consumers actively discuss the impact of their choices, and ultimately take responsibility for land use and dietary decisions.

Peters et al. (2009) developed methodology to map a hypothetical foodshed for New York State based on agricultural capability and nutritional food needs. While his proposed generic diet met nutritional needs, it failed to respond to actual food choices thus has limited application in modelling a realistic foodshed. Further, his version of a foodshed utilized Euclidian distance (as the crow flies), targeting local foods independent of route complexities or modal intensities (rail, truck, air). Peters (2005) applied a similar model to Rochester NY, evaluating the minimum distance within which the caloric food needs of Rochester could be met. In this approach he used corn grain as a yield and food energy proxy to simplify the model. While grains make up the vast majority of the direct (rice, bread, pasta, etc) or indirect (though animal feed) food choices (FAO STAT, 2009), they fail to represent the weighted influence of high input livestock operations on the food system. Producing one 1kg of meat protein requires eleven times more energy than producing the same quantity of plant protein (Pimentel and Pimentel, 2003, p661S). A more comprehensive food palette and routing methodology is needed for meaningful foodshed mapping.

In nature, a predator must on average expend no more energy in pursuit of prey than it expects to derive from the food itself. This is predicated on the first law of thermodynamics which suggests that energy cannot be created nor destroyed but can only be changed in form or transferred from one object to another. Since predators have no source of chemical energy save for prey, they must consume more energy than they expend in order to grow and develop. While not a cognizant decision, it seems that this approach to food acquisition makes common sense and should be applied to human systems as well. That is, *a sustainable food system should produce more energy than it consumes,* accounting for the full life-cycle of food and considerate of healthy dietary habits and circulation & wildland set-asides (figure 1.3). Food system energy balance is defined as the energy contained in the food purchased divided by the energy invested in its production, distribution, processing and nutrient cycling or *food energy output divided by food system energy inputs* shown in the following equation*:*

$$\boldsymbol{FS_E(net) = P_E + D_E + Pr_E + N_E}$$

$$\boldsymbol{FB_E = \frac{F_E(net)}{FS_E(net)}}$$

$Where:$

$FS_E(net) = Food\ system\ energy\ inputs\ (GJ)$

$P_E = Production\ energy\ inputs\ (GJ)$

$D_E = Distribution\ energy\ inputs\ (GJ)$

$Pr_E = Processing\ energy\ inputs\ (GJ)$

$N_E = Nutrient\ cycling\ energy\ inputs\ (GJ)$

$FB_E = Food\ system\ energy\ balance\ (no\ unit)$

$F_E(net) = Food\ energy\ for\ all\ food\ groups\ (GJ)$

Stanhill (1977) applied a similar algorithm in his evaluation of allotment garden systems of early Paris, and Leach (1975), Carlsson-Kanyama (2003) and the Pimentels (1980, 1996, 2008) are famous for detailed case studies examining energy inputs and outputs of conventional and organic food systems around the world. However, these studies struggle with setting system boundaries that respond to the complete life-cycle of food, and often use methods absent of detailed contextual data that can't inform meaningful policy change. The two problems are connected when it comes to the distribution and nutrient cycling stage of the food life-cycle which depend on local route complexities. One must consider regional form, population density, distribution options, relative location of farm and city lands, and nutrient production capacity to meaningfully apply area and energy footprints to the landscape. This study builds on past research by applying the food energy balance algorithm to the context of BC in an assessment of the energetics of Greater Vancouver's Foodshed ***fork to fork*** (figure 1.3).[1.2].

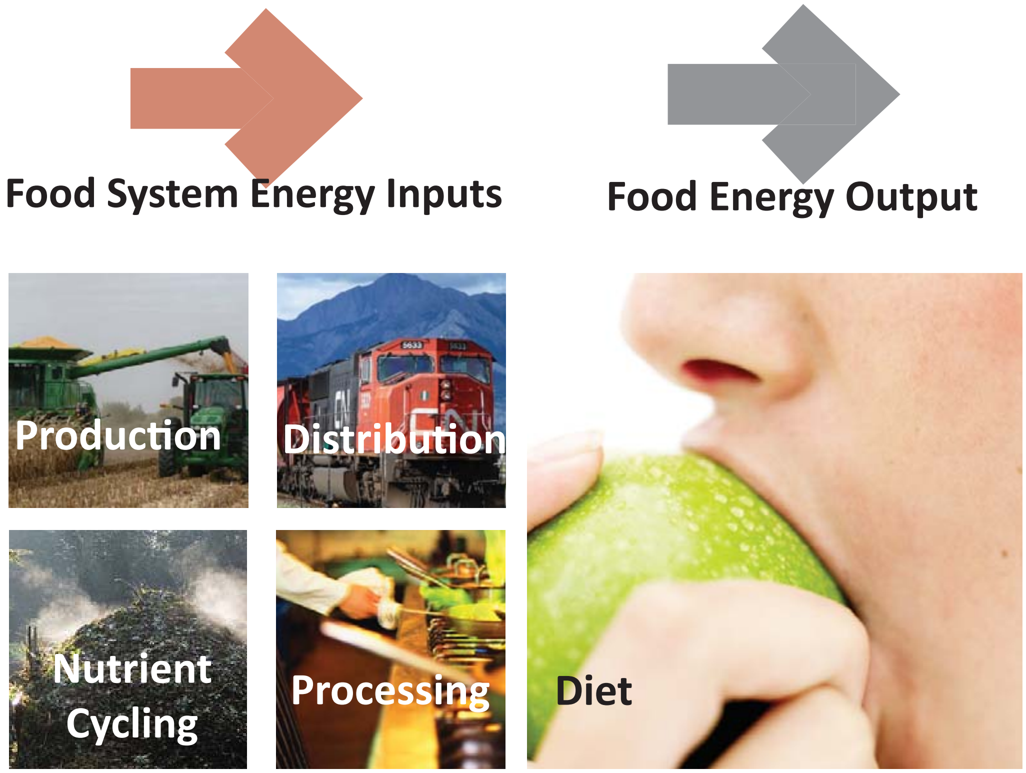


Figure (1.3). Food System Lifecycle Accounting.

Tellarini and Caporali (2000) explored several economic and energetic indicators they described as Agro-ecosystem Performance Indicators (API), and stressed the need to integrate qualitative and quantitative indicators to more comprehensively inform sustainable land use decisions. Accordingly, defining a foodshed entirely by its capacity to *meet food needs* in an *energetically productive* way is insufficient to preserve or promote sustainable foodshed design. Food lands must also be *ecologically and socially resilient* (figure 1.4). This last indicator is much more difficult to quantify and demands attention to the *shape* of food lands at *multiple levels* of scale, functionally integrating planning decisions at the provincial, regional, urban and community garden scale. All three imperatives must be met to satisfy these sustainability requirements.

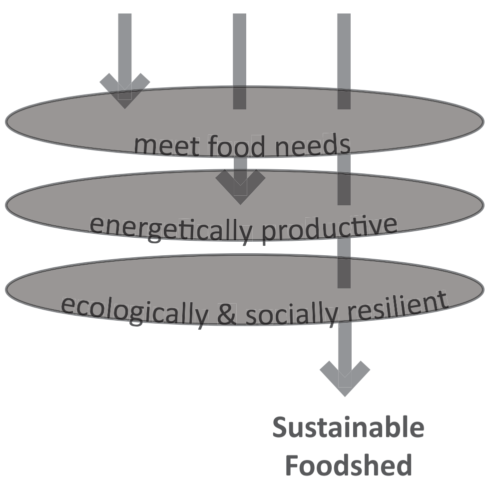


Figure (1.4). Three Imperatives of a Sustainable Foodshed.

Reading the Menu

This study seeks to answer one fundamental question in the context of Greater Vancouver: *What is the size and shape of a sustainable foodshed?*

Sections two and three set the table, exploring the impact of dietary habits and wildland and circulation allotments on the appropriate size of a foodprint. Sections four through seven identify the energetic and area implications of the four stages of the food system, and section eight applies these parameters to five scenarios, testing the impact of changing critical variables on the performance of Vancouver's hypothetical foodshed. Sections nine and ten help digest some qualitative shape-based indicators which influence the ecological and social resilience of foodsheds, and section eleven applies indicators discussed throughout the report to the design of three local farms.

Throughout the meal designers and consumers should focus on the implications of behavioural and land use change on a provincial, regional and farm scale, each of which is critical for a sustainable food system. The foodshed boundaries or specific forms identified throughout the study are much less important than the means taken to draw them. The true objective of this study is to explore *methodologies* to assess and design sustainable foodsheds and marks the beginning of this conversation rather than the end.

Endnotes

1.1 Cheap food

While Canadians spend less of their expendable income on food than most countries in the world, this doesn't imply low *absolute* food prices. Food prices in Canada are high, but so are average incomes. This translates to food insecurity for the working poor or jobless who might have greater access to food in countries where the absolute price of food is low. (USDA, 2010)

1.2 Data assumptions

The 2006 population census data is used to model "current" foodshed boundaries. (Statistics Canada, 2006)

Statistics Canada and Cansim have developed population projections to 2031 for each province and territory, and to 2056 for Canada. They've generated 13 scenarios which account for various rates of immigration, migration, births, and other demographic variables. When applied to Vancouver and extended to 2050 (the later 19yrs generated from the 1930-1931 growth rate), these scenarios predict a wide range of outcomes suggesting 2050 populations for the GVRD from 2.5 million to nearly 4 million, or 120% to 190% of the 2006 population. This model assumes a growth rate of 150% over the 2006 census population suggesting a population of 3.1 million in 2050. This rate is likely low given the recent boost in Metro Vancouver's status as a world destination, not to mention under-reporting issues inherent with Statistics Canada census collection. BC Stats predicts a that Vancouver CMA will reach 3,316,626 by 2036 (BC Stats, 2010).

Food Consumption patterns were identified by Statistics Canada, 2002 and food production patterns were observed by the British Columbia Ministry of Agriculture and Lands (BCMAL, 1996 - 2008), supplemented by Mullinix et al (2009); and modal intensities were measured by the Office of Energy Efficiency, Natural Resources Canada (NRC) in 2006 and published in 2009. (NRC, 2009).

These non-spatial parameters will be placed within the regional form and modal networks available via the following spatial data sets: The national road network compiled by ESRI Canada (DMTI Spatial, 2006, 2008); and available ALR lands compiled by the Agricultural Land Commission, 2009b.

It should be noted that a considerable amount of land is agriculturally productive but not in the ALR. While these lands are an important part of the food system, they do not represent an intentional dedication of land for agricultural function, thus are not included in this study. There is also a lot of ALR land which is available but not producing food. Although there are 4.7 million hectares of land in British Columbia's agricultural land reserve, only 2.8 million ha of land was utilized for agriculture in 2006 (Statistics Canada, 2008). This thesis models food capacity, rather than land utilization thus all ALR lands were assumed available for agriculture.

The system boundaries for the regional foodshed energy assessment are indicated in figure (1.5) below.

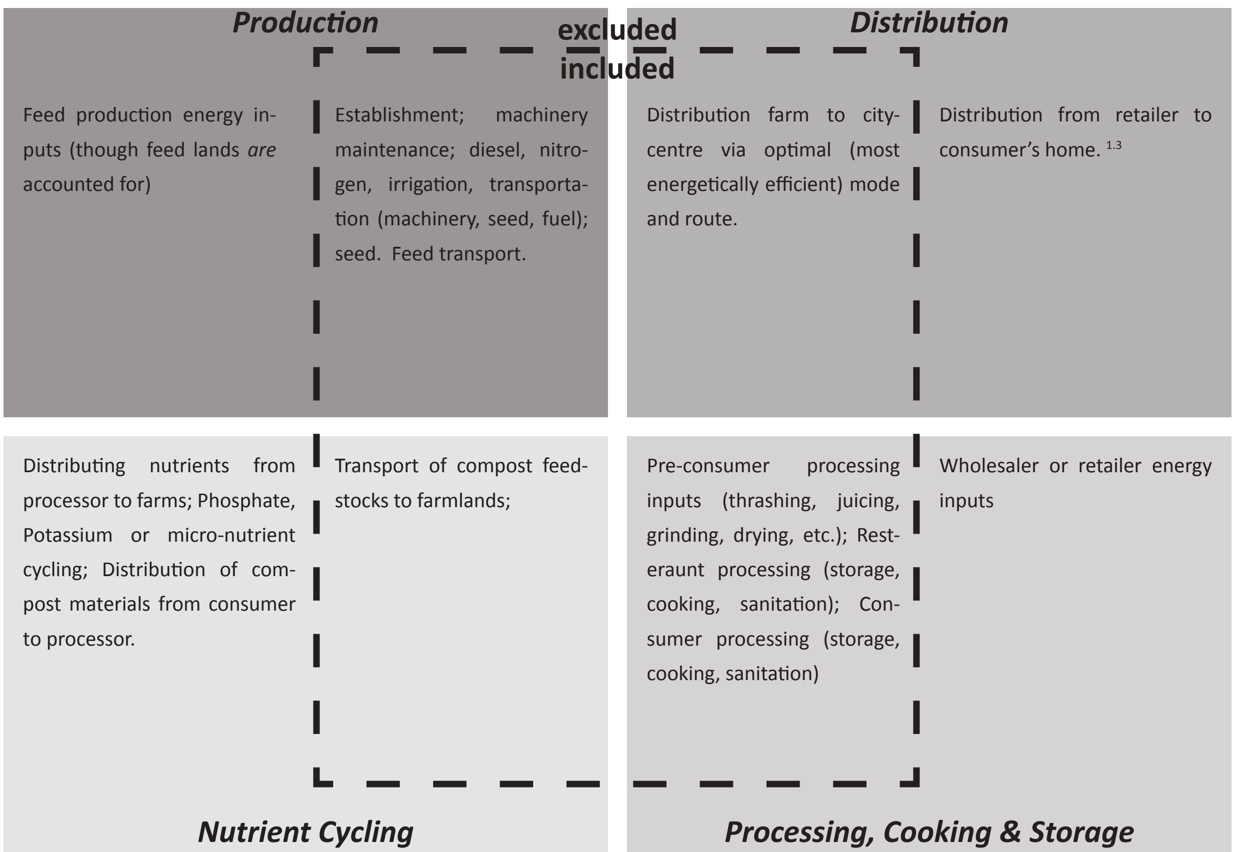


Figure (1.5) Regional Foodshed Energy Assessment - System Boundaries. Inside the dashed line are processes that are accounted for in the regional foodshed model. No metabolic energy inputs were included in the model beyond that required during the production stage of the food cycle. While distribution of food from retailer to households is discussed in section (5), it is not included in the regional model.

2 Dietary Habits

Researchers often model the space food requires by first identifying a proxy which energetically represents a standard diet. Peters (2005), for example, used corn energy yield as a proxy for generating a foodshed model in New York State and Penning de Vries et al. (1995) suggest the use of a "wheat equivalent diet" for evaluating an individual or community's annual diet, with higher consumption values attributed to higher levels of affluence. In these two examples, foodshed planning could be based on yield predictions and assumed consumption where the net foodshed size is simply population consumption divided by target yields. This simplification risks missing the many aspects of food that appear in small quantities, or cannot be measured at all. When dietary decisions reflect sociocultural patterns that extend beyond a corn diet, these models have little application in designing realistic foodsheds. This study assumes that the average Canadian diet meets the nutritional and cultural needs of society. This method lends itself to better reflect true dietary needs, and can model the implications of dietary shifts that will be discussed in section (8). This section will compare the Canadian diet with consumption patterns around the globe.

Food Energy

Food can be coarsely evaluated by the relative content of proteins, fats and carbohydrates. Each of these dietary components provides food energy, often evaluated in terms of calories, or more accurately kilocalories. Humans consume between 1,500 to 3,800 kcal in dietary energy per day (FaoStat, 2009). A nutritious diet contains *balanced* quantities of proteins, fats and carbohydrates, in addition to vitamins and minerals present in more dilute quantities. Food energy is the metric used to parameterize the food system energy balance equation introduced in section (1). It is defined as the energy contained in each individual food type multiplied by the mass of food consumed and summed to represent an individuals net food energy intake as per the following equation: [2.1]

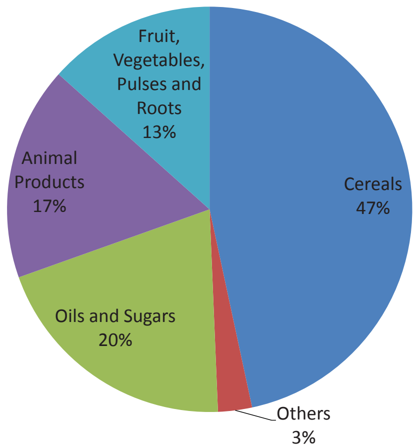
$$\boldsymbol{F_E(net)} = \sum(\boldsymbol{F_E} \times \boldsymbol{FP_m})$$

$Where:$

$F_E(net) = Food\ energy\ for\ all\ food\ groups\ (kJ)$

$F_E = Food\ energy\ \left(\frac{kJ}{kg}\right)$

$FP_m = Mass\ of\ Food\ Purchased\ (kg)$



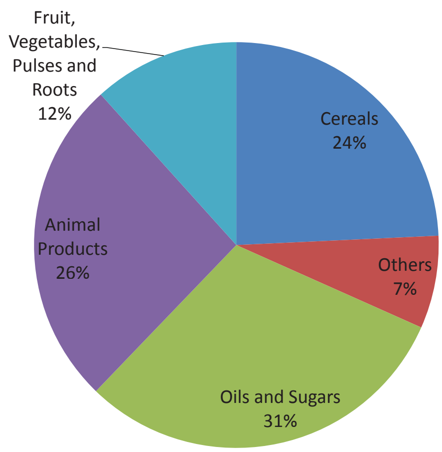


Figure (2.1) Crop Specific Food energy consumption. Relative caloric value of World (top) and Canadian (bottom) 2003 - 2005. Data source: FAO STAT Yearbook, 2009.

What the World Eats

Dietary habits differ significantly around the world both in quantity and quality. Over one billion people in the world live with chronic hunger (UN FAO, 2009), consuming less than the minimum caloric intake of 1800 kcal day^{-1}. That one sixth of the worlds population is starving to death is unacceptable and the focus of United Nations efforts to end hunger under the millennium targets to cut in half the number of people going hungry by 2015 from 1996 levels. (Ibid) Since this time, hunger has increased to its highest levels since the 1970's (Ibid, p4). It is no coincidence that this crisis coincides with rising oil and commodity prices. Even nearing the end of 2008 when oil prices receded from a high of $150 per barrel, prices for staple foods remained 17% higher than 2 years earlier (Ibid, p9).

The quality of food Canadians eat is heavily weighted to animal products, oils and sugars (figure 2.1), representing almost 60% of Canadian food intake (table 2.1). In contrast, grains make up the majority of caloric intake for those in developing countries (figure 2.1). It is important to note that Canadians are indirectly dependent on grains through the animal feed that supports the meat industry. The quantity of food energy Canadians (and North Americans) consume is not surprisingly much higher than the world average and the cause of an obesity crisis across the continent. On average, Canadians consume roughly 3,550kcal per day per capita, almost two times the minimum determined by the UN FAO and 11th highest in the world (figure 2.2).

FOOD ENERGY SUMMARY	Food Energy Purchased (kcal/day)	Food energy purchased (MJ/cap*yr)
Grains	851.03	1,300
Vegetables	341.25	521
Fruit	186.99	286
Oils and Sugars	1,043.66	1,594
Animal Products	1,087.38	1,661
Sum:	**3,510.31**	**5,361**

Table (2.1) What Canadians Eat. (see appendix 14.1 for more details.)

Modelling Food Consumption

It is difficult to accurately track food consumption with traditional survey methods. To assess Canada's capacity to meet regional food needs, Statistics Canada monitor what they call *food disappearance* [2.1], which is the food produced in Canada added to food imports, less any exports. (Statistics Canada, 2002). While limited, this is a good proxy for what food is *purchased* on a per capita basis. They also to estimated how much food is actually consumed accounting for wastage through the food cycle. However, this study focused on the *mass* of food *purchased,* a more reliable indicator than food consumed. Food *energy* pur-

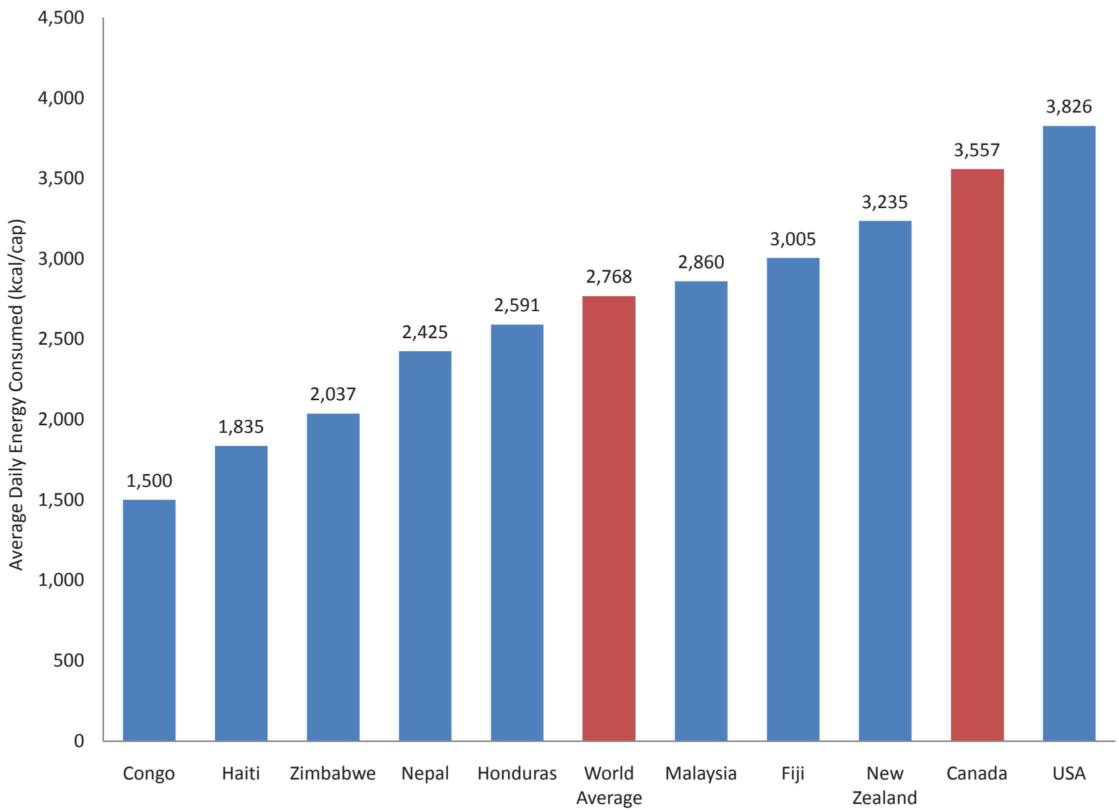


Figure (2.2). Energy Consumption for Selected Countries 2003 - 2005. Of 172 countries, Canada consumes the 11th greatest number of calories cap^{-1}. (Source: FAO STAT - 2008)

chased was modelled for each food type using estimated nutritional values calculated by USDA (2000), and supplemented with data from nutritiondata.com[2.2]. Only foods that could be grown in BC were selected and the mass of each food type was increased to compensate for foods that are typically imported. For example, rice cannot be grown in British Columbia, so every grain source that could be grown in BC was increased so the total *mass* of grains consumed remained the same. While grains required little adjustment, the fruit palette shifted significantly to compensate for the tremendous amount of citrus fruits Canadians consume. Reflecting on the data, BC can only grow 40 % of the fruit that is regularly consumed by Canadians[2.3]. Fish, soft drinks and other food groups that cannot be grown directly were excluded. This assumption has ramifications on the total modelled energy consumption which equals 2,421 kcal cap^{-1}day^{-1}, almost 30 % less than the 3,557kcal cap^{-1}day^{-1} estimated by the FAO (UN FAO 2009)[2.4]. After these considerations, the model predicted that Canadians *purchase* 3,510 kcal yr^{-1} of food, slightly less than FAO consumption estimates[2.1].

Conclusion

The modelled daily energy consumption values are well within the range of a healthy diet and *food energy purchased* is very similar to FAO estimates. Food energy purchased (or food energy output) at 3,510 kcal cap^{-1}day^{-1} or 5.36 GJ cap^{-1} year^{-1} is the benchmark against which the food system energy inputs were assessed. A central thesis of this report is that a ***sustainable foodshed should yield more energy through food energy output than is invested in its production, distribution, processing and nutrient cycling***. Pre-industrial Chinese peasant societies achieved a food energy balance of 41 joules of energy for every joule invested (Leach, 1975, p 64). As a tool to measure positive change, the chosen benchmark is less important than the methods used to evaluate progress. That is, in a post-industrial society where energy is available from many sources, it is difficult to argue for one target over another. However, the act of setting a target and observing which factors make the most difference will undoubtedly inform positive change.

Endnotes

2.1 Food disappearance

From 1988 through 2002, Statistics Canada evaluated food purchased through a proxy they call food disappearance, calculated on an annual basis according to the following equation:

$$\boldsymbol{FP_m = (P_m + I_m - E_m)/p}$$

$Where$:
$FP_m = Mass\ of\ Food\ Purchased\ (kg/cap)$
$P_m = National\ production\ (kg)$
$I_m = National\ imports\ (kg)$
$E_m = National\ exports\ (kg)$
$p \quad = Population\ of\ Canada$

(Statistics Canada, 2002)

Only food consumed and purchased for the 2001 calender year was assessed as it represented the most complete and up to date data set available, though more recent surveys have been completed. It is assumed that the food which "disappears" is purchased. However, not all food purchased is consumed as seen in appendix (14.1). By their own admission, food consumption estimates are experimental, speaking to the challenge of obtaining reliable data on what people actually eat. Needless to say, if 30% of the food energy purchased is not consumed, the food system could stand to benefit from more research and political action to improve consumption efficiency.

2.2 Food energy

Energy and moisture content of all foods were evaluated according to data from and the USDA (2000) and supplemented with Nutritiondata.com (2010). Food energy represents the energy contained in the food itself. It was calculated by dividing the energy contained in a set serving (kcal), by the serving size (usually in grams). For example, a kilogram of lettuce contains roughly 540 kJ, in comparison with a kilogram of pork which contains 10,000kJ. For this reason, energetically speaking, lettuce is less appropriate than other food groups with higher food energy intensities, thus makes up a lesser portion of the energy diet as seen below. This, of course, does not account for critical micronutrients contained in vegetables, thus people would be wise to keep eating them. The *mass of food purchased* was used as the driver for agricultural planning decisions.

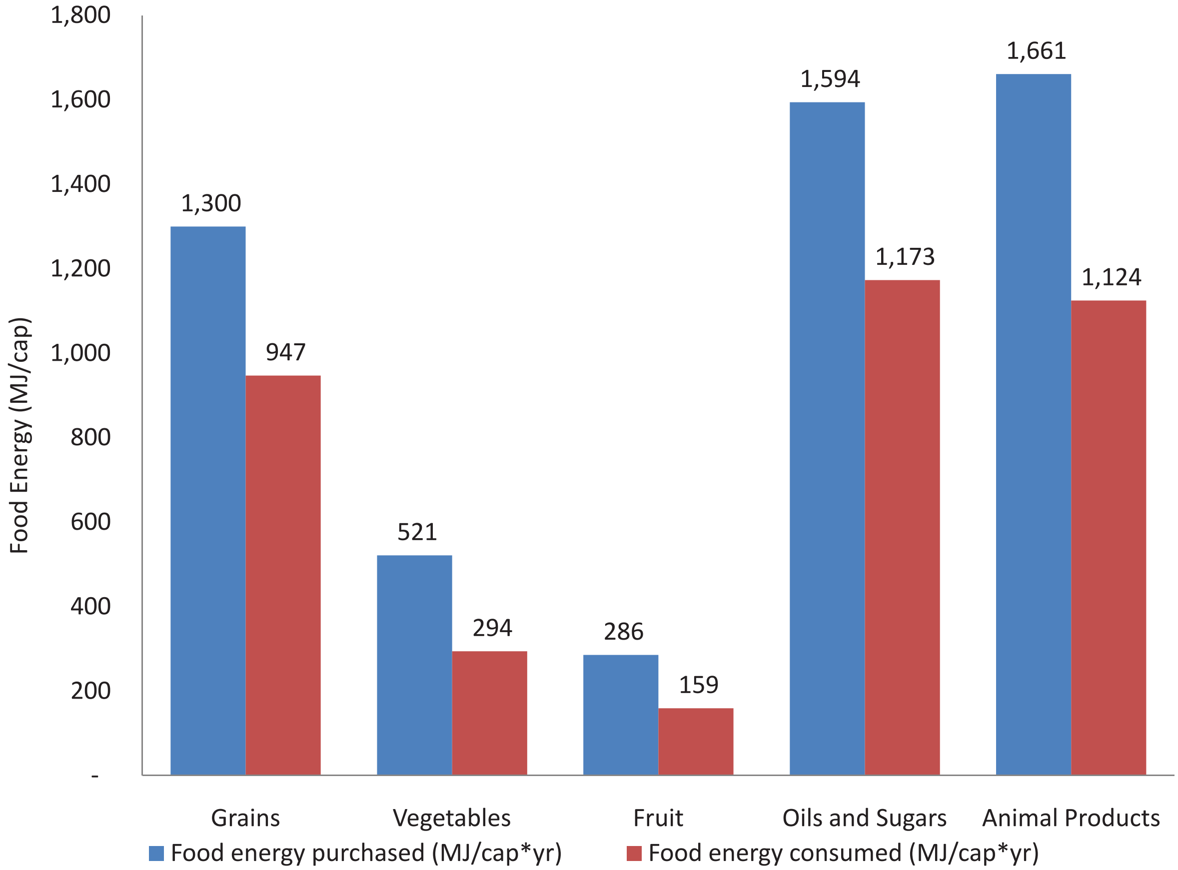


Figure (2.3). Annual Food Energy Purchased and Consumed (estimated) (MJ/cap) Based on reported consumption and purchasing values stated by Statistics Canada, 2002 and food energy values modelled in this report.

2.3 Fruit consumption shift

Bananas, pineapples, avocados, coconuts, oranges and papayas were excluded. Several fruits have growing potential in BC but were not modelled including: mangoes cranberries, dates, figs, nectarines, and quince. Fruit consumption included the "fresh equivalent" weight required for juices but not alcohol, both of which represented a significant consumption statistic. Future modelling should incorporate alcoholic beverages. Source: Statistics Canada, 2002.

2.4 Modelling error

The difference between FAO estimates and the modelling assumptions of this report are likely due to a combination of factors including: variability in assessing nutritional value of the food groups mentioned; ignoring highly processed high energy food groups such as chocolate bars; errors in estimating wastage by Statistics Canada; over estimating food consumption by FAOStat; and the misuse of proxies such as canola oil for all vegetable oils or sugar beet for all sugar consumption misrepresenting the actual energy value of consumed foods.

3 Circulation & Wildlands

A dedication of lands for ecological processes and general circulation is necessary for an ecologically resilient and accessible foodsystem. There is roughly 4.6 million ha of land in British Columbia's Agricultural Land Reserve (Agricultural land commission, 2009 p7). Only 2.8 million ha of farmland were declared in the 2006 Agricultural Census, and lesser still is actually producing food (Statistics Canada, 2006). The ALR land does not account for *macro-circulation*[3.1] (highways and streets), *micro circulation* (tractor ways, pathways, field margins), service buildings (barns, sheds or homes), wildlands (woodlands, buffer strips or hedges) or waterways (ditches, riparian areas, or streams), all of which support the function of a farming system. This section will describe the importance of wildlands, discuss the spatial implications of size and shape, and identify an allotment for circulation and wildlands.

Wildlands and Foodlands

Wackernagel et al. (2002, p 9268) estimated that agriculture has an equivalent ecological footprint of 0.63ha per capita, over six times the land footprint of infrastructure, and the dominant cause of anthropogenic land use change. Tillman et. al., (2001) noted how an 18% increase in agricultural land forecasted for 2050 from 2001 levels would represent a loss of wilderness larger than the United States highlighting the implications of "business as usual" agricultural scenarios (Tillman, et al., 2001 p283).

Some have pointed out that technological advances (genetically modified foods, chemical fertilizers), and the subsequent intensification practises have saved wildlands by feeding more people with less land, saving the rest "for nature". Waggoner (1996) pointed out how a grain yields consistent with those in arid Africa of 1ton ha^{-1} may feed 10 billion people but would save little or no space for nature. In contrast, if world yields were increased to American corn standards, 10 billion people could be fed on half of the available cropland in 1996 (Ibid). Waggoner suggested that the green revolution saved 44 million ha of wildlands in India due to the increases in productivity, lessening the land necessary to feed the population. This "model" failed to account for the long-term environmental consequences of high intensity fossil-fuel dependent agriculture. This false dichotomy between food *or* wildlands prevents real dialogue on the matter, forcing people to accept either one position or the other. Wildlands are integral to the preservation of functioning agricultural systems. Maintenance and enhancement of wildlands within organic food systems is an imperative of a sustainable food system.

Ecological Importance of Wildlands

The importance of wildlands, large or small, cannot be overstated. Animals are responsible for assisting the pollination of 35% of the world's crops (Klein et al., 2007). On a sunny day in July , bees will pollinate over 6,000,000 million blossoms of fruit and vegetables alone in New York state (Pimentel, et. al, 1997). Humanity simply does not have the technology to replace this free biological service. Wild and managed

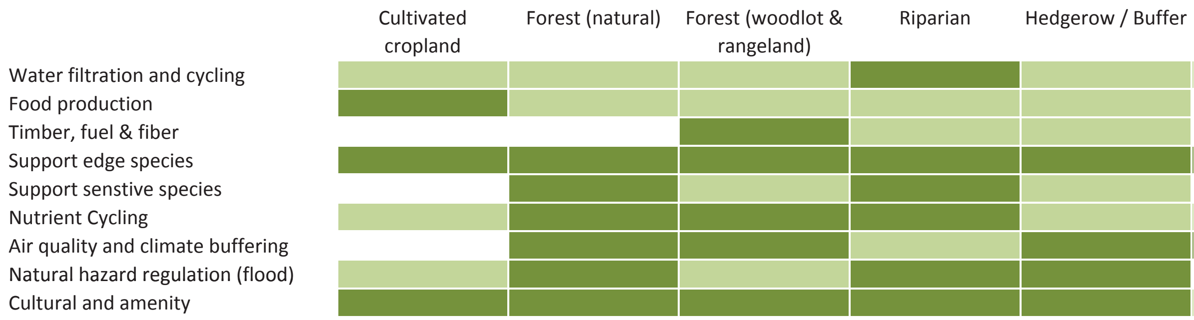


Figure (3.1) Ecological Services of Farmlands. Adapted from IUCN, 2004. Darker tones indicate greater intensity.

agricultural land are integral to a multitude of ecological services including: water filtration and cycling, habitat, nutrient cycling, air quality control and to manage flood waters, to name a few (figure 3.1), (IUCN, 2004, Pimentel et al, 1997). Beyond the biophysical services they provide, wildlands also offer inspiration on how to shape and size agricultural lands in an ecologically and socially productive way, qualities that will be discussed further in section ten.

Informing Circulation & Wildland Allotments

There is no consensus on how much land *should* be preserved for nature at a provincial scale. The interplay of local, regional and global context is simply too complex. Therefore a review of wildland and circulation patterns on *existing* small and large scale farms will informed the wildland & circulation designations for this study.

Micro-circulation:

The *function* of the farm (educational or production oriented) and scale of production dictate to a large degree the amount of land dedicated to micro-circulation (pathways, tractor lanes, etc.) and to wildlands. Operations with an emphasis on community education necessitate a degree of accessibility not found in landscapes focused on food production alone. These community gardens or urban farms feature raised beds and wide pathways to support *way-finding,* simply indicating to pedestrians where they should walk, and limiting the amount of crop or soil damage that can be done by *farmers in training*. *Legibility* is a necessary component of this type of landscape. Farms intending to demonstrate agro-ecological linkages generally dedicate more space for nature.

Scale appeared to have an important influence seen in figures. Small farms or community plots that are limited to the use of hand tools and often have not enough space for a tool shed, limiting the functionality of the space. As the farm size increased, external functions were accommodated onto the farm or community garden property. From a systems theory perspective, these new functions are known as *emergent properties (Corning, 2002)*. Tea Swamp Community Garden, for example, is limited to a 0.03ha corner of a neighbourhood park and has just enough space for 19 garden beds[3.1]. Fraser St. Garden, a 0.1 ha section has 50 planting beds and one large shade tree, taking up valuable planting space but offering a shade function not available in the smaller garden. Cottonwood Community Gardens is roughly 1ha in size but has only 7% of the land area under intensive cultivation. The remaining land is used for circulation, meeting spaces, community beds and wildlands. Strathcona community gardens of 1.6 ha has 24% of the land area under cultivation but supports an extensive espalier fruit orchard and adjacent wild space. Of the

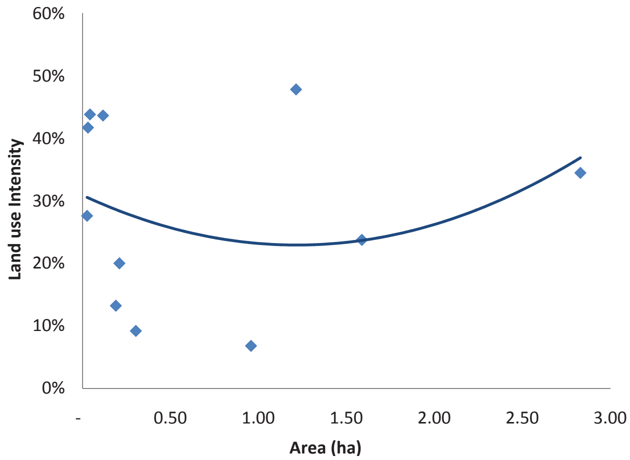


Figure (3.2a) Community Garden Land use Intensity. The land use intensity fit is purely conceptual. As the graph demonstrates there is a tremendous amount of diversity with regards to land use intensity. As garden size increases, more forms become possible including meeting places, tool sheds, and wildlands.

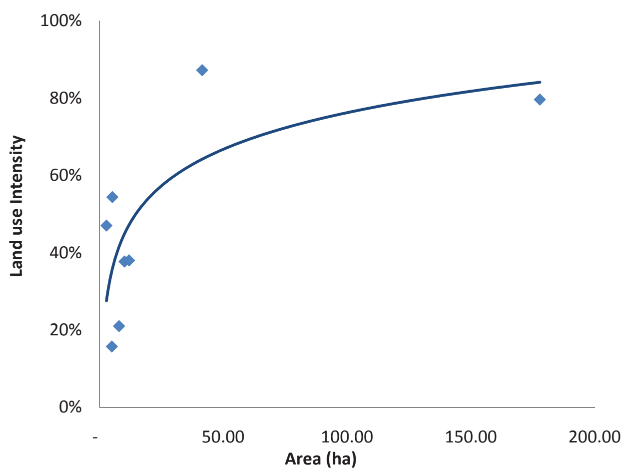


Figure (3.2b) Large Farm Land use Intensity. Once again insufficient data is available to properly quantify land use intensity on medium to large scale farm plots, in addition, the type of food produced (grains, etc.), negates the need for micro-circulation needed in community garden plots. However, it is qualitatively safe to say that larger farms can dedicate more space directly to cultivated, food producing land.

11 community gardens with available data a weak polynomial relationship emerged with an initially decreasing cultivated land use intensity in relation to garden size, followed by an increase when the garden size exceeded 1.5 ha (figure 3.2a). This land-use utilization trend continued to increase approaching 80-90% as farm size approached 200ha (figure 3.2b).

Macro-circulation:

This study assumed a set back of 10m from rail centre lines, 40m for highways and 10m for roads adapted from Harris and Dines (1998, p 342-3), reducing available ALR land from 4,647,522 to 4,543,080 ha.

Circulation and Wildlands in British Columbia:

Of British Columbia's farmland, roughly 82% is under crop production or pasture, leaving 18% percent for wildlands, fallow and circulation (Statistics Canada, 2006) (figure 3.3). It is notable that 53% of lands were assessed as natural land for pasture, highlighting the importance of rangelands in British Columbia, and the intercourse that agriculture can play with wildlands, albeit in a controlled fashion. Though unmanaged woodlots, rangeland and fallow lands do not perform the same ecological functions as old growth forests, they are viable interventions that can optimize the e*cological, economic and social services* provided by agricultural lands. BC currently protects just over 14% of the provincial land area (BC Parks, 2010) though much of it is in the north or central part of the province (figure 3.4). Without policy to protect or improve wildlands at a regional or site scale, they will continued to be threatened by development in highly contested lands in the south. As such, provincial conservation targets of 10 to 12% may be a good start, but do not account for site-specific details or species-specific habitat needs (Wiersma and Nudds, 2006, p 4555) which can only be assessed at a local scale.

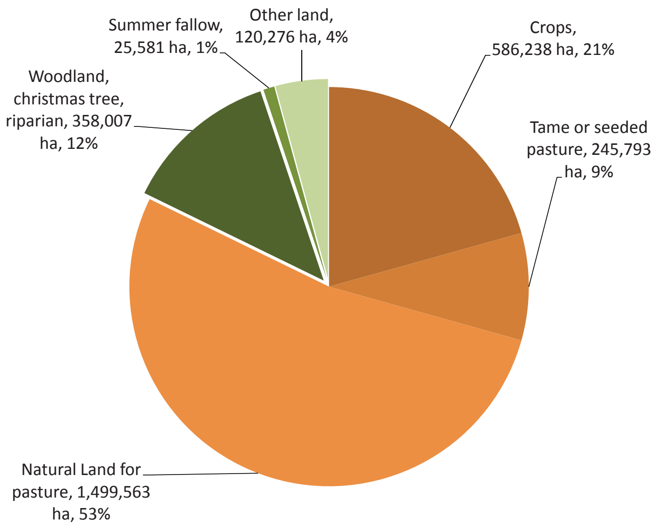


Figure (3.3). Composition of BC Farmland. 17% is currently excluded from pasture or cultivation. (Stats Can, 2006)

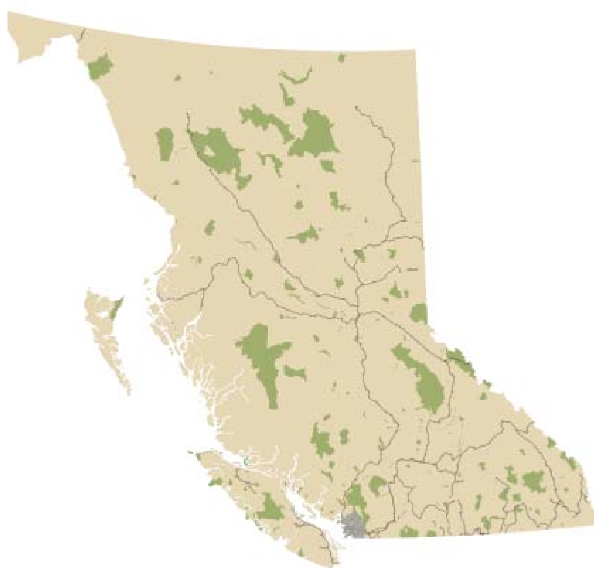


Figure (3.4). Provincial Parks in BC. Regional habitat sytems greatly influence the functioning of site based wildland reserves.

Conclusion

Given ***current land use patterns***, this study assumed ***30%*** of remaining farm lands (discounting macro-circulation) were dedicated to circulation and wildlands. Given the average farm size in British Columbia is 143 ha (Statistics Canada 2006), production from medium to large-scale farms will continue to dominate the food scene for the foreseeable future, negating efficiency losses found in small farms[3.3]. This study did not attempt to quantify how much land *should* be set aside for wildlife and circulation, though the complexities of this question will be discussed in section (10).

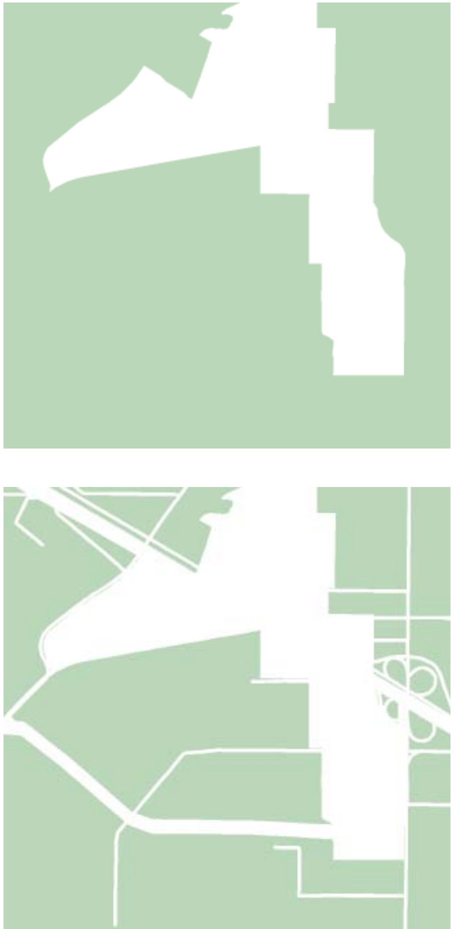


Figure (3.5). Macro-circulation Easements

Endnotes

3.1. Community Garden Assessment

Several community gardens in Vancouver were assessed using aerial imagery and Google Planinometer. A summary of methods and the function and circulation pattern for small (0.1ha) through large farms (200ha) can be seen in appendix (15.1).

3.2 Macro circulation allotment

Area required for macro-circulation (highways, roads and rail routes) was removed from existing and proposed Agriculture land (see image left). Highway easements were assumed to be 80m wide, while roads and rail assumed buffers of 20m wide (adapted from Harris and Dines 1998, p 342-3). The area required for macro-circulation represents 2% (104,000ha) of existing ALR land.

Area calculations were based on NAD 1983 UTM Zone 10 projections which estimates areas slightly larger (+0.02%) than the NAD 1983 BC Environment Albers projection method used by the Agricultural land commission.

3.3 Micro-circulation

Micro circulation (foot paths, tool sheds, meeting spots) tend to decrease cultivation intensity (area dedicated for production only) of small scale gardens making BCMAL projections somewhat inappropriate, which use production estimates based on large-scale food production systems (10 ac+)

For example, a standard raised bed of 4’ by 10’ with a 3’ pathway has a total footprint of 91sf (7’ by 13’ accounting for 1/2 of the path area) of which 40sf is actually cultivated. The net cultivation intensity is therefore 44% on this micro-scale, not accounting for other circulation allotments. In comparison a 100’ by 4’ row with 1’ pathways and has a total footprint of 505sf (101’ by 5’ accounting for 1/2 of adjacent path areas) achieving a cultivation intensity of 80%.

