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# An Integrated Framework for Regional Assessment of Water, Energy, and Nutrients from Food Loss of Selected Crops in the Lower Fraser Valley, Canada

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## Abstract

Although there is no global shortage of food or water, food security has not been achieved, as human activity has turned these vital resources into "waste". Wasted food not only loses valuable water resources but embedded calories of human energy and nutrients for healthy human populations. The Food and Agricultural Organization of the United Nations, in addressing these concerns, focuses on a global scale largely on an economic estimate of individual components of energy or water or nutrient loss. It is suggested that more information is required through local or regional assessments to provide better estimates, incorporating regional factors of the losses along the food supply chain. To address this suggestion, this study focused on an intensive agricultural and rapidly urbanizing region of Canada, the Lower Fraser Valley of British Columbia. Seven selected crops, including annual crops such as green peas, sweet corn and potato, and perennial crops that included three berry crops were assessed for their water, both constituent and virtual, as well as embedded energy, protein, and Vitamin C. Annual virtual water losses were higher for sprinkler than drip irrigation, ranging from 82 × $10^6$ kg of water for strawberry to 7570 × $10^6$ kg for blueberry. These high virtual water losses estimated along the food chain confirm the significance of food loss impacts on local water resources. Estimates of losses of food in kg were highest at the consumer level along the food chain and it was estimated that wasted food from the seven crops selected would have supplied the protein and caloric energy of over 33,000 men per year and Vitamin C of about 240,000 men per year. This assessment increases the awareness of food loss impacts from a regional perspective and provides a framework for future research on both environmental and nutritional implications of wasted food.

**Keywords**

Food Loss, Food Waste, Crop Water Demand, Virtual Water, Nutrition

## 1. Introduction

Global trade in commodities, including food, has the potential to minimize global inequities, as globalization has had numerous social and economic successes. For example, today it is possible for people to get abundant, nutritious and healthy food globally year-round [1]. Unfortunately, food security has not become a global reality. Using the Eat-Lancet reference diet [1], Willen *et al*., (2019) [2] estimated that at a global sum of US $2.84 per day, the affordability of the diet exceeded the household per capita income of over 1.6 billion people globally.

Food loss and waste have major implications on social-economic, environmental and nutritional perspectives globally. Recent United Nations Environment Programme reports estimate that 14% of total food production is wasted from the initial harvesting sectors to retail, and around 17% is lost from just the final consumers, distributed by: households 11%; foodservice 5%; retail 2% [3]. Food that is lost and wasted accounts for 30% of total energy usage in the global food system [4] [5]. Vågsholm *et al*., (2020) [6] estimate that food loss, or wasted food, accounts for 28% of the global agricultural land area and 8% of global greenhouse gas emissions. In addition to environmental impacts, global food waste also plays a role in nutrition security, since both energies (calories) and nutrients are lost [7].

Although it is generally recognized that all food produced is not consumed by the intended recipients, for example, people, there is considerable variation in the terms used to describe this concern. The Food and Agricultural Organization of the United Nations (FAO) provides three definitions, including food loss, the decrease in mass or nutritional value of food that was originally intended for human consumption; food waste, as food for human consumption being discarded and left to spoil; and food wastage (or wasted food), encompassing both [4]. This implies that a valuable resource is being wasted and needs to be managed as waste rather than as a resource [8]. Of course, from an ecological and thermodynamic perspective, there is no waste, since natural systems are based on mass and energy closed cycles [9]. However, food waste represents the loss of caloric energy, water and nutrients sources for human consumption, as well as economic losses and unnecessary greenhouse gas emissions [10] [11].

Food wastage extension causes and impacts differ along the Food Supply Chain (FSC). The sectors considered as part of the FSC vary in the literature. The Value Chain Management Centre [12] provides a general classification as: on the farm; packaging and processing; transportation and distribution; restaurants, hotels and retail; and final consumers. For the latter two sectors, the impacts are additive, and the environmental costs are higher [4] [13]. An estimate from Canada reports that the food waste along the FSC is composed of: field 10%; packaging/processing 20%; transportation/distribution 4%; restaurants, hotels and retail 19%; and consumers 47% [14]. The high value ascribed to the wasting food by households is undoubtedly the result of several factors and behavior, including consumers' misunderstandings of food labeling, for example, the expression "best before" date on food products [15].

In Canada alone, recent reports on food waste estimate that more than $27 billion of food is wasted annually [14]. British Columbia ranks as the third to first highest producer of many agriculture commodities, and the Lower Fraser Valley (LFV) is responsible for a major part. However, the LFV is a rapidly urbanizing area, located next to one of the fastest-growing metropolitan areas in Canada, Metro Vancouver. This agricultural land is highly valued and is often under threat due to the expansion of the urban center. Thus, protecting the agricultural land in this region is essential for food production in the province. The Agriculture Land Reserve was established in 1976 in British Columbia with the main goal of protecting and prioritizing farming, which had a significant impact on the growth of the region's agricultural economy. However, the continued expansion of urban areas creates increasing pressure on land and water resources, threatening food prices and food security in the region. In this context, better agriculture management practices and reducing food wastage across the FSC are important for the region [16].