4 Production

Primitive societies obtained 14 units of food energy for every unit of energy expended in its production (Rappaport, 1971), a food-energy ratio that has been declining ever since. In 1963, over 6 units of energy were required for every unit of energy produced (Kaltsas et al., 2007). Meat based diets typical of North Americans today require 25 units of energy for every unit of food energy produced (Pimentel and Pimentel, 2003, p661S). The driving force of this increase is the use of large fossil fuel inputs in cultivation practice and the production of nitrogen fertilizers (Kaltsas et al, 2007), aggravated by a meat-based diet. In 1996, production energy inputs accounted for 18 – 28 % of the food energy budget (Heller and Keoleian, 2000 and Faist et al, 2001) and likely represent more today with an increase in larger scale, higher intensity farming systems.

This section will determine the energy inputs from organic food production methods based on Canadian dietary habits and compare field based organic production with conventional and greenhouse systems.

Early Live-powered Production

Pimentel (2009, p55) estimated early hunter-gatherer societies obtained a yield of 4 units of energy for every unit of energy expended, requiring a massive search range in order to secure food. Swidden agriculture proved a more efficient way of securing food without considerable energy inputs, achieving an energy balance of 15.4 energy output to 1 joule of energy input (Rappaport, 1971). In Rappaport's analysis of New Guinea Swidden Agriculture, 45% of the communities' crops were fed to pigs reducing the land efficiency from 13 people ha^{-1} to 5.5 people ha^{-1}, but guaranteeing access to food in poor production years (Pimentel and Pimentel, 2009, & Rappaport, 1971). In the mid 1800s, Paris boasted nearly 1600ha of urban allotment gardens, engaging between 5,000 and 9,000 people (Stanhill, 1977 p 271). Using human and horse power, people would harvest a significant quantity of food with the help of biointensive methods and glasshouses, expending 4 joules of energy for every joule of energy produced.

In preliminary data comparing biointensive, market garden and small farm systems, Bomford (2009) noticed decreasing production efficiency in grams of food per kJ of energy input, but increasing labour inputs in minutes per gram of food produced with increasing use of machinery. That is, biointensive systems that use only hand tools require more human labour input (as expected), but significantly less total energy input without fossil fuel inputs. This does not necessarily imply that small garden plots are better than large farms for meeting regional food needs. Indeed, on his plot in sunny Kentucky Bomford was able to produced roughly 50g of food per minute of labour input with biointensive methods. To produce only the vegetables, grains, oil and sugar crops and fruit for a family of four based on Canadian production standards and dietary habits would require 630 hrs of work or 18 weeks of labour input assuming 35 hrs of work per week[4.1]. This model is the norm for many "developing" communities across the globe, but

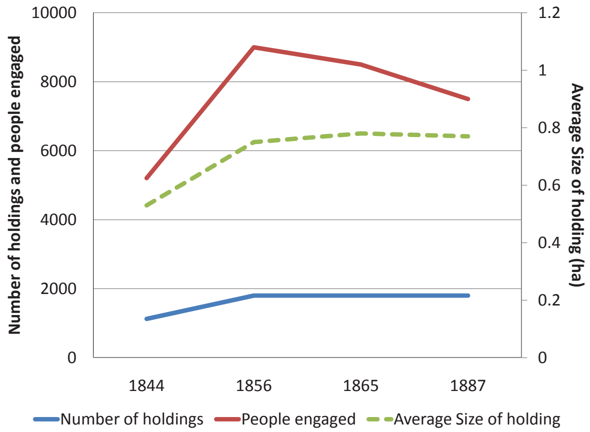


Figure (4.1). Early Urban Agriculture, Paris 1844 through 1887. For this period of time, from 4 to 5 people would work each 1ha plot. Stanhill (1977) p 271.

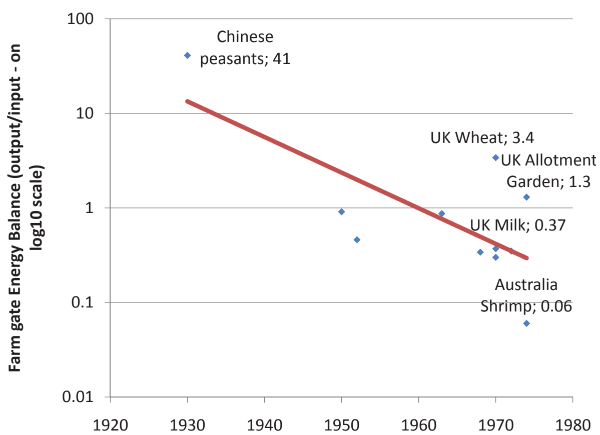


Figure (4.2). Evolution of Food Production Energy Balance, 1930s to 1974. Post farmgate energy inputs are not included. Data points without labels represent total agriculture from USA, Holland and the United Kingdom. Source: Leach (1975), p 64

may be inaccessible to busy city-bound folk in urban British Columbia. However, if fossil energy inputs become depleted as expected, this human-powered model of production may become necessary.

Human-powered agriculture was a central part of Parisian society through a network of almost 2,000 small holdings (<1ha) through the 1800's(figure 4.1) With little more than human labour as energy inputs, this form of agriculture is energetically productive in comparison to modern day agriculture (figure 4.2)

Metabolic energy inputs (from humans or animals) become more important in fossil-fuel independent agri-food systems but are inherently difficult to quantify as they depend on the intensity of the work and system boundaries of the model. Bomford (2009) assumed inputs between 0.75MJ hr^{-1} and 2.4MJ hr^{-1} but excluded metabolic energy spent on non-work tasks (sleeping, cooking, eating, etc.). Schroll (1994) assumed an agricultural labourer works 300 days $year^{-1}$ at 8hrs day^{-1} consuming 13MJ of energy per day. This equates to 0.5 MJ hr^{-1} excluding energy required for non-work tasks. Given energy expended during non-work hours (eating sleeping, etc.) is necessary to support a human during their working hours, this study assumed an expenditure of 12.5MJ day^{-1}(3000kcal day^{-1}) for 2000 working hrs yr^{-1}. The resulting ***effective hourly energy intensity*** accounting for non-work energy expenditure is 2.29MJ hr^{-1}. Under biointensive methods, Bomford's preliminary data show farmers could produce roughly 50g min^{-1} or 3kg $hour^{-1}$. This would require approximately 134 hrs of work or 307 MJ to produce the 5,350 MJ of food that makes up an individual's retail diet [2.1]. This labour input represents only 6% of the food energy output but is a little inaccurate given the embodied labour inputs necessary for producing feed for animal products.

Considerations for Organic, Conventional and Greenhouse-based Agriculture

The International Federation of Organic Agriculture Movement (2001) defines organic agriculture as "a production system that sustains the health of soils, ecosystems and people." While there is debate as to whether current practise meets this standard of sustainability, the conceptual design of the system is what should concern planners and designers first, followed by attention to professional practise and progress.

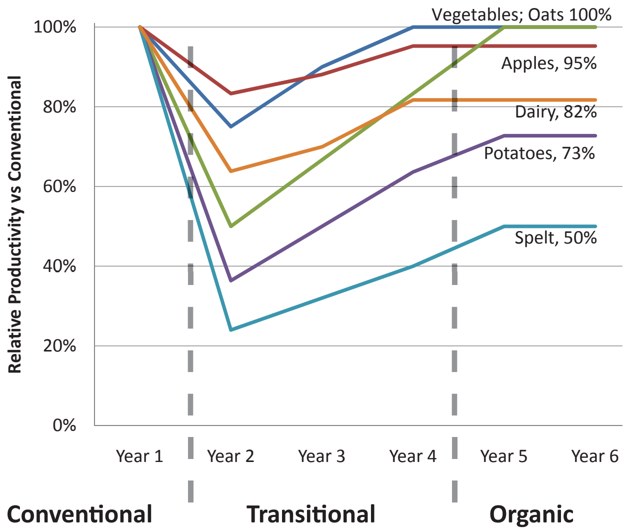


Figure (4.3). Organic and Conventional Farming Productivity. Farmers often experience intermediate losses transitioning to organic farming, but can achieve similar yields to conventional farms. Source: BCMAL

Given the finite nature of fossil fuels, known and unknown impacts of conventional agriculture on human health, and the relative energetic performance improvements of organic production over conventional farming [4.4], organic agriculture is a social and environmental imperative for a sustainable foodshed.

In British Columbia, farmers have increased no-till methods and conservation tillage methods to nearly half of all land prepared for seeding in 2006 (up 10% from 2001 levels (Statistics Canada, 2007). Of the 19,844 farms in BC, over 16% reported producing organic products (Ibid). Not only is a transition towards energetically and ecologically sound agriculture possible, it is in process.

Most studies suggest a subtle yield decrease with organic agriculture (Thomassen, 2008, BCMAL). Seen in figure (4.3), this is highly dependent on the crop type and varies according to management styles, soil conditions, and many other factors. Over many years, decades or centuries, under optimal management conditions, organic production could likely out-produce conventional methods.

Greenhouse production is catching on as a local alternative for fresh vegetables in the cold winter months, having grown in British Columbia by nearly 15% from 2001 to 2006 (Statistics Canada, 2008).

For ecological and energetic reasons, greenhouse production was excluded from the study. Ecologically, greenhouses represent a movement away from soil-based crop production, providing few if any of the regional ecological services noted in section (3). Further, they require high nutrient and pesticide inputs which can result in local and regional contamination (Ozkan, 2004 p89). In a study of BC hydroponic tomato operations, greenhouse production had an ecological footprint 14 – 21 times the size of mechanized open field alternatives accounting for increased greenhouse yields (Wada, 1993, p 46)

From an energetic perspective, local and global case studies show a net loss of energy for glasshouse production methods (Ozkan et al, 2004, Wada, 1993). In Wada's study of BC hydroponic tomatoes, only field based operations showed a net energy gain from tomato production, and only when operational expenses were not considered. In this case, operational energy inputs include fuel inputs, heating requirements, nutrient applications, and other energy inputs associated with the day to day operation of the farm. Embodied energy inputs refer to the energy required for manufacturing machinery, and direct farming related structures (greenhouses). When both the operational and embodied inputs were considered, the production of tomatoes in ***every*** scenario demanded more energy than was contained in the tomatoes before they left the farm gate (figure 4.4). This is a function of the energy value of tomatoes and the intensity

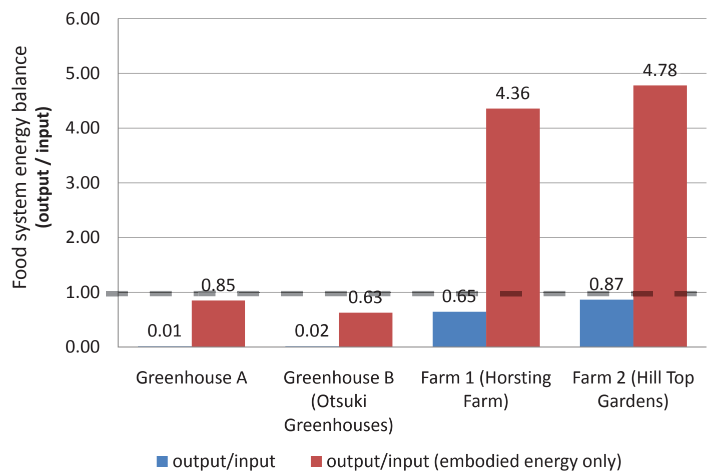


Figure (4.4). Energy balance (food energy output/input) for greenhouse and field-based Tomato Production. Values less than one represent a net loss of energy. Transportation energy inputs are not considered. Data sourced from Wada, 1993 p 80-87.

of greenhouse operations. Whether or not local greenhouse production competes energetically with transcontinental food production is a story for another thesis. I believe that seasonally appropriate diets and preservation techniques can adequately meet regional dietary needs.

The previous case study on tomato production begins to question what crops farmers *should* grow from an energetic point of view. Building on the equations developed in section (1) through (3) food energy intensity is defined as the energy contained in food multiplied by expected yields. Figure (4.5) compares the production energy efficiency of several food types accounting for yield, energy content and production energy inputs as described in the following equations:

$$\boldsymbol{FI_E = F_E \times Y}$$

$Where:$

$FI_E = Food\ energy\ Intensity\ (\frac{kJ}{ha})$

$F_E = Food\ energy\ (\frac{kJ}{kg})$

$Y = Crop\ Yield\ (\frac{kg}{ha})$

$$\boldsymbol{PE = \frac{FI_E}{PI_E}}$$

$Where:$

$PE = Production\ energy\ Efficiency\ (no\ unit)$

$PI_E = Production\ energy\ Intensity\ (\frac{kJ}{ha})$

$FI_E = Food\ energy\ Intensity\ (\frac{kJ}{ha})$

As can be expected, high cereal production efficiency combined with resilient storage qualities makes them the food group that literally feeds the world. Recent studies of winter wheat production in the lower mainland have shown yields of up to 12 tonnes ha^{-1} (Temple, 2009), enough to meet the wheat needs of 150,000 people (based on wheat consumption of 80kg cap^{-1}). Contemporary wheat yields are closer to 3 to 4 tonnes ha^{-1} [see 4.2]. In contrast, the low energy content of cucumbers, coupled with poor storage characteristics (unless pickled), makes them poor candidates despite their high yields. Cereal products dry to between 10% and 40% moisture content, but most fruit and vegetables contain well over 80% moisture[2.2]. That is, many foods are mostly water, a quality which impacts how well they store, their transport efficiency and energy content. In 2007, of the nearly 4.9 billion ha of global agricultural land only 26% of it is used for crops, the rest is in some form of permanent pasture. That the majority of this arable land is dedicated to cereals (57%) demonstrates the importance of grains to the global food supply (FAO STAT, 2009). Accordingly, the vast majority of the global caloric intake is directly or indirectly tied to cereal production (maize, wheat, rice).

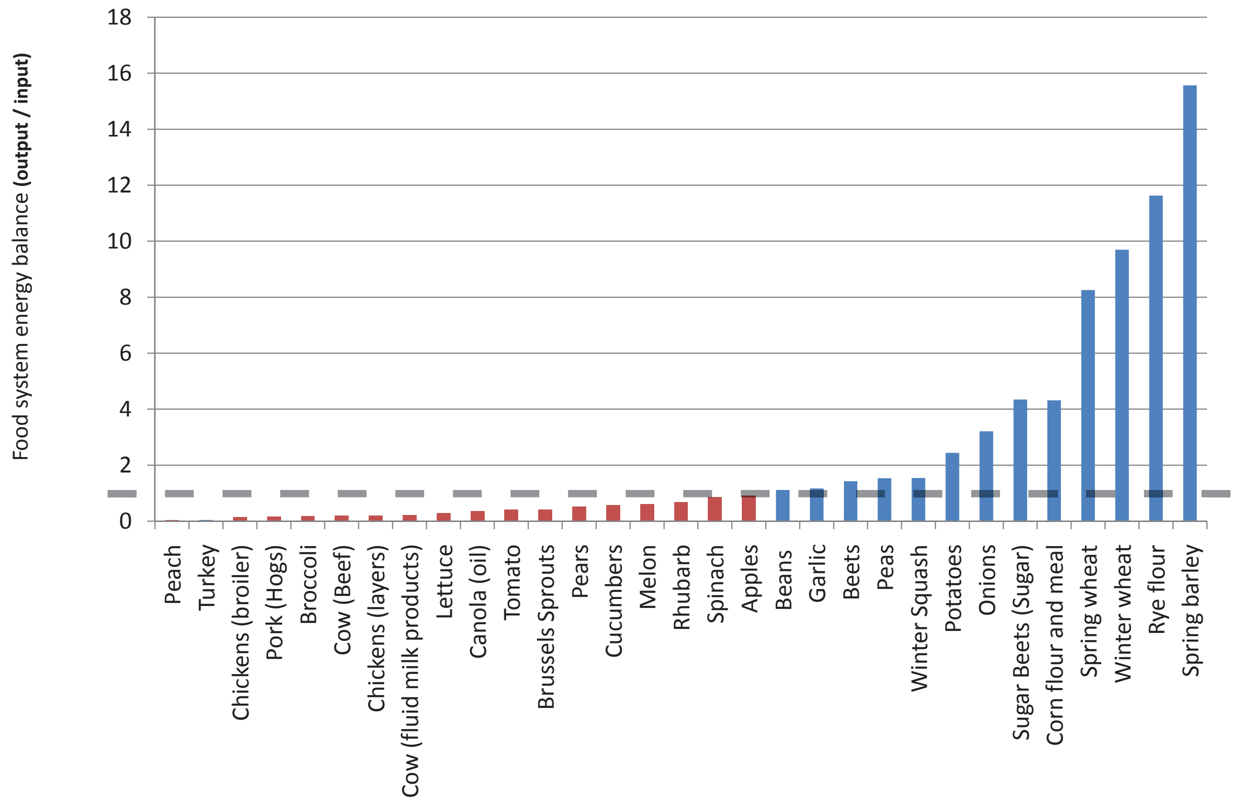


Figure (4.5). Production Energy Efficiency of Selected Foods (food energy output/production energy input). Values in Blue indicate an efficiency greater than one. Note that many food types (in red) incur an energy loss (efficiency<1.0). Production includes human metabolic labour inputs and accounts for organic farming efficiency gains. (see appendix 14.2 for greater detail)

Conclusion

Production energy inputs were based on Pimentel (1980), accounting for efficiency gains from organic production[4.5]. Based on these conditions, production inputs sum to ***8.11GJ per capita per year*** or ***1.5X*** the energy contained in the food Canadians consume[4.4] .

The area required to meet Canadian dietary habits is the mass of food *purchased* divided by target yields shown in the equation below:

$$\boldsymbol{A = C \times \frac{FP_m}{Y}}$$

$Where:$

$A = Agricultural\ Area\ (ha)$

$C =\ Wildland\ circulation\ factor\ (1.43)$

$FP_m = Mass\ of\ Food\ Purchased\ (kg)$

$Y = Crop\ Yield\ (\frac{kg}{ha})$

Anticipated rangeland and *feedsheds* were incorporated into the areas required for animal products. This model accounted for Canadian 2001 dietary habits, and considers 30% of non-productive lands dedicated to wildlands or circulation. Accordingly, Vancouverites need 0.53ha cap^{-1} (figure 4.6) to meet modelled dietary needs, ignoring land required for nutrient cycling (see section 7.0).[4.5] Future crop selections should elevate the importance of energy rich foods important for meeting food needs.

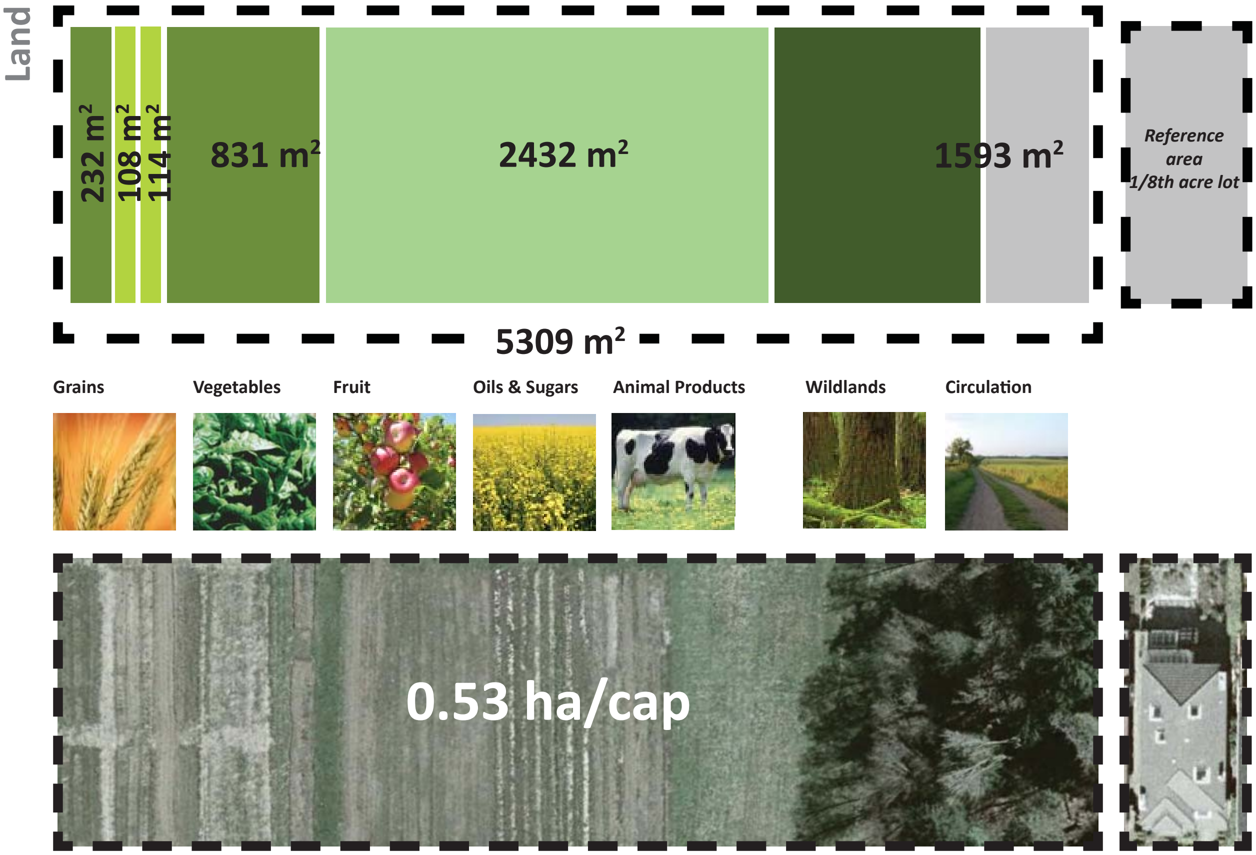


Figure (4.6). Direct Foodprint. ***0.53 ha*** of land is required to meet an individual's food needs based on Canadian dietary habits and Organic BC production patterns. This value includes the land needed to grow animal feed and an allotment for circulation and wildlands amounting to just over one acre per person. Additional land required to meet nutrient needs will be discussed in section (7). Image: Google Earth, 2010 Province of BC.

Endnotes

4.1 Labour estimates

Modern working year is assumed to be 2000hr in this study, thus 16 hrs a day at 300 days a year is 4800hr or 2.8 times the "traditional" working year.

Under Bomford's labour estimate of 50g min^{-1} or 3 kg hr^{-1}, to produce 473 kg of food (cumulative grains, fruit, vegetables, sugars and oilcrops), would necessitate 631 hours of work which when divided by the 35 hour work week totals 18 weeks - a modern part time job.

(Stanhill, 1977) noted how human input amounted to 16hrs day^{-1}, 300 days yr^{-1} exceeding the modern working year by 140%.

4.2 Food Production Intensities

Production Intensities (kg ha^{-1}) were derived from the British Columbia Ministry of Agriculture and Lands (BCMAL) Planning for Profit worksheets and are typical of target organic yields or approximated from conventional yields. Data was supplemented with direct farmer consultations completed by Mullinix et al (2009). This study identified yield intensities that are within the range expected by the industry, but by no means represent an exhaustive description of what yields are possible.

Data for estimating grain yields was based on an average yields from over 150 conventional wheat trials across BC and Alberta (ABCGAC, 2009). At 4.04 t ha^{-1}, this is still low in comparison with recent research on wheat potential in the lower mainland achieving yields of up to 12.1 t ha^{-1} in Delta, BC. (Temple, 2009) Due to these extreme yields, the low moisture content of grains, and their high caloric contents, civilizations have truly been built on this crop. At a yield of 12 tonnes or 12,000kg ha^{-1}, 150,000 people could be fed assuming the per captia consumption rate is 80kg cap^{-1}(yield divided by retail consumption).

Canola was chosen as a proxy for evaluating vegetable oil production where 40% of the 964kg/ha is oil, the reminder of which is canola meal which can be used as a fertilizer or animal feed. (Based on conventional estimates from the Peace region, Canola Council of Canada, 2003). Sugar production was based on conventional sugar beet with yields of 50 tonnes ha^{-1} of which in Ontario and Alberta of which 19% (6 tonnes) is sugar (Morrison, 2008).

It was assumed that production intensities represent optimal crop rotations specific to each crop and that a winter cover crop followed the main production cycle. Some crops (garlic, winter wheat, etc.) were assumed to be followed by a summer cover crop.

4.3 Animal Pasture Density

Animals were rotationally grazed where the actual land occupied is less than the total area depending on the paddock layout. For example, one hundred goats rotationally grazed on 10 ha in a 5 paddock layout only occupy 2 ha at any one point in time. Area per animal is based on total grazing area, not paddock area. Bee hives require negligible additional space and are placed at a density of two hives per acre or 9 hives for every two hectares.

Some animals only graze for a portion of a year before being sent for processing. For example, four to five sets of poultry can be raised for meat, each set needing only 3 months for fattening up. This means the *effective area* needed per bird is 1/4 that required for a bird at any point in time. Each animal also required land to produce feed. This study assessed wheat, barley and hay demands for each animal to determine representative "feedsheds" for each animal (3rd column in table 4.1). The net animal lands required is the sum of the rangeland, feedshed and nutrient shed associated with that animal. Each feedshed crop was followed by a winter cover crop with the same contribution as for vegetable crops.

The animal yield also accounted for cull animals which noted a loss of 0 to 8% for each animal type according the BCMAL worksheets. That is, to meet 100% of the need, a farmer must plan for between 100 and 108% of the final carcass weights needed. For example, to meet an individual's chicken needs requires almost 12 broiler chickens each with a gross yield of 2.7 kg, demanding 0.0026 ha or 26 square meters for rangeland and 261 square metres for feed production. For every 2.7 kg of meat, 9kg of grain is required necessitating a feedshed (P1 Feedshed) area, a full order of magnitude larger than the rangeland (P1) required by the bird alone.

With this in mind, the area required for animal products is calculated according to the following equations:

$$\boldsymbol{a} = \boldsymbol{FP_m} \times \boldsymbol{Y_a}$$

$$\boldsymbol{A_a} = \boldsymbol{a} \times (\boldsymbol{ER_a} + \boldsymbol{C_f}/\boldsymbol{Y_f})$$

$Where$:

$a \quad = Number\ of\ animals$

$FP_m = Mass\ of\ Food\ Purchased\ (kg)$

$Y_a = Animal\ Yield\ (\frac{kg}{animal})$

$A_a = Animal\ Area\ (ha)$

$ER_a = Effective\ rangeland\ (\frac{ha}{animal})$

$C_f = Feed\ Consumption\ (\frac{kg}{animal})$

$Y_f = Feed\ Yield\ (\frac{kg}{ha})$

4.4 Production Energy Inputs

Production energy inputs were derived from conventional energy inputs estimated from Pimentel (1980) (see appendix 14.2) and reduced according to organic energy intensity proxies listed in appendix (14.3). In his work, Pimentel (1980) assessed the embodied and direct energy inputs from machinery, diesel, gasoline, fertilizer inputs, lime, seeds, pesticides, electricity and transportation (of fertilizer, machinery, seed, etc). In this study, fertilizer transport is quantified in nutrient cycling and should be excluded on the production side. However, the proportion of mass dedicated to moving nitrogen fertilizers is low (3% for Strawberry Harvest in Indiana, Pimentel, 1980, p305), 1% for apple production, Eastern US, Pimentel, 1980 p 243). This energy input represents 1% to 3% of transportation which itself only represents from 1% to 3% (sugar beet or apple production) of total production energy inputs.

Pimentel (1980) does include costs for pesticides, and fossil-fuel based fertilizers but the "organic-production coef-

Animal Products	P1 (ha)	P1 Feedshed (ha)	P1 # Animals	Cull rate (% loss):	Gross Yield (kg or l/animal)
Pork (Hogs)	*0.00213*	*0.01877*	*0.349*	5%	87.17
Cow (Beef)	*0.08064*	*0.02155*	*0.100*	3%	317.80
Chickens (layers)	*0.00140*	*0.00720*	*0.693*	5%	16.34
Chickens (broiler)	*0.00264*	*0.02617*	*11.747*	5%	2.72
Turkey	*0.00022*	*0.00192*	*0.851*	8%	5.35
Cow (fluid milk products)	*0.01466*	*0.03589*	*0.029*	5%	3153.03
Cow (cheese)	*0.00200*	*0.00490*	*0.004*	5%	3153.03
Cow (other dairy)	*0.00426*	*0.01044*	*0.008*	5%	3153.03
Bee hive (honey)	*0.00312*	*0.00000*	*0.015*	0%	45.40
Mutton / Sheep	*0.00443*	*0.00397*	*0.044*	6%	24.97

Table 4.1 Animal Production Intensity Summary

ficient" effectively nullifies these energetic inputs. Pimentel's valuation of metabolic energy inputs were excluded. However, metabolic (human) energy inputs were estimated based on an effective human energy intensity of 2.29 MJ hr^{-1} multiplied by labour inputs (in hours) estimated by BCMAL planning for profit worksheets on a crop by crop basis. Fossil fuel-based and metabolic production energy inputs were calibrated based on energy input per unit area (GJ ha^{-1}) for all crops and for beef, but calibrated based on the number of animals required (GJ $animal^{-1}$) for all other animal products.

Production energy inputs for feed production were *not* included but likely should have been considered. If, for example, winter wheat were used as a proxy for all feed, requiring roughly 6 GJ ha^{-1}, it would require 0.78GJ of additional energy inputs, almost 15 % of the food energy output.

Further research to quantify organic yields, and energy inputs is necessary to more accurately determine foodshed boundaries and sustainability guidelines.

4.5 Nutrient Considerations

Food is obviously more than just calories, and consideration of micro nutrients, protein, storage potential and a host of other qualitative variables should be considered to properly choose a food palette. Energy is an objective and critical proxy for evaluating hunger, thus the focus of this study, but is insufficient to fully define a sustainable foodshed.

5 Distribution

Unlike production inputs, distribution has a variable energy cost dependent on the size of the foodshed, influenced by city size, population density and the relative location of farmland and consumers. This section seeks to identify the energy required to move food from farm to consumer and identify strategies to minimize this energy input through reconfiguring urban form and farmlands.

Are local foods are truly more sustainable than globally sourced foods that have lesser production energy inputs? A recent study showed when most (from farm to consumer) aspects of the food system life cycle are accounted for, it is less energy intensive to produce dairy products (milk solids) in New Zealand and ship them to the UK than to produce dairy products in the UK itself (Saunders et al, 2006). Shipping from NZ to the UK accounted for only 8.1% of the total energy cost of producing and shipping dairy solids to the UK at 24,942 MJ per tonne milk solid (MS). In contrast, the energy intensity of producing milk solids in the UK was 48,368 MJ per tonne MS, almost twice the cost associated with production AND transport from New Zealand. A host of climate (favorable rangeland conditions) and demographic (relatively sparse population) differences likely account for this reality. This intensity comparison cannot be easily translated to other food types which have much higher moisture contents, or lesser demands for specific climatic conditions, such as lettuce or other perishable foods.

For locavores (local food consumers) there is likely something that feels intuitively wrong about Saunders' findings. Where these type of studies fail, is their inability to account for nutrient cycling or the social costs of a globalized food system. Current availability of mined phosphates, potassium and the support of fossil fuel-enabled nitrogen fixation subsidizes a global food system and hides environmental and social costs attributed to exploitative agriculture. The use of pesticides or herbicides are often forbidden in the country where goods are consumed but frequently used where goods are produced (Carlsson-Kanyama, 1997). The current rising price of oil has ironically spawned a whole movement of farming biofuels for export, replacing food producing lands in developing countries, driving food prices higher (Rosegrant, 2008).

With this in mind it may well be more energetically efficient to produce and distribute food from afar, but this type of system does not satisfy the other requirements for sustainability. Distal food production is unable to guarantee a steady nutrient cycle independent of fossil fuel inputs and induces hidden social costs against those who produce the food. Thus, local food is a necessity for a sustainable food system. The following commentary will qualify what local really means.

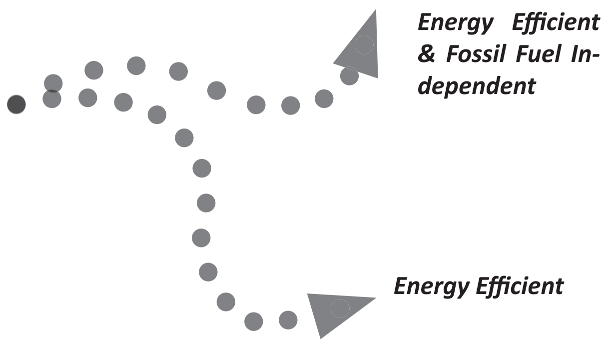


Figure (5.1). Directions for Sustainability. Pathways to an energy efficient food system may take different trajectories pending the quality of available energy sources.

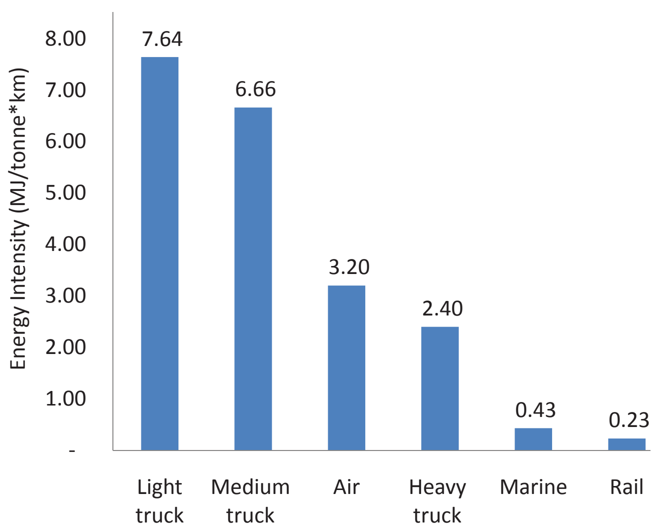


Figure (5.2). Freight Energy Intensity by Mode in Canada, 2007. Source: Natural Resources Canada (2009). Office of Energy Efficiency, Energy Efficiency Trends Analysis Tables (Transportation tables) Accessed Nov, 2009.

Energy Quality

While distribution energy inputs may represent a small portion of the total energy inputs to the food system (Saunders et al, 2006), it is important to consider the quality of energy required to move food. Fossil fuels are relatively safe, transportable, globally available (currently), and an energy rich resource that are the central to the regional and global distribution systems. Hydrogen, while energy rich, is not as easily transported or stored as oils, and electricity is fundamentally dependent on a storage medium making it an inappropriate currency for long-distance transport. While choosing *more* energy efficient modes of freight transport is a step in a better direction, it may be a different trajectory than a step in the direction of fossil fuel independence, where the *quality* of available energy sources dictate appropriate food choice, urban form and distribution modalities (figure 5.1).

Moving Food

Seen in figure (5.2), there are considerable differences in energy intensities between the mode of transport. That is, the energy required to move food depends on the means by which it is moved. Light trucks perform the worst at 7.64 MJ $tonne^{-1}$ km^{-1} and rail freight performs the best, almost 34 times more efficient at 0.23 MJ $tonne^{-1}$ km^{-1}. It is interesting to note that air freight performs much better than medium or light truck at 3.20 MJ $tonne^{-1}$ km^{-1}, despite popular belief to the contrary. The distribution energy input for an individual's food supply is equal to the modal intensity multiplied by the distance of each food must travel multiplied by the mass of food transported. In this way, a food group may have a high distribution energy input if it is sourced far from the destination location OR required to be transported via inefficient means (eg. light truck). This method accounts for food sourced at varying distances via different modes and is consistent with work done by Carlsson-Kanyama (1997) and Peters (2009).

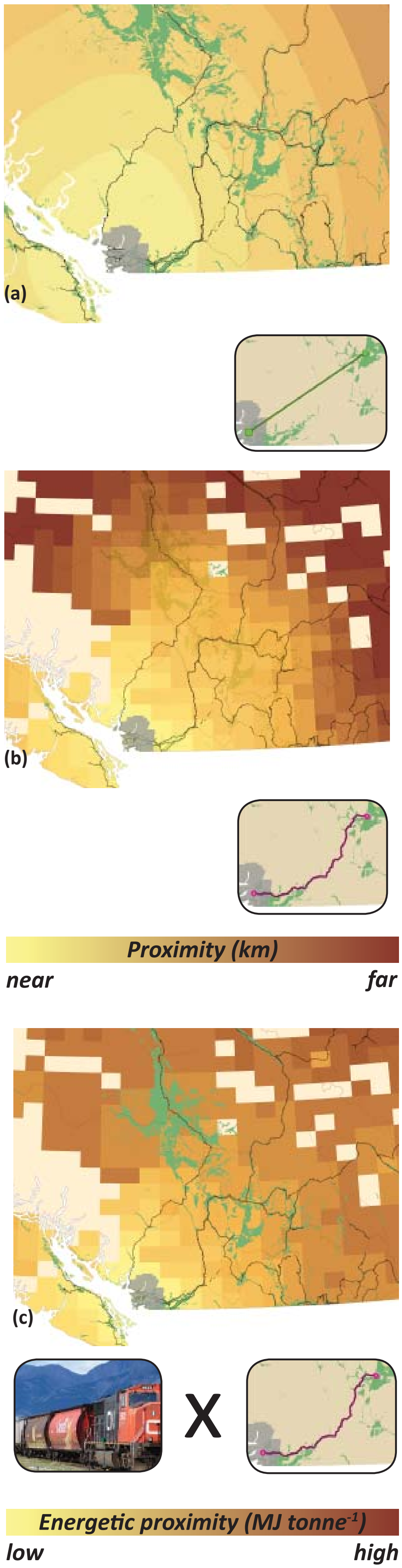
The net distribution energy input is the sum of distribution inputs from all food types from all source locations at route-specified modal intensities, illustrated in the equation below:

$$\boldsymbol{D_E(net)} = \sum(\boldsymbol{I} \times \boldsymbol{D} \times \boldsymbol{m})$$

$$\begin{aligned}
&Where: \\
&D_E = Distribution\ energy\ input (GJ) \\
&I = Modal\ Intensity\ (GJ\ tonne^{-1} km^{-1}) \\
&D = Distance\ (km) \\
&m = Mass\ of\ food\ (tonne) \\
&D_E(net) = Multimodal\ Distribution\ energy\ input\ (GJ)
\end{aligned}$$

The net distribution energy input feeds directly into the equation proposed in section (1).

The actual weighted energy intensity of *trucking freight* is 3.21MJ $tonne^{-1}km^{-1}$ after the trucking tonnage for each mode is considered (of total freight transported by truck in 2007, 83% was by heavy trucks, 9% by medium truck and 8% by light truck). The weighted average modal intensity for *total freight transport* in 2007 was 2.22 MJ $tonne^{-1}km^{-1}$ (NRC, 2009), accounting for the large contribution rail makes to Canadian freight transport (40%).



Past studies have focused on Euclidian or line of site proximity to model the energy inputs from distribution (Peters, 2009) (figure 5.3a). Since roads are inherently winding, modelling distance based on optimal actual routes is more appropriate (figure 5.3b). In addition, given the modal intensities previously discussed, energetic proximity (figure 5.3c) is a better currency to describe distribution than route proximity alone.

Using 25km by 35km grid cells across BC and Alberta cells as a proxy for the energetic proximity of ALR lands within each cell, this study utilizes ArcGIS "Network Analysis" to account for the energy needed to transport food from the centre of each cell to the rail yard on Terminal Avenue, in Vancouver. Each route origin is at the centre of the rectangular grid cells (with the exception of a few discussed in limitation #3). The energy input in MJ tonne^{-1} was the impedance variable that drove route logistics. That is, ArcGIS automatically chose the most energy efficient multi-modal route via marine, road or rail. As can be seen in 5.3(c), grid cells in close proximity to or located on rail lines were selected (lighter colour) over those that may be closer to Vancouver, but were energetically more distant.[5.1]

In the United States, Pimentel et al. (2008) estimated the average food product travels roughly 2,400km to get to consumer's tables, consuming 1.4 X the energy contained in the food itself. Hypothetically, moving 0.7 tonnes of food this distance at weighted freight intensities of 2.22MJ tonne^{-1} km^{-1} would consume 69% of the food energy modelled in this report.[5.2]

At a current population of 2.1 million, the energy required to move 1.5 million tonnes of food from existing ALR land to the centre of Vancouver amounts to 0.74GJ cap^{-1} or 14% of the food energy output. That is, for every 7 joules of food energy produced, only one joule of energy is required to move the food from its origin on designated farmlands across BC to the city centre. Distribution and nutrient cycling energy inputs together represent only

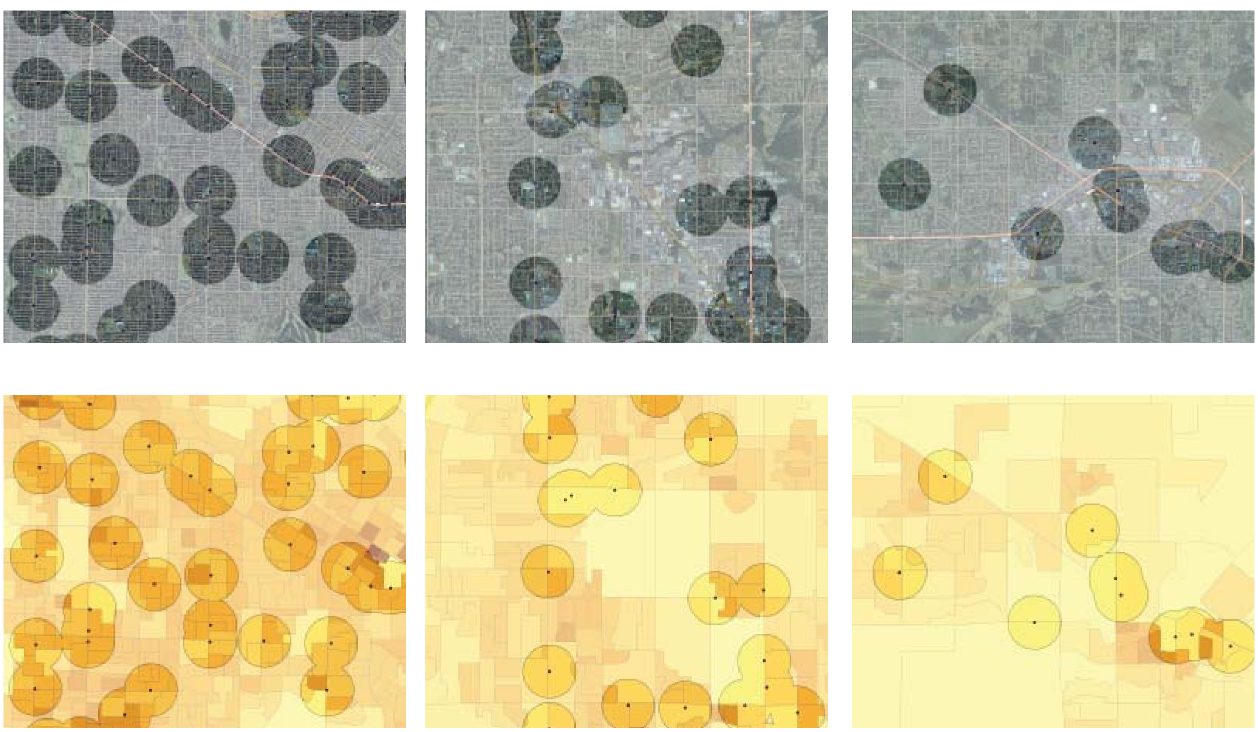
Figure (5.3) Comparing Proximity Indicators. (a). Line of Site Proximity (km): Euclidian distance independent of routes or local topography**; (b) Route Proximity (km):** The distance via the shortest route; **(c). Energetic Proximity (MJ tonne^{-1})**: The Energy per unit mass via the shortest modal energy inputs.

seven percent of all food system energy inputs (see section 8.0). This model assumes a best case scenario of full production on all available ALR lands dedicated exclusively to the Vancouver food market, thus the distribution inputs are much less than those modelled under Pimentel's food miles approximation. Distribution energy inputs are intimately connected with regional form, a variable which is much slower to change than production energy inputs and hard to reverse after farmland has been annexed for development. Though it represents only a small part of the modelled energy inputs in this report, these inputs would increase dramatically if food needs outside greater Vancouver were considered or if populations were to increase.

Moving Groceries

As the transport from farmland to city is only part of the journey it is important to consider how urban form facilitates efficient intra-urban transportation. Commute modal intensities are similar to freight, again highlighting the relative inefficiency of automobile transport relative to rail. The weighted average transit and passenger vehicle modal intensities are 1.00MJ Pkm^{-1} and 2.17 MJ Pkm^{-1} respectively (NRC, 2009).

How people shop for their food is a function of relative proximity to local amenities. It is a commonly held belief in urban planning that people will choose to walk to shopping outlets amenities when the route is less than 400 m. The placement of transit stop or local amenities within a 5 minute walk can serve to encourage sustainable transportation. Figure (5.4) shows 400 m catchment zones surrounding grocery outlets superimposed on 6.25 by 6.25 km blocks of Vancouver, Richmond and Langley. The image integrates population statistics baed on Statistics Canada 2006 Census in order to understand what percent-



Grocery Vancouver **Grocery Richmond** **Grocery Langley**

Figure (5.4) Grocery Shed. Areas of Vancouver, Richmond and Langley that are serviced (within 400m) by grocery stores. Darker shades of orange represent higher population densities. Population densities derived from Statistics Canada, 2006.

age of these populations are under-serviced (darker regions represent denser populations). As one might imagine, the density of Vancouver lends itself as a walkable city with 43% of people in the sample living within 400 m of a grocery store. Richmond serves 24 % of people, while Langley supports only 14 % of people within the sample (86% of the population lives outside catchment zones). This cursory method is not without flaws. Grocery stores were sampled using Google Earth which has display settings which are scale dependent (several smaller grocery stores were likely excluded). It is unclear if the scale dependency is related to the size of the grocer or Google's advertising revenue scheme.

Another way of looking at this question is to test the implication of driving to get groceries when compared with the energy embodied in the food itself. Specifically, how far must one drive a vehicle to pick up groceries before the energy required to move the vehicle exceeds the potential energy of the food itself? Assuming a household of 2.2 people who are served by weekly grocery or restaurant trips, one might pick up roughly 30kg of food (the aggregate weekly food purchased multiplied by 2.2). This food has an embodied food energy of 227 MJ. The energy reportedly used per passenger kilometer for the average Canadian passenger vehicle was 2.17MJ Pkm^{-1} in 2007. This energy intensity may be a little less than the energy use per vehicle kilometer travelled as the former assumes some ride sharing. At these rates of energy use, one could drive *52km* to a food outlet before total energy expenditure would negate the energy contained in the food itself (105km round trip distance), excluding energy inputs from production, processing and nutrient cycling.