According to the World Resources Institute (WRI) [10], the 1.3 billion tons of food wasted every year worldwide are linked to 173 billion cubic meters of water consumption. This lost production represents a staggering 24% of the total freshwater used for agriculture [17]. Agriculture is already the world's biggest user of fresh water, accounting for 70% of all water use around the world [18] [19]. Water security is driven largely by the use of blue water, which is water used for irrigation, as this is the largest contributor to water scarcity [20] [21]. Those freshwater resources are declining rapidly, due to increasing populations, higher food demand and fast economic growth around the world [22].

However, food products have different losses when it comes to water. As WRI (2013) [10] reports, fruits and vegetables are the largest sources of food loss and wastewater loss on a weight basis—in part, because they contain more constituent water than other foods. Although cereals contribute the most to food loss relative to other food commodities on a caloric basis, fruits and vegetables are the largest source of loss on a weight basis. This variance is dependent on differences in water content; much of the wasted weight in fruits and vegetables is water. However, fruits and vegetables are important sources of vitamins and minerals, such as Vitamin C. Therefore, reducing the loss and waste of these types of food is crucial for human nutrition [10] [23].

In addition, there is the less obvious waste of water, the virtual or embedded water. Virtual water is the water embodied in the production of food and fiber and non-food commodities [24]. It differs from constituent water, which is the amount of water within the crop. So, a question also arises, does soil type or irrigation methods influence the total water utilized by agricultural crops? The plant available water and water drainage vary with the soil texture, among other factors, and this is directly related to the irrigation water demand, *i.e.*, virtual water of crops [25] [26]. Besides, different irrigation systems show different efficiencies. Precision irrigation techniques such as drip and spray irrigation can decrease the total amount of water required to grow crops, while sprinkler systems lose water due to evaporation and wind [27].

Marston *et al.*, (2021) [28] suggest that additional studies are needed to obtain better data on water scarcity and food loss, as there is limited local information. Geographic variation needs to be assessed to complement global estimates, as food production and consumption are recognized to be regional activities. In addition, reports of food waste are focused mainly on either environmental impacts, such as water and carbon emissions, or on nutritional data [4] [10] [28] [29] [30]. Few studies evaluate both environmental and nutritional implications, with detailed nutritional studies commonly restricted to specific countries and food groups [7] [31].

The overall objective of this study was to assess the effects of food wastage on virtual and constituent water, caloric energy and selected food quality indicators, namely, protein and vitamin C, in the LFV of British Columbia, Canada. In addition, as there is limited information on the effect of soil type and alternate irrigation systems, the study also assessed if soil type, irrigation system and crop selection had a marked difference on virtual water demand.

## 2. Methods

### 2.1. Study Area

The LFV, which comprises the Fraser Valley Regional District and Metropolitan Vancouver (**Figure 1**), is the most productive agricultural region of British Columbia, with only 3.8% of total farmland (99,233 ha) but accounting for 65% of total gross farm receipts ($2.4 billion) [32]. The region is classified as having a moderate oceanic climate with warm dry summers and wet mild winters with a mean average temperature of 11.7˚C. The annual precipitation is 1552 mm with approximately 80% occurring between October and April, the non-crop growing season resulting in the need for irrigation. The average number of annual frost-free days is 212, the highest in Canada [33].

The soils are mostly alluvial or recent glacially derived and highly fertile, contributing to the high agricultural yield. The dominant Canadian Soil Classification Orders are Brunisol, Gleysol, Organic and Podzol (Cambisol, Gleysol, Histosol, and Podzol in FAO classification) [34]. There are over 200 different soil types present in the LFV, which have been grouped by Bertrand *et al.*, (1991) into Soil Management Groups, based on agricultural capability [35]. The LFV grows a range of agricultural crops, including blueberries, cranberries, raspberries,

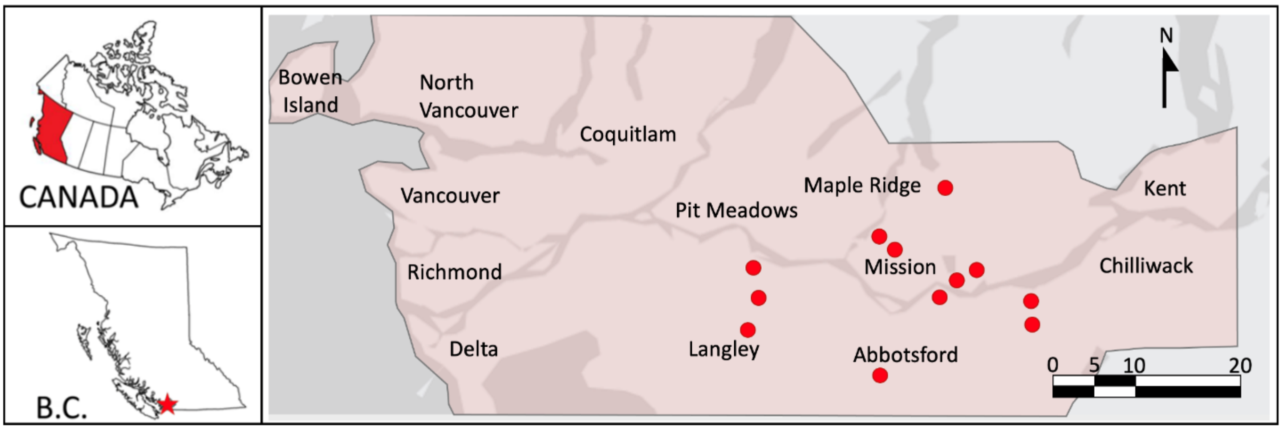


**Figure 1.** Location of the Lower Fraser Valley, British Columbia, Canada (light red), with municipalities of Anmore, Abbotsford, Belcarra, Bowen Island, Burnaby, Chilliwack, Coquitlam, Delta, Langley, Maple Ridge, Mission, New Westminster, North Vancouver, Pitt Meadows, Port Coquitlam, Port Moody, Richmond, Surrey, Vancouver, West Vancouver and White Rock. Soil parcel assessment approximate locations are also highlighted (red dots).

grapes, nursery products, tomatoes, sweet peppers, mushrooms, potatoes, squash, pumpkins, green peas, beans, sweet and forage corn [36].

## 2.2. Crops and Nutrients Selection

The following crops were selected for the study; blueberry (*Vaccinium corymbosum* L.), raspberry (*Rubus idaeus* L.), strawberry (*Fragaria x ananassa* Duch.), potato (*Solanum tuberosum* L.), sweet corn (*Zea mays* L.), pumpkin (*Curcubuta pepo* L.), and green peas (*Pisum sativum* L.), as they are representative of field crops and berries grown in the valley and are available in the model used for water demand estimations. The seven crops represent a range of both annual and perennial crops that vary in management practices and physiology (e.g., berries, peas and sweet corn grown aboveground and below ground edibles such as potato). Nutrients selected included one that a deficiency may be alleviated by soil management, such as nitrogen (N) for Protein, and one that is manufactured within the crop or a value-added factor, such as Vitamin C. Constituent water and caloric energy in each of the crops were also assessed. Virtual water for different irrigation techniques used in the LFV was calculated to show how varied irrigation management can affect water demand for each crop.

## 2.3. Virtual Water Demand ($m^3$/ha)

The BC Agriculture Water Calculator v2.1.1 [38], based on the Agriculture Water Demand Model [39], and the BC Soil Information Finder Tool (SIFT) [40] were used to estimate the virtual water demand for each crop and for different Soil Management Groups, following procedures detailed in [37].

Six Soil Management Groups were considered, as they included all the crops selected for analysis [35]:

1) Abbotsford and Ryder soil

2) Berry soil

3) Fairfield soil

4) Grevell soil

5) Monroe soil

6) Whatcom soil

Two soil series with different textures were chosen for each Soil Management Group [41]. For each soil series, one location/parcel identification (ID) was selected to calculate the water demand. A parcel ID is a unique nine-digit number provided by the Land Title and Survey Authority of British Columbia (LTSA), assigned to property boundaries across the province [42]. For the selection of parcels, each soil series was filtered by soil name using the Soil Query Tools on the SIFT to select soil polygons, which were then used to obtain parcel IDs (**Figure 2**).

The parcel IDs were used in the BC Agriculture Water Calculator to get the water demand results for each crop, each soil series (determined by the soil texture input in the model) and two irrigation systems—sprinkler and drip, as shown in **Figure 2**. Sprinkler irrigation refers to a system where water is sprayed into the air onto crops using pumps, hoses, and sprinklers, while drip irrigation refers to a system that slowly dispenses water from irrigation tubes with regular