Foodshed design must consider activities at a provincial, regional and neighbourhood scale that contribute to the sustainability of the whole. Due to the number of behavioral assumptions needed to properly assess the energy inputs of grocery trips, this step was left out of the regional energy model but should be qualitatively considered at a neighbourhood scale.

Moving Farmers

Regional form also has a huge impact on how employees commute to their workplace. Assuming an average commute of 20,000 km yr^{-1} at a modal intensity of 2.17 MJ Pkm^{-1} (NRC, 2009) would necessitate 43GJ cap^{-1} yr^{-1}. This equates to 8 times the annual food energy purchased[5.3]. If the energy embodied in food itself is indeed a limiting variable in the spatial layout of a food system, and if the system requires people to move about in order to farm, we must consider moving farmers to their place of work. Though labour inputs represent 1.58% of the 2006 working labour force (Statistics Canada, 2010), this variable becomes more important in anticipation of a transition towards a live-powered approach to food production. That is, to satisfy the resiliency dimension of sustainability, farming populations should be placed within close proximity to their workplace. If the population of farmers were to increase, dramatic shifts in regional form would be necessary to support appropriate commute distances. Again the complexity of commuting prohibits its inclusion in a regional energy analysis.

Conclusion

Freight distribution represents a relatively small but critical portion of the food system where the *mode* of transport is just as important as the *distance* travelled. Distribution energy inputs required to move food from shopping outlets to consumer are equally important to sustainable design on a neighbourhood scale and consideration of farm-worker commutes may become important if more farmers are required to support the region's food system.

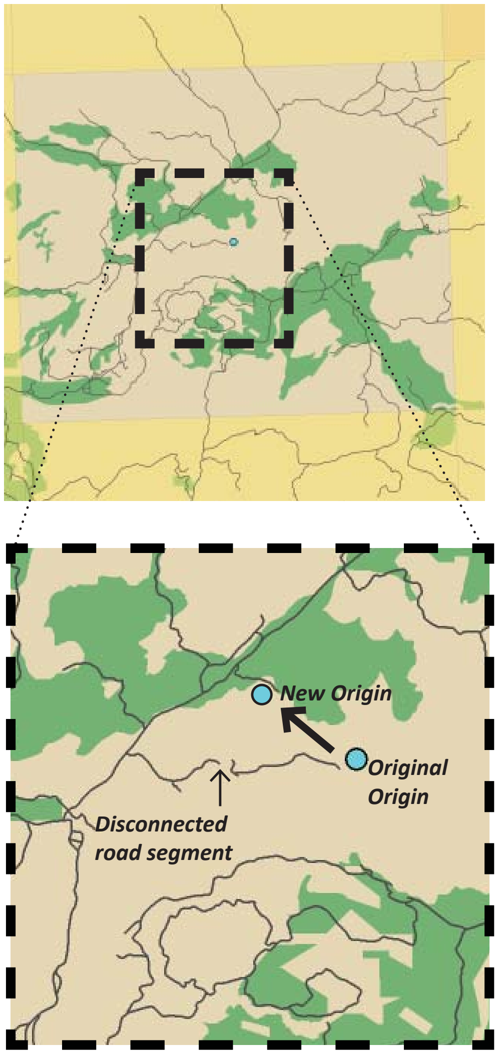


Figure (5.5). Connecting the Network

Endnotes

5.1 Assumptions and limitations

Using large data sets is inherently cumbersome and forced several major assumptions.

(1) The model did not account for additional energy inputs typical of transport through mountainous terrain and reflects only generic Canadian modal intensities observed by the office of energy efficiency in 2007 (NRC, 2009)

(2) Route connectivity assumptions were made by intersecting road and rail networks proximal to rail stations. LRT rail and subway rail stations were excluded as they likely cannot service the rail freight.

(3) Several sections of the national road database were disconnected from the network making large sections unreachable. In some instances, this reflects the vast wilderness of British Columbia. In other circumstances, the national road database is likely incomplete. In either case, the origin maker within the grid cell to connect it to the rest of the network if possible. Several sections of the national road database were disconnected from the network making large sections unreachable (seen as beige grid cells - figure 5.5). In some instances, this reflects the vast wilderness of British Columbia. In other circumstances, the national road database is likely incomplete. In either case, I took the liberty to move the origin maker within the grid cell to connect it to the rest of the network. For example, the adjacent grid cell clearly has roads that connect to the rest of the network. However, ArcGIS automatically connects each origin to the *closest* roadway which in this case is NOT connected to the network, making this patch "unreachable". Where appropriate, the origin marker (blue) was moved around the polygon to better connect grid cell to the rest of the network. Network data files were based on ArcCanada Canmap Data compiled by ESRI (DMTI Spatial, 2006, 2008)

(4) Global distribution networks incorporate many more steps than modelled here, including transport to distributors, processors, packagers, warehouses, wholesalers, large supermarkets, small supermarkets and finally to the consumer. This model represents only the distribution from farm to city along the best possible route.

(5) Each grid cell acts as a proxy for the energy required to move food from that cell to Vancouver. As each cell is 25km by 35km, there are minor impacts of the placement of ALR land within the cell and major ramifications of local topology which might make part of the cell accessible to the network and leave the remainder inaccessible to road access. A finer resolution analysis is required to more accurately represent these local variations.

(6) It deserves discussion that some food lands should be unavailable for Vancouver's use. This study assumed no

access to the American food market for political reasons, but have granted access to the remainder of BC and Alberta to simplify the model and highlight the implications of urban form and relative location on the energetics of food.

5.2 Moving food

Actual freight distances of 2,400 km suggested by Pimentel et al., (2008) require 3.7GJ of energy (2.22MJ $tonne^{-1}$ km^{-1} multiplied by a 0.7 tonnes, the mass of food shipped, multiplied by 2,400km). This represents 69% of total food energy (distribution energy (3.7GJ cap^{-1}) divided by food energy output (5.36GJ cap^{-1}).

Modelled food transport currently includes only shipment from farm to city, excluding transport to and from distributors, a step that likely takes a considerable amount of energy. Future work should consider this step to inform the appropriate placement of processing plants, distributors and other necessary components of the food system.

5.3 Moving farmers

Modal intensities are based on average weighted commute energy intensities observed by the office of energy efficiency, Natural Resources Canada (NRC), observed from 2003 through 2007 and published in 2009. The average passenger modal energy intensity is 2.0MJ Pkm^{-1} (including transit), and the average auto based modal energy intensity is 2.17MJ Pkm^{-1} accounting for only cars, trucks and motorcycles. Food energy output is roughly 5.36GJ cap^{-1}. Commute energy input is equal to distance travelled times modal energy intensity at 43GJ cap^{-1} yr^{-1}, thus the conceptual commute energy input is eight times that of the food energy output (commute energy input divided by food energy output).

6 Processing

To produce a loaf of bread requires harvesting, thrashing (removing grain seed from the stalk), winnowing (removing hull from the seed), grinding (preparing flour), mixing & kneading, and cooking in a series of steps demanding tremendous energy inputs. In a life cycle analysis of a hamburger in Sweden, Carlsson-Kanyama and Faist (2000, p8, 9) found that processing inputs consume up to 96% (for hamburger buns) of the total food energy inputs thought but can be as low as 28% for hamburger meat[6.1]. In this study, the processing, preparation, storage, and heating of food consumed 51% of the total modelled energy input. This section will quantitatively identify processing inputs for various food groups and make qualitative recommendations for how changes in food choice and *household* form can radically reduce energy inputs.

Food Processing and Preparation

Processing can be roughly classed as *pre-consumer processing, restaurant processing* and *consumer processing*.[6.2] The former includes the thrashing, grinding, juicing, packaging and storing required to get foodstuffs to the shelves in the supermarket. As is seen in table 6.1, pre-consumer processing inputs are significant, consuming 4.8 GJ per capita or 84% of the energy contained in all food purchased[6.3]. Restaurants contribute another 1.56 GJ per capita for the refrigeration, sanitation, and heating of foods processed in commercial restaurants in Vancouver [6.4]. When added to the energy required to refrigerate and cook foods in households in Vancouver, net processing energy inputs exceed food energy outputs by 80%. That is, for every joule of energy purchased, 1.8 joules of energy are required to process, store, heat and ready that food item for consumption [6.5]. This model accounts for food purchased only and declines when compared against food actually consumed.

Spatializing Processing Energy Inputs

While on the surface these inputs are non-spatial and difficult to influence from a planning and design perspective, there are spatial forms that can promote consumption of raw local vegetables which in turn require less refrigeration or preparation inputs than other food groups. This is the niche that community gardens and urban agriculture can fulfil. While urban agriculture will never *directly* meet the growing demand for local food, it has a meaningful and critical role to play in *inspiring* a local food culture.

Food Energy Summary	Food Energy Purchased (GJ/cap*yr)	Preconsumer Processing (GJ/cap)	Restaurant and Consumer processing (GJ/cap)
Grains	1.30	0.88	-
Vegetables	0.52	0.08	-
Fruit	0.29	0.11	-
Oils and Sugars	1.59	2.69	-
Animal Products	1.66	0.72	-
Sum:	**5.36**	**4.48**	**5.17**

Table (6.1) Processing Energy Intensity

Packaging

Packaging is clearly a critical component of food safety and preservation though is difficult to quantify at a regional scale. Packaging will not be considered in the regional analysis, though arguably makes up a large component of the food system energy input.

Conclusion

In addition to urban forms that encourage local eating, Michael Pollen's suggestion for sustainable food culture: "Eat food, mostly vegetables, not too much." (Pollen, 2008) resonates with this report where sustainable dietary habits are key to sustainable food systems. It is also important to consider what factors would improve processing and storage efficiency. While reducing consumption of products that necessitate long storage times or heating will help, this will not alleviate the energy input from refrigerators and freezers. These are active no matter how they are used and together represent over half of the post-purchase processing inputs. Given 24% of respondents have more than one refrigerator, and 14% have more than one freezer (NRC, 2009), decreasing appliance density might be a good place to start. Section (8) will explore the impact of shifting dietary and appliance habits on the energy balance of the food cycle.

Endnotes

6.1 Food processing inputs

Hamburger meat consumed only 28% of food energy inputs for processing and crop drying is included in the production stage of the food cycle rather than processing. Carlsson-Kanyama and Faist (2000) included shopping, transport (from shop to consumer) related energy inputs not included in this report.

6.2 Net processing

Net processing includes pre-consumer processing, restaurant processing and consumer processing. For each, sanitation, refrigeration and cooking are considered. General heating, lighting, etc. are excluded. Retail processing (supermarkets, etc.) are not included in the model.

6.3 Pre-consumer processing

Processing was calculated on a product by product basis, using proxies where needed (the processing inputs for spring wheat, for example, represented inputs for all grain products, and sugar beet for canola oil) These assumptions clearly deserve further research.

Pre-consumer processing of meat products is based on carcass weights rather than retail weights. For example it requires a carcass weight of 29 kg of pork to provide Canadians with the 22kg of pork purchased in stores of which only 12.5 kg (estimated by Statistics Canada, 2002) of pork is actually consumed. Much of the carcass is non-edible (bones, etc.) The pre-consumer processing input of animal products is based on carcass weight rather than final weight. Recall that food energy output is 5.36 GJ $cap^{-1}yr^{-1}$ thus pre-consumer processing at 4.48 GJ $cap^{-1}yr^{-1}$, represent 84% of food energy outputs (processing inputs divided by food energy output).

6.4 Restaurant processing

Restaurant processing is based on area dedicated to this service rather than the amount of food processed. In 2000 there were just over 2 million square meters of restaurant floor space in BC (NRC, 2000). For the population of the day, that represented 0.51 square metres per capita (BC Stats, 2009). Natural Resources Canada assumed a total average energetic intensity of 6 GJ per square meter of restaurant floor space (NRC, 2003). Fifty one percent of this is assumed directly required for sanitation (dishwasher), refrigeration and heating, the remainder of which was required for indirect inputs (HVac, lighting, etc.), (Ibid, p16). This equates to 1.56 GJ per capita.

6.5 Consumer processing

In Greater Vancouver, energy dedicated to cooking, freezing, refrigeration or dish washing summed to 8.75 GJ household^{-1}yr^{-1} or 3.6 GJ cap^{-1}yr^{-1}. These findings account for the number of appliances per household and the relative efficiency of each with regards to their age. Older models are less efficient, thus processing efficiency is assumed to improve as these appliances are phased out. Data was derived from provincial survey data collected from NRC (2009b, 2009c) and applied to Greater Vancouver's population in 2006 (Statistics Canada, 2006) according to the following equations:

$$\boldsymbol{I_{EW}} = \sum_{\mathbf{1984-2007}} (\boldsymbol{I_E} \times \boldsymbol{pr})$$

$$\boldsymbol{CS_E} = \sum_{\boldsymbol{all\ appliances}} (\boldsymbol{I_E} \times \boldsymbol{u})$$

$$\boldsymbol{CS_{Ec}} = \boldsymbol{CS_E}/\boldsymbol{d}$$

$Where$:

$I_{EW} = Weighted\ Appliance\ Energy\ Intensity\ (\frac{kJ}{unit})$

$I_E = Appliance\ Energy\ Intensity\ (\frac{kJ}{unit})$

$pr = proportion\ of\ appliances\ in\ age\ bracket\ (\%)$

$CS_E = Cooking\ and\ Storage\ Intensity\ (\frac{kJ}{household})$

$u = appliance\ density\ (\frac{units}{household})$

Since older models are generally less efficient, a weighted appliance intensity was calculated for each appliance based on its age and the average energy intensity during that time period, based on 5 year brackets from 1984 to 2007. The cooking and storage energy intensity per household was found by multiplying the number of appliances by the weighted appliance efficiency. See appendix (14.4) for a more detailed description of processing inputs.

7 Nutrient Cycling

The greatest gap in contemporary food systems exists between a consumer's fork and farms that produce his or her food. Perhaps a history laden with sanitation-related illnesses has helped drive a philosophy of waste management schemes that exit waste from urban areas as quickly and quietly as possible. Given evidence of eutrophication of streams and rivers, red tides and ocean "dead zones", the linear approach to *waste management* must change in order to maintain a healthy environment. Unlike past studies which have focused exclusively on transport of food from farms to urban environments (Carlsson-Kanyama, 2002), this section will complete the cycle by quantifying the additional *energy* and *land* required to transport and *grow* nutrients required by the food system.

Global and Regional Nutrient Cycling

Before the industrial revolution the global nitrogen cycle was in dynamic equilibrium (Smil, 1999) with equal amounts produced annually by N_2 fixing processes, used by crops, and then immobilized again in denitrification stages of the cycle (Waggoner, 1994). Yields of grain were about 0.5 to 1.0 metric tonnes ha^{-1}, with N supplied primarily from crop rotations and manures. An average farmer could support 3-5 people at this level of production (Waggoner, 1994) with production processes not dissimilar to subsistence farming in developing countries today.

The industrial revolution and *green revolution* that followed enabled a farmer to feed more than 100 people by increasing production of grains to 7 metric tonnes ha^{-1} through the addition of nearly 90Tg of N globally in 2000 (Vance, 2001). From 1960 to 1995, the use of nitrogen fertilizer-use increased seven-fold, and is expected to triple again by 2050 (Tilman et al., 2001, 2002, Cassman & Pingali, 1995). To achieve a grain yield of 5 to 9 metric tonnes ha^{-1}, 200 to 300 kg N ha^{-1} must be added to the fields with an efficiency of N recovery of 50% on average (Socolow, 1999). The remaining 50% is lost to the environment and contributes to the eutrophication of nearby water bodies, or denitrifying processes (Socolow, 1999) with a nutrient loading of up to 20 times that of preindustrial times (Howarth et al, 1996). Not only is this method of application wasteful, it leads to reduced biodiversity and ecosystem functioning (Tilman et al, 2001, Carpenter, 1998).

Increases in fertilizer application will unlikely result in the yield increases seen in the 1960s because of diminishing nitrogen use efficiency with every increase in nutrient application (Tilman, 2002, Cassman et al., 2002, p135) (figure 7.1). In this figure, nitrogen input and accumulation in plant tissue has less of an effect on overall grain yields as productivity approaches a theoretical yield maximum. This is consistent with the law of diminishing returns, an economic theory which suggests that the incremental gain in productivity decreases with every incremental increase in a set input when other inputs are fixed (Samuelson & Nordhaus, 2001). When applied to an agricultural system which must feed a projected population of

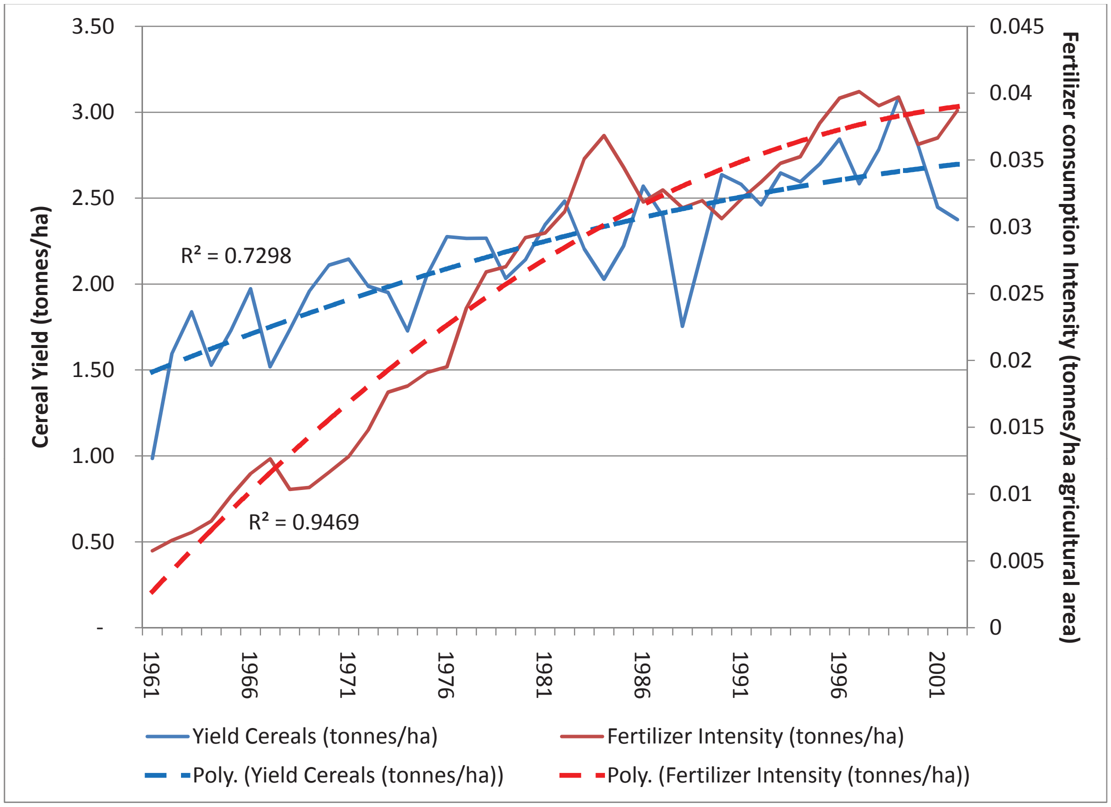


Figure (7.1). Canadian Cereal Yield and Fertilizer Use Intensity, 1961 to 2008. Cereals can act as a proxy for food production given their direct and indect contribution to the Canadian food supply. Yields appear to be approaching a theoretical maximum negating the value of additional fertilizer input (Tilman, 2002). Data Source: FAO STAT

10 billion people, without radical technological or biological innovations, increases in fertilizer inputs will have negligible effects on long-term food security.

From an energy perspective, the Haber-Bosch system of fossil-fuel powered nitrogen fertilizer production is responsible for 1.2% of the world's energy consumption and supports nearly 50% of the world's food supply (IFA, 2009), making it a dominant energy sink of the world's agricultural system. A 300% increase in price of nitrogen fertilizers from 1998 to 2008 has resulted in decreased application highlighting a deep connection between food production fertilizer application and the price of oil. (Pimentel et al., 2008, Peoples et al., 1995)

In British Columbia, almost a third of farms in the Fraser Valley have residual nitrogen values in the high (100kg ha^{-1}) to very high (>200kg ha^{-1}) range indicating applications of fertilizers that greatly exceed the plant needs (IRES and Environment Canada, 2004). This trend is most evident in intensive agricultural systems including forage corn, raspberries and blueberries and repeated for phosphorus and potassium (80% of fields reported high to very high concentrations of phosphorus while 47% of fields had high to very high concentrations of potassium) (Ibid)

In regions of intensive animal foraging, or poultry operations, the manures can be over-applied or stored improperly leading to ground or surface water contamination (BC Agriculture Council, 2004). This is an

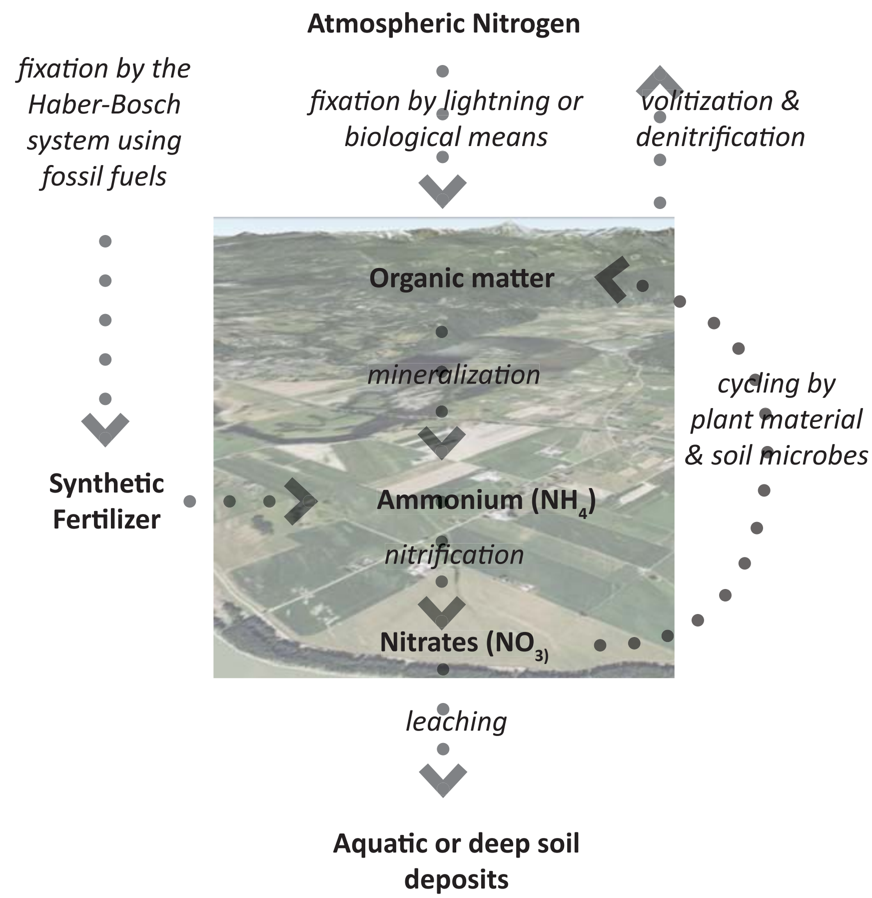


Figure (7.2) Simplified Nitrogen Cycle. Most nitrogen must be converted to nitrates before it can be used by plants. Image source: GoogleEarth: 2010 IMTCAN, 2010 Digital Globe, 2010 Province of BC, 2010 Cnes.

issue in the Fraser valley where intensive dairy, poultry and berry production has led to a net glut of nutrients in the region. (Bomke, 2010)

Agricultural Nutrient Cycles

The major limiting nutrients of agricultural systems are nitrogen (N) phosphorus (P) and potassium (K).

Nitrogen is the most common limiting factor for most terrestrial agricultural systems, second in importance only to sunlight and water (Smil, 1999), thus was the focal nutrient of this study. Though it is readily available in inorganic forms in the atmosphere and in organic forms in the soil, it must be present as Ammonia (NH_3) or Nitrate (NO_4) to be available for plant uptake. Nitrogen is made available to plant growth through nitrification or nitrogen fixation (figure 7.2). It is then assimilated by plants or immobilized by micro-organisms, binding nitrogen in organic compounds. Microbial nitrogen is re-integrated into the N pool when micro-organisms die and are broken down. Lastly, nitrogen is denitrified producing nitrogen gas.

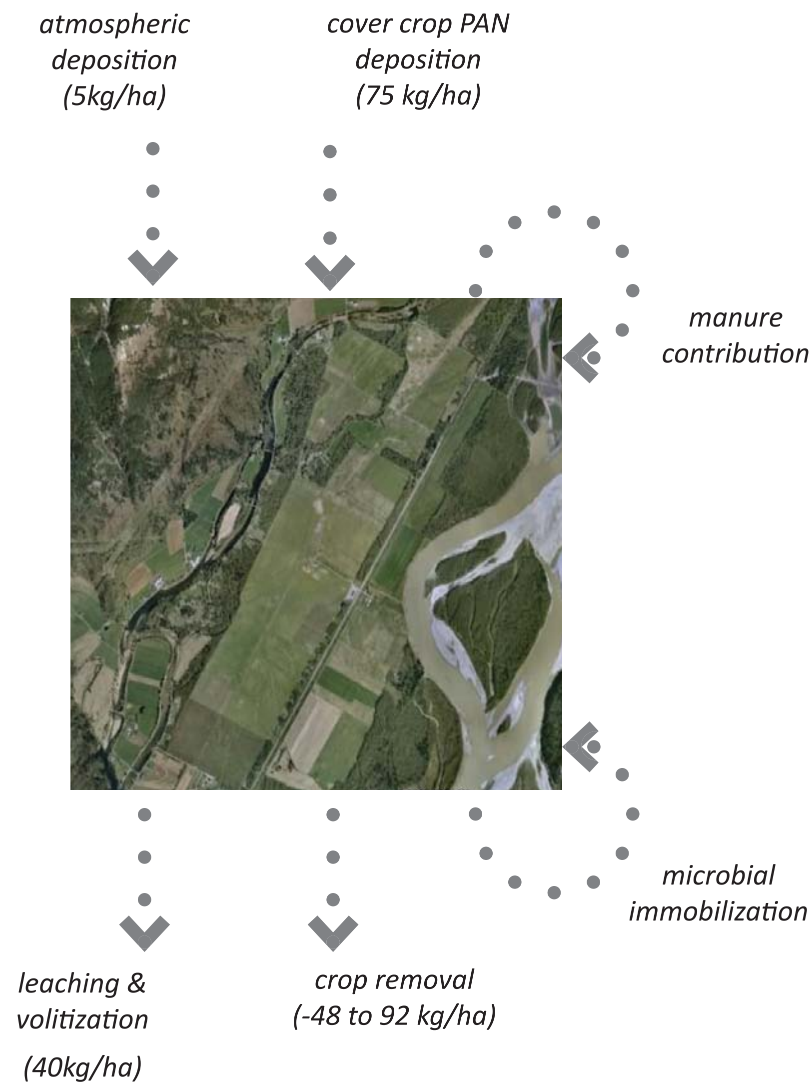


Figure (7.3). Conceptual Nitrogen Demand from Terrestrial Agricultrual Systems. Note that plant available nitrogen depends on the quality of the feedstock timing of application among other variables (climate, etc). Also, some crops contribute nitrogen to the soil even after the crop is removed, thus nitrogen removed is negative eg. Pea, bean, etc.

Meeting Nutrient Needs:

Nitrogen demands depend on how much nitrogen leaves the system through harvested material (as calculated by USDA, 2009), leaching, volatilization and how much additional nitrogen can be sourced from atmospheric deposition, cover crops or local manures (figure 7.3)

Nitrogen demand can be calculated according to the equation below adapted from Hansen et al. (2000) 68.

$$\boldsymbol{D_N = H_N + L_N + V_N - (CC_N + A_N + M_N)}$$

$Where:$

$D_N = Nitrogen\ Demand$

$H_N = Nitrogen\ removed\ from\ harvested\ material$

$L_N = Nitrogen\ removed\ by\ leaching$

$V_N = Nitrogen\ lost\ to\ atmospheric\ volitization$

$CC_N = Nitrogen\ added\ through\ cover\ crops$

$A_N = Atmospheric\ deposition$

$M_N = Local\ manure\ contributions$

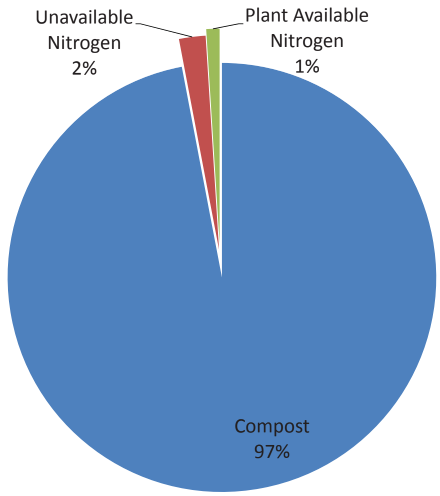


Figure (7.4). Plant available nitrogen (PAN) relative the mass of total compost.

For example, cabbage has a plant available nitrogen demand of 67kg ha^{-1} based on the yield per hectare and nitrogen contained in the plant material harvested. When leaching and volatilization is considered, this demand is roughly 107kg ha^{-1} of plant available nitrogen (PAN). Assuming cover crop and atmospheric deposition sum to 80kg ha^{-1}, the net demand is 27kg ha^{-1}. The Canadian Environmental Farm Plan (EFP) nutrient management guide recommends addition of baseline applications of 50 to 300 kgN $ha^{-1}yr^{-1}$ depending on the crop type: typically, forage grass requires considerably more applied nitrogen (300kgN $ha^{-1}yr^{-1}$) than berries, tree fruits and vegetables (50kg N $ha^{-1}yr^{-1}$) (Schmidt, 2005). Mader et al., (2002) show how biodynamic farms and organic farms require less nitrogen application (99kgN $ha^{-1}yr^{-1}$) than conventional farms at 149kgN $ha^{-1}yr^{-1}$.

Chicken Manure:	**3.75%**
Fresh Bovine waste:	**2.86%**
Dry Corral manure:	**0.79%**
Canola Meal:	**1.80%**
Kitchen compost:	**0.13%**
Yardtrimmings:	**0.10%**
Biosolids:	**2.00%**

Table (7.1) Net PAN for Selected Feedstocks. Adapted from Pratt et al. (1973), Gale, et. al (2006), Cogger et al (ND) and Kempe (2010) where the NET PAN is the cumulative nitrogen available after 4 years as a percentage of the original mass of compost[7.2].

Plant Available Nitrogen:

Nitrogen, which must be converted to ammonia (NH_4) or nitrate for use by most plants (figure 7.2). Plant available nitrogen (PAN) is a percentage of total nitrogen that is available to the plant for uptake, and varies according to a "decay series" specific to each amendment. Available nitrogen can be adsorbed by plants, leached from the system, volatilized into the atmosphere as ammonia, or immobilized by microorganisms. This is why application of a nutrient to a field rarely translates to the uptake by plants with up to 86% of nitrogen lost to ammonia volatilization, denitrification and leaching (Wrisberg et al., 2001). This report assumes losses of 40kg ha^{-1}, characteristic of well-managed organic farming systems (Hansen et al., 2000).

It takes years, even decades for nitrogen to become liberated from organic tissues, and even then, much of the nitrogen is not available for plant use. The net plant available nitrogen values for some common organic feedstocks are represented in table (7.1). This is the percentage by mass of original compost that is in a form of nitrogen available for plant use and is only a small fraction of the total compost mass (figure 7.4, 7.5). This illustrates the value of synthetic fertilizers which don't have nearly the bulk organic fertilizers do. However, even after the energetics of shipping and application are taken into account, the energy intensity of fossil fuel powered nitrogen production is so great, use of organic fertilizers is still more efficient (Pimentel et al., 1983).

Though synthetic fertilizers will likely be the driving force of British Columbia's agricultural system for many years to come regional and urban form may need to be redesigned to better respond to the sourc-

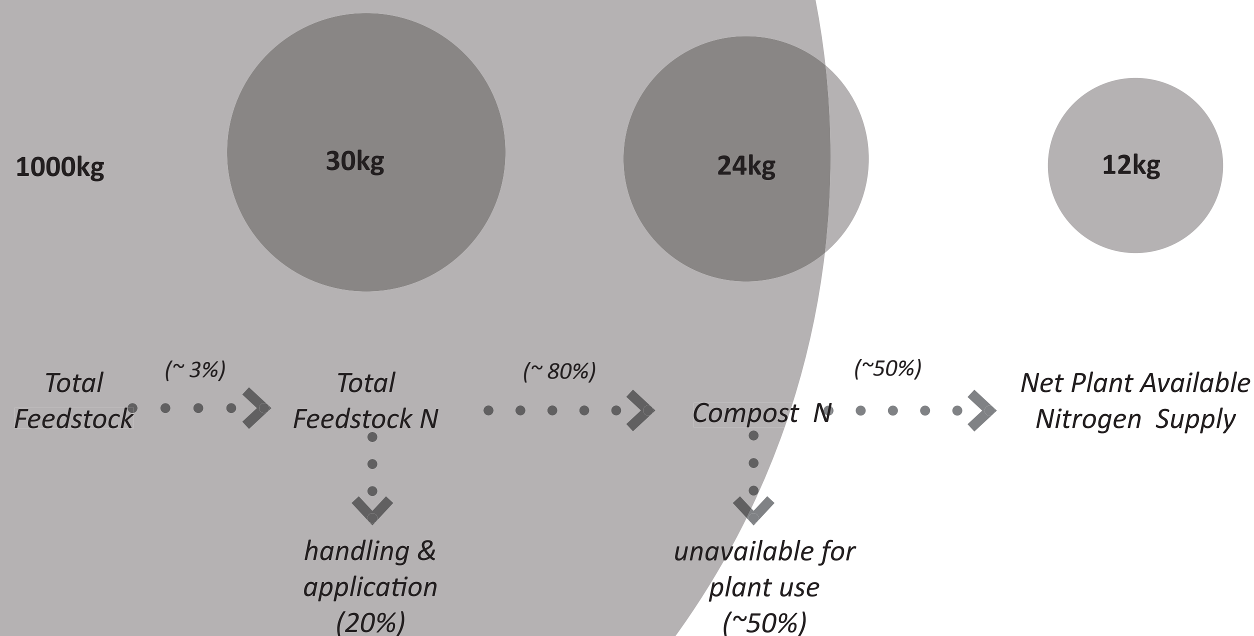


Figure (7.5). Conceptual Plant Available Nitrogen from Compost Feedstocks. Of the nutrients supplied in the form of compost, only a portion of that is available to plants. For example a feedstock of 1000kg might have a total nitrogen content of 3%. This would translate to only 30kg of Feedstock N, and 24kg of compost N after losses due to handling and application[7.4]. A further 40-70% of that total nitrogen is unavailable for plant use, leaving only 12kg (1%) of the original 1000kg of compost as plant available nitrogen. Table 7.1 describes Net Plant Available Nitrogen (PAN) concentrations found in typical compost mixes.

ing and distribution of organic fertilizers for the future. For environmental and energetic reasons, organic fertilizers are an imperative for a sustainable agriculture system.

Nutrientshed Vancouver

To determine the dimensions of a sustainable foodshed in practise, farmers and designers should ask:

1. How much additional plant available nitrogen is required by the farm system[7.1]?
2. Where can it be sourced?
3. How much energy and area is required to move and grow it?

Nutrient Production Capacity:

Optimally, the nutrients supplied from atmospheric deposition, cover crops and anthropogenic sources should equal nutrient demand, but as mentioned before, is often not the case where local conditions cause excesses or depletions of certain nutrients.

Weathering & Atmospheric Deposition:

Nitrogen is applied from atmospheric deposition at rates dependent on local soil, climate and land use conditions. Landscapes downwind from dairy or poultry operations have high atmospheric nitrogen contributions, due to the volatility of these manures. Nonhebel (2002), measured stems of poplar stands with no other external nitrogen inputs, identifying rates of 24kgN ha^{-1} yr^{-1} available through natural sources (Nonhebel, 2002). This value is consistent with rates assumed by Hansen et al. (2000, p76) in a comparison of Organic and Conventional farm systems. However, a more conservative background rate of 5kg ha^{-1} was assumed in this model.

Manure and crop-residue amendments:

Applying manures from farm animals can help satisfy the nutrient needs of an agricultural system (Shepherd et al., 1999) which are more easily supported by mixed farm systems where animal wastes are located close to crops with high nitrogen needs.

Composting manures or biosolids helps decrease the risk of pathogens and stabilizes the compost mix to ensure it won't contribute too much nitrogen on application (leading to leaching and eutrophication), nor immobilize available nitrogen in the soil needed by plants (Watson et al., 2002). The mobilization / immobilization dynamic is tied to the carbon to nitrogen ratio (C:N) of the feedstock. Mixes with low C:N ratios (below 30:1) tend to contribute nitrogen to the soil, while mixes with C:N ratios greater than 30 tend to immobilize available nitrogen. A feedstock specific composting process where carbon rich material (straw, woodchips, leaf mulch) is mixed with nitrogen rich material (eg. chicken manure) to produce a stabilized compost mix at an optimal C:N ratio of 30:1 release of nutrients slowly when the plants need it, while minimizing nitrogen loss in the composting process (figure 7.10). A considerable amount of nitrogen can be lost in the application and handling (Watson et al., 2002, Sutton et al., 1985). With application losses, this study assumes 80% of original total nitrogen remains at the time of field application to the field.

Crop residues contain significant value as carbon or nutrient sources for the soil. Cereal straw can contribute 35kgN ha^{-1} and vegetable residues up to 150kgN ha^{-1} (Rahn et al. 1992, Jarvis et al. 1996). These support the slow release of nutrients due to higher C:N than more soluble fertilizers. Placing high C:N residue on can immobilize N through the winter season to prevent loss during the rainy season (Jenkinson, 1985). The application of residues just prior a planting season will compete with crops for nitrogen and reduce overall yields, thus timing is critical for effective nutrient planning.

Cover Cropping:

Cover cropping has long been used in agricultural systems as a biological source of carbon and nitrogen. By planting crops that associate with nitrogen fixing bacteria, farmers can meet the nutrient needs of that crop and meet a portion of the subsequent crop's nutrient needs (Peoples et al., 1995). The extent to which a crop contributes to the soil depends if some of the seed or vegetable matter is removed for sale and the culitivar selected. For example, nutrients are often contained in the root, shoot or seed pending the stage of the plant's life cycle, and removal of this negates its use as a cover crop. (Peoples et al., 1995). Planting cool-season peas, for example, can fix up to 183kgN ha^{-1} but will contribute only 21kgN ha^{-1} if the seed is removed (Peoples et al., 1994).

There are several cover crops that are grown for amendment use, including canola meal and alfalfa meal. One hectare of land can produce roughly 580kg of canola meal and 390 kg ha^{-1} of oil (Canola Council of Canada, 2003). Assuming no additional production energy inputs are required given the oil is necessary for human consumption, the canola meal could be used for feed or as a fertilizer. The cumulative canola meal produced from the Vancouver foodshed is a little under 100,000 tonnes. With a total nitrogen value of 3% (USDA, 2010) and PAN of 60% (Gale et al., 2006), 1,800 tonnes of available nitrogen could be sourced from this by product, meeting 7% of the additional foodshed nitrogen needs ignoring handling losses.[7.2,7.4]

Biosolids and kitchen organic "wastes":

Current nutrient management systems induce linear flows from rural farmlands to cities and eventually to oceans leading to eutrophication of aquatic environments and leaving nutrient deficits in rural agricultural lands (Socolow, 1999). In a world of finite resources, a linear system of nutrient input and exodus is inherently unsustainable.

Though not exposed in popular media, biosolids (composted sewage) is routinely used in forage crops, woodland fertilization, landscaping (Metro Vancouver, 2010). It is not so much a question of whether human waste should be used, but rather a question of how they should be used appropriately that is a topic of current discussion. Large scale *humanure* (human manure) systems are catching on in practice across BC, in municipalities such as Kelowna, and now Vancouver. The pressures are more urgent for inland regions with limited capacity to send effluent "away".

Though not as nutritious as sewage effluent, kitchen food scraps have long been used to build soil and reduce inputs to the waste stream. It has been suggested to add food scraps to the black water stream to assist the break down of food scraps and bulk up the sewage effluent (Jenssen and Etnier, 1997).

Metro Vancouver produces 50,000 tonnes of biosolids (wet mass) and 3.5 million tonnes of solid wastes annually, the latter of which 5% represents yard wastes and 13% is food wastes (Metro Vancouver, 2010, Kempe, 2010) If fully utilized, they would meet roughly 6% of the remaining nutrient needs of the regions foodshed (table 7.2).

LAND SUMMARY:	Nutrient summary (kg PAN)	Nutrient demand (% of total)
Grains	1.01	8%
Vegetables	0.03	0%
Fruit	- *0.16*	*-1%*
Oils and Sugars	- 0.90	-8%
Animal Products	12.03	100%
Sum:	**12.01**	**100%**

Table (7.2). Net Plant Available Nitrogen *Demand* from Seleted Food Groups (per capita). Vancouver's current population of 2,293,438 demands roughly 20,400 tonnes of plant available nitrogen. Note that fruit model a net production of nitrogen to the system assuming contribution of nitrogen through intercropping. See appendix 14.5 for greater detail.

Additional Nutrient Needs:

After local sources and sinks are accounted for, the Foodshed Vancouver requires an additional 12 kg cap^{-1} or 25,440 tonnes of plant available nitrogen (table 7.2, 7.3), but would likely be much higher if compost moisture contents were accounted for[7.2]. To contextualize this mass of nitrogen, assuming kitchen compost has a total nitrogen value of 2% and PAN% of 7%, it would require over 9 tonnes of compost to satisfy the 12kg per capita plant available nitrogen requirement. [7.2]

	Available compost (tonnes)	Total N (%)	Total PAN (%)	PAN (tonnes)	Nutrient needs met (%)
Nutrifor / Biosolids	50,000.00	5%	40%	928	3.5%
Yard trimmings compost	175,000.00	2%	5%	179	0.7%
Kitchen compost	455,000.00	2%	7%	573	2.2%
Canola meal	92,771,677.38	3%	60%	1,670	6.3%
Sum:				***3,351***	***12.6%***

Table (7.3). Nutrient Energy Summary. Only 13 % of the 25 thousand tonnes of PAN required can be met with local feedstocks. Additional nutrients must be sourced by growing additional cover-crops, aquatic sources, improving composting efficiency or radical transformation of the urban landscape. This additional land in cover-crops sums to another 300,000 ha of land or 15% of the Foodshed Vancouver 2006 agricultural land allotment (see figure 7.13). [7.2]

To meet this demand, an additional 294,000ha or 0.15ha cap^{-1} (15% of agricultural allotment) of growing space was required for cover crop nitrogen production. This assumes a PAN contribution of 75kgN ha^{-1} with negligible leaching, volatilization or atmospheric deposition. In context, this represents an extra cover crop cycle or the placement of a laneway where a row of vegetables would have previously been to benefit adjacent plants. No additional direct energy inputs were modelled for this but there are indirect energetic implications when food must be shipped extra distance on account of a larger foodprint.

Management of Sustainable Nutrient Systems:

Managing for efficient nitrogen usage is just as important as securing resilient supplies of nutrients. Sustainable nutrient management strategies include:

1. Match the timing of nutrient application with crop needs.
2. Consider low or no-till techniques, and perennial agricultural systems to support mycorrhizae associations and nutrient buffering.
3. Utilize Agroforestry for nutrient buffers and to apply non-food grade nutrients such as sewage sludge and raw manures.
4. Time irrigation with nutrient application, as uptake is positively influenced with appropriate irrigation regime.
5. Consider higher plant densities and larger bed width for improved nutrient uptake, weed competition and overall productivity.
6. Locate consumption, waste processing and food production in close proximity to optimize cycling efficiency. Mixed agricultural farms can support sub-system nutrient cycling.
7. Leave crop residues on site to maximize residual nutrient uptake, and biomass gain.
8. Optimize biogas produced in composting processes for heating or electricity. [7.5]

Adapted from Cassman et al.(2002), Jeavons(2006), Hansen et al.(2000), Mollison(1988), Pang and Letey (2000). Morken and Sakshaug (1998), and Mader, (2002).

Modelling Considerations and Future Research:

The work by John Jeavons of Ecology Action, California (2006), David Holmgren (2002) and Bill Mollison (1988), founders of the Permaculture concept, Elliot Coleman (1999) author of the Four Season Harvest have inspired this work. While techniques they suggest can help guide the design of ecologically sound and productive food systems, discretion must be applied when applying yields typical of warm climates to temperate British Columbia. Jeavons (2006, p 249) for example, suggests under Biointensive © production methods, an individual's dietary needs can be met on 372 square meters of land in stark contrast with the 6740 square meters required to meet the needs identified in this report. While Jeavons accounting assumes a purely vegetarian diet, the level of productivity he achieves on intensively managed land in a warm California are likely not transferable to British Columbia. From a nutrient management perspective, Jeavons advocates for up to 19lb $100sf^{-1}$ of alfalfa meal @ 2-3% total N (Jeavons, 2006 p 51). Assuming a total N of 2.5%, this contribution translates to 231kgN ha^{-1}, much higher than the Environmental Farm plan background recommendation of 50kgN ha^{-1} of total manure N for vegetables (BCMAL, 2003, p 2). Given this level of nutrient loading and intensive planting scheme, it is not surprising he is able to achieve yields up to four times that of a conventional farmer (Jeavons, 2006 p 17).

Ward Teulon of City Farm Boy, Vancouver suggest the application of three to four 32 l bags of sea soil $1000sf^{-1}$ (Teulon, 2009), equating to 134kgN ha^{-1} assuming 2.1%N in every 17kg bag^{-1} (assuming 37lbs bag^{-1} according to Fawks (2010)). Given the considerable variability in nutrient mineralization and plant uptake and likely absence of vegetated buffers and permeable surfaces, applying intensive nutrient schemes in urban areas requires considerable planning. A measured approach to nutrient management is needed to respond to both food and environmental needs.

The lower mainland faces its own challenges when applying organic fertilizers to pasture or forage crops. Market and climate forces have motivated farmers to specialize in high intensity dairy and poultry farming in the lower fraser valley, leading to gluts of organic manures in these regions. The valley has exceptional levels of phosphorus and potassium largely due to the over application of these manures (Bomke, 2010). As phosphorus and potassium aren't as volatile as nitrogen, they tend to build up in a system and will leach into local water bodies after reaching threshold levels. Some organic manures while necessary for their nitrogen content will be *inappropriate* in these regions because of high phosphorus and potassium contents. That is, by applying nitrogen in the form of manure compost, farmers may exceed environmental phosphorus limits. A whole systems approach to nutrient cycling is important to adequately meet the nutrient needs of the farm without threatening local ecosystems.