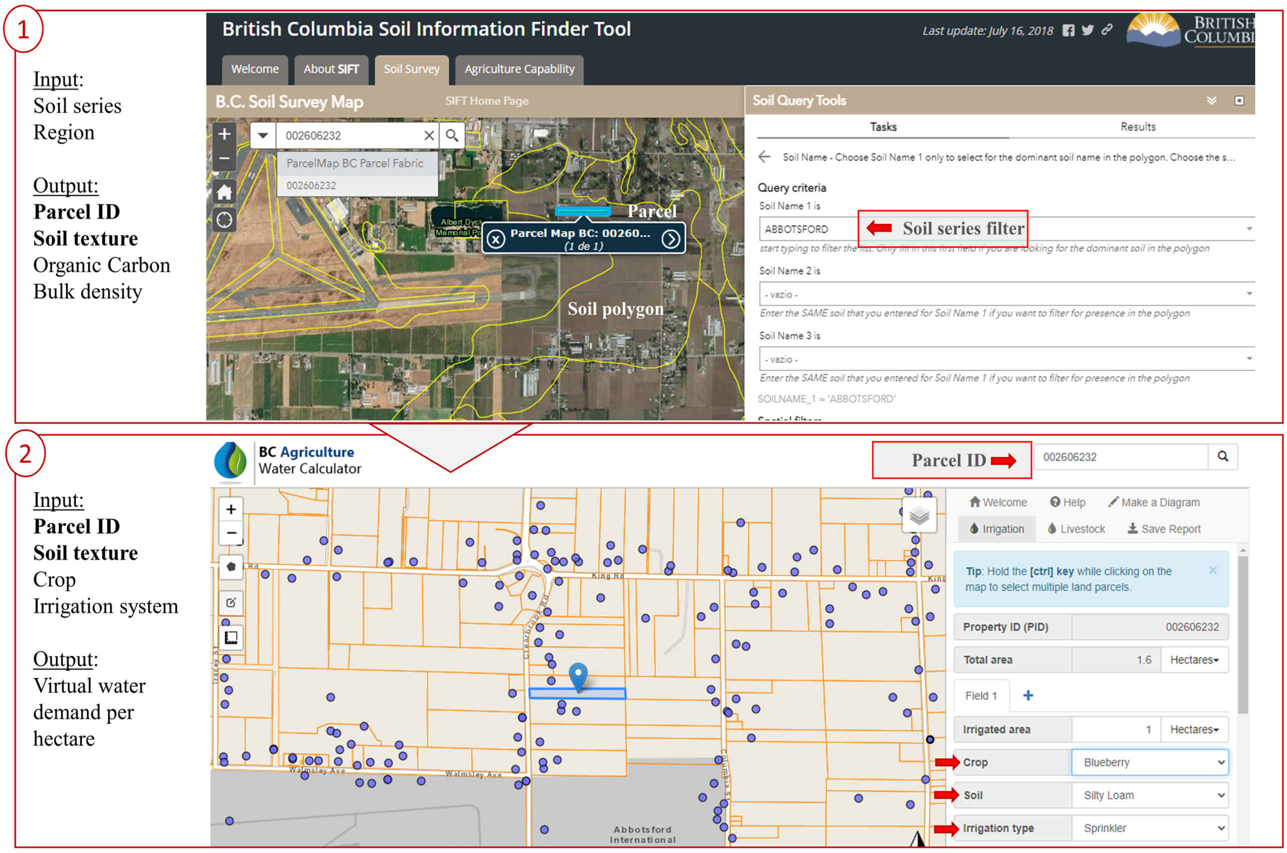


**Figure 2.** Example of how the parcel ID was obtained using the SIFT. Yellow lines represent soil polygons with different soil series and blue lines represent the parcel ID chosen for the Abbotsford soil series. The property ID, crop, soil texture and irrigation type were manual inputs in the BC Agriculture Water Calculator.

punctures over the crops rooting zone either on the soil surface or slightly buried. The local climate data is automatically incorporated into the model, and the water demand was calculated as described by [37]. For more detailed information on the study sites, the inputs and outputs from the BC Water Calculator and the latitude and longitude of each parcel are shown in the Supplemental Materials (**Table S1**).

Principal component analysis (PCA) was completed using the FactoMineR package [43] on soil properties using texture (% sand, silt, clay), organic carbon content (%), soil bulk density, growing season and each virtual water demand for each crop, to assess any variability in these properties inherent in the Soil Management Groups. Organic carbon, bulk density and soil texture for each soil series were gathered from the SIFT (**Figure 2**) [40], and when detailed soil texture information was unavailable for a textural class, it was estimated using the Canadian soil texture triangle as the average % sand, silt, and clay [34]. The growing season was based on the BC Agriculture Water Calculator outputs for the parcel IDs used [38]. For the PCA, two additional soil textures found in each of the soil series descriptions [41] were manually changed in the BC Water Calculator on the same parcel IDs to gather additional virtual water demand data. The complete database used for the PCA is given in the Supplemental Materials (**Table S2**).

## 2.4. Regional Agricultural Production

Annual Yield (kg/ha) values for each crop were based on averages of British Columbia data between 2015 and 2019 [36], while harvested area (ha) was based on Lower Fraser Valley District and Greater Vancouver values reported in the 2016 Statistics Canada Agricultural Census [44]. The percentages of each crop area in the region were calculated based on the sum of the total crop area in Lower Fraser Valley District (37,214 ha) and Metro Vancouver (24,886 ha). The total crop areas were reported in 2016 and include hay crops, field crops, field vegetables, fruits and nuts, sod and nursery products [32].

Total annual production (kg) for each crop was calculated by multiplying each yield (kg/ha) by the harvested areas (ha) in the LFV. To examine virtual water in relation to local yield (kg of water/kg of crop), the virtual water demand results from the BC Agriculture Water Calculator ($m^3$/ha) were divided by the yield (kg/ha) of each crop and multiplied by the density of water (999.07 kg/$m^3$ at 15.6˚C [45]).

## 2.5. Nutritional and Water Content

The nutrients, constituent water and caloric energy contents for each crop were based on the Canadian Nutrient File (CNF) [46].

Total caloric energy (kcal), protein (kg), Vitamin C (kg), constituent water (kg) and virtual water (kg) for each crop were calculated by multiplying the content per kg of crop by the annual production.

### 2.6. Food Losses: Energy, Water, Protein, Vitamin C

The last step was to calculate the effects of wasted food on water (virtual and constituent), caloric energy, protein and Vitamin C along the food chain. Total losses were calculated based on estimated percentages of food loss in Canada available in the literature. The total food loss (30%) and food loss per sector were the same for all crops. Supply chain losses were considered at Field (3%), Packaging/processing (6%), Transportation/distribution (1%), Restaurants, hotels and retail (6%) and Consumers (14%), and grouped into three main categories: Field (3%), Processing/Distribution (7%) and Retail/Consumers (20%) [14].

The total losses found for Caloric energy, Protein and Vitamin C for the seven crops considered in the study were compared to daily nutritional guidelines available in the literature. The daily calorie guideline considered was 2600 kcal/day for 30-year-old males [47]; the daily protein was 64 g/day for 80 kg adults [48] and the daily vitamin C was 90 mg/day for men [49]. The daily guidelines were multiplied by 365 to get the annual nutritional requirements per person. Then, the sum of the food losses for the seven crops selected was divided by the annual nutritional requirements to get the number of people per year that could be supplied by the food loss in the region.

## 3. Results and Discussion

### 3.1. Virtual Water Demand ($m^3$/ha)

**Table 1** summarizes the sprinkler and drip irrigation virtual water demand values estimated by the BC Agriculture Water Calculator for two soil series in each Soil Management Group.