Modelling nutrient cycling is extremely sensitive to available nitrogen contributions which in turn is sensitive to moisture content[7.2], weather, soil texture, soil biology and other variables difficult to model on a regional scale. In one study Janzen et al. (1990) noted how the total nitrogen contribution from Lathyrus can range from 76kgN to 110 kgN ha^{-1}, and the available nitrogen depends on a host of variables already mentioned. For this reason, local soil testing and climate considerations is important when applying these figures in context. It doesn't, however, negate the need for modelling nutrient cycling given its significance in net foodshed size and energy balance.

Conclusion

Due to the bulk involved with organic nutrient cycling, the energy implications of moving 680,000 tonnes of organic matter are not insignificant at 0.54 GJ cap^{-1} or 10% of the total food energy consumed [7.3]. The net footprint of food, accounting for nutrient cycling needs, is 0.68 ha cap^{-1} (figure 7.6). Additional circulation and wildlands has been added to retain 30% of the land base for these functions. This *life-cycle* foodprint requirement will drive the land use allotments for city foodprints and foodsheds for the remainder of the study and is consistent with Robins (2006, p2) who suggested British Columbians require roughly 0.524 ha cap^{-1}, Wackernagel et al. (2002, p 9268) who identified a foodprint of 0.63ha cap^{-1} and Wackernagel and Rees (1994, p95) who assumed a land-based foodprint requirement of 0.71 ha cap^{-1}. It is significant that this study arrived at a very similar foodland requirements to other reports.

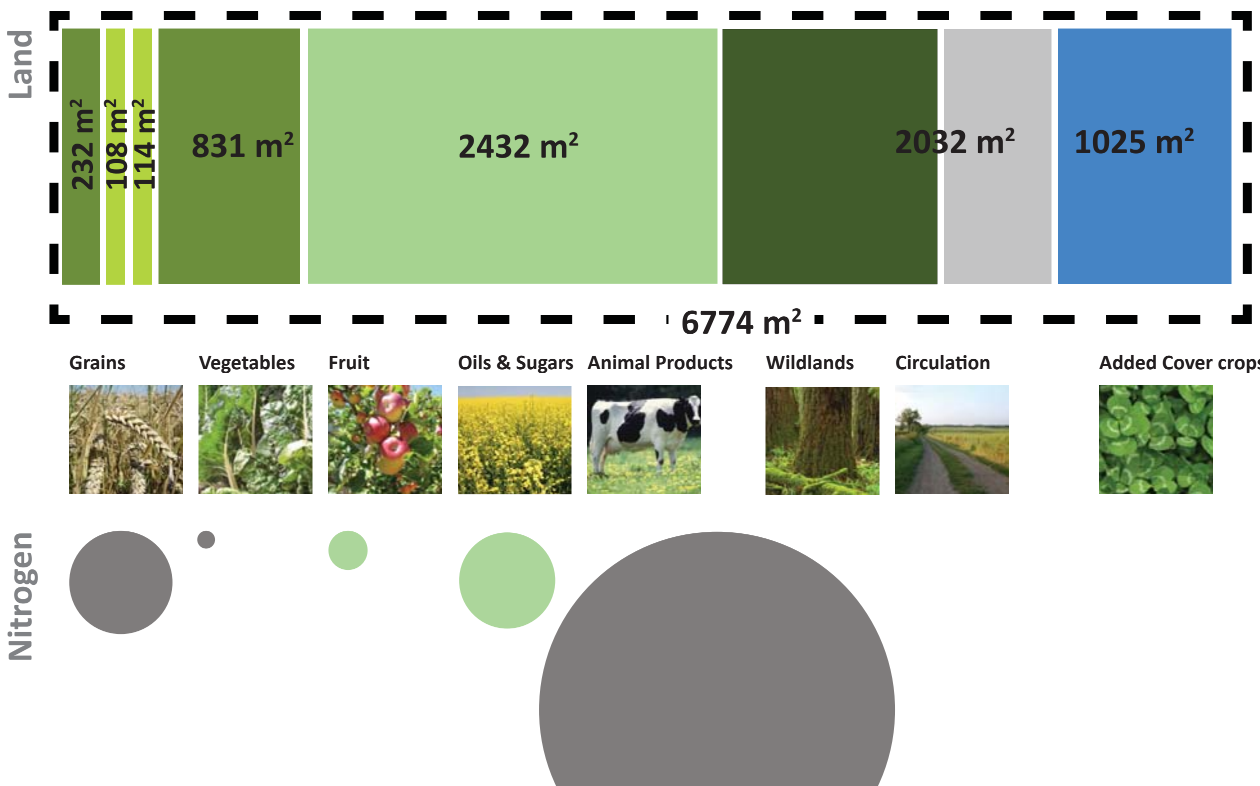


Figure (7.6). Life-cycle Foodprint. Land and nutrients required to meet an individual's food needs based on Canadian dietary habits and BC production intensities. Currently the fruit, oil and sugar crops model as net producers of available nitrogen (green circle) for use elsewhere in the system. The nutrient shed (in blue) represents additional lands required by the system after all available organic nutrients are used (composts, biosolids, canolameal). Wildlands and circulation increased to account for the larger "foodprint".

Endnotes

7.1 Nutrient Cycling

Nutrient demand was calculated on a crop by crop basis according to the following equation:

$$\boldsymbol{D_N = H_N + L_N + V_N - (CC_N + A_N + M_N)}$$

$Where:$

$D_N = Nitrogen\ Demand$

$H_N = Nitrogen\ removed\ from\ harvested\ material$

$L_N = Nitrogen\ removed\ by\ leaching$

$V_N = Nitrogen\ lost\ to\ atmospheric\ volitization$

$CC_N = Nitrogen\ added\ through\ cover\ crops$

$A_N = Atmospheric\ deposition$

$M_N = Local\ manure\ contributions$

This value is the Plant Available Nitrogen demand (PAN), not to be confused with Total Nitrogen demand. The difference in this case is that only a fraction of the total nitrogen contained in manure or compost feedstocks is available for plant uptake.

Nutrient demand for animal pasture is equal to 100 kg PAN ha^{-1} or 250kg manure N ha^{-1}, assuming a manure mineralizable N of 40%. (BCMAFF, 2005 table 6.6 and, Andrews et al. 1996) Excreted Nitrogen was accounted on an animal by animal basis, assuming a 20% handling loss according to Environmental Farm plan guidelines, (BCMAFF, 2005, table 6.7). Nutrient demand for each animal's feedshed (the area required to grow feed) is essentially the same as above except the crop removed is a grain of some sort, specific to each animal's diet. Net nutrient demand for animal related products is equal to the pasture requirement added to the feedshed demand.

Nutrient demand for fruit accounted for cover crop contributions on unplanted laneways. This was different for each crop according to row spacing suggested by the BCMAL. Slender spindle apples, for example, are spaced on 12' rows which supports 10' lanes with 2' of managed row into which the apple trees are planted. The nitrogen contribution is thus 10/12 (83%) of 75kg ha^{-1} or 62.5kg ha^{-1}, given not all of the area is planted in a cover crop. Since laneways are planted perennially through the entire growing season, this assumption is likely a little too conservative. See appendix (13.4) for a more detailed assessment of nutrient cycling dynamics.

7.2 Estimating PAN

Data from Cogger et al (ND), Kempe (2010), Gale et. al., (2006) and Pratt et al., (1973) was used to determine what fraction of compost feedstock translated to plant available nitrogen. For each case the This value is calculated by multiplying total nitrogen by PAN %. Thus for a feed stock with 3% nitrogen and 60% PAN, only 2% PAN is available for plant use (much of which is leached from the system).

To supply 12 kg of compost requires 9 tonnes of compost from kitchen compost where compost mass required is equal to PAN requirement / (total N%*PAN%)

Nitrogen content is usually calculated by DRY mass, rather than fresh wet mass. Kempe (2010) estimated biosolids treated in Matro Vancouver were roughly 70% moisture by weight, thus the actual total nitrogen would be 30% of 2% of the total mass of original biosolids produced, or 0.6% of the original biosolids by weight, much less than the estimated values above. The moisture content of yard trimmings and kitchen compost are not available, thus the PAN available through these feedstocks is likely far too liberal. If the dry content of biosolids, yard trimmings, kitchen compost, and canola meal is assumed to be 30%, 45%, 45% and 87% respectively, the total life cycle food-print increases to 0.6841ha cap^{-1} to compensate for the additional nutrient lands necessary to meet the nutrient needs of the region. Accordingly, Metro Vancouver's nutrient self-sufficiency decreased to 9% when accounting for moisture.

7.3 Moving Nutrients

City based composts are moved to the most proximal lands, using similar energetic costs as the shipping of food from country to city. As city based composts only meet 7% of the nutrient needs of the foodshed, this distribution cost was relatively small and the distance quite short. If the nutrients generated in the city were to meet the nutrient needs of the entire foodshed, these energetic costs would be much higher. This is important when considering other nutrients such as phosphorus and potassium which require cycling and cannot be grown in place in the way nitrogen can. In other words, if potassium and phosphorus become limiting nutrients in the future, cycling them through the system will be mandatory.

All available canola meal was assumed shipped 50km at rail freight energy intensity levels. It is more likely the canola meal would be used as feed.

Modelling nutrient demand and supply required many assumptions making the model sensitive to errors. Further research is necessary to develop appropriate assumptions for regionally-scaled analysis.

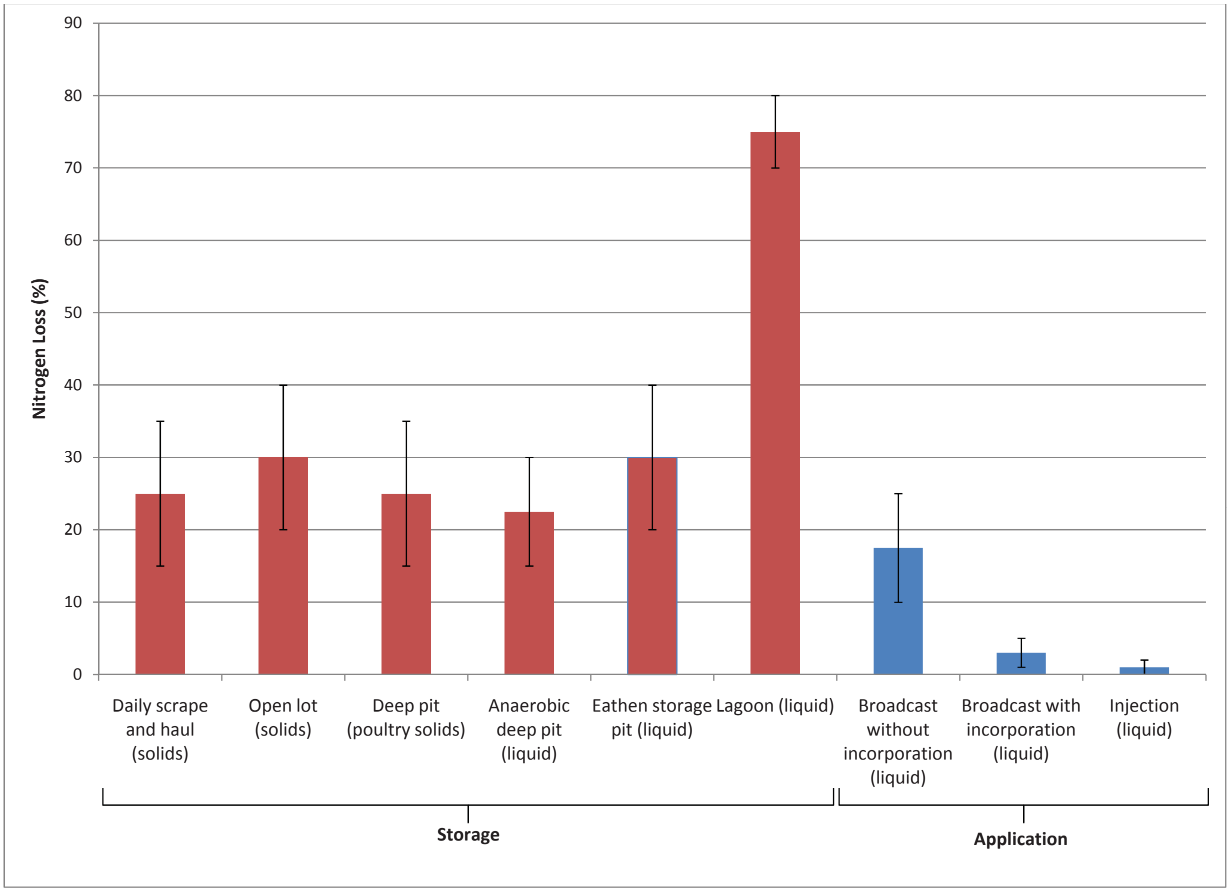


Figure (7.7). Nitrogen Losses in Manure Storage and Application methods. From Sutton et al., (1985)

7.4 Modelling handling loss

This report assumes 20% loss of nitrogen from handling and application though as can be seen in figure (7.7), losses can be ***much*** higher pending the methods used.

7.5 Cogeneration and Biogas potential of Composting Biosolids

Local and international evidence has shown cogeneration biogas plants to be a safe and economical means of power or heat generation, utilizing methane off-gassed in the composting process. In British Columbia, it is estimated that 4 million tonnes of digestible manure produced in BC yr^{-1}, 80% of it in the lower mainland. The energy production potential of this source is estimated at 39MW electrical power, enough energy to heat and electrify 40,000 homes, or to replace 500,000 barrels of crude oil (Rogstrand, 2010).

In the treatment of human sewage, roughly 50% of the energy consumed at Annacis Island, a Vancouver waste treatment facility, are met on site. At Iona Island, the plant sources almost 80% of their energy needs from digester gas. This study assumed no additional energy requirements for the processing and composting of nutrient feedstocks.

8 Modelling Foodshed Vancouver

At a regional scale, energy is an appropriate currency to evaluate foodshed performance. This section will integrate the food system energy inputs developed in sections three through six and compare it to the food energy output identified in section one (figure 8.1). Further, by changing each variable according to hypthetical future conditions, the model will uncover which ones matter most in determining the *size* and *energetics* of a foodshed for Greater Vancouver in 2050.

Figure (8.1) Modelling the Energetics of Foodshed Vancouver. The food system energy balance is equal to the food energy output divided by the food system energy inputs (production, distribution, processing, and nutrient cycling).

Business as Usual 2006

How much land?

Modelled dietary habits demanded approximately 0.68 ha of net food land per person, requiring 1.4 million hectares of farmland for the 2.1 million people living in the Greater Vancouver Regional District (GVRD). Using existing ALR land this necessitated a foodshed that consumed 32% of British Columbia's Net ALR land (figure 8.2). Only 13% of the nutrient needs could be met by available sources. Small sections of Eastern British Columbia were prioritized over closer sections due to their connectivity to the rail system. The whole of Vancouver Island was consumed within Vancouver's foodprint, largely due to the efficiency of marine which is assumed to connect the lower mainland to the island. These findings highlight the difference between Euclidian proximity and energetic proximity, the latter of which accounts for modal choice and route availability, and is arguably a better indicator for sustainable agricultural planning.

How much energy?

Under optimal production and distribution conditions, for every joule of energy produced by the food system, 3.6 joules of energy were invested. Together, production and processing inputs made up 94% of net energy inputs, representing over 3 times the energy contained in the food (table 8.1). These conditions made it impossible to complete the food cycle with a net positive energy balance, no matter how Vancouverites sourced their food. With more energy expended in the *production* of food before it leaves the farm gate than is contained in the food, radical transformation of production, processing and dietary patterns must accompany the changes in urban form to make the food system energy positive.

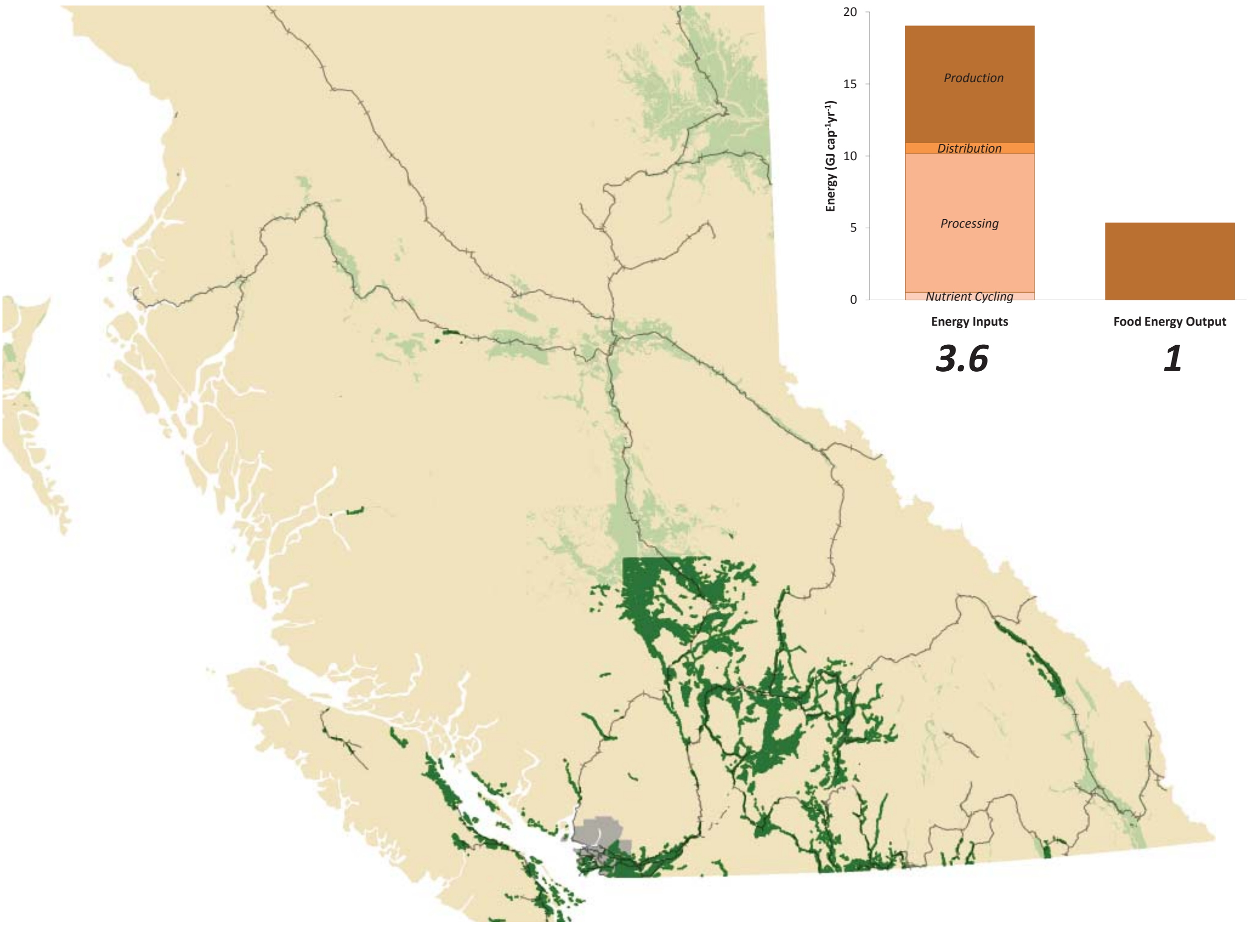


Figure (8.2). Foodshed Vancouver 2006. Foodshed Vancouver 2006 is 1.4 million ha representing 32% of the provinces net ALR land, demanding 0.68 ha per person.

Food Energy Summary	Food Energy Purchased (GJ/cap*yr)	Production (GJ/cap)	Distribution (GJ/cap)	Preconsumer Processing (GJ/cap)	Restaurant and Consumer processing (GJ/cap)	Nutrient Cycling (GJ/cap)	Total Foodsystem Inputs (GJ/cap)
Grains	1.30	0.15	-	0.88	-	-	-
Vegetables	0.52	0.36	-	0.08	-	-	-
Fruit	0.29	0.80	-	0.11	-	-	-
Oils and Sugars	1.59	2.95	-	2.69	-	-	-
Animal Products	1.66	3.86	-	0.72	-	-	-
Sum:	**5.36**	**8.11**	**0.74**	**4.48**	**5.17**	**0.54**	**19.03**
Percentage of food system energy inputs		***43%***	***4%***	***24%***	***27%***	***3%***	***100%***

Table (8.1) Food Energy Summary for Foodshed Vancouver, 2006. Distribution inputs are based on ArcGIS spatial analysis as are Nutrient Cycling Inputs, thus are not specified on a crop by crop basis.

Business as Usual 2050

How much land?

An increase in Metro Vancouver's population to 3.1 million people demanded 2.1 million ha of land occupying 47% of the provinces ALR land (figure 8.3).

How much energy?

Processing & cooking methods increased in efficiency to 2006 standards as old models were replaced. This created a modest energy efficiency gain making Foodshed 2050 more efficient than Foodshed 2006, despite incurring larger distribution inputs.

Nutrient cycling of all available organic feedstocks was increased in kitchen compost and biosolid availability by 50% (with population increase) over 2006 levels, though there was no assumed increase in yard trimmings availability. In fact, it is likely that yard trimming availability would actually decrease with an increasing urbanization, decreasing the proportion of single family homes in the region.

It is important to notice how little nutrient cycling and distribution actually contributed to food energy inputs (8%), only 1% more than the 2006 scenario. It is also interesting to note the location of prioritized ALR land allotments. This model selected pockets of ALR adjacent rail stations (figure 8.4a, b), minimizing

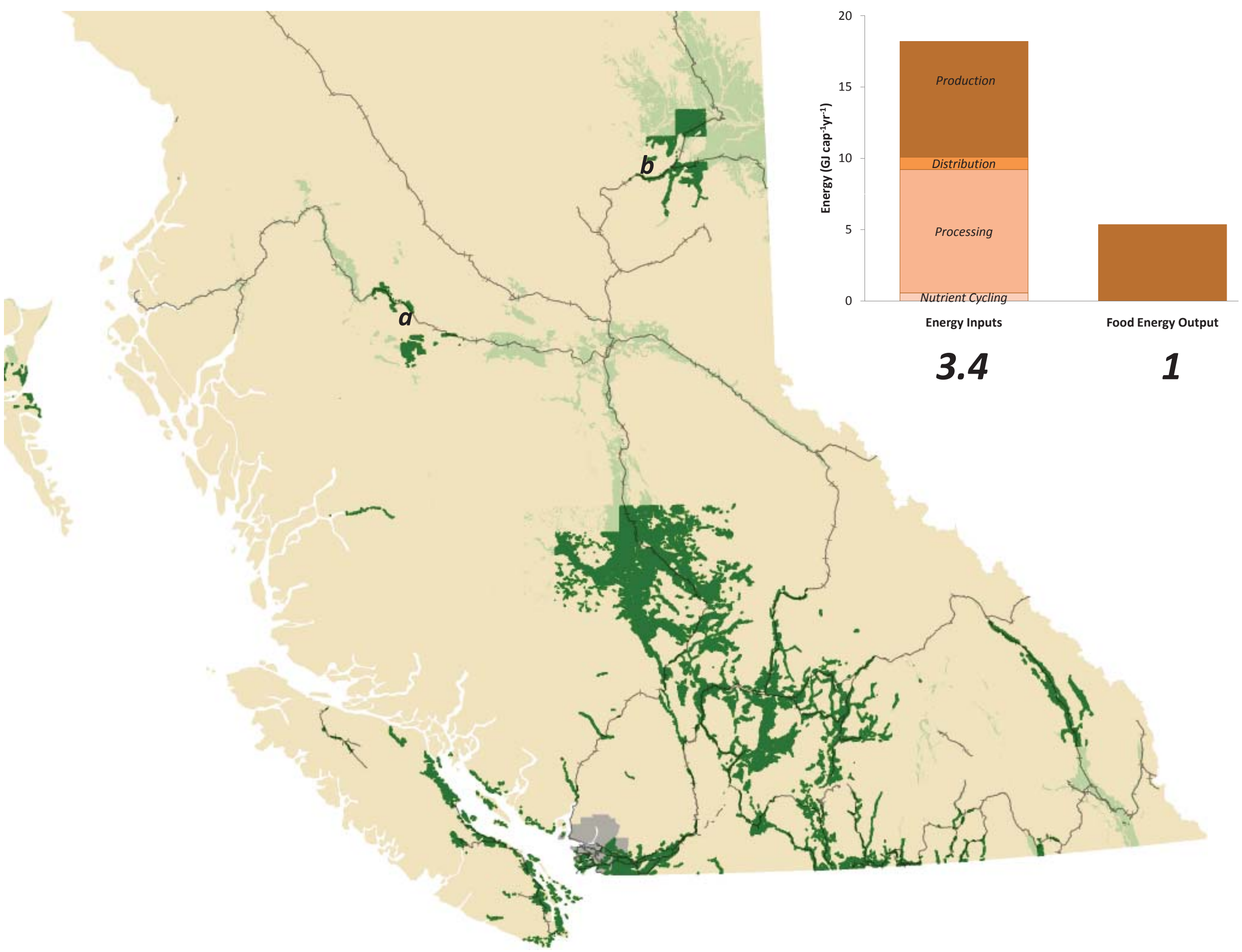


Figure (8.3). Foodshed Vancouver 2050 - Business as Usual. Foodshed Vancouver 2050 is 2.1 million ha representing 47% of the provinces net ALR land.

Figure (8.4). One-hundred Mile Diet. This target does not account for the modal efficiencies or route logistics that in turn inform an efficient food shed. Without agricultural land reform, in no way will the city of Vancouver ever be able to source its food within the 100 mile limit.

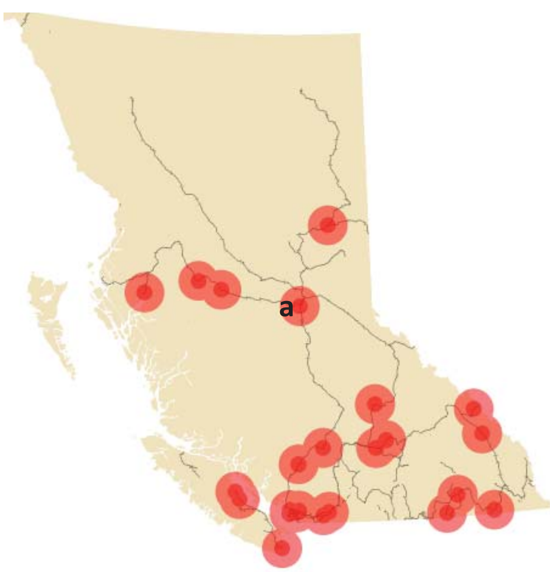


Figure (8.5). Designated Rail Freight Stations and a 50km Catchment Zone. Addition of a rail station at point a improved distribution efficiency by 1% over the previous scenario.

the amount of road travel necessary. Large stretches of ALR land were passed over due to poor accessibility to the rail line. A small section of the Queen Charlotte Islands was also selected for access to energy efficient marine freight. Intuitively, these planning decisions don't make the most sense highlighting the need to start with accurate and detailed data and to weed out computational errors. They do, however, highlight the inadequacy of the hundred mile diet concept which sets arbitrary limits independent of modal efficiencies or route logistics (figure 8.4). Further, there is insufficient agricultural land within this 100-mile catchment basin to satisfy more than 17% of Vancouver's 2006 population, not to mention a projected population of 3.1 million in 2050 [8.1].

Energy Efficient 2050

This scenario assumed a 10% energy savings in production as per Brown and Elliot, 2005[8.2], and the addition of rail station in Prince George to improve connectivity of ALR lands in that area.[8.3]

Given processing contributes a significant amount to the total energy footprint, secondary stoves, fridges and dishwashers were "removed" to improve household energy efficiency. All household and restaurant appliances are assumed to have improved by 50% from 2006 energy intensities. These improvements are consistent with efficiency gains from 1984 to 2007 as per statistics collected by Natural Resources Canada (2009).

How much land?

The total land footprint remained the same at 2.1 million ha, but the location of those lands changed with the addition of a rail station at point (a) in figure (8.5). This slight change to regional form induces a distribution efficiency gain of only 1% from the previous scenario, but radically altered the shape of Vancouver's foodshed seen in figure (8.6).

How much energy?

Energy efficiency gains in other sectors (processing, production) induced a 30% decrease in energy inputs, but was still insufficient to achieve net energy gain.

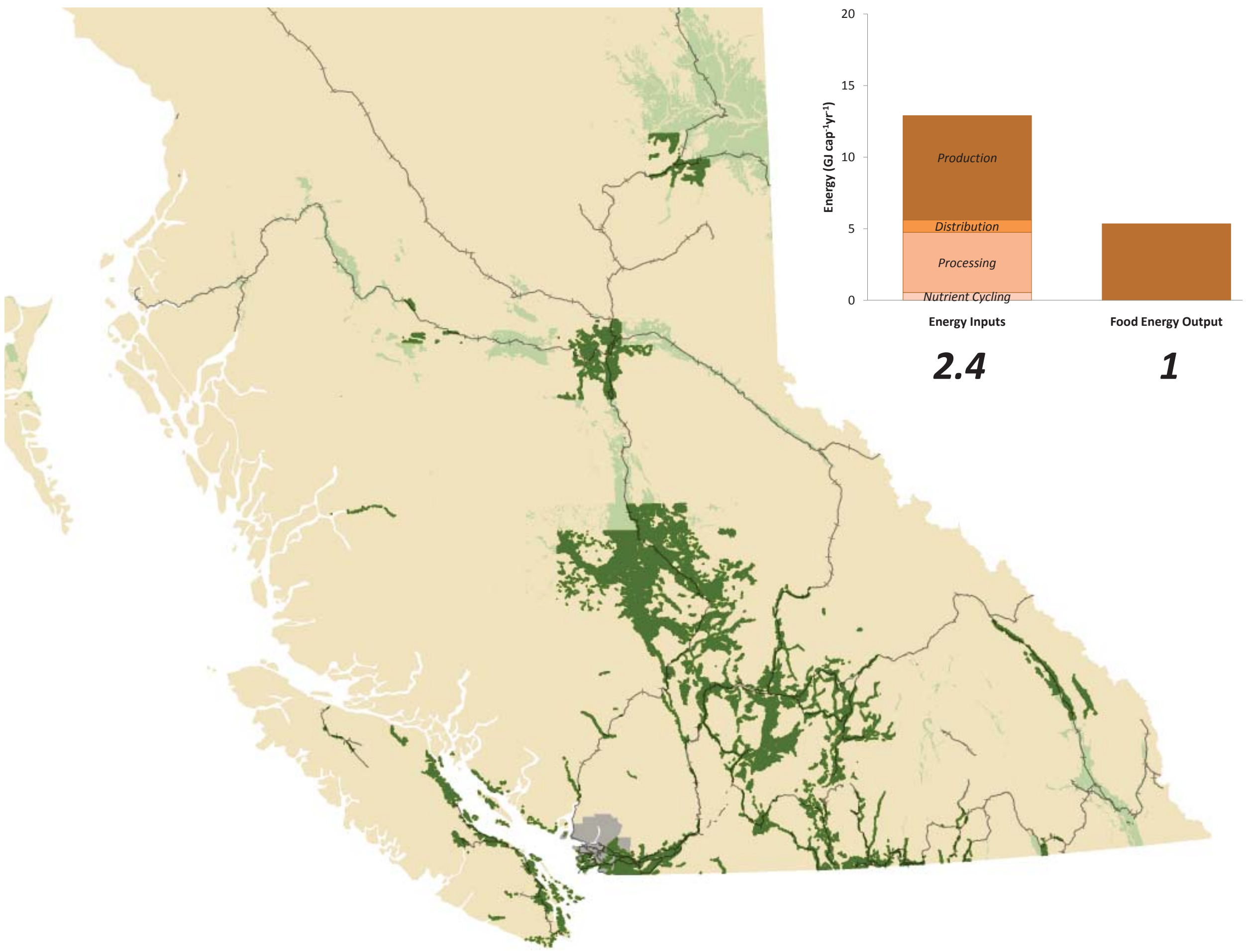


Figure (8.6). Foodshed Vancouver 2050 - Energy Efficient. An improvement in energy efficiency decreased energy inputs of 30% over the BAU 2050 scenario.

Lactovegetarian 2050

To assess the impact of dietary shift on the food energy balance, a lactovegetarian diet was imposed on food items selected. The selection maintained the total calories purchased at 3,510kcal day^{-1}, but allowed only eggs, milk and honey for animal products. In addition, the sugar and oil consumption was reduced by 50% for energetic and nutritional reasons. Other food items were increased in volume to account for lost calories. Household stove use was decreased by 50% from the previous scenario resulting from an assumed increase in raw food consumption. Other energy savings from the energy efficient scenario was preserved.

How much land?

The shift to a lactovegetarian diet reduced the individual foodprint to 0.45 cap^{-1} but increased the mass of food necessary to supply this diet to 860 kg, a 22% increase over previous scenarios[8.4]. This reduction in land intensive animal products resulted in a total land area foodshed reduction of 36% over the 2050 Business as usual scenario, to 1.4 million hectares, representing 31% of the province's ALR land (figure 8.7).

How much energy?

The total energy footprint of this scenario was 47% less than the BAU case and 25% better than the energy efficient scenario. In addition there was a slight relative increase in distribution energy input, now 9% of the total energy input (versus 5% for the 2050 BAU case), on account of a greater mass of food transported.

A shift to a *lactovegetarian diet* in addition to previous *energy efficiency* improvements was insufficient to achieve an *energy producing* foodshed. This is consistent with Pimentel and Pimentel (2003, p660S) who noted that a hypothetical lactovegetarian diet, while more sustainable than a meat-based diet, still required more energy to produce the food than was contained in the food itself.

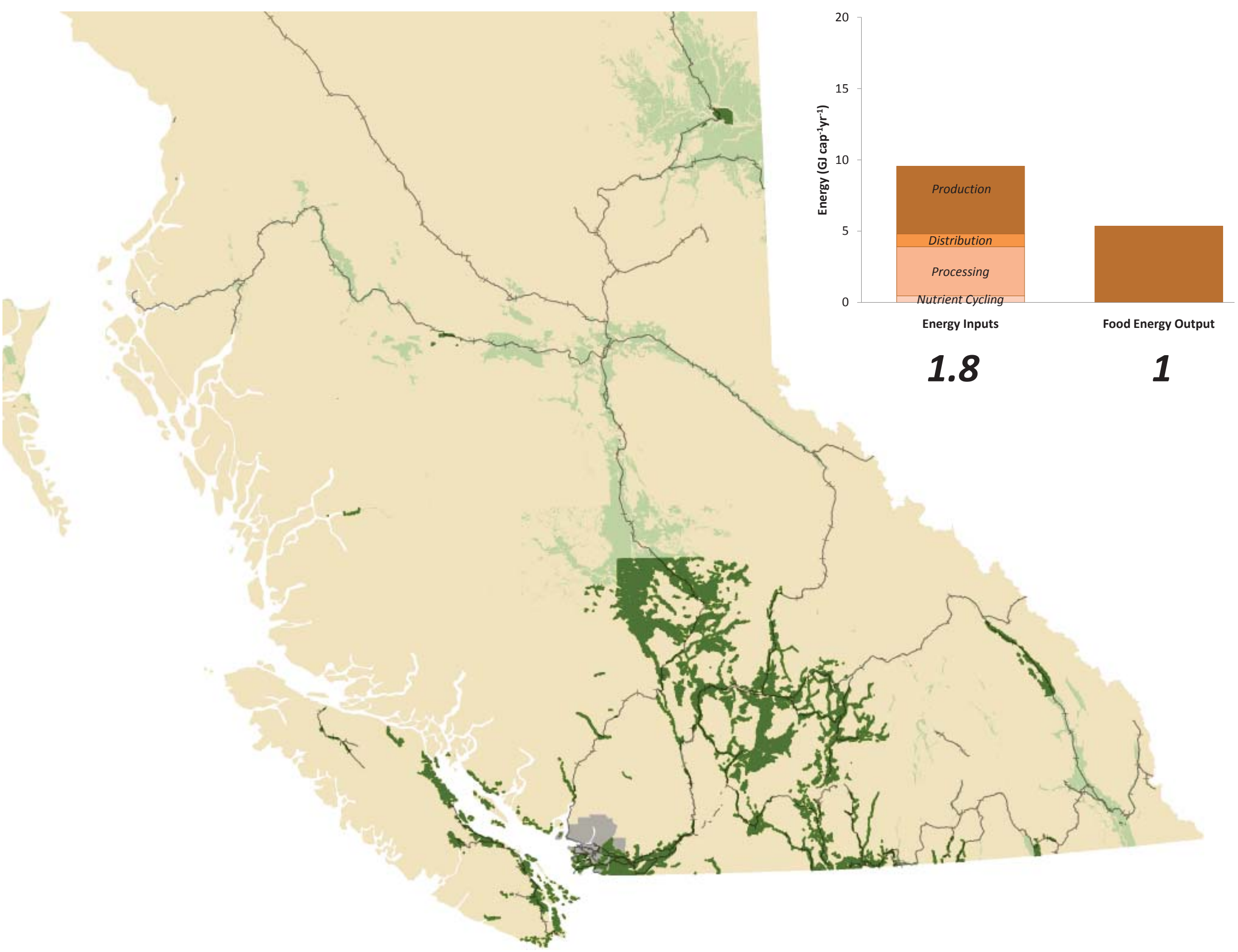


Figure (8.7). Foodshed Vancouver 2050 - Lactovegetarian Diet. Dietary shifts induce a 36% reduction in foodprint area and 47% decerase of energy inputs over the BAU 2050 scenario.

Almost Sustainable 2050

In this scenario, the lactovegetarian diet was preserved and the total caloric purchases were reduced by 1000kcal to 2,510kcal cap^{-1} day^{-1}. This implied 582kg cap^{-1} yr^{-1} was purchased at an energetic intake of 3.8 GJ cap^{-1} yr^{-1} [8.5]. Processing inputs were reduced again from the previous scenario accounting for reduced appliance densities in Vancouver households.[8.6]

How much land?

The per-capita foodprint was reduced to only 0.31ha cap^{-1} and Greater Vancouver's foodshed decreased to just below one million hectares, 54% less than the 2050 BAU scenario, now occupying only 21% of the provinces ALR land (figure 8.8). In addition, nearly 20% of the nitrogen needs of the foodshed can be met locally, versus 13% in previous scenarios [8.7].

How much energy?

Though the absolute energy inputs to this scenario were reduced, the food energy balance (output divided by input) remained roughly the same as the lactovegetarian scenario at 1.79 joules invested for every joule of energy in return.[8.8] This shows that without dramatic changes to processing or production inputs, it is impossible to achieve an energetically productive food system.

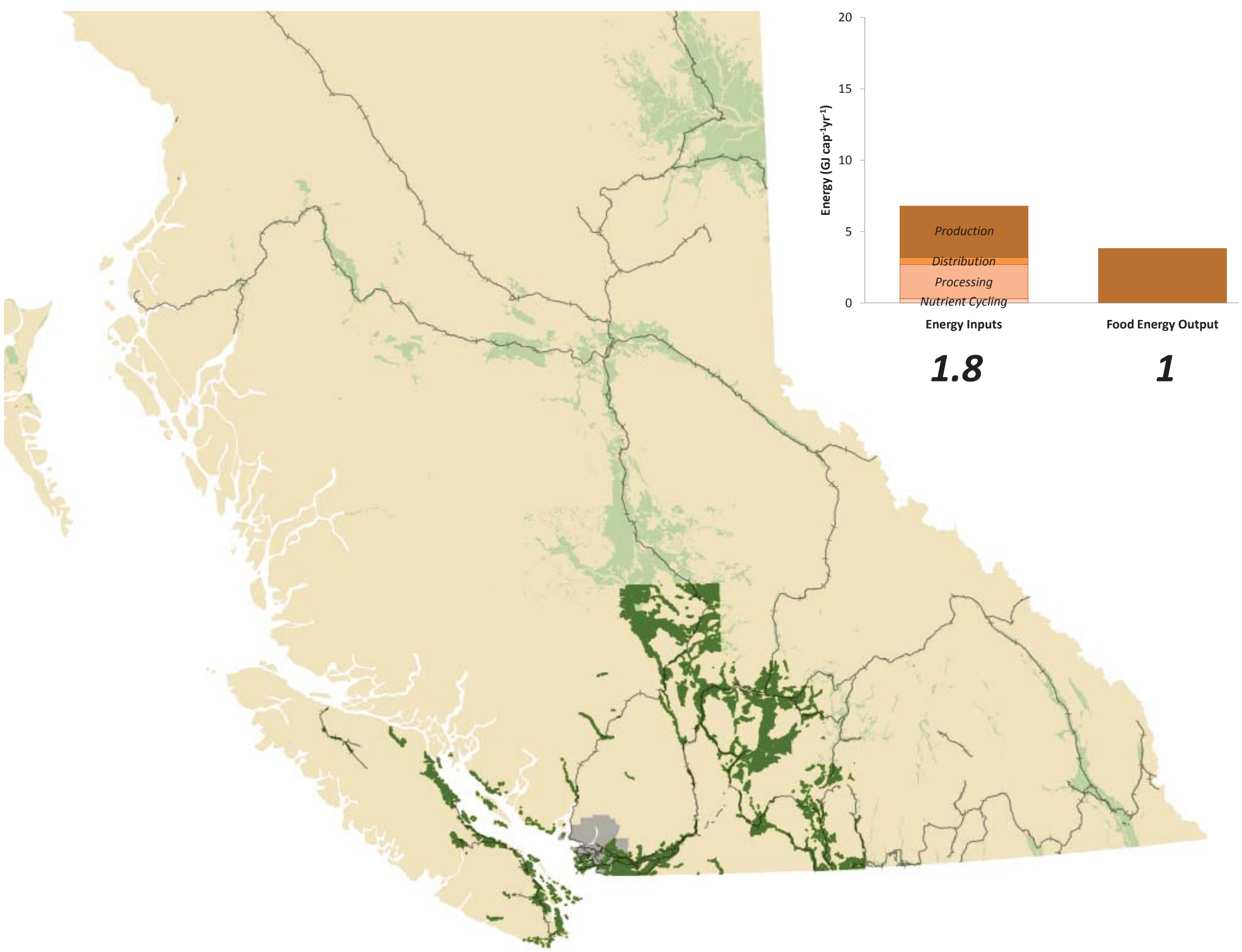


Figure (8.8). Foodshed Vancouver 2050 - (Almost) Sustainable. Radical dietary shifts, energy efficiency improvements and a shift towards human-scaled agriculture could help achieve an "energetically sustainable" foodshed for 2050.

In his preliminary analysis on the energetics of small farming systems in Kentucky, Bomford (2009) noted a decrease in energy inputs of nearly 30% in systems dominated by hand tools in a biointensive gardening system in comparison with small-scale farming where tractors are used. If production and processing energy inputs were reduced by 30%, the food system energy balance would reduce to 1 joule of energy gained for every 1.31 joules of energy invested. Using Bomford's (2009) estimation of labour input for biointensive farming would necessitate 43% of the population of Greater Vancouver be engaged in full time agriculture, double the agricultural labour intensity typical of the late 1800s in British Columbia. [8.9]

It would require a 50% reduction in production and processing inputs on top of efficiency gains discussed in previous scenarios to achieve a food system where food energy outputs were equal to food system energy inputs. It clearly require massive transformations in behaviour and regional form to facilitate such a food system.

Conclusion

While changes in diet the distribution network and production and processing techniques achieve a much reduced land foodprint, no scenario was able to achieve a net positive energy balance (figure 8.10, 8.11). Since the data used to calibrate the model is based on production and processing efficiencies typical of the 1970's, there are likely few present-day precedents in the *developed* world from which to draw energetically sustainable approaches to agriculture.

Figure (8.9). Foodprint Comparison. Business as Usual (top), lactovegetarian (middle), and Almost Sustainable (bottom).

Endnotes

8.1 Reconsidering the one hundred mile diet

Vancouver has a foodshed of 1.4 million hectares. The available ALR land within 100 miles of the city centre is 232 thousand hectares satisfying 17% of Vancouver's food needs (available foodshed divided by required foodshed).

8.2 Food production energy savings potential

Brown and Elliot (2005, p ii) predicted an average of 10% potential energy savings for the agricultural sector.

8.3 Rail station assumptions

Rail stops were generated from a transportations stops shape file developed by DMTI spatial, published in 2008. It contains a data set of Canadian transportation stops including rail, transit and subway stops. LRT rail and subway stops were excluded as they likely could not support rail freight.

It is highly likely that not all rail stations are accounted for in this model, generating a selection pattern that does not accurately reflect reality. From aerial imagery, there is likely a rail freight station in Prince George already, but was noted as a passenger stop by the rail data generated by DMTI Spatial (2006, 2008), thus excluded from the spatial data set. This highlights the needs for accurate spatial data to direct agricultural planning.

8.4 Food energy compensation

Previous scenarios required 704 kg cap^{-1} ignoring non-land based food (fish and highly processed foods - chocolate bars). The lactovegetarian diet required a greater mass of food to compensate for the exclusion of energy rich animal products.

8.5 Food mass wastage

This food energy intake is still well above the minimum suggested by the UN FAO of 2000kcal cap^{-1} day^{-1}, but accounts does not account for food wastage which is on average 33% of the mass of food purchased. Wastage was calculated according to consumption and food purchasing statistics provided by Statistics Canada, 2002 where percentage wastage is: food purchased less food consumed divided by food purchased for available foods grown in BC. Average wastage was calculated for each food group (grains, vegetables, fruit, oil and sugar crops, animal products), and then averaged again for all food groups.

8.6 Appliance density assumptions

Only one set of appliances were assumed available for every two households. Freezer and dishwashers were not available for this scenario. This behavioural shift may seem shocking, but is a standard for "developing countries". Co-housing systems will also program shared kitchen spaces for energy saving and to facilitate community building.

8.7 Nitrogen demands

Recall that nitrogen demand accounts for *losses* due to crop removal, nutrient handling and leaching and *additions* from cover-crops, manures, atmospheric deposition. A change in the food palette alters both losses and demands, and in the above case, results in a lesser demand that must be supplied by local compost supplies (yard trimmings, biosolids, canola meal, kitchen compost). While nitrogen can be *grown*, cycling phosphorus and potassium through compost systems is critical for a "sustainable" food system.

8.8 Food energy balance considerations

The total number of output calories was dramatically reduced switching from the lacto-vegetarian diet to the "almost sustainable" diet, hence the ratio of output to input remained the same.

See Appendix 15.2 for a summary of the food energy balance scenarios.

8.9 Labour intensity changes

Bomford's (2009) estimates labour of inputs of 16-18 min per m^2 which equates to 2,800 hr ha^{-1} or almost 1.4 million labourers at 2000 hr $year^{-1}$ to work the 973,000 ha of Vancouver's "sustainable" foodshed. This labour input is consistent with Pimentel (1980. p68) who estimates a labour intensity of roughly 1,100 hr ha^{-1} for human-powered corn production in Mexico and anecdotal evidence that suggests one labourer can work roughly one hectare of land (Though Stanhill (1977), noted a labour intensity of 5 ppl ha^{-1} for high intensity urban agriculture plots in Paris).

Labour intensity likely increases with crop diversity. That is, the more diverse the farming system, the more labour required per unit area.

Making use of work animals could reduce this labour input but require additional land for feed. Pimentel and Pimentel (1996) suggest that a work horse can increase work output by ten fold, but requires 2.3ha $pair^{-1}$ of horses for feed (Morrison, 1946). In this scenario, 973,000 ha of farmland would require an additional 224,000 ha of feed land, but need only 4.3% of Greater Vancouver's total population to work the land (assuming 10 fold decrease in human labour for addition of a pair of horses per 10 ha). It isn't surprising that almost half of the land base was required for feed land in early American agriculture (Hassebrook and Hegyes, 1989).

8.10 Mapping considerations

Generating a map requires the projection of a 3-dimensional spherical object on to a 2 dimensional sheet of paper (or computer screen). There are many standards used to project maps in such a way to minimize spatial distortion (area, length, etc.), but all projection standards have some distortion. The two images of British Columbia below are based on a NAD 1983 UTM Zone 10 projection of BC and a GCS North American 1927 coordinate system respectively. This report uses the NAD 1983 UTM Zone 10 projection for generating all images and area calculations. Variability in calculating BC ALR land between NAD 1983 BC Environment Albers used by the ALC and the UTM Zone 10 projection amounts to 0.02 % difference, and is considered negligible by this report.

NAD 1983 UTM Zone 10 projection; GCS North American 1927 Coordinate System projection

8.11 Refrigerator Usage

Heat produced from refrigerator use isn’t necessarily “waste” heat as it contributes to the household heating for a significant portion of the year.

9 Placing Foodlands

Though distribution appeared to have an almost negligible input to the food system energy balance, previous sections identified how the local placement of urban agriculture and regional farms contribute to the social connectivity and resilience of the food system as a whole. This section will identify what biophysical and social factors should be considered when placing food lands on an urban, regional and provincial scale with Greater Vancouver as a focal case.

Variables which drive the placement of food spaces change with the local context and the primary program of the farm. The availability of light, water, soil, labour and financial resources differ dramatically between regional farms where expansive field space (usually) permits access to light, unavailable in urban environments (figure 9.1).   Conversely, soil can be readily amended in an urban context with available composts, but is more difficult to amend in rural settings where the scale of application and poor access to organic matter prohibit large-scale soil building efforts.

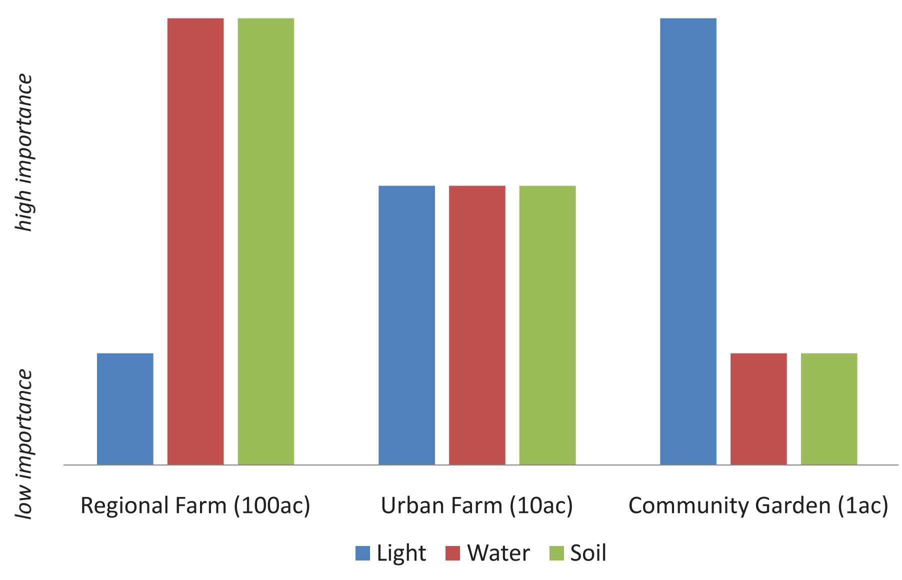


Figure (9.1) Importance of Suitability Factors for Urban and Regional Agricultural Planning. Though clearly these factors are critical at every scale, the influence of *microclimates* and the capacity for the landscape manager to *modify* the soil has impacts which factor needs most attention.

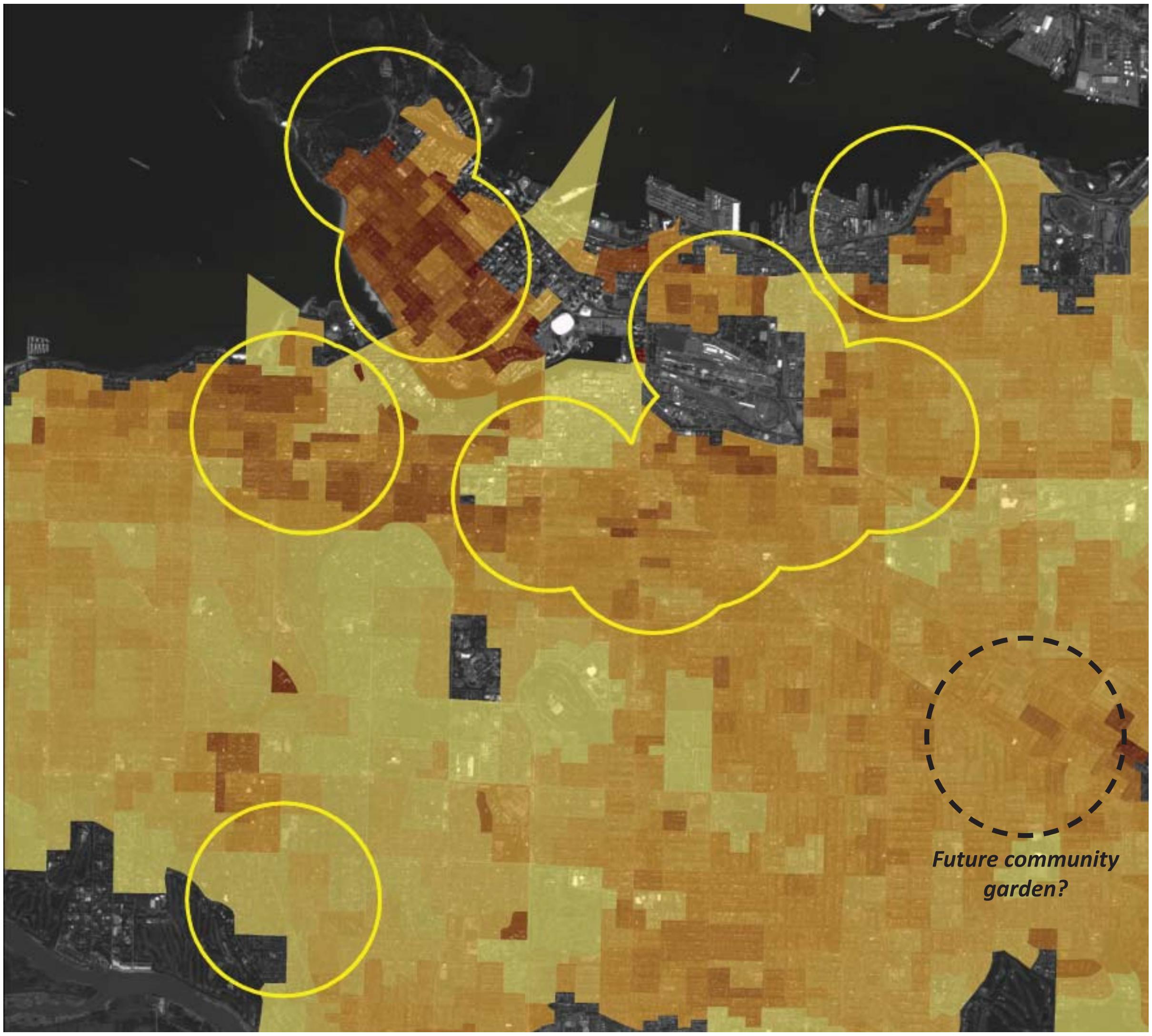


Figure (9.2). Designing for Accessibility. Population density data were sourced from Statistics Canada 2006 census (Statistics Canada, 2007) and community garden locations were identified from the City of Vancouver's VanMap (2010) (but do not represent all of Vancouver's community gardens).

Placing Urban Foodlands

Realistically, a standard 10' by 4' plot could meet 1.6 % of a person's fruit and vegetable needs[9.1] and the cumulative food producing area of community gardens in the city could meet the fruit, vegetable and grain needs of only 100 people[9.2]. However, the function of community gardens extend far past food production. They provide a place for people to learn about food, participate in community work parties and indirectly engage those who walk by and simply enjoy the sight of a socially and ecologically productive space.

Therefore, the shape and placement of community gardens should also respond to social factors. On an urban scale, planners might consider placing community gardens within walking distance of major population centres. From a cursory evaluation of known community gardens in the city of Vancouver, figure (9.2) explores what proportion of Vancouverites live within a one kilometer catchment zone of these gardens. In this assessment, 34% of the sample population lives within these catchment zones[9.3]. Future placement of community gardens should respond to the location of large population pockets (dashed circle), that might have limited access to food producing opportunities.

Figure (9.3). Placing Urban Agriculture. Placing food in an urban context requires greater attention to light access and population density than in rural contexts. Image: G. Earth, Province of British Columbia, 2010.

Climate, Light and Soil

In an urban environment, light, moisture and to a lesser extent, soil are also important considerations. The first two are influenced by adjacent structures or trees creating micro climates of sunny, or more often, shady conditions that prohibit the planting of sun-loving plants. Trees often draw up what moisture (and nutrients) are available making it difficult to meet plant needs. Cottonwoods, for example, are voracious water-loving trees that make it difficult to plant anything close by. Trees can also provide protection, raising the temperature by just enough to protect plants underneath from killing frosts, or shading intolerant leaf crops from the mid-summer sun.

Soil becomes important on disturbed sites where soils have been added, removed or polluted from adjacent land uses. Urban soils can be extremely variable in chemical, physical and biological composition. Accumulation of heavy metals are an issue on sites previously used by industry or in waste disposal (Armstrong, 2000). Soil issues are dealt with more easily in the urban context than their rural counterparts with relatively good access to composts and clean fill from city projects. For example, Cottonwood community gardens of Vancouver was able to "cap" a previously contaminated site with a sand layer that prevented possible contaminants from entering their vegetable plots. However, these soil conditioning efforts have implications on drainage characteristics. In the example above, a two-foot sand layer will likely cause adverse drying of vegetable plots necessitating more irrigation than would normally be necessary during summer months.

For this reason, site-specific soil assessments can assist choosing appropriate sites for new urban agriculture. Though the City of Vancouver has relatively detailed soil maps available through VanMap, a micro-scale assessment for contaminants and soil texture is necessary to determine the viability of sites for urban agriculture.

Placing Regional Foodlands

As most of British Columbia's food comes from large-scale farms 40 hectares or more in size (Statistics Canada, 2007b), a regional-scaled suitability analysis is critical to account for the contextual factors that affect agricultural capability, market suitability, distribution connectivity and food needs from a number of municipalities.

A survey of soils, moisture conditions and yield potential was completed by Agriculture Canada (2008) to

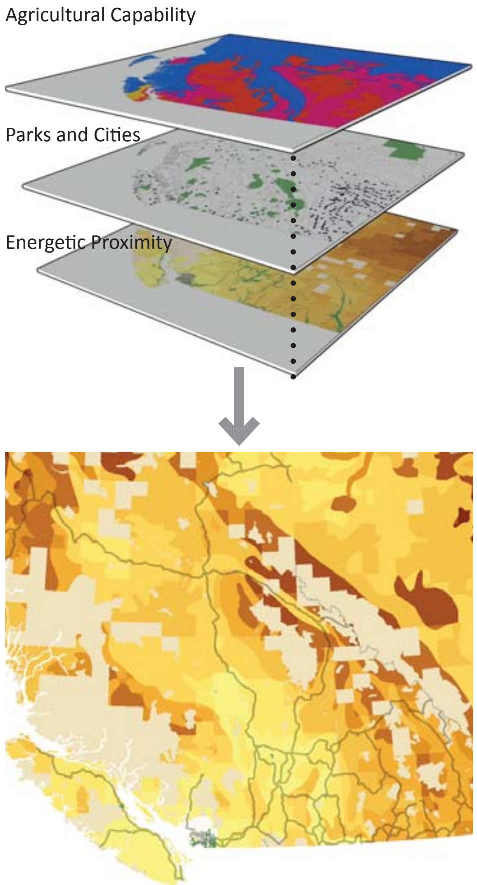


Figure (9.4). Composite Regional Suitability Analysis. This lower image represents the aggregation of agricultural climate, energetic proximity and the removal of park and city lands. Lighter yellow indicates greater suitiability for agriculture. Beige cells are excluded.

assess the agricultural potential across the country. This assessment was done at a scale of 1:5,000,000 based on data collected in the 1970s, thus only has applications at a provincial or bioregional scale without the resolution necessary for detailed agricultural decisions. Agriclimate index (AC, or agricultural capability) coarsely describes the ability of the Canadian landscape to support agriculture based on predicted forage yields, growing season length, temperature and moisture[9.4, 9.5] (see Runka, 1973). Energetic proximity represents a second factor which ranks the relative energetic distance from the grid cells discussed in section (5) to the centre of Vancouver. This index was normalized to generate a coefficient between zero and one, where zero implies *no* connectivity to Vancouver and 0.99 indicates the grid cell is close to Vancouver, relatively speaking. A third variable was introduced to prohibit placing agricultural lands on already built landscapes and parkland (PC). This third index has a value of zero for each polygon. In combination these variables indicate what parts of BC are both energetically close to the city AND appropriate for agriculture according to the following equation:

$$\boldsymbol{S = P_E \times AC \times PC}$$

$$Where:$$

$$S = Agricultural\ Suitability\ (0-1)$$

$$P_E = Energetic\ Proximity (0-1)$$

$$AC = Agricultural\ Capability\ (0-1)$$

$$PC = Parks\ and\ Cities\ (0)$$

Figure (9.4) shows an early product of this planning tool showing how areas proximal to the rail lines and along agricultural valleys are prime for agriculture while areas disconnected from major transportation corridors are excluded.

Conclusion

The Land Potential Database (LPDB) was utilized data published in the mid 1970's at a very coarse scale, and cannot account for recent changes in conditions or variations within cells. A site by site analysis is necessary to ascertain local suitability. In addition, equal weight was placed on coefficients AC and P_E implying equal importance of agricultural capability and energetic proximity. A more detailed sensitivity analysis is necessary to attribute coefficient weight to both variables and include other coefficients likely excluded from this analysis.

While the vast majority of food is grown in network of regional farms, critical instances of urban agriculture and peri-urban farms can inform a culture of sustainable food choices. Appropriate placement of farms with reference to their intended function, proximity to distribution networks or population pockets, and in consideration of soil, moisture and light access can guide sustainable foodshed design. This multi-scale approach is necessary to shape food lands that meet scale-specific functions.

Endnotes

9.1 Calculating individual fruit and vegetables needs

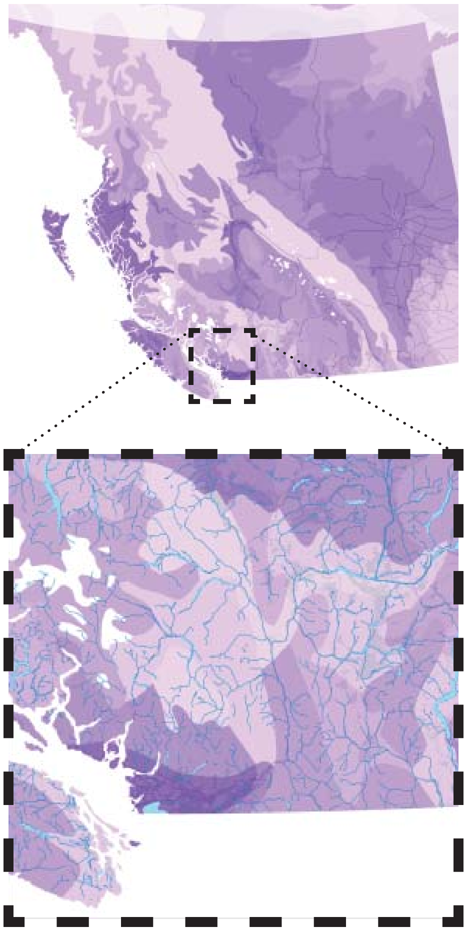


Figure (9.5). Climatic Available Moisture Use Index (CAMUI). Darker shades indicate greater soil moisture availability and holding capacity. Index based on the Land Potential Database (LPDB)

Forty square feet is roughly 3 square meters which is 1.6% of the 222 square metres required for producing the fruit and vegetables consumed by one person

9.2 Community Garden Growing Capacity

Vancouver boasts 2500 garden beds in the city (City of Vancouver, 2010). If each were 100sf (high for Vancouver), they could cumulatively meet the fruit and vegetable needs of just over 100 people or 0.02% of Vancouver's population of 578,041 based on the model developed in this report.

9.3 Community garden access

Using ArcGIS and population density statistics derived from Statistics Canada, 2006, this assessment calculated the number of people living within community garden catchment zones divided by the population of the entire sample area.

9.4 Agriclimate Resource Index (ACRI)

The Agriclimate Resource Index (ACRI) provides an approximate method for quantitatively comparing quality of the agriclimate for agriculture in different parts of Canada (Williams, 1975, Runka, 1973). It was calculated in consideration of length of growing season, temperature and moisture as they relate to forage yields.

9.5 Soil climate index

This index is part of the land potential database and represents the ratio of actual evapotranspiration to potential evapotranspiration during the growing season., determined by monitoring daily soil moisture in consideration of precipitation, evapotranspiration, soil water holding capacity and runoff. It indicates areas that are appropriate for agriculture with reference to moisture availability and holding capacity (figure 9.5)

Note that the source for the LPDB was taken at a coarse scale (1:5,000,000) and misrepresents differences in soil texture that occur at local scales. (Stewart, 1981, Agriculture Canada, 2008, Canada Land Inventory, 1972)

10 Shaping Foodlands

As urban populations now exceed rural populations for the first time in human history, the question of urban form takes precedent in regional decision making. Since planning decision today will have implications that may outlast contemporary energy systems it is important to understand key drivers for sustainable urban form.

It is implicit throughout this report that urban form should respond to the dynamics of the food system. This section will explore this relationship drawing upon city forms proposed by Ebenezer Howard, Peter Calthorpe and Kevin Lynch. Large-scale regional forms will be refined to farm scale typologies, informing the design of wildlands and foodlands in British Columbia.

An early city planner, Ebenezer Howard (1898) developed the garden city concept, responding to a need for local food self-sufficiency through integration of food land into the fabric of the region (figure 10.1). His early drawings called for cities to occupy roughly 1000 acres, surrounded by 5000 acres of agricultural land, and hold a population of 32,000 (Howard, 1898 in LeGates and Stout (ed) 1996). This amounts to 0.14 to 0.16 acres (0.064ha) of agricultural land per person, much less than the 1.65 acres 0.67 ha cap^{-1} assessed by Statistics Canada survey of Agricultural lands in 2006[10.1] and less than 0.68 ha cap^{-1} recommended in this report. Arguably Howard was relying upon agricultural land from external sources.

Urban form in developing countries can yield important clues into city design that must be energy efficient out of necessity. While China has radically changed in the last 20 years, Girardet (1992, p 162) asserted how most of China's largest cities have allotted sufficient land (60-80% of the total city area) to make the cities population largely food self-sufficient. This evidence must be taken with a grain of salt since many developing countries are sufficient in fruit and vegetables but receive grain donations from the World Food program, supported from donors countries such as Canada. China and Cuba, while actively engaged in Urban Agriculture, are consistent recipients of cereal donations (FaoStat, 2009b). European cities that developed before the industrial revolution provide other insights into sustainable urban form. Their relatively autonomous and compact form support

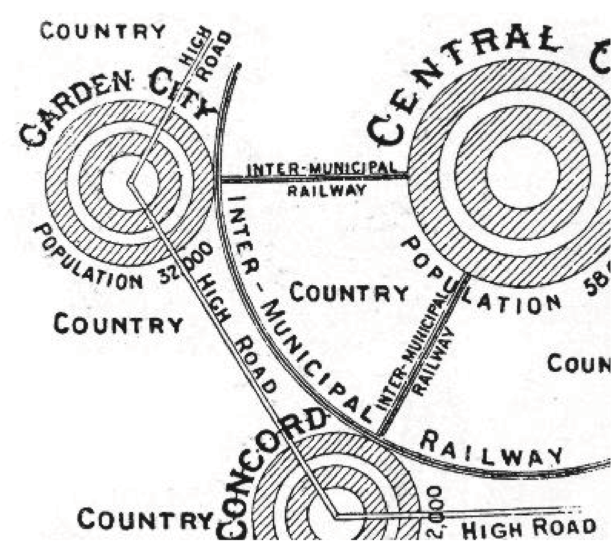


Figure (10.1). Garden City. Howards vision of a garden city as (Howard (1898) in LeGates and Stout (ed), 1996).

walkable communities balancing the need for transit efficiency and urban amenity with access to available foodlands and open space. Greenbelts that surround communities, and a highly efficient rail network in the UK reflect a contemporary evolution of this form.

Optimal Regional Size

Several large North American cities have recently questioned the potential of urban agriculture to feed cities and are worth critiquing. City radius (r_c), Foodprint radius (r_f) and Foodprint radial difference (r_d - the difference between city radius and foodprint radius) were be used to compare foodprint dynamics of cities and regions. As seen in figure (10.2) and appendix (15.3), there is an interesting intercourse between *city size*, *population* and the resulting *foodprint*. Detroit, for example has a population of almost a million, but a large land base resulting in a much less radial foodprint difference (r_d) in comparison with Manhattan which shows a rather extreme radial foodprint difference[10.2]. Metro Vancouver is an interesting case which diagrammatically performs well with a lesser radial foodprint difference (r_d) than Manhattan or Detriot, but the city of Duncan on Vancouver Island performs the best with a foodprint radius (r_f) one 20th that of Metro Vancouver at 3.2km and a radial foodprint difference one fifteenth the length of Metro Vancouver's.[10.3] Even with liberal land estimates, the *foodprint* of cities assessed far exceeded the land area of the cities themselves.

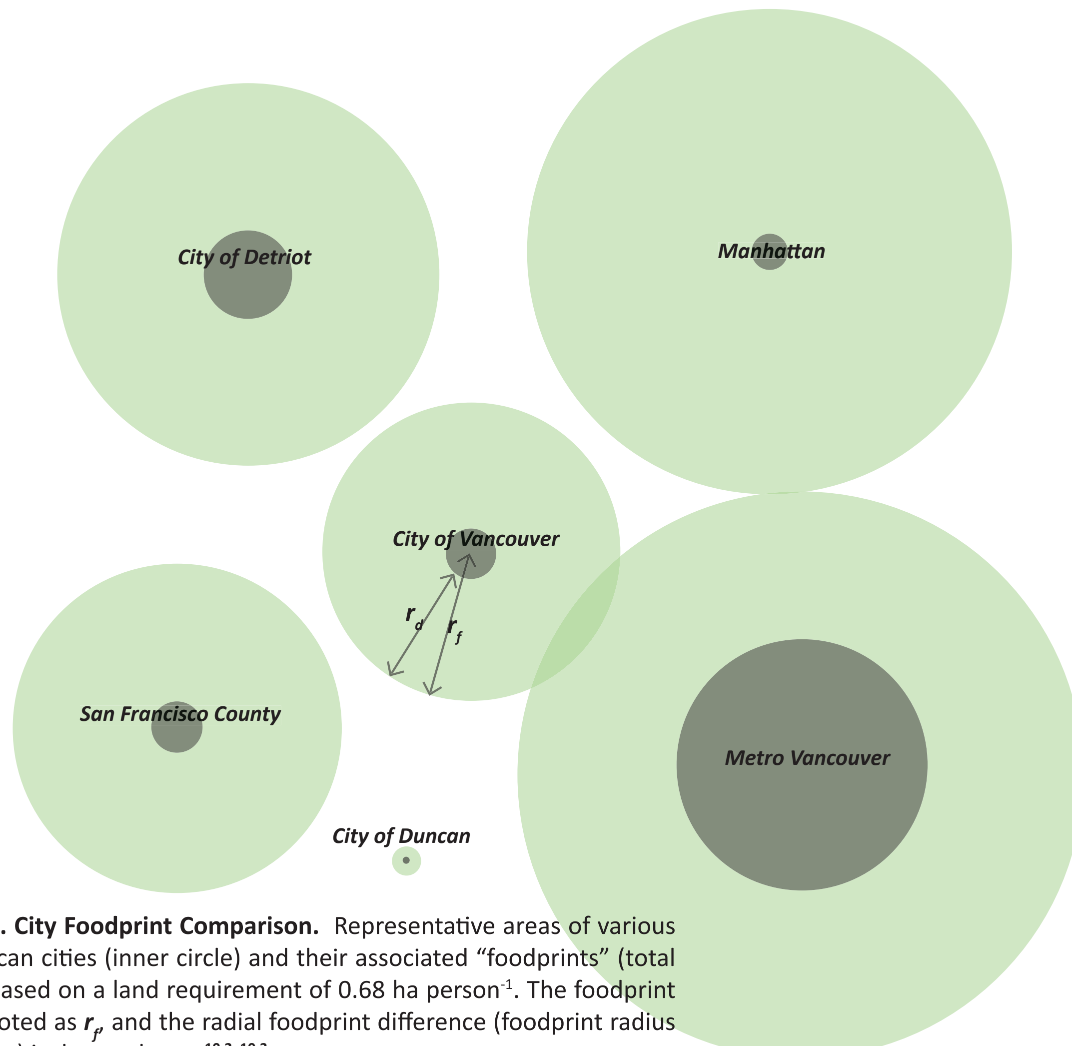


Figure (10.2). City Foodprint Comparison. Representative areas of various North American cities (inner circle) and their associated "foodprints" (total circle area) based on a land requirement of 0.68 ha person^{-1}. The foodprint radius is denoted as r_f, and the radial foodprint difference (foodprint radius less city radius) is denoted as r_d.[10.2, 10.3]

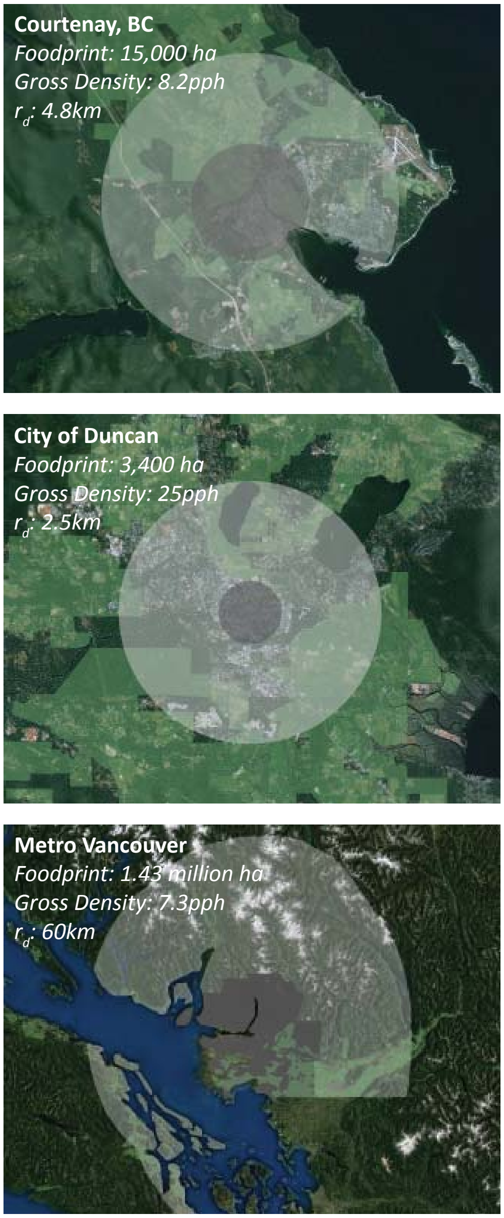


Figure (10.3) Conceptual Gross Foodprints for Courtnay, Duncan and Vancouver. Radial differences (r_d) are measured in ArcGIS. Adapted from images available from ESRI Canada.

Assuming city lands are *not* accessible for meaningful agriculture, and *all* land area is available for agriculture immediately outside each city or region Courtenay, Duncan and Greater Vancouver have radial foodprint differences of 4.8km, 2.5km, and 60km respectively [10.3]. This model does not account for macro-circulation or adjacent land use and thus not a realistic planning tool, but does better highlight the relationship between population density, city size, and local topography. Radial foodprint difference (r_d) might become an important indicator if the food system necessitates the human-powered approach to agriculture discussed in section (8), scenario #5. Currently 1.52% of the workforce or 0.82% of the total population of BC is engaged in farming (Statistics BC, 2010). If this proportion were to return to values characteristic of pre-industrial labour society (48% of the working population or 16% of the total population in the late 1800's [10.4], where might these farmers live? Section (5) illustrated the energetic issues embeded in the daily commute - a practise society currently takes for granted. Farmers would be energetically limited to short commutes to preserve the food energy balance, ruling out large regional districts like Vancouver.[10.5] Small cities such as Courtenay and Duncan allow for more resilient farmer transport with a labour force placed within a reasonable distance of available farm land.

In reality, no city, or even region, operates independently from the context of the province or state. Vancouver shares a foodshed with Victoria, Whistler, Seattle, and all the municipalities that make up the bioregion. In addition, unless positioned in the centre of ripe agricultural land, there is no possibility that a perfectly circular area with no circulation easements will be available for agricultural use. A more wholistic approach is necessary to shape agricultural lands for the region *and* bioregion.

Optimal Regional Shape

Greater Vancouver's projected population of 3.1 million people in 2050 will need a foodshed roughly 2.1million ha in size to meet 2006 dietary habits. If *every* available surface were used to grow food, 17 % of the population could be fed, assuming a foodshed of 0.68ha per capita [10.6]. This *gross* regional retrofit is unlikely and production capacity inadequate to meet food needs. *Urban agricultural retrofits will be unable to meet the food needs of the modern mega city.* A more creative approach is required to *shape* the role of city and country in food production

Given the growing conditions for grains are arguably more appropriate in Eastern BC and the Southern Interior supports a strong fruit crop, it is important to consider the implications of a foodshed that is *shaped* according to climate, soil, and proximity factors. In this regard, if 30% of private and park land area was dedicated to food production in the city, it could technically support 18% of its fruit and vegetable needs, ignoring land required for parcel-specific circulation or nutrient cycling [10.7]. Local ALR lands (within Metro Vancouver) could support 35% of the total fruit and vegetable needs of the region leaving production of 47% of fruit and vegetable production, animal products and grains to the larger bioregion (figure 10.4). The first of these assumptions is a tremendous ask and unlikely for all but the seasoned urban farmer. A standard Vancouver lot of 40m by 15m, with a building of 12m by 15m leaves only 60% of the land area

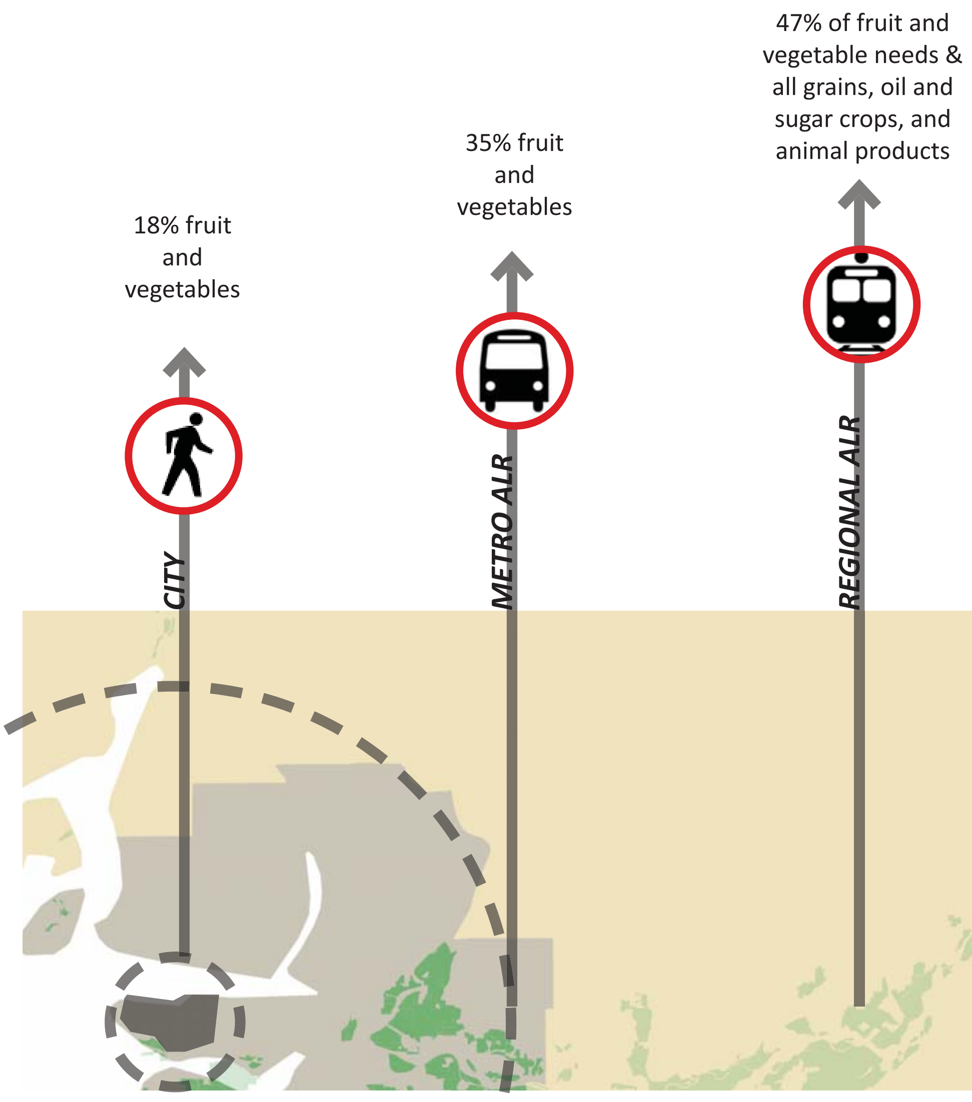


Figure (10.4) Feeding the Region. Regional Foodland shape should be informed by market and agricultural capability, and the potential for selected crops to engage the city through urban agriculture. Foodshed analysis based on Statistics Canada (2010) and modelled foodprint requirements.

available for such purposes. With shading effects, circulation, and other urban functions, it would be nearly impossible to retrofit 30% of private and public land area with urban agriculture.

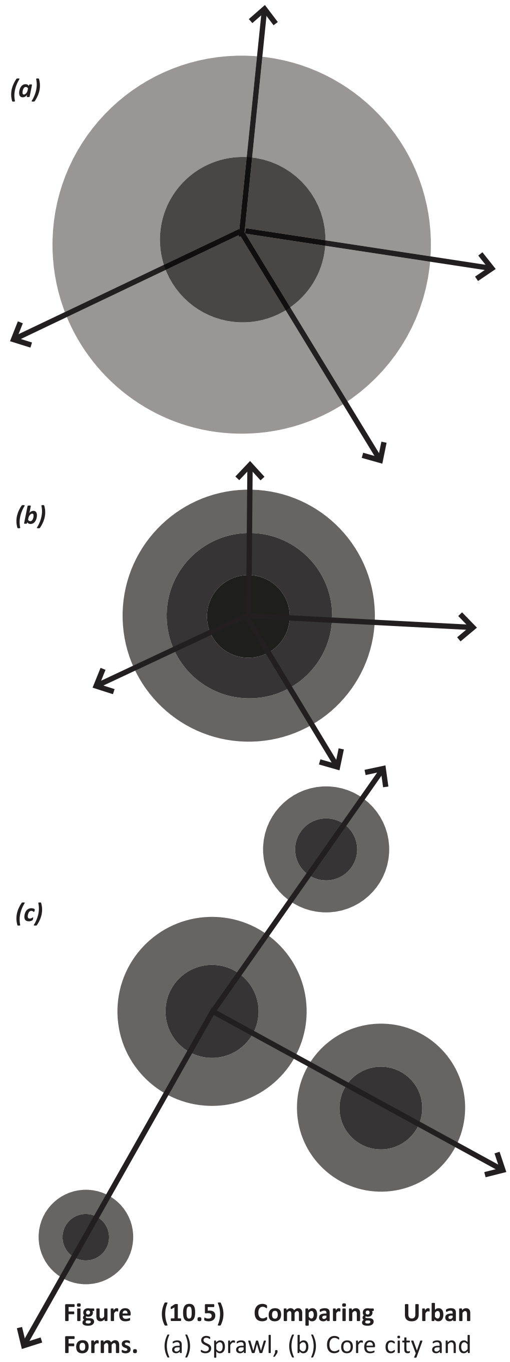


Figure (10.5) Comparing Urban Forms. (a) Sprawl, (b) Core city and (c) Distributed citiy network. Adapated from Frey (1999) p 28.

Though cities cannot on their own meet food needs, there are important qualitative forms that can support a culture of sustainable food choices. Based on city-centric indicators, Frey (1999) favoured a distributed regional network of compact cities (10.5c) over suburban sprawl (10.5a) or core city (10.5b) for its accessibility to open country, support for a sense of place, ratio of population to land required, and viability for public transport (Frey, 1999, p 66). In comparing city typologies, Frey(1999) suggested observing transport distance, length of open land fingers, and maximum distance from city to open land (r_c). The core city performed the best for compactness, but did not beat out the decentralized regional city in proximity to open land.

While immediately criticized by new urbanists and farmers alike, the suburb (figure 10.4a) does have its benefits. The compact city conserves the greatest amount of space for farmland but tends to spatially disconnect farm from city with little growing area in the city itself, whereas the suburb provides some opportunity for agriculture in backyard gardens. The decentralized regional city (10.5c) may be the greatest of the three, maintaining the transport related benefits of urban dwelling, but maximizing the edge where farm and city meet. This form is becoming more prevalent across Canada and is adopted by regions such as the Greater Toronto Area, Greater Winnipeg and is manifest in Greater Vancouver's Regional Growth Strategy (2009). In it they acknowledge of the potential synergies among distinct municipalities avoiding simple annexation of smaller townships. This wholistic perspective, while riddled with bureaucratic challenges, can take into account the needs of the country and city, and embrace the regional city models embedded in Howard and Calthorpe's work. Relevant components of the regional growth strategy include:

(Strategy 1.1) Contain urban development within the Urban Containment Boundary.;
(Strategy 1.2) Focus growth in Urban Centres and Frequent Transit Development Corridors;
(Strategy 1.3) Protect the region's rural lands from urban development.
(Strategy 2.3)Protect the region's supply of agricultural land and promote agricultural viability with an

emphasis on food production.

(Strategy 3.1)Protect the lands within the Conservation and Recreation areas.

(Strategy 3.2) Protect and enhance natural features and connectivity throughout the region.

These strategies highlight the importance of planning for homes, jobs *and* agriculture to achieve a sustainable region and speak to the qualities of appropriate regional size and shape. Operationally they imply increased density in urban cores and a properly contained urban footprint. Surrey, for example, is set to experience more growth than Vancouver's metropolitan core over the next thirty years, becoming a centre unto itself rather than a bedroom community for Vancouver (Metro Vancouver Board, 2009, p17). Urban containment boundaries aim to limit growth to currently developed regions and preserve farm and wildlands (Ibid, p27 to 35). Connectivity is important for both natural areas and agriculture to support flows of wildlife or food throughout the region and into cities. This rural-urban interface is particularly important for reasons briefly discussed in section (6) to support a culture of sustainable food choices and takes the form of backyard and community gardens, food-producing street trees and regional farms.

Figure (10.6) Agricultural Regionalism. Without a vision of the region and the city, agriculture cannot function sustainably. Agricultural Regionalism can serve to focus attention on the region and its relationship with the city. Adapted from HBLanarc's "Agricultural Urbanism" (HBLanarc, 2009)

The transition from country to city requires a hardening of the agricultural edge with appropriate buffers (hedges, raised planters) to increase the community access required for urban agriculture. Conversely, the city should soften where entering the countryside to maintain the integrity of the agricultural landscape (figure 10.6). The latter can be accomplished with pervious surfaces to support water infiltration and to minimize heavy surface flows; appropriate buffers and barriers to manage nutrient discharge to or from agricultural landscapes and to prohibit trespassing where appropriate; and design cues that encourage appropriate community assess.

The Shape of Living Systems

To shape sustainable cities and farmlands, it is helpful to observe the shape and rhythm of natural living systems for inspiration.

The way a wound heals, a forest re-grows, or a community comes together when faced with challenge exemplifies regenerative systems. Living "regenerative" systems are resilient to environmental stresses, dynamically responding to change. Living Systems Theory was developed by James Miller (1978) as a

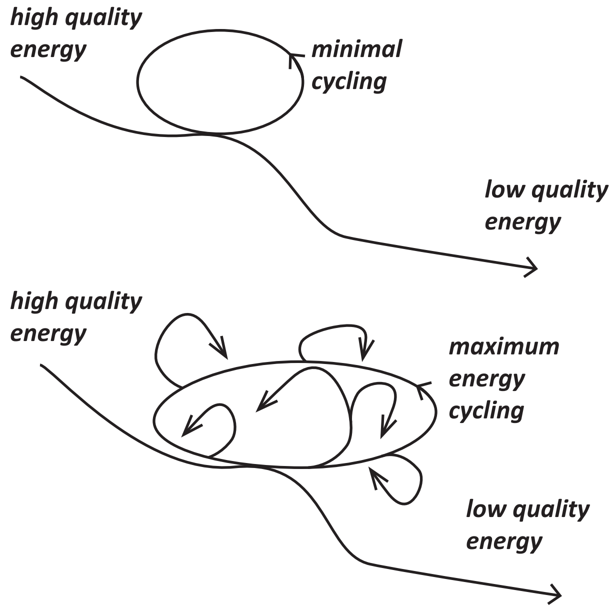


Figure (10.7). Energy Dynamics of (a) "Simple" and (b) "Living" Systems. Simple systems rapidly transform energy from one form to another with limited sub cycles in place to store or recycle energy. Combustion is a relatively simple chemical process yielding water, carbon dioxide and heat energy from the oxidation of a hydrocarbon. This simplifed this process is:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + heat energy

Combustion is chemically very similar to cellular respiration, but the *rate of energy transformation* from a high quality (chemical) to a low quality (heat) is rapid, and spatially homogeneous, leaving lesser opportunity to catch and store the energy for use. The spatial & temporal compartmentalization of cellular respiration enables maximum cycling of energy within the system. Adapted from Ho and Ulanowicz (2005) p 43.

sub branch of General Systems Theory. Miller (1973, 1978) identified eight "nested" hierarchical "levels" following the cell with organ, organism, group, organization, community, society, and supranational system, each of which have spatial, energetic and temporal characteristics important for each level.

While it may appear difficult to apply these qualities to regional design, in their paper entitled "Sustainable systems as organisms" , Ho and Ulanowicz (2005) identified some key energetic and spatial characteristics of living systems that have application in foodshed design. Their capacity to capture, store and efficiently cycle energy is a key characteristic of living systems. Simple "non-living" systems incur rapid transformation of energy from high to low quality (10.7a). In contrast, "living systems" are able to cycle energy, minimizing dissipation and maximizing system efficiency. In this context, high "quality" energy is that which can be readily stored or used for a variety of purposes (10.7b). In the body, tissues store energy in the form of glucose or fat for use when needed in a processes where the glucose is broken down into more simple forms that support nervous system functioning, muscular contractions, digestive enzyme production, and a host of other essential processes characteristic to life. Energy is eventually transformed into heat and lost to the environment, but not before supporting many life functions in the process. Despite some literature to the contrary, living systems do not cheat entropy, they just slow it down, maximizing the amount of useful work energy can do in the process. Arguably, modern industrial society does a good job of simplifying energy tranformation processes through the combustion of fossil fuels which through direct heating and indirect contributions of greenhouse gases, has led to global climate change.

The essential spatial forms that characterize living systems is *spatial* and *temporal* heterogeneity. Spatial heterogeneity is the compartmentalization of processes so that the product (heat energy, chemical energy, etc.) can be siphoned off for storage or use elsewhere in the system. The compartmentalization of organelles inside cells inside organs inside organ systems inside organisms provides a system of nested systems designed to efficiently capture, store and transform energy, minimizing dissipation through the process. On a broader scale, organisms fit into populations inside communities inside ecosystems in a system of individuals working together to maximize system efficiency.

Temporal heterogeneity infers the juxtaposition of processes with different "life histories" working together. Where life history refers to the *rate* of energy transformation, a diversity of nested "life histories" enable capture and storage of energy at a controlled rate. In living systems larger spatial scales often accompany phenomena with longer life histories (figure10.8) (Miller, 1972, 1978).

Ho and Ulanowicz (2005) argued that agricultural, economic and social systems that are ***spatially and temporally heterogeneous and reflect the spacio-temporal characteristics of living systems are more resilient.*** In an agricultural context, this is important for the nested placement of short season food crops, perennial fruit trees, woodlots and wildlands. With this in mind, both large scale regional farms *and* urban agriculture have roles in supporting a resilient food system. Large scale farms can take generations to build the market relationships and soil integrity to be viable where small scale agriculture or community garden plots require less investment over a shorter time span and for a reduced yield. Together, they occupy a diversity of scales characterized by living system and are required in combination to meet the sociocultural and food needs of a region.

Shaping Wildlands

Wildlife are integral to ecosystem services, discussed briefly in section (3). The size and shape of wildland set-asides determine what species can cohabit the space according to their habitat needs.

Van Burkirk and Willi, (2004) suggested striving for *landscape heterogeneity* (between farm), *farm heterogeneity* (between field) and *field heterogeneity* (between row) to support greater species diversity in farming ecosystems. They called for placing a farm within a network of park lands and wild spaces to improve the connectivity and function of wild spaces; using hedgerows (figure 10.8), irrigation ditches, field margins and set asides to improve inter-field wildlife value; and using inter cropping, crop rotations introduction of beneficial to create a vertical and horizontal heterogeneity within a field (Ibid).