From the comparison of the different Soil Management Groups shown in **Table 1** and **Figure 3**, minor changes in soil texture do not seem to influence virtual water demand. The PCA found that 82.2% of the variability in the data showed a response to the grouping of Soil Management Groups. The six Soil Groups grouped in the PCA ellipses overlap and seem to show similar characteristics, except for Grevell Soil, which has higher sand content. Therefore, Soil Management Group and soil texture were not considered important factors for changes in water demand in the LFV.

However, when comparing the two irrigation systems, the virtual water demand estimated for sprinkler systems was consistently higher than drip systems for all crops selected (**Figure 4**). This trend was expected since sprinkler systems lose more water due to wind and evaporation [27]. An average reduction of 22% may be reached in annual irrigation water demand by changing irrigation from sprinkler to drip systems [37]. Thus, the irrigation system has important impacts on local water allocation in agriculture.

**Figure 4** shows that the crops selected in the study have high variability in virtual water demand. Pumpkin had the highest virtual water demands per hectare, while sweet corn had the lowest. Blueberry had the second-highest water

**Table 1.** Virtual water demand ($m^3$/ha) calculated using the BC Agriculture Water Calculator for selected crops in Lower Fraser Valley. Values per Soil Management Group, soil series, soil texture (SiL = silt loam, L = loam, SiCl = silty clay loam, SL = sandy loam, S = sand), crop and irrigation systems—sprinkler (S) and drip (D)—are shown.

| | | | Virtual water demand ($m^3$/ha) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Management Group | Soil series | Soil texture | Blueberry | | Strawberry | | Raspberry | | Potato | | Sweet corn | | Pumpkin | | Green peas | |
| | | | S | D | S | D | S | D | S | D | S | D | S | D | S | D |
| Abbotsford/ Ryder | Abbotsford | SiL | 2690 | 2110 | 2200 | 1730 | 1920 | 1510 | 2590 | 2030 | 1750 | 1370 | 4020 | 3150 | 2550 | 2000 |
| Abbotsford/ Ryder | Keystone | L | 2470 | 1930 | 2020 | 1580 | 1760 | 1380 | 2370 | 1860 | 1600 | 1250 | 3690 | 2890 | 2340 | 1830 |
| Berry | Berry | SiCl | 2600 | 2030 | 2130 | 1660 | 1860 | 1450 | 2500 | 1950 | 1690 | 1320 | 3880 | 3040 | 2460 | 1930 |
| Berry | Tunbridge | SiL | 2210 | 1730 | 1810 | 1420 | 1580 | 1240 | 2120 | 1660 | 1440 | 1120 | 3300 | 2580 | 2100 | 1640 |
| Fairfield | Henderson | SiCl | 2700 | 2110 | 2210 | 1730 | 1930 | 1510 | 2600 | 2030 | 1750 | 1370 | 4030 | 3160 | 2560 | 2000 |
| Fairfield | Fadden | SiL | 2760 | 2160 | 2260 | 1770 | 1970 | 1540 | 2650 | 2080 | 1790 | 1400 | 4120 | 3230 | 2620 | 2050 |
| Grevell | Grevell | SL | 3410 | 2670 | 2790 | 2180 | 2440 | 1910 | 3280 | 2560 | 2210 | 1730 | 5090 | 3990 | 3230 | 2530 |
| Grevell | Seabird | S | 3920 | 3070 | 3210 | 2510 | 2800 | 2190 | 3770 | 2950 | 2550 | 1990 | 5860 | 4590 | 3720 | 2910 |
| Monroe | Matsqui | SiCl | 2660 | 2080 | 2170 | 1700 | 1900 | 1490 | 2550 | 2000 | 1730 | 1350 | 3970 | 3100 | 2520 | 1970 |
| Monroe | Monroe | SiL | 2650 | 2070 | 2170 | 1700 | 1890 | 1480 | 2550 | 1990 | 1720 | 1350 | 3960 | 3100 | 2510 | 1970 |
| Whatcom | Milner | SiCl | 2630 | 2060 | 2150 | 1680 | 1880 | 1470 | 2530 | 1980 | 1710 | 1340 | 3930 | 3070 | 2490 | 1950 |
| Whatcom | Durieu | L | 2260 | 1760 | 1850 | 1440 | 1610 | 1260 | 2170 | 1700 | 1460 | 1150 | 3370 | 2640 | 2140 | 1670 |

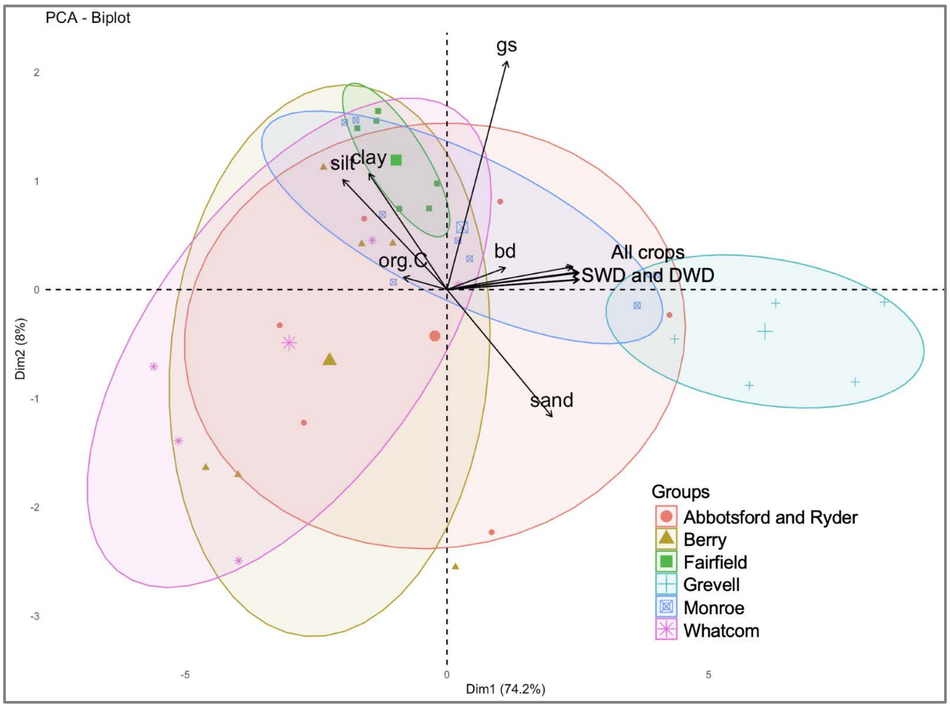


**Figure 3.** Principal component analysis (PCA) biplot created in R-4.1.3 with variables (org. C: organic carbon, bd: bulk density, gs: growing season days, sand: % Sand, clay: % Clay, silt: % Silt, and All crops SWD and DWD: sprinkler and drip virtual water demand for each crop and irrigation type (*i.e.* R.SWD: raspberry sprinkler water demand, R.DWD: raspberry drip water demand) grouped by the six Soil Management Groups.

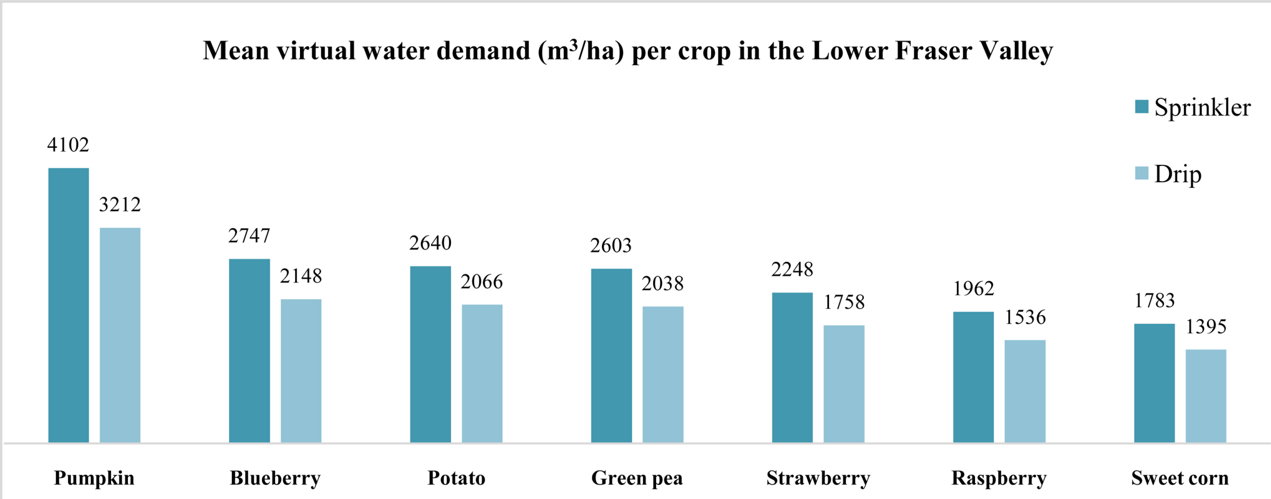


**Figure 4.** Mean of the virtual water demand ($m^3$/ha) for selected crops in the Lower Fraser Valley. The mean virtual water demands were calculated from Table 1, n = 12 soil series. Values per crop type and irrigation system, sprinkler and drip, are shown.

demand per hectare, with higher results than other common berries in the region. This can represent a potential issue for water allocation since blueberry has had a 56% increase in production and a 24% increase in harvested area from 2012 to 2016 in British Columbia [50] and was the crop with the largest harvested area in the LFV (Table 2). This exemplifies the impact of shifting land uses on the local water resources, with more producers choosing crops with higher water demand.

### 3.2. Caloric Energy, Nutrients, Constituent Water and Virtual Water

Annual yield values in the literature varied considerably among crops selected for the study, ranging from 4976 kg/ha for green peas to 34,010 kg/ha for potato (Table 2). Potato and pumpkin had a much higher yield than the other crops, while blueberry had the largest harvested area in the LFV. The seven crops selected for the study represented around 23% of the total crop area in Lower Fraser Valley District and Metro Vancouver regions (Table 2).

Energy, water and nutrient content also varied among the crops selected. Table 3 shows that annual crops, such as potato, sweet corn and green peas, have higher caloric energies and protein contents than the perennial berries studied. Vitamin C varied among crops, with the highest value for strawberry, 0.59 g/kg, followed by green peas, 0.40 g/kg. Constituent water showed a smaller range between the crops, ranging from 0.76 kg/kg for sweet corn to 0.92 kg/kg for pumpkin.