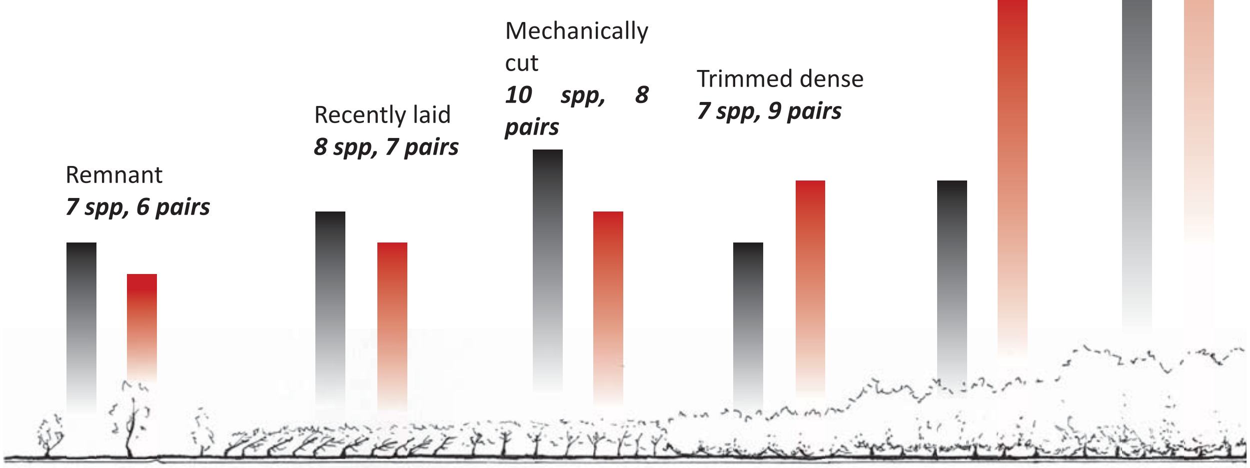


Figure (10.8). The Shape of Wild - Hedgerows. Tree height, age and hedge width support more bird species (in number of bird species).[10.8]

The Rhythm of Wild:

There is a hierarchical relationship between phenomena that occur at small and large scales (figure 10.9). Municipalities and even regions are poorly aligned to deal with large scale phenomena that impact the functioning of small scale ecosystems. The jurisdiction of municipal or provincial governments simply don't account for transcontinental migration or microbial reproduction. Given the maximum four year mandate of most governments, spatially-oriented failures are reflected in temporal scales. While humanity seems to understand processes that occur within yearly life-cycles (migration), processes that last shorter (pollination) or longer (evolution) seem hard to comprehend and even harder to plan for. To design for sustainable wildlands, designers should plan for the 1 yr, 10 yr, 100 yr and 1000 year cycles inherent in natural systems. Some parks in New Zealand, for example, have adopted 500 yr growth plans that facilitate healthy succession and evolution of the park system.

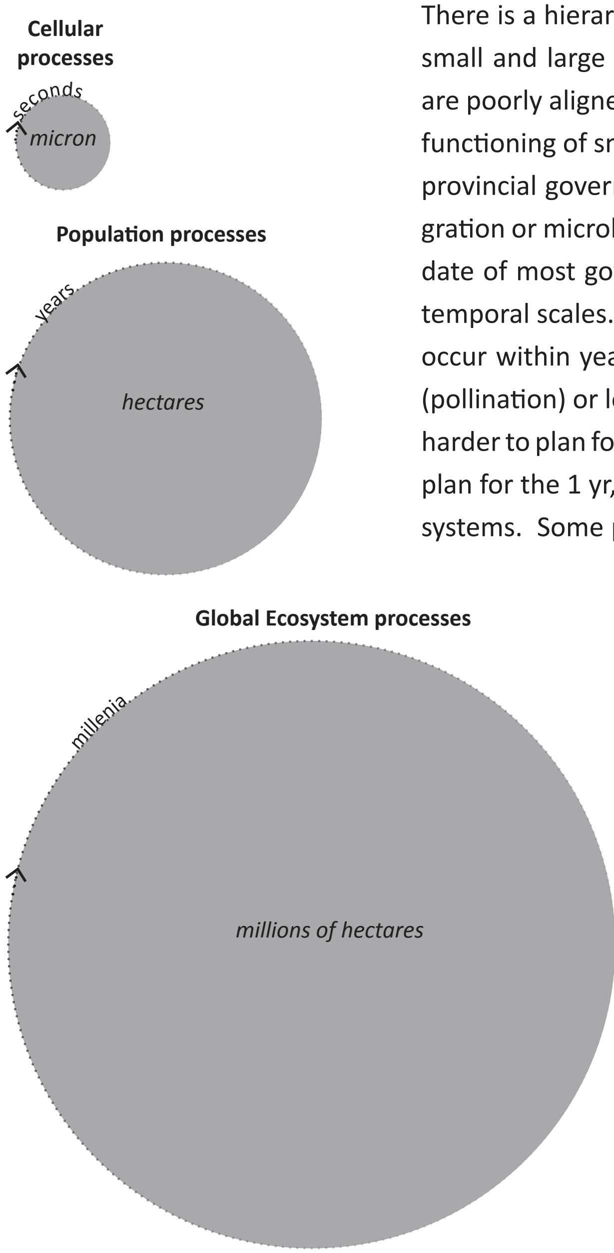


Figure (10.9). Space and Time in Living Systems.

Optimal Design Strategies:

The performance of ecological functions depends on the size, shape, regional context of wildlands. Design strategies must therefore respond to regional conservation and ecological goals. In other words to ascertain optimal wildland configuration, designers must first ask which species and landscape form is most important to protect.

Margules, Pressey (2000) formatted a valuable planning tool that prompts designers to consider wildlife spaces that protect species under the greatest threat *and* have the highest ecological function. While there are surely many other layers to consider, this multidimensional approach to optimizing land use function is a good start to making choices that benefit humanity *and* nature.

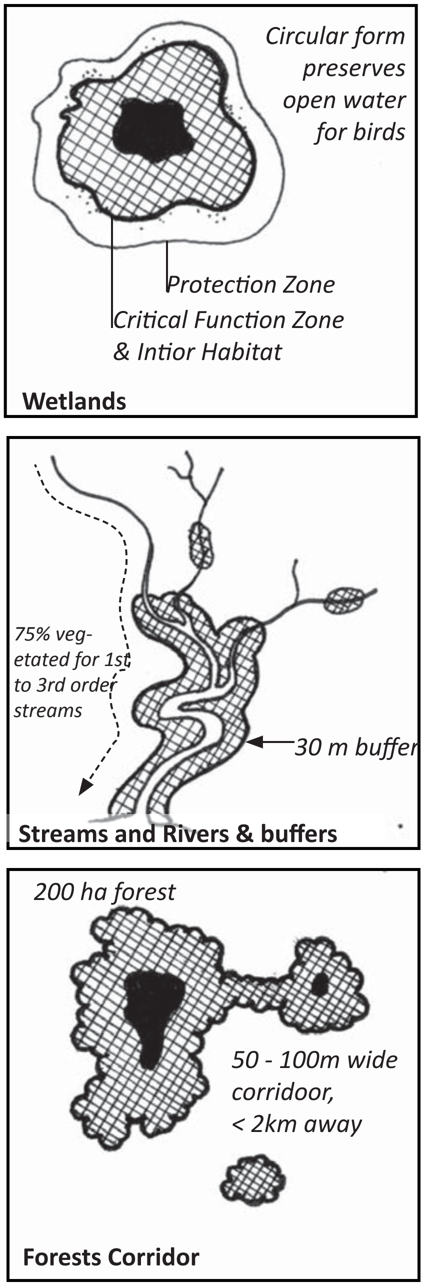


Figure (10.10). Wildland typologies.
Adapted from Environment Canada, 2004.

Wildland Taxonomy:
Figure (10.10) Illustrate various typologies appropriate for wildland design of forested, wetland, and streams systems.

The implementation of these patterns should reflect local context and ecological goals (Margules and Pressy, 2000). For instance, a 30m buffer around drainage ditch in the context of a low intensity farming system (grains) is less necessary than if that stream were salmon bearing adjacent high input farming. Fish bearing streams necessitate the micro climate and nutrient cleansing functions of a wide riparian buffer. Using biological means, one can trap nutrients (cattails, water milfoil) and manage duckweed (Talapia or Carp), and also serve as food or nutrient sources. If the desired function of the wetland is for storm water management or nutrient cleansing it would benefit from a greater edge to area ratio typified by wetlands with longitudinal undulating patterns, not circular ones. From a regional perspective, a network of riparian habitat provided by connected ponds, irrigation ditches and riparian buffers is an important ecosystem that supports biodiversity of the region. (Andrews and Rebane, 1994)

Hedgerows can act as perennial foraging systems or food forests, providing a diversity of wildlife and food services and creating sheltered micro climates for adjacent cropland. The use of diverse hedgerow plants & trees, and aquatic vegetation can provide fantastic habitat for avian, terrestrial and aquatic life. Maintaining a three to four meter buffer strip of unsprayed vegetation will support populations of beneficial species including bees, spiders and game birds.

Shaping Foodlands

The principles of heterogeneity and connectivity that drive wildland design are just as important for designing sustainable foodlands. Crops with shorter life histories (salad greens or cucumbers) might have lesser areas relative long cycle crops such as perennial fruit trees or woodlot products. Annual crop rotation cycles can nest within larger ecological processes such as soil building. Areas dedicated to annual crops can be replaced with perennial fruit trees followed with woodlots in a cycle that can meet the food and ecological needs of the community (figure 10.11). Traditional swidden agriculture and hunter-gather societies recognized these cycles, leaving significant portions of the landscape to regenerate (Pimentel, 1996). Agri-

Figure (10.11). Relative Size and Timing of Mixed Farm Units.

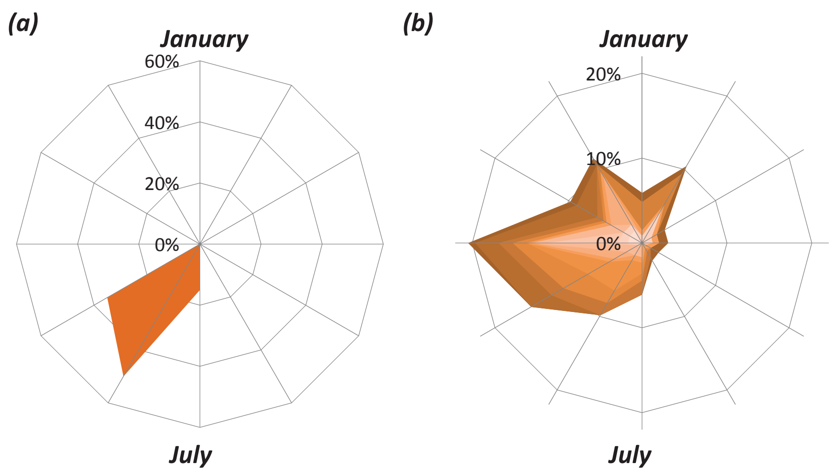


Figure (10.12). Relative Income schedule for sweet corn production (a) and Mixed farm (b) systems. Incomes were adapted from BCMAL planning worksheets for a hypothetical mixed farm and for Sweet corn, Fraser Valley, 2001.

culture in developing countries respond to this pattern dedicating the majority of annual cropping area to long-season cereals (FaoStat, 2009). Reconfiguring dietary habits and regional form to reflect these cycles through permaculture practise and investing more in perennial crops could improve the efficiency and health of the food system.

There are also economic advantages to mixed farming systems which increase resilience against market or yield fluctuations, and provide a more consistent income source throughout the year (figure 10.12a and b). Though the timing of income differs, the total ***relative*** income for both scenarios is the same at 100%. Diverse cropping and animal systems can often meet nutrient needs on-site, reducing the need for external inputs. This can be applied to the use of manures for fertilizing soils, but extended to the rotating nitrogen fixers with light feeders and heavy nitrogen users or inter cropping these plant types in adjacent rows. Relative placement of "companion plants" can help attract pollinators (alfalfa for bees), encourage predatory insects (Dill for ladybugs) or ward of nematodes (marigolds) (USDA, 2008).

Before the introduction of the steam plow, an acre was originally conceived as the area of land one man and two oxen can plow in a day[10.9], or the area of grass that one man can scythe in a day (figure 10.13). Spatially, it was defined as one furlong (furrow long) in length by four rods in width. A furrow is the raised section of earth made with the pass of a plow and was 220 yards in length. A rod was equal to 5.5 yards or one chain, and anecdotally may have been the length of an ox goad, a long pole used to urge on reluc-

Figure (10.13) The Time of Space. Originally an acre of land was defined as the amount of land a man can scythe over a day. Space was defined not objectively, but in direct reference to the human experience.

tant oxen. This is roughly 200 m long by 20 m wide - a long and narrow agricultural section that minimized the amount of turning a team of oxen would need to do at the end of the furrow. Early definitions of an acre were roughly the same across Europe since the relationship between humans with the landscape with support of animal power was roughly the same. It is likely that Asian societies had slightly different definitions of space reflecting their rice-based grain diet contrasting wheat-based diets of western society.

Contemporary land use patterns reflect this preindustrial form where typical blocks in Vancouver are almost exactly 660 yards by 88 yards, or 4 acres, and arranged in an east west direction (figure 10.14). A row of 17 single family houses make up exactly two acres. Who would have guessed that the shape of neighborhoods in the 21st century is informed by the turning radius of a team of oxen. With this in mind, the size, shape and rhythm of food spaces should respond to the dimensions of a human being, and the ecology of living farming systems. The images and precedents which follow will explore this relationship (Figure 10.15 - 10.26)

Figure (10.14). Application of Agricultural Form to Contemporary Landuse Patterns. An acre was traditionally defined as 220 yards by 22 yards. Many of Vancouver's neighbourhoods reflect this traditional landuse form. Image: Tele Atlas 2010

The shape of food producing spaces must respond to the shape of a human being (figure 10.15, 10.16). A 2' reach necessitates beds not wider than 4' so they can be accessed from either side. Humans stand 5' tall with reach up to 7 or 8' tall, requiring ladders for tree crops taller than this height. Traditional Apple trees led to many pruning and harvesting related injuries and produce less fruit per unit area, a driving force behind shorter dwarf or espalier orchard trees in contemporary fruit production.

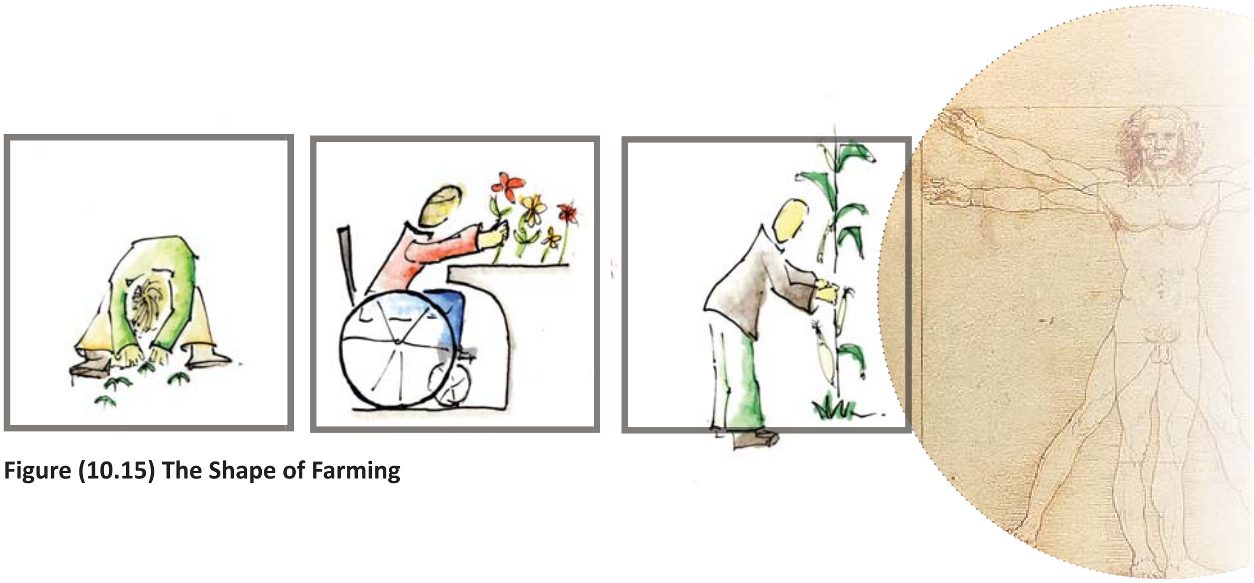


Figure (10.15) The Shape of Farming

Figure (10.16) The Shape of Food lands. The following are relative areas for vegetable, grain, animal and wildland land designations. Areas adapted from Environment Canada (2004), modelled land requirements and personal experience.

Vegetable land Shape:

The spatial layout of vegetable plots (figure 10.17) depend on the agreed upon function of the farm. As discussed in section (3) the rate of productivity (kg ha^{-1}) conceptually decreases with increasing community access. One-foot pathways are typical of high intensity vegetable producers and leave little room for error when treading through the cucumbers. Larger two to four foot path or lane ways should be considered for community oriented agriculture. If pathways are to be planted in grasses, designers should consider the width of a standard mower, planning for two passes of a mower or five foot pathways.

The ultimate size of the vegetable block should be considerate of inter-farm rotations (vegetables -> animals -> grains), and intra-vegetable rotations (heavy givers -> heavy feeders -> light feeders). In this regard, the block of heavy givers should be the same size of heavy feeders and light feeders.

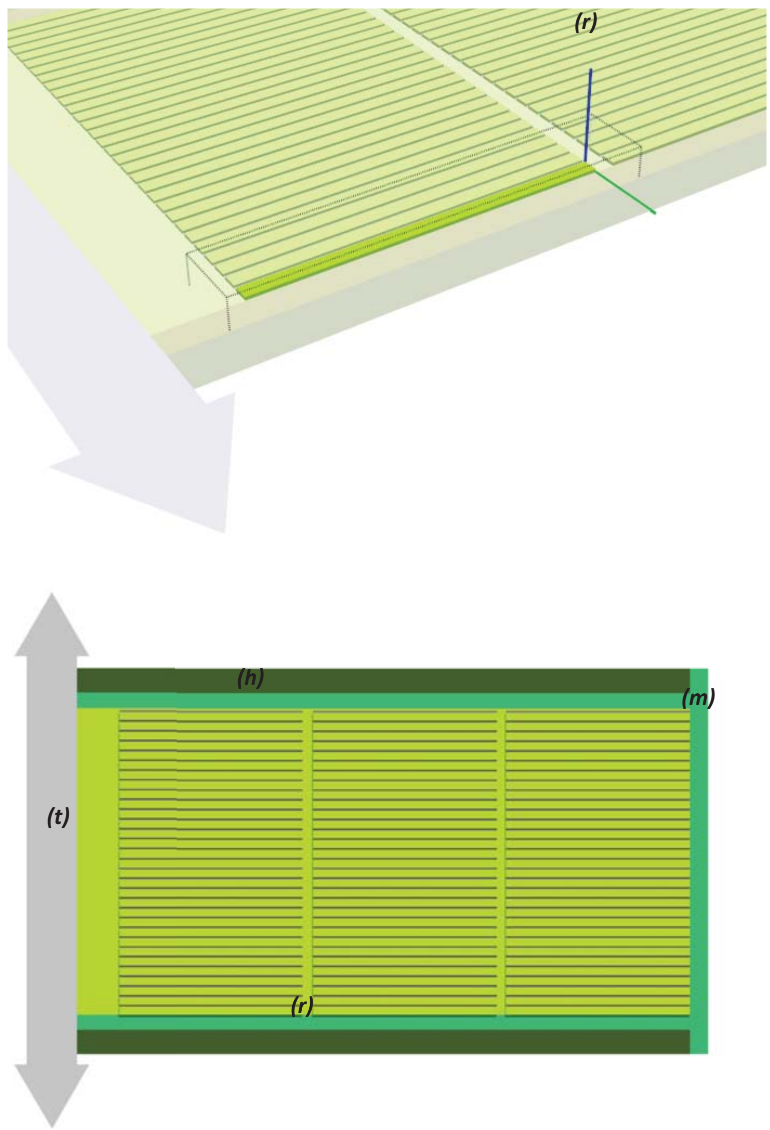


Figure (10.17). Vegetable Field Units. Composed of 4'(1.3m) X 100' (30m) rows *(r)* with 1' (0.3m) pathways, surrounded by 3m field margin *(m)* and bounded with 4m hedgerows.*(h)*. An 8 m tractor lane *(t)* connects the space to the rest of the farm. A small greenhouse can assist in vegetable starts. A vegetable patch of 1/2 ha could conceivably meet the vegetable needs of 46 people based on modelled dietary habits and production patterns.

Fruit land Shape:

Modern orchards favour smaller trees more closely spaced for ease of management, safety and productivity. Significantly higher yields can be achieved with high stem densities and espalier planting. Smaller trees typically require replacement sooner than larger trees incurring a higher indirect expense with this planting schedule. There are also implications to soil and wildlife communities traditionally dependent on perennial ecosystems.

Farmers may also consider how to inter-plant vegetable crops along lane ways to take advantage of the micro climates generated by short or large canopy trees (figure 10.18). Alternatively, a cover crop of hairy vetch and clover can contribute a valuable nitrogen supply to adjacent tree roots and maintain accessibility to labourers. Melon and Watermelon clearly belong in an annual rotation and typically need larger plant spacing, often sprawling well into lane and pathways.

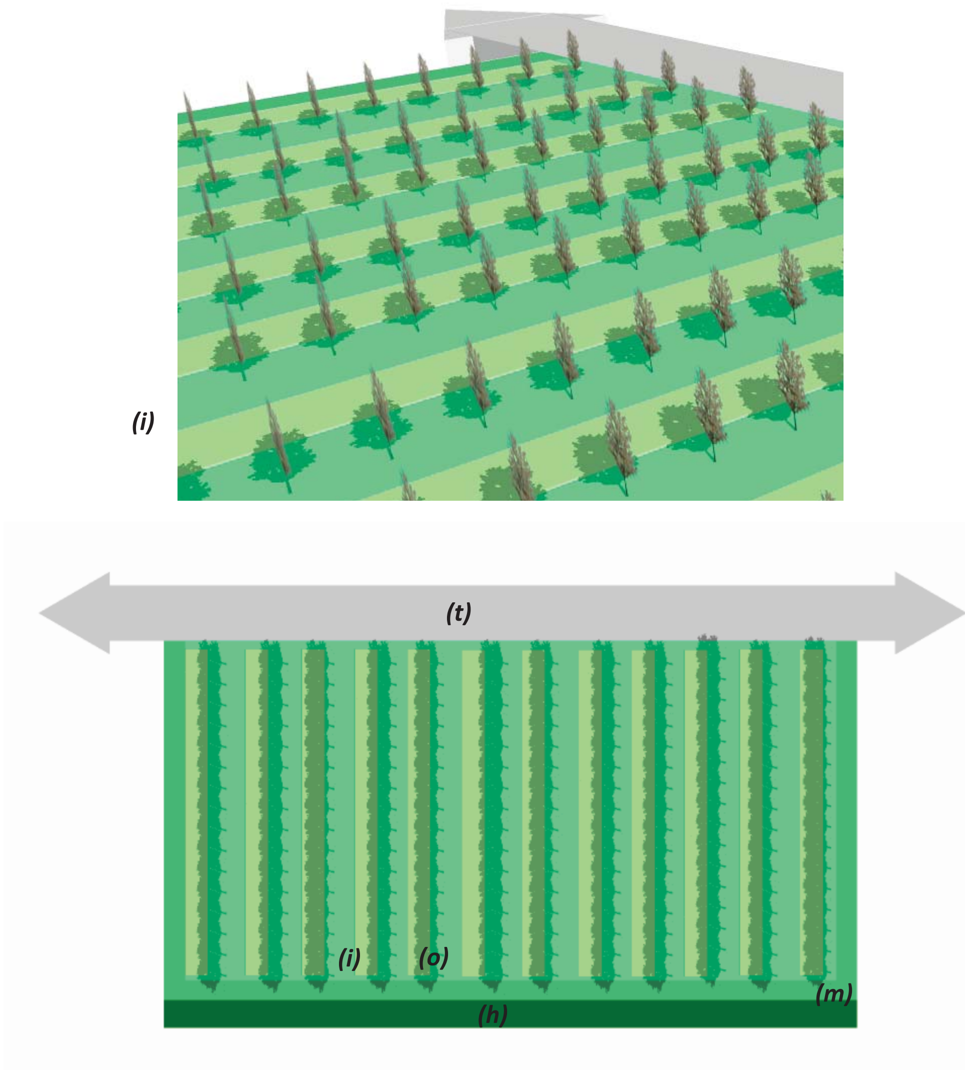


Figure (10.18). Orchard Field Units. Composed of 12 X 30m rows of dwarf to standard orchard trees (o) spaced 3m on centre with 9m between rows allowing for inter cropping or cover cropping strips (i) between the rows of 3.5m each. This configuration takes advantage of the micro climates of an orchard environment. A 3m field margin *(m)* and 4m hedgerow *(h)* buffers any nutrient discharge and an 8 m tractor lane *(t)* services the field. A 0.5 ha fruit patch could meet the fruit needs of 43 people based on modelled production and consumption patterns.

Animal land Shape:
For both disease management purposes and to increase grazing efficiency, it is helpful to rotate animals through a number of paddocks. Increasing the number of paddocks in a field helps to ensure grasses are grazed effectively and given sufficient time for regrowth (figure 10.19) (Ekarius, 1999). For example, 10 animals on one acre of land with only one paddock will more selectively graze a pasture leaving weed species to flourish, while those same 10 animals will intensively graze all species on 1/4 acre leaving the other three paddocks to regenerate plant material, recover from soil compaction, and adsorb nutrients excreted by the animals. From a disease management perspective, poultry will get parasites if kept in the same shelter, thus require rotation through paddocks and shelters throughout the year.

Rotating animals through old berry fruit or vegetable crops can take advantage of the cultivation that animals will do free of charge following a harvest. Alfalfa is a common pasture grass that can also be harvested for hay if excess paddocks are available. Where multiple rotations of animals cycle through a field, the effective pasture requirement is calculated, dividing the pasture requirement per animal by the number of animal cycles in a year. For example, 4.5 cycles of broiler chickens can be cycled through a farm in a year reducing the pasture requirement per animal from ten square meters per bird to animal to 2.2 square metres per bird. Gross yields below represents the carcass weight for each animal which is generally significantly higher than the retail or consumed weight. Wastage and cull losses (animal discards) were factored in to determine gross animal lands required per capita. Net animal lands incorporated additional feed and nutrient cycling lands required to support each animal products. Land footprints were estimated from data supplied by the British Columbia Ministry of Agriculture and lands (see section 4 endnote 4.3).

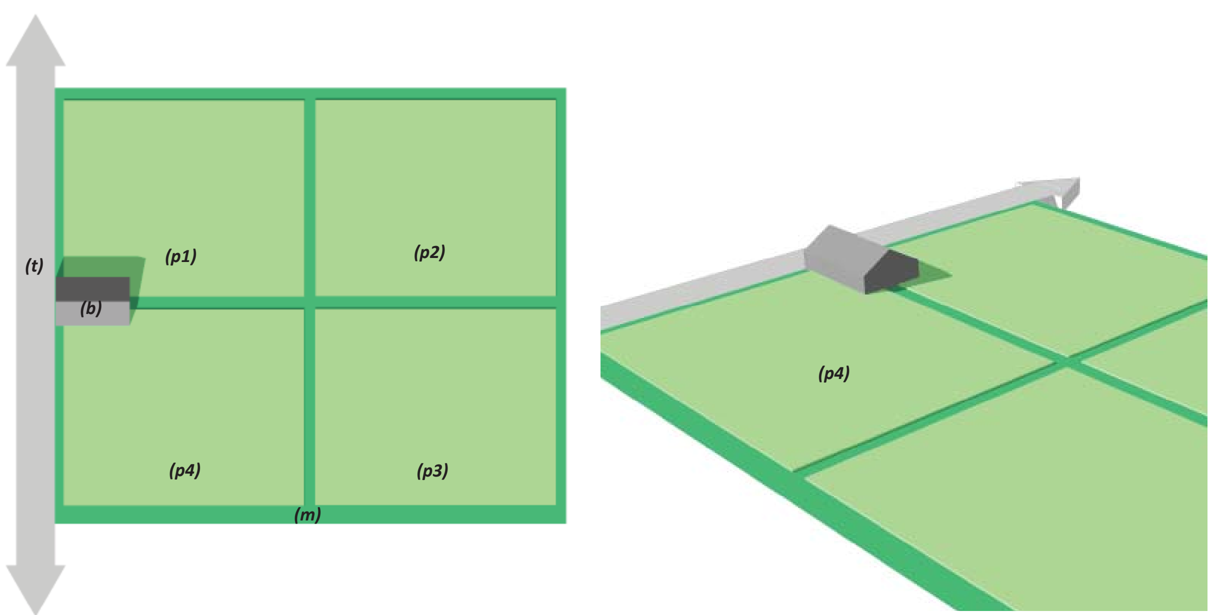


Figure (10.19). Animal Field Units. Four quarter hectare paddocks (p) could provide pasture for 2 dairy cows, 12 dairy goats, or 500 free range chickens [10.10]. Rotating animals through the paddocks supports healthy pasture growth. The area is serviced by a tractor lane (t), and barn (b), and surrounded by a 3m field margin (m) to help control nutrient discharge. A 1 ha animal section could meet the animal food needs of 4 people based on modelled dietary habits and production intensities.

Grain land shape:

The variability in grain yields make it difficult to model large-scale agricultural systems given the direct (wheat for bread, pasta, etc) and indirect (grains as feed) dependency on cereal crops. This variability has an impact on land footprints required by animals who depend on grains for feed. Increasing winter wheat yields to 12t ha^{-1} (achieved by recent trials in the lower mainland as per Temple, 2010, unpublished) reduces the direct food only foodprint from 0.372 ha to 0.311 ha cap^{-1}. If yields are modelled at 2.79 t ha^{-1}, a yield achieved by urban grains in 2009 (Grieshaber, personal communication, 2010), the direct food print increases to 0.412 ha.

Placement of grainlands must pay careful attention to grazing pressures from migrating geese and fungal damage (from moist conditions), making it difficult to grow grains in the lower mainland.

There is clearly an efficiency of scale when producing grain crops using conventional methods, conceptualized in figure 10.20. Contemporary techniques enable farmers to cultivate, fertilize and harvest a hectare of grain in only 4.7 hrs [10.11]. Sufficient crop densities are also required for effective pollination (eg Corn), all factors which favour large scale production in central Canada. Efficient production without the use of fossil fuels is a pressing concern. Those who have spent the time to plant, weed, scythe, thrash, mill and bake a pound of wheat will appreciate the efficiency of large scale cereal production. New cultivars of "naked" oats and "hull-less" wheat will make for considerably easier process, currently driven by heavily automated processes, but likely won't make up for the ease of automated tractor harvesting. The future methods involved in the production, processing and distribution of grain crops may well be the "tipping-point" which dictates the trajectory of post-oil food production.

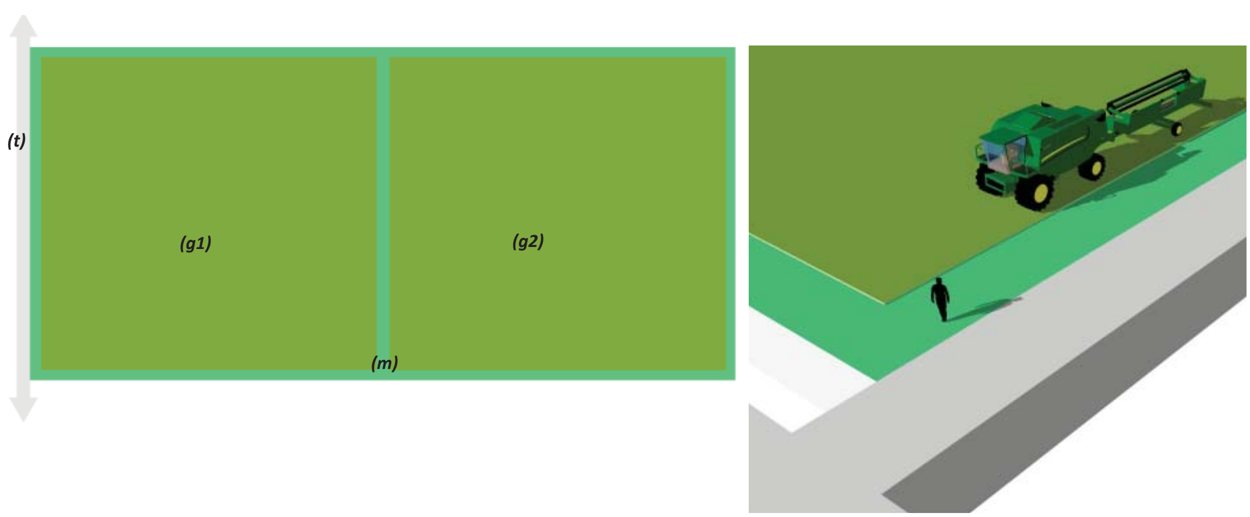


Figure (10.20). Grain Field Units. Two 1 ha grain (g1) & (g2) patches could satisfy the feed needs of 1.7 milk cows or 86 people based on current diet statistics [10.11]. A 3 m field margin (m) bounds the space which is serviced by a smaller 4m tractor road given the lesser frequency that people work the field.

Integrated Permaculture Food-forest Shape:
Bill Mollison and David Holmgren, founders of the permaculture concept, argue that the productivity of a permaculture system is limited only by the imagination of the observer.

By seeing the forest as a garden and replicating natural ecosystem processes in farming practise, the productivity of these systems is conceptually infinite (figure 10.21). More specifically, radically changing dietary patterns to take advantage of what is already provided, and allowing the system to increase in complexity can exponentially increase the number of micro climates thus the spatial and temporal heterogeneity of the system.

This philosophy is not one of making the land do more, but rather doing more with what the land provides and letting the forest garden the way she always has.

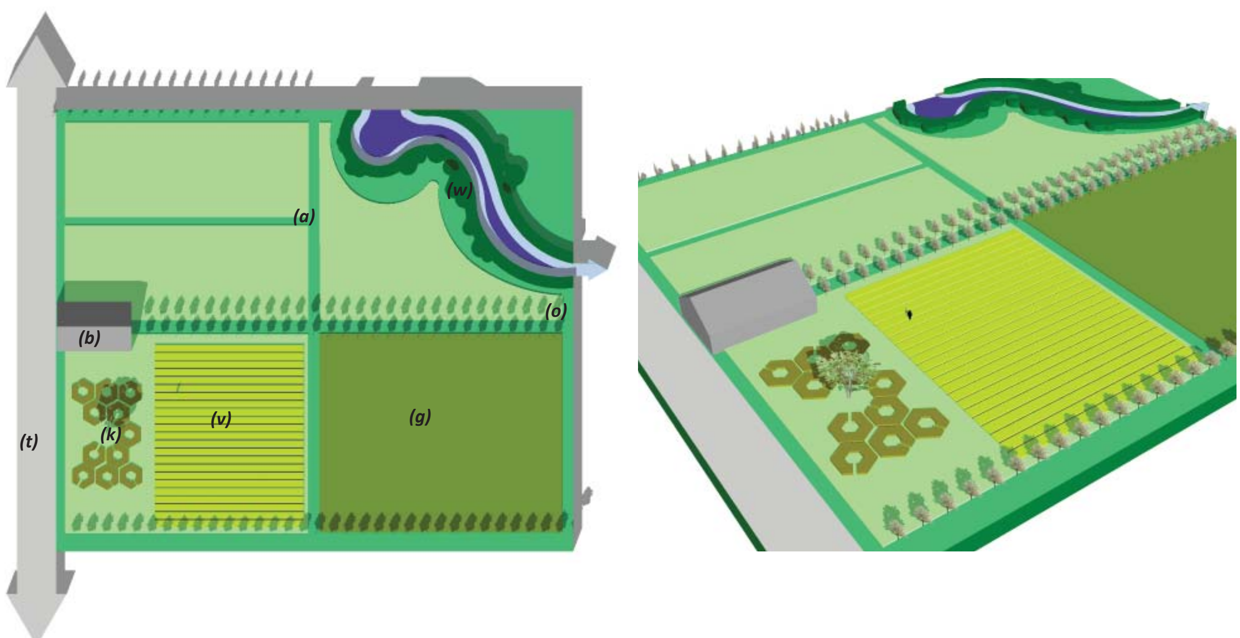


Figure (10.21). Permaculture Food Forest Units. An integrated grain (g), vegetable (v), orchard (o) and animal system (a) supports a dynamic permaculture ecosystem. A keyhole bed system (k) takes advantage of diverse micro-climates inherent with these spatial forms. An integrated wildland (w) provides a source of inspiration and woodland products. The placement of a barn, shelter or greenhouse (b) takes advantage of relative proximity to high maintenance crops (vegetables, herbs and animals), minimizing high intensity circulation area (t).

Conclusion

In summary, *energetic sustainability* is informed spatially by relative location and modal options, and can be evaluated a at foodshed scale. In contrast, social and ecological resilience is informed by the qualities of a human being and the nature of living systems, and is much more difficult to quantify. *Diversity, flexibility* and *connectivity* are qualities that resonate with healthy food and wildland systems.

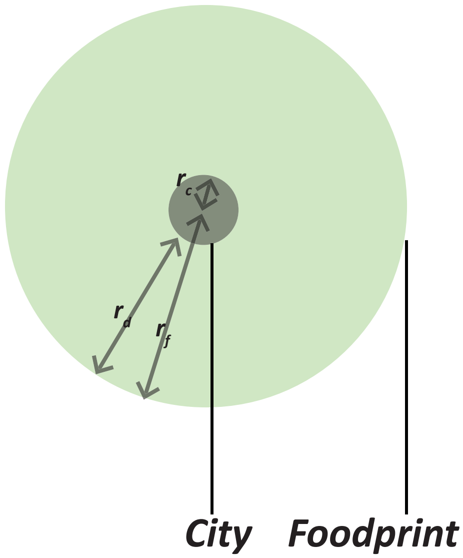


Figure (10.22). Radial Foodland Indicators

Endnotes

10.1 British Columbia Agricultural land

Statistics Canada's survey of agriculturally productive land in 2006 noted 2.8 million ha, which for a population of 4,243,580 at the time averages 0.67 ha capita^{-1}. By coincidence, this is the same foodprint allotment recommended in this report. That is, the foodlands under production in 2006 would just meet the food needs of the province at the time based on modelled food-print allotments. (Statistics Canada, 2006) Note that BC Stats predicts a slightly higher population than Statistics Canada, compensating for under-reporting inherent in census surveys.

10.2 Radial foodland indicators (see figure 10.22)

City radius (r_c) is the minimum radius required to generate a circle with an area equal to a known city area. Foodprint radius (r_f) is the minimum radius required to generate a circle with an area sufficient to meet a cities food needs, assuming foodprint allotment of 0.68ha cap^{-1}Radial foodprint difference (r_d) is the difference between foodprint radius and city radius (r_f - r_c). In reality, these indicators are a rather abstract way of evaluating a city as they assume complete agricultural coverage independent of current land use or local topology, and perfectly circular typologies. Therefore, they cannot imply realistic travel distances, but may help evaluate the relationship between city size, population and food. This abstract conceptualization is consistent with methods used by Howard (1898) and Frey (1999).

10.3 North American City Comparison

Several cities in North America were compared with regards to their land area and food print. Population and land area data were derived from Statistics Canada 2006 Census for Duncan, Metro Vancouver and Vancouver, (Statistics Canada, 2010) and from US Census Bureau 2000, 2006, 2008 Census for Manhattan, NY, San Francisco County, CA and the City of Detroit respectively. Foodprints were calculated by multiplying the population by 0.68 ha.

10.4 Traditional Agricultural Labour force

In 1881, 48% of Canada's working population (660 thousand of 1,4 million Canadians) were engaged in agriculture. (Statistics Canada, 1971)

10.5 The Daily commute

Assuming 10% of the food energy output was dedicated to the farmer commute, in today's labour conditions (1.5% labour pool, of a projected 3.1 million) this implies a max commute of 52km for the 17,000 farmers engaged in producing Vancouver's food (0.82% of 3.1 million). Commute energy intensity is based on current average modal intensities of 2.17 MJ Pkm^{-1} at 150 working days twice a day, and available food energy output is 5.35GJ cap^{-1} yr^{-1}. If farm labour intensity increased to 16% of the *total* population, this commute distance is reduced to 5km one way.

10.6 Gross Regional Agricultural Retrofit

The region has an area of 287,852 ha (Statistics Canada, 2010), and a foodshed need of 2.1 million ha, thus if every

Figure (10.23). Measuring Parcel Coverage
Image from City of Vancouver, 2010.

available surface was used, 17% of the foodshed allotment could be placed could be applied (area available divided by foodshed area).

10.7 Net Regional Agricultural Retrofit
Vegetables necessitate 108 m^2 per capita and fruit 114 m^2. Applied to the city of Vancouver with a population of 578,000 million in 2006 necessitates a foodshed 382,000 ha hectares, but only 13,000 ha for fruit and vegetables.

Vancouver city was taken as a proxy for urban form for the region. For calculating food production capacity in the city, parcel area and population of the city of Vancouver was used. The total parcel area defined by data provided by City of Vancouver's VanMap (2010) is 7560 ha of which 30% is set aside for agriculture. When calculating the potential of the region, the *regional* ALR and *regional* population were used. Actual building sizes, shapes and areas vary, and likely would provide much less room than given in the example, especially for higher density structures. As can be seen in figure (10.23), boulevard areas are not included in parcel area, providing additional area for urban agriculture.

10.8 Hedgerow shape and size considerations
It is interesting how mechanical trimming can have an apparently positive effect on the species richness, though likely increases habitat for "edge" tolerant species. While the species richness increases in a bimodal fashion, the number of breeding pairs per 1000 yards of hedge increases exponentially with increasing hedge height and width and decreasing hedge management for Hawthorn hedges in a UK study by Moore et al (1967), p 218. The intensity of adjacent land use has a large impact as well (pasture>large arable > small arable). Adapted from Andrews and Rebane (1994), Hooper M.D. (1974), Moore et al., (1967) Hinsley S. and P. E. Bellamy (2000) and Moore, (1974).

10.9 Traditional definitions of area.
A traditional acre was ten times as long as it was wide at 220 yards by 22 yards. It was understood to be 32 furrows of the plow (Ellis, 1882), thus would demand 32 turns of the team of oxen pulling the plow (the width of an acre equals 22 yards or 66 feet). If the field were square, the width increases by 3.16 times, now demanding 101 passes of the plow and 101 turns of the oxen. It was likely difficult enough getting the oxen to go straight let alone turn them, thus the reluctance for square fields. Arguably the length of the furlong was limited by some other subjective human quality - possibly sight. That is, an acre longer than one furlong (200m), would prohibit the farmer from seeing what was going on at the end of his or her block. That these subjective human qualities are the basis for measurement and land use patterns worldwide is telling of our historical relationship with space and should also inform how we use and design space in the future - from a human perspective.

10.10 Pasture land area
Chickens are assumed to be placed at a density of 200 layers acre $^{-1}$ or 500 chickens ha $^{-1}$ (BCMAL, 2008). This equates to 215 square feet chicken^{-1} which is well in line with European Union's stipulation of at least 43 square feet (4 m^2) chicken^{-1} (Eur-Lex, 1999). Humans require nearly 0.25 ha cap^{-1} yr^{-1} to meet modelled animal dietary trends discussed previously.

10.11 Feedland area

Milk cows are assumed to require 1.2 ha of feedland to produce the 6 tonnes of hay, 500 kg of straw, 2.7 tonnes of grain assuming alfalfa hay and straw and winter wheat production intensities as proxies. Morrison (1946) suggests that a pair of work horses require 2.3ha $pair^{-1}$ of horses for feed. Humans require 0.0232ha cap^{-1} for grains as per previous analysis in this report, thus 2 ha would support 86 people (2ha divided by 0.0232 ha cap^{-1})

10.12 Grainland labour efficiency

Labour efficiency is based on large scale (300 ac) organic oat production at 1.9hr $acre^{-1}$ or 4.6 hr ha^{-1}. (BCMAL, ND). Clearly there is an efficiency of scale where smaller grain plots take more than 4.6 hr to work.

10.13 Forest buffer specifications.

The Agricultural Land Commission recommends a buffer with a minimum of 20 meters (ALC, 1998) for trespassing prevention, removal of particulates as a visual screen and noise reduction. It likely needs to be thickened significantly to support a meaningful wildlife population. Environment Canada(2004) suggest forest corridors should be 50 to 100m in width. I have chosen a buffer 40m wide for explanatory purposes.

11 Regional Applications

Foodsheds can be described in terms of their size, shape and rhythm. Foodprint size is well documented in this report and in other studies as roughly 0.5 to 0.7 ha cap^{-1}.   This type of indicator can help preserve the total area of the ALR, but cannot protect the shape of the regions foodshed important for distribution efficiency and community connectivity. Part of the problem is an inability to scale sustainability indicators from a provincial scale to a regional or farm scale where the farming actually takes place. Sustainable foodsheds must: meet food needs, achieve a positive food system energy balance,   and be ecologically and socially resilient. While the first two indicators are most appropriately applied at a regional scale, the last fits better at a farm or community garden scale where local biophysical and social conditions can inform farm management and design. For this reason, more synergy is needed between provincially governed bodies such as the ALC, regional and municipal governments, and local neighbourhood groups to visualize qualities of a sustainable foodshed at multiple levels of scale.

This section will unpack the *resilience imperative* and apply it in a critique of the size and shape of three regional farm case studies.

Design Guidelines for a Resilient Foodshed

Though many more qualitative and quantitative indicators could apply, the checklist below will be used to evaluate the capacity of three regional farms and, if nothing else, can be a starting place for *discussing* what matters most in food land design.

Ecological resilience:

As mentioned in section (10) the appropriate shape of wildlands should respond to local conditions, necessitating a case by case approach to farm and wildland design. In this regard, farms should:

1.1 Mitigate nutrient loading to local ecosystems with appropriate buffers and planting plans.

1.2 Provide appropriate wildlife habitat on site & good connectivity to regional habitat.

1.3 Support soil building practises with local nutrient cycling.

1.4 Adapted to the probability of climate change and sea level rise.

Social resilience

While urban agriculture will never be fully responsible for meeting food needs in cities, it has a profound role in socially connecting people to their food system. Though difficult to quantify, this relationship encourages a sense of responsibility that can lead to consumers eating less meat and processed foods, two variables which have a huge effect on the energy balance of the food system. Michael Pollen argues that consumers should "Eat Food. Mostly Plants. Not too much." (Pollen, 2008) There is no better teacher for this lesson than by engaging people in agriculture. Therefore while regional farms grow food, community gardens and urban farms encourage people to buy local food in a synergy that can result in the development of sustainable food system (figure 11.1). This is an interesting example where a small part of the foodshed that produces very little food can inform the performance of the whole through agricultural education and engagement. Accordingly, farms should:

2.1 Meet some local food needs as appropriate.
2.2 Provide community access as appropriate.
2.3 Be economically viable (can provide steady positive marginal return).
2.4 Provide meaningful jobs.
2.5 Be able to transition out of fossil fuel dependence through a "human-scaled" approach to agriculture

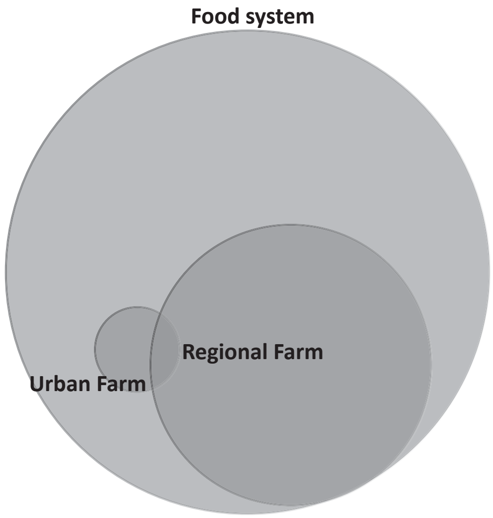


Figure (11.1). Where does Urban Agriculture Fit in the Foodsystem? Conceptual relationship between urban agriculture, large scale farming and sustainable food systems.

I have judged the capacity of each proposed farmland design to meet these qualitative sustainability indicators where ✓ indicates presence, ✗ indicates an inadequacy and = indicates neutrality in performance. As capacity indicators, these do not infer actual performance.

Southlands Farm | 217 hectares

Program:

In 2006 Southlands Farm in Tsawwassen, BC began a planning process to re-engage the landscape with a "human-scaled" approach to agriculture. Of the site, 69 ha 30% is slated for conversion to a "compact complete community", leaving the remainder for wildlife conservation, open space and agriculture (Duany Plater-Zyberk & Company, 2007). The program called for explicit evaluation of the economic, ecological and nutritional capability of the agricultural land in relation to the projected community of 1900 residents. I completed this assessment in January 2010 in conjunction with Kent Mullinix and Arthur Fallick of Kwantlen University, Vancouver. Evaluations and images are shown through figure (11.2-11.3)

Medium scale farms such as Southlands represent an important interface for residents to actively engage with the food system via community supported agriculture, community gardens, or farming apprenticeships. Initial visions of the plan called for *agriculture fingers* which improved the agricultural interface but were ultimately rejected in favour of a tuck plan making the agriculture and housing more compact and manageable.

Form:

A 12 year cycle was designed to respond to local food needs and the ecological needs of the landscape. Conceptually, vegetables are followed by animals which are followed by grains, each consisting of 4 year intra cycles. Within vegetable plots, nitrogen fixers (beans and peas) are followed with heavy feeders (broccoli, cucumbers), medium feeders (potatoes, lettuce) and light feeders (carrots, beets) following the biointensive advice of Jeavons (2006). Goats and chickens were chosen to supplement animal based dietary needs. Cattle were excluded for their likely impact on the low lying, ecologically sensitive site (0.5m above sea level). Following vegetables with animals takes advantage of the soil cultivation that goats and chickens will do, free of charge. Grains including wheat, oats and barley were chosen to meet a critical and often ignored component of the regions diet. Fruit trees require a longer life-cycle and were excluded from the 12 year rotation. They were placed on a gently sloping hillside on the north west of the site, which as part of the entrance, would make obvious the agricultural theme behind Southlands Farm and minimize the potential for frost damage.

A thirty meter buffer zone was requested around all ponds and ditches to improve the ecological value of these riparian corridors. This meets the buffer requirement suggested by Environment Canada (2004), but is really only realistic for fish-bearing streams in proximity of high-intensity agriculture. Given the diversity of agriculture types, it would be more appropriate to combine smaller buffers with low-input perennial fruit trees to maximize agricultural productivity and ecological integrity.

The *shape* of the pond and ditch system could also be improved to meet ecological programs. The large pond to the northwest is intended to manage sediment and nutrient loading from the existing neighborhoods. The circular shape will certainly provide a lot of interior habitat for nesting wildlife but does not have the edge or length necessary to maximize residence time and nutrient buffering. The rectilinear nature of existing ditch systems will certainly assist drainage but will not support the needs of fish life that need a more meandering network of streams for reproduction. In this regard, clarity on appropriate synergies, and exclusion of programs that simply do not fit would assist this project.

Capacity:

Organic direct market prices add a premium to the price of foods that often have very small profit margins. For this reason community-based organic farms stand a better chance at becoming financially viable than their conventional counterparts. The research we completed on marginal returns predicted a profit of $1.27 million annually[11..2], excluding loan repayment costs often required for farming systems. We also predicted the likelihood of up to 40 full-time equivalent seasonal jobs that could easily be sourced from the local community.

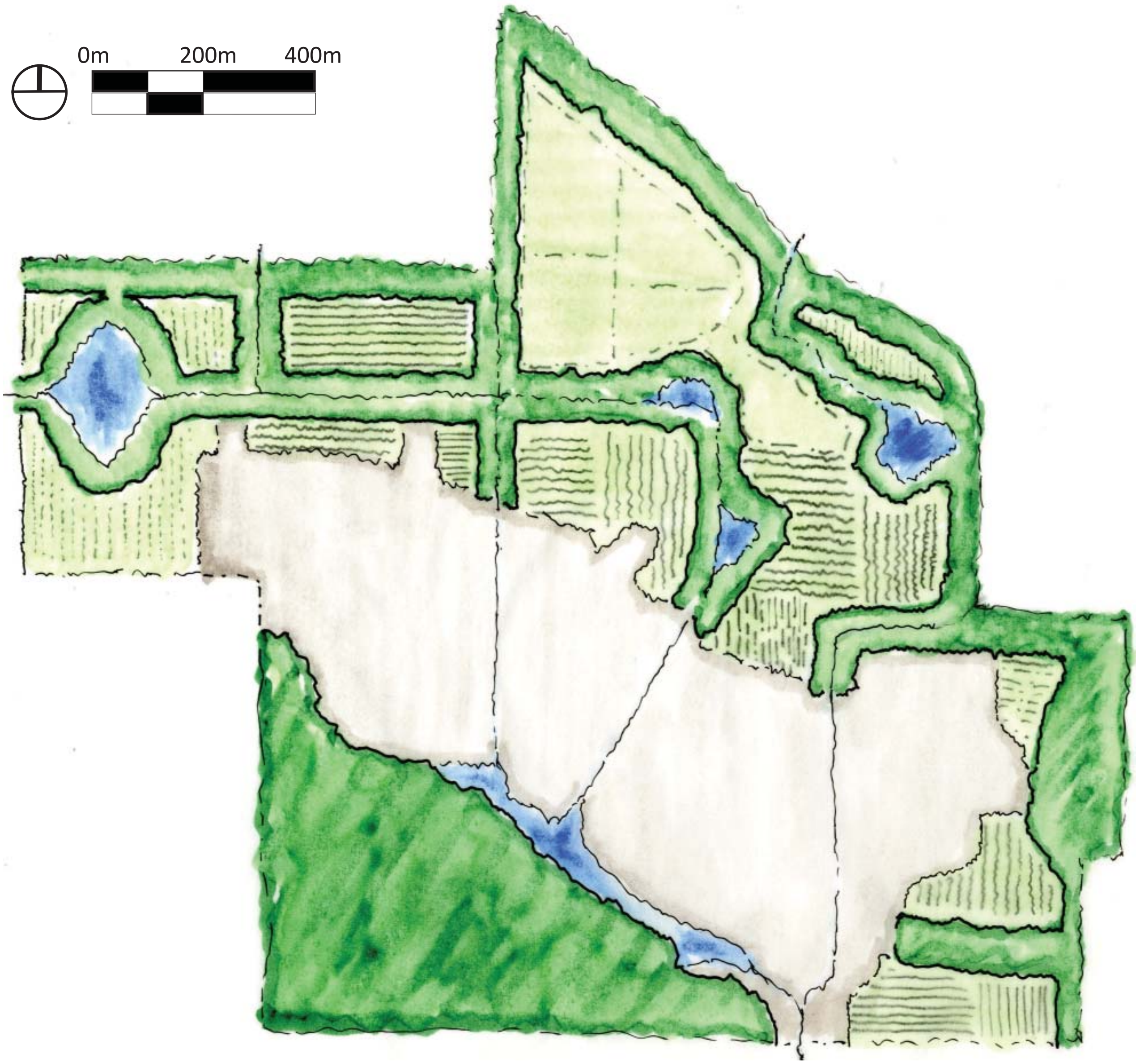
We received interesting feedback from some community members who wondered why bother growing food at all if we could only meet a fraction (8% to 40%) of the dietary needs of the community. That the food system could only meet a small portion of food needs *is in fact reason* to properly evaluate and expand the food system. *Delivering this message* in a useful, truthful and kind way is critical to sustainable agricultural planning. Specifically, designers should consider framing the question in such a way to induce optimism, empowerment and action, rather than create a sense of gloom that often typifies modern environmentalism.

The local elevation of Southlands farm is of great concern. At 0.5 m above sea level, the region would need considerable engineering to protect against even minimal sea level rise. However, proximity to the ocean (kelp), and city (compost) and will likely provide Southlands with a resilient supply of organic nutrients for some time to come.

Southlands intends to be a place of agricultural education for young and old farmers through apprenticeships and workshops. As a large farm, Southlands is well positioned to provide teachings small to medium-scale farmers of the future, a function that small farms or community gardens cannot meet. A *gradient of engagement* from passively observing fruit producing street trees to active participation in farm-schooling helps connect small-scale agriculture to the larger foodshed.

- ✓ *1.1 Mitigate nutrient loading to local ecosystems with appropriate buffers and planting plans.*
- ✓ *1.2 Provide appropriate wildlife habitat on site & good connectivity to regional habitat.*
- ✓ *1.3 Supports soil building practises with local nutrient cycling.*
- ✗ *1.4 Adapted to the probability of climate change and sea level rise.*
- = *2.1 Meet some local food needs as appropriate.*
- ✓ *2.2 Provide community access as appropriate.*
- ✓ *2.3 Economically viable (can provide steady positive marginal return).*
- ✓ *2.4 Provide meaningful jobs.*
- ✓ *2.5 Able to transition out of fossil fuel dependence through a "human-scaled" approach to agriculture*

Figure (11.2) Southlands Farm Summary



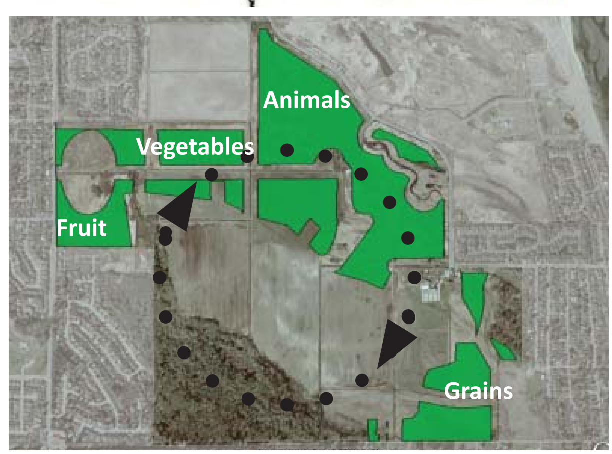


Figure (11.3) Southlands Farm

Cottonwood Community Garden Extension | 2907 m²

Program:

Cottonwood community garden planned for an extension to the north end of the existing Cottonwood community garden (figure 11.4 - 11.5). Cottonwood is located in Vancouver's Strathcona neighbourhood, a culturally rich medium density neighbourhood that stands to benefit from urban agricultural opportunities. The lot size is 2,907 square meters of which 1,866 square meters (64%) is dedicated to wildlife and circulation, leaving 80 planting beds of approximately 140 sf each. The community requested a garden with universally accessible planting beds for the main portions of the site in a way that maximized agriculturally productive space.

Form:

The plot size is larger than contemporary plots throughout Vancouver (typically 4' by 10', 40sf beds), allowing gardeners to plan more creative fruit and vegetable beds within their plots. Community members requested a more intensive plot layout, and were shocked to see the amount of land dedicated to circulation. The program, however, called for universally accessible pathways through the centre of the site, to a tentative meeting space at the northern end of the site and a tool shed in the centre of the garden. Ten raised accessible beds border the main pathways. This level of land use intensity (34%) is typical of community gardens and difficult to increase without sacrificing community access. Micro-circulation between conventional plots was left up to individual gardeners to manage and typically transect the large 10' by 14' plots into four beds. Irrigation was planned to ensure all plots were within 25' of water access, but minimized the number of faucets to lessen the potential for vandalism - a common problem in this downtown neighbourhood. Raised berms in conjunction with dwarf fruit trees on the north-west portion of the site were designed to increase visual accessibility into the site but discourage access by those who might abuse the site. A native plant hedgerow is planned for the east section of the site to provide a barrier and buffer the site from the adjacent roadway.

A massive cottonwood tree rests in the centre of the site which prohibited placement of gardens or meeting spaces underneath for safety and ecological reasons (branch fall, shading, water competition, etc.). The site also rests on the north side of an existing wildlife refuge creating a shading issue for plots on the south end of the site. The balancing of ecological, social and economic needs was a challenge created by this design problem. It created a dynamic opportunity for people to share their values and interests in a charette-style design exercise that produced a meaningful design *and* a sense of community from the people involved in the process.

Capacity:

The existing small wildlife patch provides an urban refuge for local wildlife and likely helps cleanse nutrient and water discharge from on and off-site. However, unlike Southlands which hopes to help treat neighbourhood storm water on-site, there is a limitation to the cleansing a small patch of wildlands can do in the midst of an urban jungle.

In this urban context, animal and grain products are inappropriate and don't engage the gardeners in the same way that vegetables or fruit do, thus are excluded from the model. Based regionally-scaled predictions, this plan would meet the annual fruit and vegetable needs of nearly 5 people[11.1]. Unlike Southlands, Cottonwood wasn't designed with the presumption that it could meet the food needs of the community - but rather as a tool for agricultural engagement. The added meeting space and accessible beds will most certainly add to the already vibrant community garden. It is likely that food producing areas of community gardens such as this can be more productive than the same area on regional farms with diverse crop layouts, creative rotations and many hands to deal with continuous harvest schedules. Land utilization of bed space in the Strathcona region is as variable as the population that inhabits the neighbourhood. Some beds are neglected by overworked professionals who miss their weeding every now and then, where others are in pristine condition, producing more per square foot than any high-intensity regional farm could ever hope to. This leads to conflict at times which again provides opportunity for social engagement and community growth.

1.1 Mitigate nutrient loading to local ecosystems with appropriate buffers and planting plans.

1.2 Provide appropriate wildlife habitat on site & good connectivity to regional habitat.

1.3 Supports soil building practises with local nutrient cycling.

1.4 Adapted to the probability of climate change and sea level rise.

2.1 Meet some local food needs as appropriate.

2.2 Provide community access as appropriate.

2.3 Economically viable (can provide steady positive marginal return).

2.4 Provide meaningful jobs.

2.5 Able to transition out of fossil fuel dependence through a "human-scaled" approach to agriculture

Figure (11.4) Cottonwood Community Garden Extension Summary

With an anticipated production intensity of roughly 1.5 tonnes for the garden, and using Bomford's (2009) estimation of 3kg hr^{-1} it would take almost 500 hrs or 14 weeks of labour at 35 hrs $week^{-1}$ [11.2, see section 8, endnote 8.9].

The city regularly provides compost and soil for gardening plots. Thus, community gardens such as Cottonwood are ironically adapted to nutrient deficits that could cripple large-scale farms without access to fossil fuels. In any event, community gardens such as Cottonwood can encourage a culture of food system sustainability and must work in synergy with larger-scale regional farms to meet the food needs of cities.

Figure (11.5) Cottonwood Community Garden Extension

Organivanico | 696 m²

Program:

The Organivanico is a Cuban-inspired high-intensity raised bed garden at UBC farm, designed to communicate the spatial requirements to satisfy nutritional needs of an individual in a profitable and ecological way and engage a set of young farmers who plan to attend the garden (figure 11.6-11.7).

Form:

The form of this garden was designed to support the fruit, vegetable, and grain needs of one person, demanding 232 square metres in grains, 387 row feet in vegetables (3'row) and 410 row feet in vegetables (3' rows). If half of the garden is in fruit and vegetables (642 row feet), placed in 80' raised beds, this leaves the remaining 3,570sf or 331 square meters, more than sufficient to meet an individual's grain needs.

The site has a south-facing aspect, thus crops were placed to take advantage of southern solar gain, avoid shading and keep high maintenance crops close to high traffic areas where they're likely to be attended to. This prioritization scheme follows the principle of *relative location* outlined in Molllison and Holmgren's Permaculture concept where zone one crops (herbs, leaf crops, etc.) are placed closer to the centre of activity than zone 3 crops (fruit trees, etc.) which can stand some lack of tending (Mollison, 1988 and Holmgren, 2002). The garden experience is dominated by what can happen at arms length and within a farmer's gaze, thus attention to small, human-scaled processes were critical for this site.

Beds were designed at 3' width in consideration of the short arms of children that will likely attend to them. Paths were kept at 2.5' between mound beds and 5' between raised beds for ease of mowing and community access. The shape of beds was also informed by the nature of back yard gardens across Vancouver. The garden was designed to answer the question: "What might a (partially) self-sufficient garden look like in my backyard?" With yards not often larger than 40' by 20', the shape and aesthetic of the raised beds needed to match the character of the modern Vancouver backyard. Accordingly, beds were shaped not longer than 40' with attractive rot resistant cedar that make food production accessible, tasty and attractive. Where the entire space was originally designed to accommodate raised planters, we compromised with only four or five long planters to minimize the amount of wood required. Well-designed "mound beds" can be accessible at significantly less cost, though are more difficult with the sandy soils of UBC which tend to lose their shape and moisture more easily than soils with higher clay content.

The long rectilinear beds lend themselves to drip irrigation which are easier to manage with less wastage than hand or overhead irrigation. The east-west direction of the beds created natural berms to support water infiltration and optimizes solar gain. The use of timed irrigation is another application of Mollison (1988) and Holmgren's (2002) Permaculture principle of *redundancy* where critical functions (watering) are supported by multiple design features (drip irrigation, hand watering, overhead watering) to protect against system failure.

A small removable hoop house was designed to fit over one of the set of raised beds to demonstrate technologies that can extend the growing season in the Vancouver climate. Forms and management strategies

✓ *1.1 Mitigate nutrient loading to local ecosystems with appropriate buffers and planting plans.*

= *1.2 Provide appropriate wildlife habitat on site & good connectivity to regional habitat.*

✓ *1.3 Supports soil building practises with local nutrient cycling.*

✓ *1.4 Adapted to the probability of climate change and sea level rise.*

= *2.1 Meet some local food needs as appropriate.*

✓ *2.2 Provide community access as appropriate.*

✓ *2.3 Economically viable (can provide steady positive marginal return).*

✓ *2.4 Provide meaningful jobs.*

✓ *2.5 Able to transition out of fossil fuel dependence through a "human-scaled" approach to agriculture*

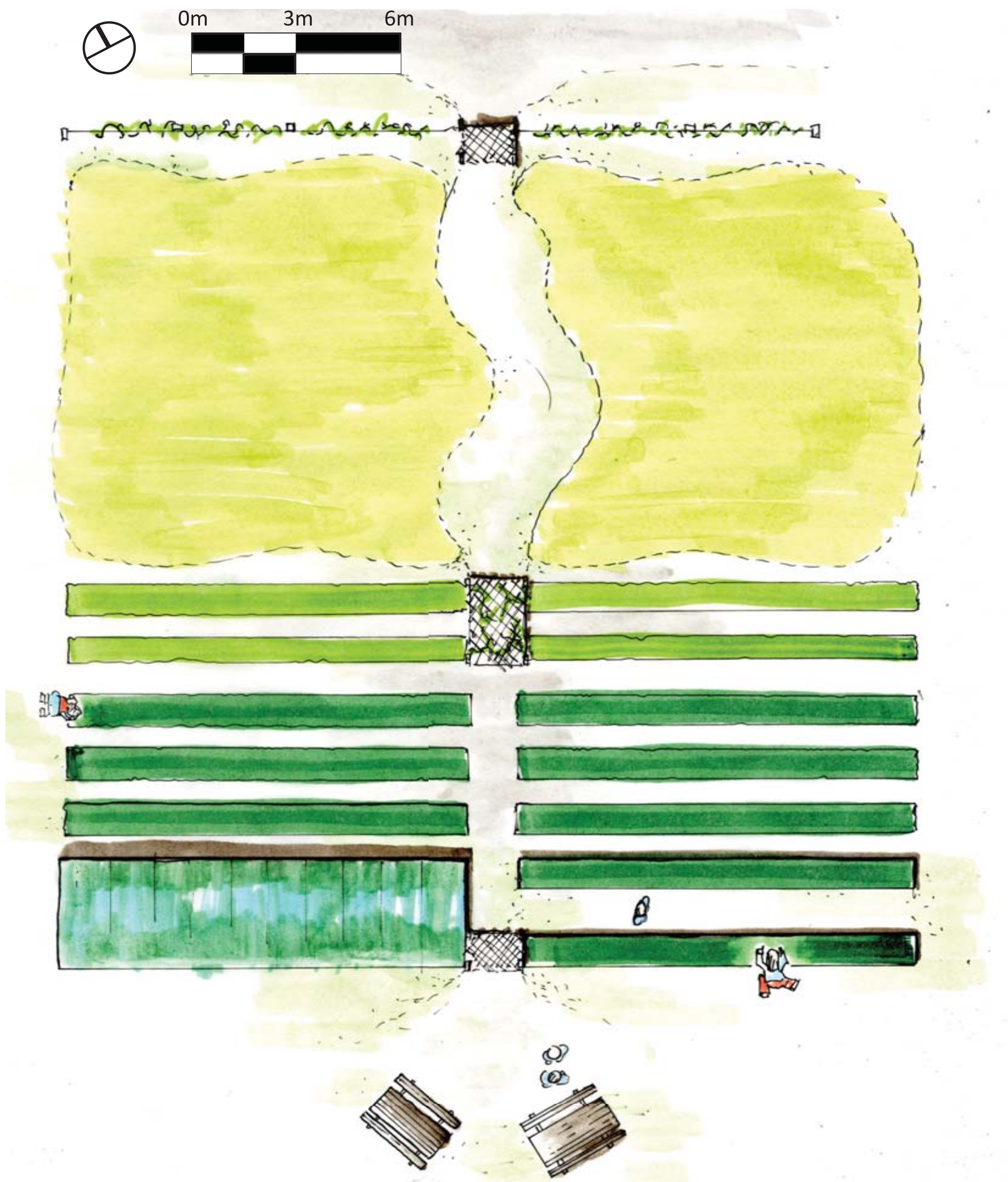
Figure (11.6) Organivanico Summary

that support a four-season harvest are critical for adapting farms for energy decline.

Capacity:

It remains to be seen if the garden will meet the target food production projections, but will likely meet a significant part of the lunch requirements for daily kids camp lunches. Like Cottonwood, meeting food needs is a qualitative challenge and community engagement takes precedent.

Bomford's (2009) estimation of 50g min^{-1} (3kg hr^{-1}) was used to approximate the time required to do the work with only the assistance of hand tools. To harvest 402 kg of food in this fashion would take 134hrs or roughly 4 weeks at 35 hrs wk^{-1} [see section 8, endnote 8.9]. Based on direct market prices and marginal profit projections, a farmer could earn $900 or save twice that in grocery purchases [11.2]. Farmers of this garden (children) will likely take significantly more time, with more financial investment given the programmatic needs of raised bed planters. In an educational context such as UBC farm, this is entirely appropriate where educational programs are more important than the food produced. In fact, the camp that will service the garden will likely earn indirectly significantly more than if the food were sold directly for sale. Value adding through eduction, local processing (preserving, juicing), and local enterprise (cafe / restaurant), can dramatically improve the financial viability of farmland.



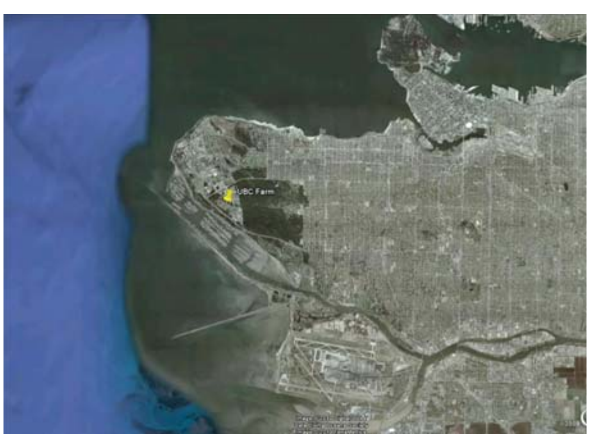


Figure (11.7) Organivanico

Conclusion

Designing for a sustainable foodshed requires different questions at different levels of scale (figure 11.8) and must intimately relate to the desired function of the farm or community garden, making standard way of evaluation schemes somewhat inappropriate. For example, while none of the above examples met significant food needs they served other food related functions often missed in a purely quantitative discussion. In this regard, foodshed indicators should serve as discussion points to help community members evaluate goals, building the integrity of both the farmland and community.

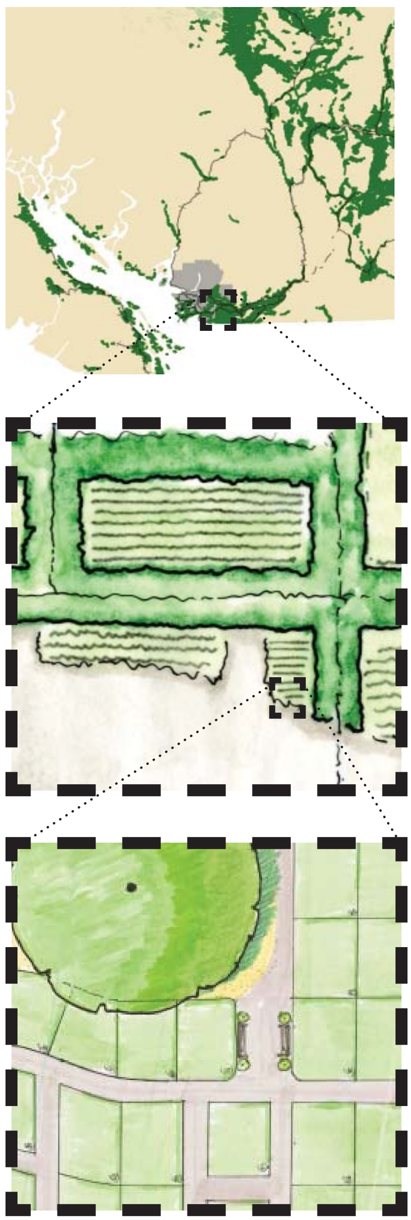


Figure (11.8) Multi-scale Approach to Sustainable Foodshed Design.

Foodshed Scale Indicators

1.1 Meet food needs

1.2 Energetically productive. (food energy outputs exceed food system energy inputs).

Farm Scale Indicators

1.1 Mitigate nutrient loading to local ecosystems with appropriate buffers and planting plans.

1.2 Provide appropriate wildlife habitat on site & good connectivity to regional habitat.

1.3 Supports soil building practises with local nutrient cycling.

1.4 Adapted to the probability of climate change and sea level rise.

2.1 Meet some local food needs as appropriate.

2.2 Provide community access as appropriate.

2.3 Economically viable (can provide steady positive marginal return).

2.4 Provide meaningful jobs.

2.5 Able to transition out of fossil fuel dependence through a "human-scaled" approach to agriculture.

Endnotes

11.1 Calculating Fruit and Vegetable Capacity

Eighty plots at 140 sf is equal to 11,200 sf or 1041 square meters. Note that there is a lot of opportunity along the edges to produce fruit on small fruit trees, though this planning wasn't programmed as yet into the plan. If the footprint of these foods is 108 and 114 square meters for fruit and vegetables respectively, the 1041 m^2 of growing space could only meet the annual needs of 5 people (1041 divided by 222) ignoring additional land required for nutrient cycling.

11.2 Large Scale Labour inputs and Marginal Revenues

Labour input at 40 FTE jobs was estimated assuming 1750 hr yr^{-1} (35 hr per week times 50 wks) for animal products and 840 hr work yr^{-1} (35 hr per week at 24 wks) for the remaining crops. Labour requirements were based on crop-specific labour inputs suggested by BCMAL worksheets.

Marginal revenues are discussed in Appendix 14.6.

12 Transitions

Measuring the Footprint of Food

Using the modelling methods explained in this study it takes 0.68 hectares to feed an average Canadian. Vancouver's projected population of 3.1 million in 2050 would generate a foodshed that consumes half of the provinces Agricultural Land Reserve and the southern half of the province.

Under business as usual conditions, it would take at least three times more energy to make, move, and process food than is contained in the food itself. Though improvements in efficiency and diet achieve a much reduced energetic footprint (figure 12.1), this study was unable to ascertain a food system scenario with a net positive food system energy balance.

Despite emergent arguments to the contrary, *retrofitting the city for agriculture cannot meet the food needs of city dwellers*. Retrofitting the region for agriculture is a more appropriate focus to achieve food system resilience. It is important that planners and developers see the placement of food lands as a necessary component of regional planning and that landscape architects can design such spaces in amongst the built environment to encourage a *sustainable food culture*. In this approach, understanding the relationship between backyard gardens, urban agriculture, and regional farms, is critical to developing a culture of greater food awareness, appreciation and involvement, and could indirectly decrease the energy and land requirement of Metro Vancouver's foodprint.

Energetically speaking Foodshed Vancouver is more strangely shaped than initially thought, responding to the energetics of modal choice and route logistics specific to British Columbia. In this regard, the "hundred-mile diet" concept is insufficient to set objective targets for sourcing local food as it doesn't meet energetic or resilience targets discussed in this report. If, for example, the drastic 50%+ reduction in production and processing inputs proposed in section (8) were achieved, citizens of Vancouver would

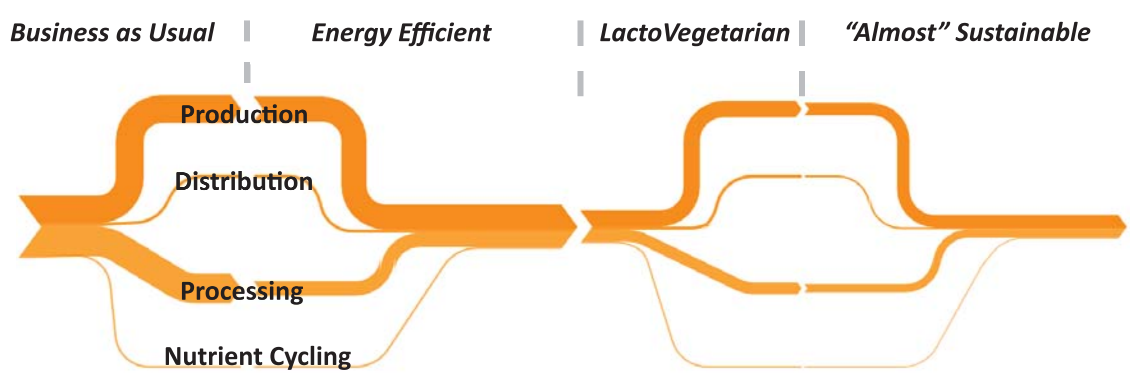


Figure (12.1) Footprinting the Energetics of Foodshed Vancouver Scenarios

What are key methods for sustainable foodshed assessment & design?

Consider the full life cycle of food

Observe important quanititative and qualitative indicators at multiple levels of scale

Evaluate the system with reference to regional capacities

Expand system boundaries to consider other inputs

Start with a focus on capacity

still need to source their food within 66 km to maintain a positive food energy balance[12.1]. *The 41 mile diet (66km)* does not sound quite as digestible as its 100-mile counterpart, but has a much more rooted foundation.

Methods for Sustainable Foodshed Design

The objective of this study was to explore *methods* for designing sustainable foodsheds with Greater Vancouver as a focal case. While past research has analyzed parts of the food system, this study highlights the need to account for the *complete life cycle* of food, ensuring food and farm needs are met in conjunction with an ecologically and socially resilient food system.

Throughout the study it became obvious that different design indicators should be applied at different levels of scale. Since the distribution and nutrient cycling energy input amount to very little, the energy balance indicator deserves placement at a regional scale where the size and shape of a region become more important for the food system energy balance. Community access and wildland shape should be considered at a municipal and farm scale where the context and community need can be accounted for to design the rhythm of crop rotations and the size and shape of functional wildlands.

Energy is a robust and flexible indictor that enables the assessment and comparison of the various stages of the food system (production, distribution, etc.) with other societal energy systems. Given its strength as a quantitative indicator there is a danger in missing more qualitative indicators such as social and ecological resilience. Since the focus of indicators will drive future land use decisions it is vitally important that assessment schemes properly integrate quantitative and qualitative indicators with an emphasis on variables that matter most. For example, distribution and nutrient cycling required much less of an energy footprint than was initially expected, though low energy inputs do not imply insignificance. Energy as a metric was unable to discern the *quality* of energy inputs, thus could not be used a complete measure of system sustainability. As discussed in section (1), fossil fuels have served as a cheap and extremely versatile form of energy that has shaped the contemporary agriculture and the modern city. *If* planners hold that abstention from fossil fuel use and full nutrient cycling of organic wastes are necessary for a sustainable food system, local food becomes an environmental imperative, trumping energy balance as an indicator and demanding a focus on regional resources (food, energy, water, shelter, etc.) and capacities (distribution networks, ecological services, agricultural skill base etc.). In the context of agriculture, social capital represents the ability of a population to work (with) the land. Arguably with less than two percent of the population currently engaged in agriculture (Statistics Canada, 2010), food production is becoming a lost art that may well need to be found again. Section (9) briefly discussed the importance of soil, light, temperature and water for producing food - elements that are too often taken for granted. Though there are ways to transform soils to some degree with the help of composts, grading techniques that can improve light access, and even micro-berm solutions to improve water capture and retention, there are many places in the world where agriculture cannot thrive having inadequate resources to support human populations.[12.2]

However, since human societies do obtain energy from solar, hydro, wind, and geothermal sources, it seems reasonable to expand system boundaries in a regional focus of total energy systems. Future studies should consider local transportation routes and energy sources, and socio-ecological conditions specific to the region. Like a foodshed, energysheds should consider the capacity of the region to support its own energy needs in a place-based approach to life-cycle assessment. This wholistic method can help designers make changes to policy, and land use and is a more meaningful approach to system analysis than an evaluation of each energy system independently.

As was done in this study, *system capacity* is a meaningful place to start this discussion as it is difficult if not impossible to design for energy system performance. With strategic policy interventions and the assistance of market forces, society will likely become more efficient by necessity.

Sustainability indicators play a dual role of *assessing* and *informing* the design process. That the set of criteria developed in the introduction was unable to help design a sustainable foodshed was due to a failure in their construction. Indicators used in this study operated primarily as filters, designed to *exclude* options from a mix of examples (figure 12.2a). This practise was unable to come up with *new* ideas, and failed since the set of examples were based within the current fossil-fuel dependent energy paradigm. A *constructive model* (figure 12.2b) is necessary to inform a new sustainability paradigm where questions *start* with a focus on ecological and social resilience, drawing on precedents in nature and social sciences, and finish with an understanding of regional carrying capacity. These two approaches do not arrive at the same destination as the former seeks only to *do no harm*, where the latter actively seeks to *improve system health.*

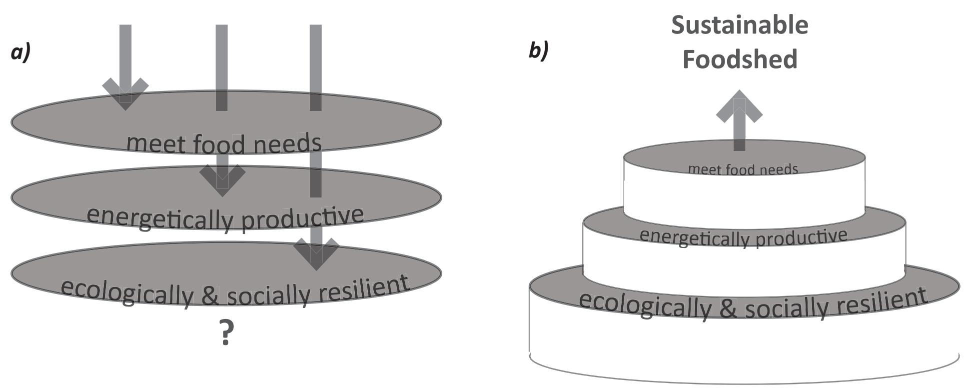


Figure (12.2). Redefining a Sustainable Foodshed. *Filtration* approaches to sustainable design (a) are unable to generate new ideas in the way that *constructive approaches* to design can (b).

What is the shape of a sustainable foodshed?

Scaled to reflect qualities of natural and human systems

Diversified

Well-connected

Flexible

The Shape of a Sustainable Foodshed

With this in mind, the shape of a sustainable foodshed should be informed by qualities of human-scaled systems and similar in form and complexity to natural ecological processes. That is, where the shape of an agricultural bed was traditionally defined by the length of a farmer's arm, and length of a field by his relationship with a horse or team of oxen, the shape of a contemporary sustainable foodshed should be defined by walking or cycling distance and be informed by the qualities of natural systems which have been quietly and productively gardening for millennia. A sustainable foodshed should be *shaped* to respond to the qualities of a human and community systems, and natural ecosystems in a series of nested systems that work together.

The *rhythm* of a foodshed should follow a *dynamic equilibrium* - a concept overlooked in the current sustainability paradigm which seeks to achieve an optimal steady state. This *flexibility* allows for periods of growth, death and regrowth, cycles inherent in living systems. The qualities of diversity and connectivity can apply to either human or natural systems and generally assist in regaining equilibrium following a disturbance - the essence of resilience. From a human perspective, connectivity is manifest in the relationship between urban agriculture and regional farms while wildlife corridors on a field, farm and regional scale are critical for resilient wildlife migrations and the ecological services they provide.

Transitions

Availability of cheap energy in the form of fossil fuels has enabled the form of the modern industrial agricultural system. It follows that the depletion of this resource could be the factor which through market forces will drive a reformed agricultural system and new regional form. Considerably more compact and less auto-dependent regional forms dominate many European cities where the price of gasoline is \$1.86 l^{-1}, nearly twice the price in Canada and nearly 2.5X the price in the US[12.3]. In mid 2008, the rise of oil prices to nearly \$150 USD $barrel^{-1}$ sparked food riots around the world where increasing transport and production costs, biofuel use, grain consumption, and drought conditions led to food prices 130% higher than they were in 2002 (Tenenbaum, 2008, Mitchel, 2008). While market forces have a buffering effect on "developed" countries, for many in the developing world this price marked a tipping point beyond which many civil society broke down. Arguably structural changes to regional form and the global agricultural system should occur before this point is reached again.

The spot price for crude oil was roughly \$80 USD bbl^{-1} on March 25, 2010. The US Energy Information Administration (EIA) expects a marginal price rise to \$82 by the end of the year and to \$85 per barrel by the end of 2011. Assuming a linear rise of \$5 $year^{-1}$, prices would double by 2042 to \$160 USD bbl^{-1}. Assuming a non-linear increase of 3% $year^{-1}$, this tipping point would be reached by 2033[12.4]. Availability of fossil fuels is clearly not a linear function as seen by the volatility over the last few years. However, it is hard to deny the probability that the price of oil will increase over the next century, and likely at a rate faster than society's capacity to pay for it.

Discussing food security and the collapse of the modern energy paradigm is likely to ruffle a few feathers. Working through the social structures that frame this discussion is therefore just as important as the biophysical and spatial qualities of the foodshed itself. The "Transition Town" movement inspired by Rob Hopkins' book, *Transition Town Handbook: From oil dependency to local resilience*, provides some interesting tools that speak directly to the biophysical forms that support post-oil communities *and* the social pathways leaders can follow to get there. This study paints a picture that can be taken as catastrophic or beautiful. I recommend framing the picture as the latter, and sincerely believe that the transition or "Great turning" described by deep ecologists Joanna Macy and John Seed will be a period of positive growth and rejuvenation for humanity.

In the interim, planners might consider the following perspectives when prioritizing policy and land use change:

A) Make the most change with the least effort: What matters most is a function of the relative energy contribution of an input to the food cycle and society's capacity to change it.

B) Consider hidden variables that really matter: There are several variables that are embedded in each energy input, such as dietary habits and labour. These variables deserve immediate attention given their effect on others, though are difficult to change from a planning perspective.

C) Focus attention on what will matter most in the future: Designers should consider "sticky" variables like urban and regional form, due to their lasting effects on the region. While distribution makes up a small portion of the food energy input today, improvements in other sectors might make it a more dominant variable in the future.

The objective and subjective methods discussed in this report are much more important than the final design and are intended to be the beginning of this conversation rather than the end. Future discussions should seek to better quantify nutrient cycling capacity of neighborhoods and cities, obtain more accurate organic yield data to recalibrate a sustainable foodprint, and elaborate on the spatial qualities of a human-scaled agriculture. These conversations should engage farmers, planners, designers and consumers, the result of which will undoubtedly lead to more informed and sustainable foodshed planning.

Endnotes

12.1 Reconceptualizing the 41-mile (66km diet).

After reducing production and processing inputs by 50% as described in the last scenario in section 8, 0.84 GJ cap^{-1} is available for distribution and nutrient cycling. At a modal efficiency of 2.22 MJ, (typical of the weighted freight efficiency described by NRC, 2009), 581kg of food could be shipped 640 km before the 0.84 GJ of energy runs out.

This distance reduces to 66km if nutrient cycling is considered which necessitates an additional 6kg of PAN cap^{-1}, equating to roughly 5 tonnes of kitchen compost (assuming 3%total N and 6% PAN availability). In other words, 5.6 tonnes of material must be shipped, and it takes 0.84 GJ of energy to ship that material 66km.

12.2 Carrying capacity

Carrying capacity is defined as the “environment’s maximum persistently supportable load” (Catton 1986). Some have suggested that the Earth can support as many as 10 billion people (Smil, 1994, Waggoner, 1996). Malthus (1798) predicted that population would eventually overrun available food supplies since the former increases at a geometric (non-linear) rate and the latter in a linear fashion. He was proven wrong when food supplies increased at a geometric rate of growth, following advances in crop technologies and increases in fossil fuel-based fertilizer use in the 1960s.

12.3 Oil prices

Average British oil prices sourced from petrolprices.com on April 14th, 2010, found to be 120.5p l^{-1} or \$1.86 CAD l^{-1} (Petrolprices.com). Canadian prices for the same day were \$1.044 CAD l^{-1} based on average Canadian prices (BCgasprices.com, 2010). Average American prices for the same day were \$2.857 USD gal^{-1} or \$0.75 CAD l^{-1}, (FuelGuageReport.com, 2010). (note that the Canadian dollar was on par with the American dollar at the time)

12.4 Oil price projections

Dated Brent Spot price http://www.bloomberg.com/energy/, accessed March 29th, 2010., http://www.eia.doe.gov/steo accessed March 29, 2010.

At \$2.5 USD increase per year would result in a \$25 increase over ten years, \$50 in 20 years and \$80 increase in 32 yrs. A non-linear increase assumes only 3.1% per year compounded every year.