The virtual water demand estimated by the Agriculture Water Demand Model provides a total estimate of the water required to produce a product, both food or commodity, but does not consider the size (volume or mass) of the product. Pumpkin had the largest virtual water demand of the crops considered (Figure 4); however, if divided by the total productivity the value drops to one of the lowest (Table 3). The differences in virtual water demand in relation to yield

**Table 2.** Agricultural yield (kg/ha) and harvested area (ha) for selected crops in the Lower Fraser Valley. Percentages of each crop area in the region are also shown [32] [36] [44].

| Crop | Yield (kg/ha) | Harvested area (ha) | % Share of total crop area |
|---|---|---|---|
| Potato | 34,010 | 2266 | 4% |
| Pumpkins | 28,749 | 294 | 0.5% |
| Blueberry | 7752 | 9195 | 15% |
| Sweet corn | 7514 | 772 | 1% |
| Raspberry | 6901 | 1162 | 2% |
| Strawberry | 6224 | 121 | 0.2% |
| Green peas | 4976 | 468 | 1% |
| | Total: | 14,278 | 23% |

**Table 3.** Energy content (kcal/kg), Protein content (g/kg), Vitamin C content (g/kg), Constituent water (kg/kg) [46], and Virtual Water (kg/kg) for selected crops in Lower Fraser Valley. The virtual water and water ratios are shown per irrigation system, sprinkler (S) and drip (D).

| Crop | Energy content (kcal/kg) | Protein content (g/kg) | Vitamin C content (g/kg) | Constituent water (kg/kg) | Virtual water divided by yield (kg/kg) | | Water Ratios (Constituent water to Virtual water) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | S | D | S | D |
| Blueberry | 570 | 7.40 | 0.10 | 0.84 | 354 | 276 | 0.24% | 0.30% |
| Strawberry | 330 | 6.70 | 0.59 | 0.91 | 361 | 282 | 0.25% | 0.32% |
| Raspberry | 530 | 12.00 | 0.26 | 0.86 | 284 | 222 | 0.30% | 0.39% |
| Potato | 770 | 20.20 | 0.20 | 0.79 | 78 | 61 | 1.02% | 1.31% |
| Sweet corn | 860 | 32.70 | 0.07 | 0.76 | 237 | 186 | 0.32% | 0.41% |
| Pumpkin | 260 | 10.00 | 0.09 | 0.92 | 143 | 111 | 0.64% | 0.82% |
| Green peas | 810 | 54.20 | 0.40 | 0.79 | 523 | 409 | 0.15% | 0.19% |

were consistent with global assessments, with potato and pumpkin showing lower virtual water than berries and peas [51] [52]. This suggests that virtual water in relation to production would be useful to consider in future studies on food loss. Local productivity and soil management would also likely influence the estimates of energy, protein and Vitamin C for each crop.

Thus, crop choice and yield are important considerations for local water demand [53]. There are many different approaches for increasing agricultural yield, including improving the density and timing of seed planting, using modeling to guide planting, using appropriate crop genotypes, soil management using organic manures and mulch and irrigation scheduling techniques, among others [53] [54]. These have positive impacts on both water allocation and total revenue for farmers.

The ratio of Constituent water to Virtual water (Table 3) provides an estimate of the amount of water in the crop relative to the amount of water allocated for production. For example, all the water allocated for the sprinkler irrigation of blueberry (354 liters of water per kg of blueberry), only 0.24% ends up as constituent water within the crop. The water ratio results were consistent with the virtual water results, since irrigation systems and crops with higher virtual water showed lower ratios. In general, using sprinkler irrigation decreased the constituent to virtual water ratios compared to drip irrigation. The crop with the highest ratio was potato, followed by pumpkin, and green peas were the lowest (Table 3).

### 3.3. Total Losses in the Food Supply Chain

Tables 4-9 show the ranking of crops for total Food Production, Energy, Protein, Vitamin C, Constituent water and Virtual water, within the LFV. The losses along the food chain were focused on total losses and on three food sector categories; Field, Processing/Distribution and Retail/Consumption. The final category accounted for more than half of the food waste in Canada (20% out of 30%). Figure 5 synthesizes the losses from all food sectors separately—field,