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14 Appendix A - Modelling Assumptions

Crop	Adjusted Retail Consumption (kg/cap*yr)	Adjusted Actual Consumption (kg/cap*yr)	Moisture content (%)	Wastage (% of retail)	Energy content (kJ/kg)	Total Energy purchased (kJ/cap*yr)	Total Energy consumed (KJ/cap*yr)
Grains							
Winter wheat	39.65	28.95	10%	27%	14,500	574,940	419,713
Spring wheat	39.65	28.95	10%	27%	14,500	574,940	419,713
Spring Oats	0.85	0.49	37%	42%	15,864	13,410	7,848
Breakfast foods	5.70	4.22	4%	26%	13,983	79,667	59,029
Corn flour and meal	3.23	2.39	10%	26%	15,103	48,742	36,028
Pot and Pearl Barley	0.05	0.03	NA	40%	14,740	809	486
Rye flour	0.48	0.26	10%	45%	14,814	7,155	3,908
Sum:	**89.61**	**65.29**				**1,299,662**	**946,726**
Average:			**13%**	**32%**	**14,772**		
Vegetables							
Beans	5.63	5.85	89%	11%	1,472.77	8,288	8,621.17
Beets	0.63	0.51	91%	31%	1,220.33	775	627.16
Broccoli	4.23	2.41	91%	51%	1,188.64	5,027	2,860.65
Brussels Sprouts	0.28	0.21	87%	35%	1,636.05	458	348.63
Cabbage	5.26	3.62	92%	41%	1,075.89	5,661	3,897.43
Carrots	8.35	6.41	88%	34%	1,787.71	14,927	11,450.71
Cauliflower	2.64	0.98	92%	68%	965.54	2,545	944.02
Corn	10.41	1.86	70%	85%	4,510.03	46,928	8,366.73
Cucumbers	4.56	2.87	96%	46%	542.11	2,473	1,556.11
Garlic	0.39	0.29	59%	36%	5,578.67	2,161	1,608.32
Lettuce & Salad Greens	11.89	8.35	96%	40%	539.04	6,409	4,500.00
Onions	8.78	5.53	90%	46%	1,595.15	14,006	8,817.69
Peas	4.63	4.71	89%	13%	1,752.05	8,107	8,257.51
Peppers	3.48	2.46	92%	39%	1,123.22	3,904	2,759.54
Potatoes	80.35	46.59	71%	50%	4,556.83	366,131	212,309.95
Pumpkin	0.81	0.50	94%	47%	836.80	678	419.56
Rhubarb	0.15	0.10	93%	42%	891.67	134	90.76
Spinach	1.11	0.69	92%	47%	976.27	1,082	673.05
Winter Squash	0.81	0.50	89%	47%	1,632.78	1,324	818.66
Tomato	31.99	15.66	94%	58%	883.29	28,257	13,828.66
Turnip/Sweed / Rutabaga	1.32	0.76	94%	50%	885.08	1,171	676.75
Zuchini	0.81	0.50	94%	47%	851.61	690	426.99
Sum:	**188.50**	**111.36**				**521,137**	**293,860**
Average:			**88%**	**44%**	**1,659**		
Fruit							
Apples	57.11	31.47	84%	36%	2455.83	140,263	77,286.72
Blackberries	0.60	0.43	86%	17%	2179.17	1,310	945.28
Blueberries	2.45	1.74	85%	18%	2337.27	5,738	4,055.45
Cherries	1.63	1.04	81%	26%	3014.94	4,909	3,138.77
Grapes	19.74	11.97	81%	30%	3012.48	59,465	36,066.43
Kiwifruit	1.15	0.63	83%	37%	2532.42	2,918	1,592.85
Melon (Cantelope, wintermelon)	10.95	4.03	90%	57%	1455.30	15,931	5,870.93
Watermelon	8.92	2.97	92%	62%	1345.90	12,003	3,999.21
Peach	6.24	3.45	88%	36%	1793.14	11,185	6,183.75
Pears	7.06	4.27	84%	30%	2470.07	17,449	10,553.97
Plums	2.35	1.41	85%	31%	2282.18	5,374	3,217.39
Rasberries	0.60	0.43	87%	17%	2040.98	1,227	885.34
Strawberries	6.19	4.08	92%	24%	1260.24	7,798	5,138.68
Sum Fruit:	**125.00**	**67.93**				**285,568**	**158,935**
Average:			**86%**	**32%**	**2,168**		
Oils and Sugar:							
Canola (oil)	29.14	21.49	16%	26%	34,079	993,065	732,359.82
Canola (meal)	0	0	na	na	10,083	-	-
Maple Syrup	0.13	0.1	32%	23%	14,560	1,893	1,456.03
Sugar Beets (Sugar)	40.94	30.01	1%	27%	14,628	598,874	438,989.31
Sum:	**70.21**	**51.6**				**1,593,832**	**1,172,805**
Average:			**16%**	**25%**	**18,338**		
Animals							
Pork (Hogs)	22.29	12.53	58%	43%	10,042	220,815	125,821
Cow (Beef)	22.64	13.61	47%	39%	14,422	322,199	196,290
Chickens (layers)	10.91	8.93	75%	17%	6,276	67,530	56,045
Chickens (broiler)	30.81	10.72	65%	65%	6,908	210,017	74,059
Turkey	4.27	2.21	65%	48%	7,113	29,945	15,719
Cow (fluid milk products)	87.96	64.15	89%	26%	2,075	180,056	133,102
Cow (cheese)	12.00	8.75	37%	26%	17,035	201,693	149,055
Cow (other dairy)	25.58	18.79	3%	26%	16,178	408,336	303,987
Bee hive (honey)	0.71	0.67	17%	4%	12,725	8,907	8,526
Mutton / Sheep	1.03	0.42	57%	54%	10,780	11,103	
Sum:	**218.21**	**147.19**				**1,660,600**	**1,124,464**
Average:			**55%**	**29%**	**9,624.32**		

Appendix (14.1) Food Consumption

Crop	Adjusted Retail Consumption (kg/cap*yr)	Area req'd(ha)	Area req'd (m^2)	Total Energy purchased (kJ/cap*yr)	Food Energy Intensity - OUT (kJ/ha)	Production Energy Intensity - IN (kJ/ha)	Target Yield (kg/ha)
Grains							
Winter wheat	39.65	0.0098	98.15	574,940	58,580,000	6,043,152	4,040.00
Spring wheat	39.65	0.0115	115.26	574,940	49,880,000	6,043,152	3,440.00
Spring Oats	0.85	0.0002	1.97	13,410	67,898,765	6,098,600	4,280.00
Breakfast foods	5.70	0.0009	9.32	79,667	85,436,441	6,043,152	6,110.00
Corn flour and meal	3.23	0.0005	5.47	48,742	89,105,128	20,655,643	5,900.00
Pot and Pearl Barley	0.05	0.0000	0.09	809	89,914,000	5,701,185	6,100.00
Rye flour	0.48	0.0001	1.40	7,155	50,959,216	4,383,223	3,440.00
Sum:	**89.61**	**0.0232**	**231.67**	**1,299,662**			
Average:					**79,491,461**	**10,381,298**	**5,383**
Vegetables							
Beans	5.63	0.0004	4.16	8,288	19,922,947	17,854,568	12,069
Beets	0.63	0.0000	0.30	775	26,117,003	18,283,321	19,094
Broccoli	4.23	0.0006	5.85	5,027	8,585,241	47,220,002	6,444
Brussels Sprouts	0.28	0.0000	0.24	458	19,364,611	47,220,002	10,560
Cabbage	5.26	0.0002	1.96	5,661	28,813,960	40,575,841	23,894
Carrots	8.35	0.0003	2.96	14,927	50,402,474	18,283,321	25,154
Cauliflower	2.64	0.0003	2.88	2,545	8,848,271	47,220,002	8,176
Corn	10.41	0.0007	6.88	46,928	68,243,416	18,433,599	13,500
Cucumbers	4.56	0.0003	3.44	2,473	7,181,555	12,521,704	11,819
Garlic	0.39	0.0001	1.01	2,161	21,447,293	18,283,321	3,430
Lettuce & Salad Greens	11.89	0.0005	4.79	6,409	13,394,220	47,220,002	22,169
Onions	8.78	0.0002	2.39	14,006	58,626,085	18,283,321	32,790
Peas	4.63	0.0006	5.75	8,107	14,096,065	9,190,470	7,178
Peppers	3.48	0.0003	3.33	3,904	11,708,366	55,977,271	9,300
Potatoes	80.35	0.0045	44.81	366,131	81,700,051	33,489,942	15,996
Pumpkin	0.81	0.0000	0.28	678	23,869,336	48,292,662	25,449
Rhubarb	0.15	0.0000	0.06	134	24,136,277	35,716,959	24,150
Spinach	1.11	0.0001	0.77	1,082	14,115,820	16,402,468	12,900
Winter Squash	0.81	0.0000	0.24	1,324	55,086,128	35,716,959	30,100
Tomato	31.99	0.0015	14.78	28,257	19,112,633	47,220,002	19,305
Turnip/Sweed / Rutabaga	1.32	0.0000	0.31	1,171	37,568,536	18,283,321	37,870
Zuchini	0.81	0.0001	0.65	690	10,616,269	12,521,704	11,122
Sum:	**188.50**	**0.0108**	**107.85**	**521,137**			
Average:					**28,316,207**	**30,191,398**	**17,385**
Fruit							
Apples	57.11	0.0026	26.27	140,263	53,400,741	58,575,715	19,400
Blackberries	0.60	0.0001	0.55	1,310	23,643,608	27,460,531	9,680
Blueberries	2.45	0.0003	2.51	5,738	22,870,248	28,904,183	8,730
Cherries	1.63	0.0003	2.85	4,909	17,234,432	86,933,034	5,100
Grapes	19.74	0.0026	25.90	59,465	22,960,484	60,989,367	6,800
Kiwifruit	1.15	0.0000	0.41	2,918	70,961,677	61,707,181	25,000
Melon (Cantelope, wintermelon)	10.95	0.0004	3.91	15,931	40,779,489	66,936,407	25,000
Watermelon	8.92	0.0003	2.65	12,003	45,256,678	41,316,685	30,000
Peach	6.24	0.0035	35.20	11,185	3,177,567	83,194,766	1,581
Pears	7.06	0.0003	3.33	17,449	52,326,226	101,636,369	18,900
Plums	2.35	0.0003	3.09	5,374	17,394,306	42,623,486	6,800
Rasberries	0.60	0.0001	0.58	1,227	21,098,810	27,595,393	9,223
Strawberries	6.19	0.0007	7.11	7,798	10,972,630	99,483,797	7,768
Sum Fruit:	**125.00**	**0.01**	**114.36**	**285,568**			
Average:					**30,928,992**	**60,565,916**	**13,383**
Oils and Sugar:							
Canola (oil)	29.14	0.0756	755.71	993,065	13,140,900	36,636,467	386
Canola (meal)	0	0.0000	0.00	-	5,832,262	36,636,467	578
Maple Syrup	0.13	0.0007	6.91	1,893	2,739,467	112,589	188
Sugar Beets (Sugar)	40.94	0.0068	68.23	598,874	87,768,605	20,202,670	6,000
Sum:	**70.21**	**0.083**	**830.85**	**1,593,832**			
Average:					**27,370,308**	**23,397,048**	**1,788**
Animals		(includes feedshed)					
Pork (Hogs)	22.29	0.020899857	209.00	220,815	56,175,624	340,282,999	12,105
Cow (Beef)	22.64	0.102194186	1021.94	322,199	2,001,195	10,477,280	339
Chickens (layers)	10.91	0.008601948	86.02	67,530	39,558,011	192,325,877	6,840
Chickens (broiler)	30.81	0.028811232	288.11	210,017	27,977,337	199,154,215	10,260
Turkey	4.27	0.002132154	21.32	29,945	72,862,370	1,680,594,118	17,434
Cow (fluid milk products)	87.96	0.050546463	505.46	180,056	4,056,495	18,805,891	5,278
Cow (cheese)	12.00	0.006896406	68.96	201,693	33,295,196	18,805,891	5,278
Cow (other dairy)	25.58	0.01470146	147.01	408,336	31,853,163	18,805,891	5,278
Bee hive (honey)	0.71	0	0.00	8,907	2,732,625	na	200
Mutton / Sheep	1.03	0.008400103	84.00	11,103	937,698		207
Sum:	**218.21**	**0.24**	**2431.84**	**1,660,600**			
Average:					**27,144,971.44**	**275,472,462.38**	**$ 6,765.63**

Appendix (14.2) Food Production Energy Intensity

FOOD ENERGY SUMMARY	Production Conventional (GJ/cap)	Production Organic (GJ/cap)	Organic Input as % of Conventional	Production Energy Efficiency Proxy	Reference
Grains	0.22	0.15	68%	Spring wheat	Pimentel et al., 1983; Briggle, 1980
Vegetables	0.65	0.36	55%	Potato	Pimentel et al., 1983; Schreiner and Nafus, 1980
Fruit	1.01	0.80	79%	Apples	Pimentel et al., 1983; Funt, 1980
Oils and Sugars	4.38	2.95	67%	Spring Wheat & Potato (weighted)	Pimentel et al., 1983; Briggle, 1980
Animal Products	6.93	5.04	73%	Pig and cattle	Dalgaard et al, 2001. (Denmark)
Sum:	***13.19***	***9.29***	***70%***		

Appendix (14.3) Production Energy Input Comparison: Conventional vs Organic. Proxies based on research are used for each food group to estimate energy efficiency improvements. See appendix (14.2) for a crop by crop analysis of production energy inputs.

Crop	Adjusted Retail Consumption (kg/cap*yr)	Total Energy purchased (kJ/cap*yr)	Processing Energy Intensity (kJ/kg)	P1 Processing Energy Input (kJ/cap*yr)
Grains				
Winter wheat	39.65	574,940	6,213.24	246,361.34
Spring wheat	39.65	574,940	6,213.24	246,361.34
Spring Oats	0.85	13,410	2,025.06	1,711.73
Breakfast foods	5.70	79,667	65,584.20	373,657.12
Corn flour and meal	3.23	48,742	2,025.06	6,535.68
Pot and Pearl Barley	0.05	809	2,025.06	111.15
Rye flour	0.48	7,155	2,025.06	978.13
Sum:	**89.61**	**1,299,662**		**875,716.49**
Average:			**10,017.89**	
Vegetables				
Beans	5.63	8,288	400.49	2,253.85
Beets	0.63	775	400.49	254.26
Broccoli	4.23	5,027	400.49	1,693.62
Brussels Sprouts	0.28	458	400.49	112.05
Cabbage	5.26	5,661	400.49	2,107.33
Carrots	8.35	14,927	400.49	3,344.15
Cauliflower	2.64	2,545	400.49	1,055.82
Corn	10.41	46,928	400.49	4,167.25
Cucumbers	4.56	2,473	400.49	1,827.21
Garlic	0.39	2,161	400.49	155.14
Lettuce & Salad Greens	11.89	6,409	400.49	4,761.96
Onions	8.78	14,006	400.49	3,516.52
Peas	4.63	8,107	400.49	1,853.07
Peppers	3.48	3,904	400.49	1,391.96
Potatoes	80.35	366,131	400.49	32,178.78
Pumpkin	0.81	678	400.49	324.65
Rhubarb	0.15	134	400.49	60.33
Spinach	1.11	1,082	400.49	443.88
Winter Squash	0.81	1,324	400.49	324.65
Tomato	31.99	28,257	400.49	12,812.04
Turnip/Sweed / Rutabaga	1.32	1,171	400.49	530.06
Zuchini	0.81	690	400.49	324.65
Sum:	**188.50**	**521,137**		75,493.23
Average:			400.49	
Fruit				
Apples	57.11	140,263	881.51	50,346.80
Blackberries	0.60	1,310	881.51	529.97
Blueberries	2.45	5,738	881.51	2,164.03
Cherries	1.63	4,909	881.51	1,435.33
Grapes	19.74	59,465	881.51	17,400.56
Kiwifruit	1.15	2,918	881.51	1,015.77
Melon (Cantelope, wintermelon)	10.95	15,931	881.51	9,649.80
Watermelon	8.92	12,003	881.51	7,861.17
Peach	6.24	11,185	881.51	5,498.40
Pears	7.06	17,449	881.51	6,227.10
Plums	2.35	5,374	881.51	2,075.70
Rasberries	0.60	1,227	881.51	529.97
Strawberries	6.19	7,798	881.51	5,454.24
Sum Fruit:	**125.00**	**285,568**		**110,188.84**
Average:			**881.51**	
Oils and Sugar:				
Canola (oil)	29.14	993,065	23,681.44	1,725,192.90
Canola (meal)	0	-	23,681.44	-
Maple Syrup	0.13	1,893	-	-
Sugar Beets (Sugar)	40.94	598,874	23,681.44	969,518.15
Sum:	**70.21**	**1,593,832**		**2,694,711.06**
Average:			**17,761.08**	
Animals				
Pork (Hogs)	22.29	220,815	5,045.90	145,624.79
Cow (Beef)	22.64	322,199	5,045.90	154,656.96
Chickens (layers)	10.91	67,530	-	-
Chickens (broiler)	30.81	210,017	5,045.90	153,395.48
Turkey	4.27	29,945	5,045.90	21,243.26
Cow (fluid milk products)	87.96	180,056	1,481.14	128,532.98
Cow (cheese)	12.00	201,693	1,673.60	19,815.42
Cow (other dairy)	25.58	408,336	3,681.92	92,931.66
Bee hive (honey)	0.71	8,907	-	-
Mutton / Sheep	1.03	11,103	5,045.90	5,197.28
Sum:	**218.21**	**1,660,600**		**716,200.55**
Average:				

Appendix (14.4) Processing Energy Intensity

Crop	Adjusted Retail Consumption (kg/cap*yr)	Total Energy purchased (kJ/cap*yr)	Target Yield (kg/ha)	Net Nutrient Demand Intensity (PAN kg/ha)	P1 PAN Nutriend Demand (kg)
Grains					
Winter wheat	39.65	574,940	4,040.00	42.21	0.41
Spring wheat	39.65	574,940	3,440.00	42.39	0.49
Spring Oats	0.85	13,410	4,280.00	21.96	0.00
Breakfast foods	5.70	79,667	6,110.00	84.33	0.08
Corn flour and meal	3.23	48,742	5,900.00	43.62	0.02
Pot and Pearl Barley	0.05	809	6,100.00	82.82	0.00
Rye flour	0.48	7,155	3,440.00	20.57	0.00
Sum:	**89.61**	**1,299,662**			**1.01**
Average:			**5,383**		
Vegetables					
Beans	5.63	8,288	12,069	- 32.85	- 0.01
Beets	0.63	775	19,094	17.78	0.00
Broccoli	4.23	5,027	6,444	1.89	0.00
Brussels Sprouts	0.28	458	10,560	39.30	0.00
Cabbage	5.26	5,661	23,894	26.95	0.01
Carrots	8.35	14,927	25,154	10.75	0.00
Cauliflower	2.64	2,545	8,176	- 3.34	- 0.00
Corn	10.41	46,928	13,500	46.25	0.03
Cucumbers	4.56	2,473	11,819	- 25.43	- 0.01
Garlic	0.39	2,161	3,430	- 0.79	- 0.00
Lettuce & Salad Greens	11.89	6,409	22,169	7.21	0.00
Onions	8.78	14,006	32,790	- 10.60	- 0.00
Peas	4.63	8,107	7,178	- 95.87	- 0.06
Peppers	3.48	3,904	9,300	- 23.32	- 0.01
Potatoes	80.35	366,131	15,996	18.76	0.08
Pumpkin	0.81	678	25,449	28.46	0.00
Rhubarb	0.15	134	24,150	- 2.10	- 0.00
Spinach	1.11	1,082	12,900	30.85	0.00
Winter Squash	0.81	1,324	30,100	3.86	0.00
Tomato	31.99	28,257	19,305	- 7.54	- 0.01
Turnip/Sweed / Rutabaga	1.32	1,171	37,870	44.89	0.00
Zuchini	0.81	690	11,122	- 16.31	- 0.00
Sum:	**188.50**	**521,137**			0.03
Average:			**17,385**		
Fruit					
Apples	57.11	140,263	19,400	- 14.45	- 0.04
Blackberries	0.60	1,310	9,680	10.52	0.00
Blueberries	2.45	5,738	8,730	- 15.86	- 0.00
Cherries	1.63	4,909	5,100	- 18.57	- 0.01
Grapes	19.74	59,465	6,800	- 12.87	- 0.03
Kiwifruit	1.15	2,918	25,000	17.33	0.00
Melon (Cantelope, wintermelon)	10.95	15,931	25,000	2.03	0.00
Watermelon	8.92	12,003	30,000	10.44	0.00
Peach	6.24	11,185	1,581	- 27.16	- 0.10
Pears	7.06	17,449	18,900	- 14.46	- 0.00
Plums	2.35	5,374	6,800	- 20.09	- 0.01
Rasberries	0.60	1,227	9,223	13.01	0.00
Strawberries	6.19	7,798	7,768	29.58	0.02
Sum Fruit:	**125.00**	**285,568**		**-**	**0.16**
Average:			**13,383**		
Oils and Sugar:					
Canola (oil)	29.14	993,065	386	- 9.53	- 0.72
Canola (meal)	0	-	578	- 9.53	-
Maple Syrup	0.13	1,893	188	-	-
Sugar Beets (Sugar)	40.94	598,874	6,000	- 26.92	- 0.18
Sum:	**70.21**	**1,593,832**		**-**	**0.90**
Average:			**1,788**		
Animals				*nutrient demand / animal	
Pork (Hogs)	22.29	220,815	12,105	0.22	0.08
Cow (Beef)	22.64	322,199	339	66.05	6.58
Chickens (layers)	10.91	67,530	6,840	0.29	0.20
Chickens (broiler)	30.81	210,017	10,260	0.01	0.10
Turkey	4.27	29,945	17,434	- 0.33	- 0.28
Cow (fluid milk products)	87.96	180,056	5,278	129.35	3.75
Cow (cheese)	12.00	201,693	5,278	129.35	0.51
Cow (other dairy)	25.58	408,336	5,278	129.35	1.09
Bee hive (honey)	0.71	8,907	200	na	na
Mutton / Sheep	1.03	11,103	207	12.68	0.55
Sum:	**218.21**	**1,660,600**			**12.58**
Average:			**$ 6,765.63**		

Appendix (14.5) Nutrient Cycling

Appendix (14.6) Financial Return

Gross return is simply the market price (current organic direct market prices assumed for most products) multiplied by the mass of foods sold. This is equal to the "Money saved" simulated for section (11).

The contribution margin or marginal return is the gross returns less direct costs (labour, machinery, fertilizer, etc.) The BCMAL model direct and indirect costs in their planning for profit guidelines, but many are calculated from indirect market sales or old pricing schemes. This report has maintained the *proportion* of gross margins that should be counted towards direct costs and that which should be counted towards marginal return. For example, if organic potato production had a gross earnings of $4,160 and direct costs of $3,751 in North Okanagan in 2002 (see: http://www.agf.gov.bc.ca/busmgmt/budgets/budget_pdf/specialty_organic/transitional_organic_potato.pdf, accessed March 25, 2010), the marginal proportion is retained at 10% of gross earnings (gross earnings less direct costs divided by gross earnings). *Current* marginal returns are calculated by finding current gross margins (based on direct marketed sales), less the proportion of income that should be dedicated to direct operational costs.

$$\boldsymbol{MR} = \boldsymbol{F_{MR}}(\boldsymbol{FP_m} \times \boldsymbol{V})$$

$Where:$

$MR = Marginal\ Return\ (\$)$

$F_{MR} = Marginal\ Return\ fraction$

$FP_m = Mass\ of\ Food\ Purchased\ \left(\frac{kg}{cap}\right)$

$V = \ Market\ Value\ (\frac{\$}{kg})$

This method accounts for inflationary pricing and costs but does have several drawbacks. The method does not account for land taxation, loan repayments, nor does it account for all savings or extra costs associated with organic farming as some of the profit schedules are based on conventional practise. The method also fails where marginal returns are negative in BCMAL worksheets, forcing negative returns no matter what pricing or yields are possible in today's market. Carrots and beef, for example, lose money in every simulation.

Crop	Adjusted Retail Consumption (kg/cap*yr)	Target Yield (kg/ha)	Gross revenue ($/ha)	Direct Market Value ($/kg)	Contribution margin ($/ha)	Contribution Margin per Capita ($)	Money saved on groceries ($)
Grains							
Winter wheat	39.65	4,040.00	17,089.97	$ 4.19	$ 13,378.51	$ 131.30	$ 166.09
Spring wheat	39.65	3,440.00	14,542.02	$ 4.19	$ 11,383.90	$ 131.22	$ 166.09
Spring Oats	0.85	4,280.00	1,689.66	$ 0.32	$ 1,322.71	$ 0.26	$ 0.27
Breakfast foods	5.70	6,110.00	25,764.45	$ 4.19	$ 20,169.14	$ 18.81	$ 23.87
Corn flour and meal	3.23	5,900.00	1,394.23	$ 0.24	$ 1,091.44	$ 0.60	$ 0.76
Pot and Pearl Barley	0.05	6,100.00	3,365.48	$ 0.52	$ 2,634.59	$ 0.02	$ 0.03
Rye flour	0.48	3,440.00	14,597.24	$ 4.19	$ 11,427.13	$ 1.60	$ 2.02
Sum:	**89.61**					**$ 283.81**	**$ 359.13**
Average:		**5,383**	**$ 15,267.72**	**$ 2.73**	**$ 11,952.00**	**$ 31.53**	**$ -**
							$ -
Vegetables							$ -
Beans	5.63	12,069	67,102.08	$ 4.96	$ 33,073.59	$ 13.76	$ 27.92
Beets	0.63	19,094	129,751.33	$ 6.06	$ 54,622.69	$ 1.62	$ 3.85
Broccoli	4.23	6,444	35,827.81	$ 4.96	$ 4,492.52	$ 2.63	$ 20.98
Brussels Sprouts	0.28	10,560	28,377.58	$ 2.40	$ 13,200.37	$ 0.31	$ 0.67
Cabbage	5.26	23,894	94,469.38	$ 3.53	$ 51,610.22	$ 10.14	$ 18.56
Carrots	8.35	25,154	138,609.86	$ 4.92	-$ 44,408.25	-$ 13.15	$ 41.05
Cauliflower	2.64	8,176	70,711.68	$ 7.72	$ 31,830.68	$ 9.16	$ 20.34
Corn	10.41	13,500	33,359.23	$ 2.20	$ 21,683.50	$ 14.91	$ 22.94
Cucumbers	4.56	11,819	65,712.12	$ 4.96	$ 31,355.02	$ 10.80	$ 22.63
Garlic	0.39	3,430	76,281.43	$ 19.84	$ 53,397.00	$ 5.38	$ 7.69
Lettuce & Salad Greens	11.89	22,169	219,123.17	$ 8.82	$ 152,137.62	$ 72.80	$ 104.85
Onions	8.78	32,790	121,538.78	$ 3.31	$ 90,554.24	$ 21.63	$ 29.04
Peas	4.63	7,178	46,648.90	$ 5.80	-$ 17,715.91	-$ 10.19	$ 26.83
Peppers	3.48	9,300	54,004.88	$ 5.18	$ 20,262.63	$ 6.76	$ 18.01
Potatoes	80.35	15,996	73,124.91	$ 4.08	$ 29,815.78	$ 133.62	$ 327.70
Pumpkin	0.81	25,449	102,503.93	$ 3.59	$ 43,611.14	$ 1.24	$ 2.91
Rhubarb	0.15	24,150	53,708.35	$ 1.98	$ 24,125.45	$ 0.13	$ 0.30
Spinach	1.11	12,900	127,506.38	$ 8.82	$ 116,229.15	$ 8.91	$ 9.77
Winter Squash	0.81	30,100	111,568.08	$ 3.31	$ 98,417.92	$ 2.36	$ 2.68
Tomato	31.99	19,305	131,185.16	$ 6.06	$ 50,925.66	$ 75.29	$ 193.95
Turnip/Sweed / Rutabaga	1.32	37,870	104,340.37	$ 2.46	$ 81,760.65	$ 2.55	$ 3.25
Zuchini	0.81	11,122	44,797.39	$ 3.59	$ 17,216.98	$ 1.12	$ 2.91
Sum:	**188.50**					**$ 371.78**	**$ 908.83**
Average:		**17,385**	**$ 87,738.76**	**$ 5.39**	**$ 43,554.48**	**$ 16.90**	$ -
							$ -
Fruit							$ -
Apples	57.11	19,400	95,876.89	$ 4.41	$ 41,241.16	$ 108.32	$ 251.83
Blackberries	0.60	9,680	125,339.76	$ 11.55	$ 55,965.43	$ 3.10	$ 6.95
Blueberries	2.45	8,730	64,501.18	$ 6.59	$ 31,796.60	$ 7.98	$ 16.18
Cherries	1.63	5,100	43,982.29	$ 7.69	$ 28,157.97	$ 8.02	$ 12.53
Grapes	19.74	6,800	33,606.33	$ 4.41	$ 24,919.05	$ 64.54	$ 87.04
Kiwifruit	1.15	25,000	74,131.61	$ 2.65	$ 16,605.48	$ 0.68	$ 3.05
Melon (Cantelope, wintermelon)	10.95	25,000	30,888.17	$ 1.10	$ 16,723.29	$ 6.53	$ 12.07
Watermelon	8.92	30,000	22,239.48	$ 0.66	$ 12,735.43	$ 3.38	$ 5.90
Peach	6.24	1,581	11,720.21	$ 6.61	$ 3,921.62	$ 13.80	$ 41.25
Pears	7.06	18,900	105,081.56	$ 4.96	$ 71,155.82	$ 23.73	$ 35.04
Plums	2.35	6,800	35,622.71	$ 4.67	$ 11,919.47	$ 3.68	$ 11.01
Rasberries	0.60	9,223	159,305.80	$ 15.41	$ 68,474.87	$ 3.98	$ 9.26
Strawberries	6.19	7,768	66,799.11	$ 7.67	$ 13,214.58	$ 9.39	$ 47.47
Sum Fruit:	**125.00**					**$ 257.14**	**$ 539.57**
Average:		**13,383**	**$ 66,853.47**	**$ 6.03**	**$ 30,525.44**	**$ 19.78**	**$ -**
							$ -
Oils and Sugar:							$ -
Canola (oil)	29.14	386	316.71	$ 0.82	$ 142.52	$ 10.77	$ 23.92
Canola (meal)	0	578	131.01	$ 0.23	$ 58.95	$ -	$ -
Maple Syrup	0.13	188	3,064.32	$ 16.28	$ 301.28	$ 0.21	$ 2.12
Sugar Beets (Sugar)	40.94	6,000	3,301.41	$ 0.55	$ 1,518.65	$ 10.36	$ 22.52
Sum:	**70.21**					**$ 21.34**	**$ 48.56**
Average:		**1,788**	**$ 1,703.36**	**$ 4.47**	**$ 505.35**	**$ 5.34**	**$ -**
Animals							
Pork (Hogs)	22.29	12,105	82,256.44	$ 6.06	$ 15,108.33	$ 315.76	$ 135.13
Cow (Beef)	22.64	339	4,185.97	$ 11.02	-$ 284.00	-$ 29.02	$ 249.61
Chickens (layers)	10.91	6,840	56,340.03	$ 7.35	$ 16,902.01	$ 145.39	$ 80.14
Chickens (broiler)	30.81	10,260	69,467.25	$ 6.04	$ 13,893.45	$ 400.29	$ 186.14
Turkey	4.27	17,434	29,729.57	$ 1.52	$ 7,432.39	$ 15.85	$ 6.49
Cow (fluid milk products)	87.96	5,278	52,170.87	$ 4.00	$ 4,959.90	$ 250.71	$ 351.85
Cow (cheese)	12.00	5,278	140,506.82	$ 23.75	$ 4,959.90	$ 34.21	$ 285.03
Cow (other dairy)	25.58	5,278	43,232.87	$ 7.31	$ 4,959.90	$ 72.92	$ 186.96
Bee hive (honey)	0.71	200	1,119.88	$ 5.00	$ 447.95	$ -	$ 3.54
Mutton / Sheep	1.03	207	2,716.61	$ 11.68	$ 597.65	$ 5.02	$ 12.04
Sum:	**218.21**					**$ 1,211.11**	**$ 1,496.93**
Average:		**$ 6,765.63**	**$ 42,291.62**	**$ 7.72**	**$ 9,230.81**	**$ 121.11**	**$ -**

15 Appendix B - Form Considerations and Typological Comparisons

Appendix (15.1) Comparing Farm Size, Shape and Function

The following case studies are rough approximations of the amount of space allotted to circulation, wildlands and cultivation for community gardens, small farms and regional farms. Data was based on aerial approximations of land use using Google Planimeter http://www.acme.com/planimeter/, informal interviews with community garden leaders and City Farmer (http://www.cityfarmer.org/vanccomgard83.html, accessed Feb 1st, 2010). Assessment from aerial imaging is difficult and depends entirely on the quality of the image and the precision of the map itself. Area designations are rough estimates that indicate a general relationship (larger the farm, the greater the land utilization), but do not represent an accurate account of cultivation intensity.

In no way do low land cultivation values indicate community gardens are under-utilized. Small-scale, community oriented production necessitates highly accessible beds to meet the social and habitat functions central to these gardens.

Tea Swamp Community Gardens, Sofia St @ 16th
Total Area: 0.0314 ha
Number of Beds: 19
Bed Area: 6.88 sqm
Area under cultivation: 0.0131ha
Percentage of total area under cultivation: 42%
(image: Province of BC, 2010)

Cedar Cottage Community Gardens*Victoria at Hull St.*
Total Area: na
Number of Beds: 28
Bed Area: 2.51 sqm
Area under cultivation: 0.007 ha
Percentage of total area under cultivation: na
**note severe restrictions as garden is under the skytrain.*
(image: Province of BC, 2010)

Fraser St Garden, Fraser @ 8th
Total Area: 0.1133 ha
Number of Beds: 50
Bed Area: 9.29 sqm
Area under cultivation: 0.051ha
Percentage of total area under cultivation: 45%
(image: Province of BC, 2010)

Cottonwood Community Gardens, Malkin St. DT ES
Total Area: 0.958ha
Number of Beds: 50
Bed Area: 13 sqm
Area under cultivation: 0.065ha
Percentage of total area under cultivation: 7%
(image: Province of BC, 2010)

Maple Community Gardens Maple @ 6th Ave
Total Area: 0.21ha
Number of Beds: 80
Bed Area: 5.129 sqm
Area under cultivation: 0.41ha
Percentage of total area under cultivation: 20%
(image: Province of BC, 2010)

Strathcona Community Gardens, Keefer St, DT ES
Total Area: 1.588ha
Number of Beds: 290
Bed Area: 13 sq m
Area under cultivation: 0.377ha
Percentage of total area under cultivation: 24%
Note: Large area for perennial fruits. Considerable wildlands preservation.
(image: Province of BC, 2010)

Fairview Gardens, Goleta, CA
Focus: Intensive Production
Context: Suburban
Total Area: 12.58 acres
Intensive Annual Cultivation: 5.25 acres
Perennial Cultivation: 1.59 acres
Intensive utilization of cleared area: 54%
(image US geological Survey, Google Earth)

Four Season Farm, Harborside, ME
Focus: Intensive Production
Context: Rural, Coastal Forest
Total Area: 12.09 acres
Intensive Cultivation: 1.9 acres
Intensive utilization of cleared area: 16%
(image: 2010 Digital Globe)

Hazelmere Farms, Surrey, BC
Focus: Intensive Production
Context: Rural, Small Acreages, adjacent municipal greenway
Total Area: 6.86acres
Intensive Cultivation: 3.29 acres
Intensive utilization of cleared area: 47%
(image: City of Surrey)

Fraser Common Farm, Aldergrove, BC
Focus: Intensive Production, Biodiversity (TLC Conservation Partner)
Context: Rural, Small Acreages
Total Area: 19.09 acres
Intensive Cultivation: 3.97 acres
Intensive utilization of cleared area: 21%
(image: Digital Globe)

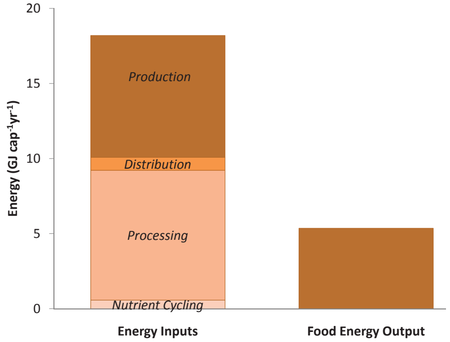
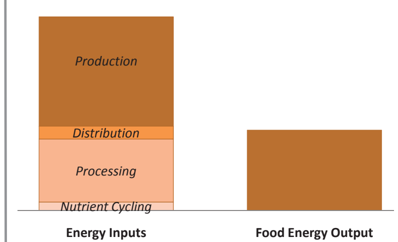
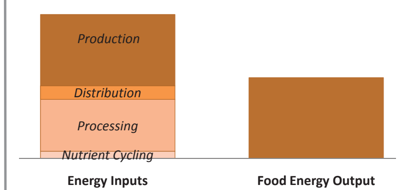
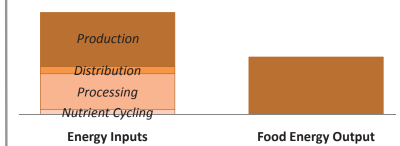
UC Santa Cruz Farm, Santa Cruz, CA
Focus: Teaching and Research
Context: Semi-Desert Institutional (extensive preserved habitat surrounding)
Total Area: 24.41 acres
Intensive Cultivation: 9.21 acres
Intensive utilization of cleared area: 37.7%
(image: Google 2009)

UBC Farm, Vancouver, University of British Columbia
Focus: Teaching and Research and Community Agriculture.
Context: Temperate Rainforest, Institutional (extensive preserved habitat surrounding)
Total Area: 24 ha
Wildlands area 12 ha
12 ha cleared, Intensive Cultivation: 4.6 ha
Intensively cultivation of cleared area: 38%
(image: Province of BC, 2010)

Southlands Farm, Tsawwassen, BC*
Focus: Potato and hay production
Context: Temperate rainforest, rural residential
Total Area: 508.3ac; Buildings and residential: 4.73 ac ; Forested area: 79.7ac; Cleared area: 428.6 ac; Under production: 341.2 ac
Area under production of cleared area: 79.6%
Area under production of total area: 67%
(image: Digital Globe, Province of BC 2010)

Cedar Island Farm (Urban Grains), Aggasiz, BC*
Focus: Milling grain production
Context: Temperate Rainforest, Rural residential Total Area: 100 acres
Intensive Cultivation: 87.174 acres
Intensive utilization total area: 87.2%
(image: IMTCAN 2010)

* These last two examples illustrate the difficulty in alloting a specific area for wildlands and circulation. Southlands farm has a large forested area important to the functioning of the local ecosystem, where Cedar Island Farm is next to existing forest, thus doesn't "need" to designate as much land for wildlife. The context is critical for assessing appropriate size and shape of wildland allotments.

	Business as Usual	Energy Efficient	LactoVegetarian	"Almost" Sustainable
				
Diet			Meats are excluded, oil and sugar crops reduced by 50%	Meats are excluded, oil and sugar crops reduced by 50%, and total caloric consumption is reduced to 2,500kcal cap^{-1} day^{-1}
Production		Ten percent improvement in agricultural production efficiency over 2006 assumptions.	Ten percent improvement in agricultural production efficiency over 2006 assumptions.	Ten percent improvement in agricultural production efficiency over 2006 assumptions.
Processing		Single set of appliences per household with 50% energy improvements over 2050 assumptions.	Single set of appliences per household with 50% energy improvements over 2050 assumptions and stove use is reduced by 50% on account of dietary changes.	One set of appliences for every two households[8,11] with 50% energy efficiency improvements over 2050 levels; no freezer, dishwasher are used and stove use is reduced 50% from 2006 levels accounting for dietary changes.
Distribution		Improved distribution network through added rail station.	Improved distribution network through added rail station.	Improved distribution network through added rail station.

Appendix (15.2). Comparison of Food System Energy Balance Scenarios - 2050.

City Typology	Density (pph)	Population	City Area (ha)	Foodprint (ha)	Reference
Garden City	79	32,000	405	21,760	Howard, (1898), Frey (1999), p54
Group of Slumless cities	9	250,000	26,709	170,000	Howard (1898)
Urban Neighbourhood	70	8,000	115	5,440	Frey (1999), p38
Core City	357	250,000	700	170,000	Lynch(1985), p373, Frey, 1999 p 46
Transit Oriented Development*	100	8,000	80	5,440	Calthorpe(1993, p42), Frey (1999) p 51

City	Density (pph)	Population	City Area (ha)	Foodprint (ha)	Reference
City of Duncan	25	5,035	205	3,424	Statistics Canada (2010) of Census 2006 Community Profiles
Courtney	8	21,940	2,668	14,919	Statistics Canada (2010) of Census 2006 Community Profiles
Greater Vancouver	7	2,100,000	287,900	1,428,000	Statistics Canada (2010) of Census 2006 Community Profiles
City of Detroit	27	951,270	35,741	646,864	US Census Bureau (2010) - 2000 land and population estimates
Manhattan	258	1,537,195	5,956	1,045,293	US Census Bureau (2010) - 2000 land and population estimates
Sanfrancisco County	64	776,731	12,092	528,177	US Census Bureau (2010) - 2000 land and population estimates

Appendix (15.3). Summary of Foodprint Typologies in North America.

For each of these examples, adjacent land use is ignored. For example, the city of Duncan lives within the North Cowichan which has a population unto itself. The needs of these proximal communities are not considered. [10.3] Note that densities are gross and include areas for circulation and open space. The city of Vancouver has a density of 50pph, but the region performs much lower at 7.3pph. Some areas and densities are calculated from available data, indicated by a (*). [10.3] Calthorpe's TOD sugggests a population of 7,000 to 10,000.

16 Appendix C - Supporting Documents

Appendix (16.1) Glossary of Terms

This list of terms will help clarify how each word is used in this report, but is in no way exhaustive or entirely accurate in how the word is defined in professional dictionaries.

Agricultural Land Reserve (ALR): An area of land protected by provincial legislation in 1974 for use in agriculture. While the Agricultural Land Commission (ALC) is charged with protecting the total land area, submissions for additions and removals have been entertained since the beginning of the ALR land resulting in shift of ALR land throughout the province. The ALR covers roughly 4.7 million hectares. See http://www.alc.gov.bc.ca/alr/alr_main.htm for more details.

Carrying Capacity: An environment's carrying capacity is its maximum persistently supportable load (Catton, 1986).

Cultivation intensity: the area of land cultivated divided by the total land area.

Density (gross): The number of people divided by total land area, in people per gross hectare (pph).

Density (net): The number of units or people divided by the parcel area, in people per hectare (pph). In this case street easements have been subtracted from total area as seen in the figure below.

Energetic proximity: A measure of relative location that considers the most efficient modal route possible from origin to destination. See section (5).

Embodied energy: The energy required manufacturing and maintenance of a piece of machinery or product spread over its life. For example, if a tractor required 100 GJ to manufacture and maintain, but has a life expectancy of 20 yrs. The embodied energy input is 5 GJ yr^{-1}. Often embodied energy will include the energy required for disassembly, but this stage of the life cycle is not accounted for in this report.

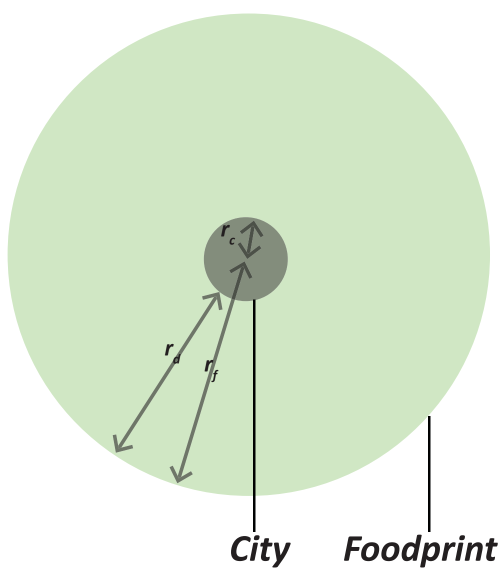
Euclidian distance: The straight line (as a crow flies) distance between two points. See section (5) for further details.

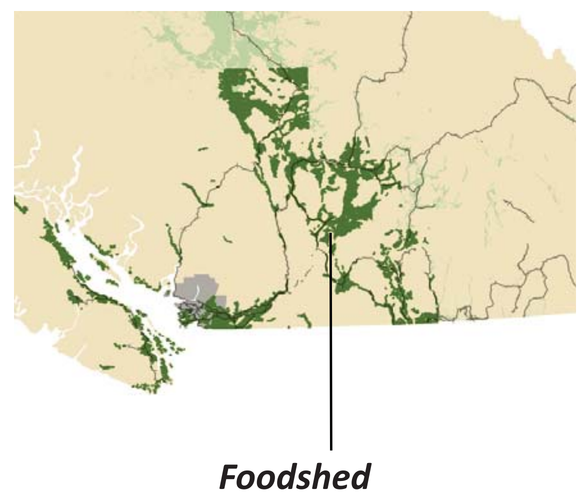
Food Energy: The energy contained in food, in kcal or joules.

Food energy balance: The ratio of food energy output to the energy required to produce, distribute, process and cycle nutrients.

Food Energy Intensity: The food energy that can be grown per unit area for a specified crop.

Foodprint: An abstract conceptualization of the minimum area required to meet a person's or cities food habits. It is represented as a circle generally taken out of context to explore the relative areas required for food growing purposes and other land uses as seen below. A foodprint placed in the context of available lands becomes a foodshed.





Food security: The United Nations defines food security as a condition when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food" (UN FAO, 2009). From a biophysical perspective, this requires all members of the population to have access to more than the minimum energy requirements of 1,800kcal/day. (Ibid).

Food sovereignty: *Food sovereignty* is a later iteration of food security with a focus on decentralizing power structures within the food system and providing communities the *capacity* to meet their own food needs (From Forum for Food Sovereignty, Declaration of Nyéléni, 2007).

Food system energy inputs: The direct and indirect energy invested in producing, processing and distributing food in addition to the energy required to cycle nutrients back to farmlands. This energy input is generally measured in GJ cap^{-1}.

Foodshed and Foodprint: The area required to grow a city or communities food supply in hectares (ha) in spatial reference to that community. This area can be grossly defined with no attention to transportation easements, growing potential or build up areas (foodprint), or can be placed in consideration of topographic features, and available growing spaces (foodshed). For efficiency purposes, foodsheds are located as energetically proximal to the city as possible, or within the city itself. This does not necessarily mean closer, given efficient modal choices (rail), will often support more efficient freight than closer areas impeded by low efficiency trucking.

Greater Vancouver Regional District (GVRD): Greater Vancouver includes the following municipalities, districts and first nations areas: Abbotsford (park purposes only), Anmore, Belcarra Bowen Island, Burnaby, Coquitlam, Delta, Electoral Area A, Langley City, Langley Township, Lions Bay, Maple Ridge, New Westminster, North Vancouver City, North Vancouver District, Pitt Meadows, Port Coquitlam, Port Moody, Richmond, Surrey, Tsawwassen, Vancouver, West Vancouver, White Rock. Metro Vancouver delivers regional planning services, on their behalf. See http://www.metrovancouver.org/about/Pages/default.aspx

Locavore: Local food consumer.

Life Cycle Analysis (LCA): Analysis of the inputs and outputs through the entire life-cycle of a product. Early LCAs were typically a cradle to grave style analyisis, accounting for the resources required for decommissioning a product. This study uses a cradle to cradle approach, or fork to fork, assessing the energy required (food system energy inputs) for the entire life cycle of food.

Metro Vancouver: see Greater Vancouver Regional District.

Organic Farming: "Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved." International Federation of Organic Agriculture Movements, accessed April 1st, 2010 http://www.ifoam.org/growing_organic/definitions/doa/index.html.

For the purpose of this report, organic farming methods are a prerequisite of a sustainable food system.

Proximity: A measure of relative location that considers the shortest route possible.

Proxy: A substitute variable that is representative of another. For example, wheat is often used as a proxy for grain yield and consumption due to the relative intensity of wheat consumption in Canada versus other grains. Maize would be a more appropriate proxy for grain yield and consumption in some South American countries where maize (corn) is a staple of the diet.

Resilience: While many definitions could apply, resilience is taken as the ability of a system to respond to environmental or social perturbations and return to a dynamic equilibrium.

Sustainability: In this study, a sustainable system is one that meets food needs, produces more energy than it consumes and is socially and ecologically resilient. Thus, for the purpose of this report, farming systems are constrained to Organic methods which are both more efficient and have the mission of benefiting the local and regional ecology (see Organic Farming).

Tipping point: The point at which a system becomes unstable and takes on a new direction. In the context of this study, the price of oil at $150 USD per barrel is defined as a tipping point beyond which societal systems (civil society, leadership, financial markets, etc) changes. The food riots of 2008 and collapse of many industrial financial markets in 2008 and 2009 bolster this claim.

Vancouver CMA: see Greater Vancouver Regional District

Appendix (16.2) Common Unit Conversions

Length

meter	m	0.001km	3.28 ft
feet	ft	0.33 yards	0.3048 m
furlong	fur	220 yards	201.168 m
rod	rd	5.5 yards	5.029 m

Area

hectare	ha	10,000 m^2	2.47 ac
acre*	ac	43 560sf	0.4046 ha
rood	ro	1 quarter acre	1 012 m^2
square feet	sf	2.30×10^{-5}	0.0929 m^2
square meter	m^2	0.00001 ha	10.764 sf
row foot**	rf	4sf	

Energy

gigajoules	GJ	100,000,000 joules	239 005.736 kcal
kilocalorie	kcal; Cal	1000 calories	4.1868×10^3 J

* the concept of an acre has changed slighly in size and shape over the last thousand years but remains roughly 43,560 sf. Traditionally, an acre was 22 yards wide (4 rods) by 220 yards long (1 furlong) (Oxford English Dictionary, 2010)

** a linear row foot is generally based on a four foot wide bed. Thus one row foot is actually 4 square feet of planting space. A three foot wide bed would have 3sf per linear row foot.