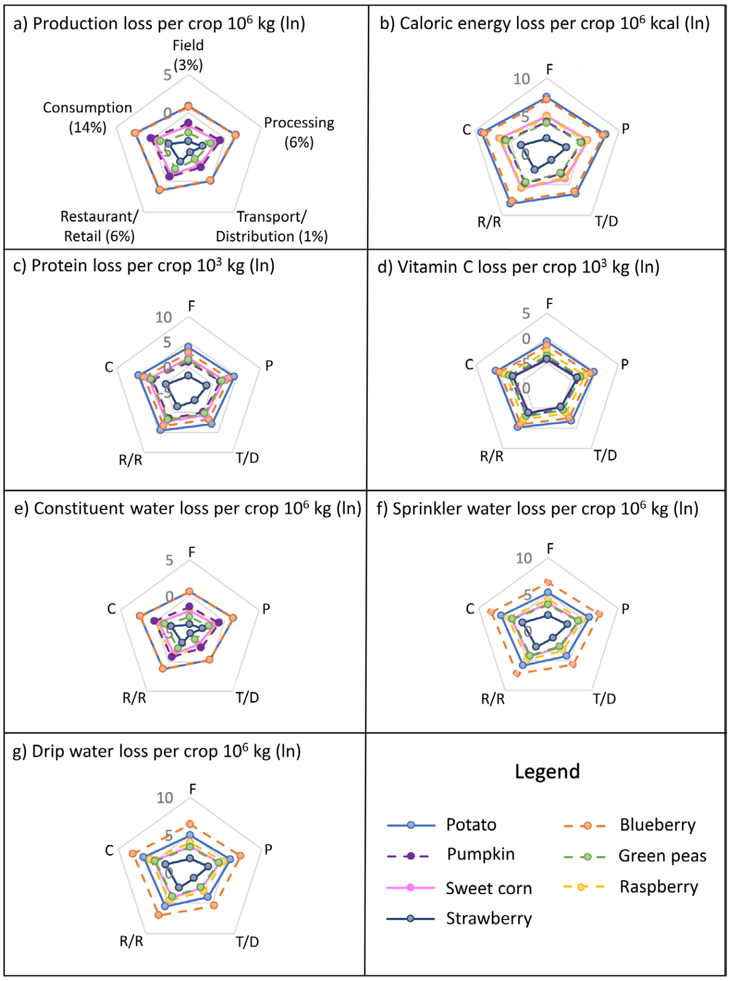


Figure 5. Production (a), Caloric energy (b), Protein (c), Vitamin C (d), Constituent water (e) and sprinkler/drip virtual water annual losses ((f), (g)) for the seven crops selected (as natural log-*ln*). The losses were compared between food sectors: Field (F), Processing (P), Transport and distribution (T/D), Retail and restaurant (R/R) and Consumption (C).

**Table 4.** Annual production data, total loss and losses from each crop and food sector category ($10^6$ kg).

| Crops | Annual production | Annual production loss (30%) | Field loss (3%) | Processing/ Distribution loss (7%) | Retail/ Consumption loss (20%) |
|---|---|---|---|---|---|
| Potato | 77.07 | 23.12 | 2.31 | 5.55 | 15.26 |
| Blueberry | 71.28 | 21.38 | 2.14 | 5.13 | 14.11 |
| Pumpkins | 8.45 | 2.54 | 0.25 | 0.61 | 1.67 |
| Raspberry | 8.02 | 2.41 | 0.24 | 0.58 | 1.59 |
| Sweet corn | 5.80 | 1.74 | 0.17 | 0.42 | 1.15 |
| Green peas | 2.33 | 0.70 | 0.07 | 0.17 | 0.46 |
| Strawberry | 0.75 | 0.23 | 0.02 | 0.05 | 0.15 |
| Total: | | 52.11 | 5.21 | 12.51 | 34.39 |

**Table 5.** Total energy, total energy loss and losses from each crop and food sector category ($10^6$ kcal).

| Crops | Total energy | Total energy loss (30%) | Field loss (3%) | Processing/ Distribution loss (7%) | Retail/ Consumption loss (20%) |
|---|---|---|---|---|---|
| Potato | 59,341 | 17,802 | 1780 | 4273 | 11,750 |
| Blueberry | 40,629 | 12,189 | 1219 | 2925 | 8045 |
| Sweet corn | 4989 | 1497 | 150 | 359 | 988 |
| Raspberry | 4250 | 1275 | 128 | 306 | 842 |
| Pumpkins | 2198 | 659 | 66 | 158 | 435 |
| Green peas | 1886 | 566 | 57 | 136 | 373 |
| Strawberry | 249 | 75 | 7 | 18 | 49 |
| Total: | | 34,063 | 3406 | 8175 | 22,481 |

**Table 6.** Total protein, total protein loss and losses from each crop and food sector category ($10^3$ kg).

| Crops | Total protein | Total protein loss (30%) | Field loss (3%) | Processing/ Distribution loss (7%) | Retail/ Consumption loss (20%) |
|---|---|---|---|---|---|
| Potato | 1557 | 467.02 | 46.70 | 112.09 | 308.24 |
| Blueberry | 527 | 158.24 | 15.82 | 37.98 | 104.44 |
| Sweet corn | 190 | 56.91 | 5.69 | 13.66 | 37.56 |
| Green peas | 126 | 37.87 | 3.79 | 9.09 | 24.99 |
| Raspberry | 96 | 28.87 | 2.89 | 6.93 | 19.05 |
| Pumpkins | 85 | 25.36 | 2.54 | 6.09 | 16.74 |
| Strawberry | 5 | 1.51 | 0.15 | 0.36 | 1.00 |
| Total: | | 775.78 | 77.58 | 186.19 | 512.01 |

Table 7. Total vitamin C, total vitamin C loss and losses from each crop and food sector category ($10^3$ kg).

| Crops | Total Vitamin C | Total Vitamin C loss (30%) | Field loss (3%) | Processing/ Distribution loss (7%) | Retail/ Consumption loss (20%) |
|---|---|---|---|---|---|
| Potato | 15.2 | 4.55 | 0.46 | 1.09 | 3.01 |
| Blueberry | 6.9 | 2.07 | 0.21 | 0.50 | 1.37 |
| Raspberry | 2.1 | 0.63 | 0.06 | 0.15 | 0.42 |
| Green peas | 0.9 | 0.28 | 0.03 | 0.07 | 0.18 |
| Pumpkins | 0.8 | 0.23 | 0.02 | 0.05 | 0.15 |
| Strawberry | 0.4 | 0.13 | 0.01 | 0.03 | 0.09 |
| Sweet corn | 0.4 | 0.12 | 0.01 | 0.03 | 0.08 |
| Total: | | 8.02 | 0.80 | 1.92 | 5.29 |

Table 8. Total constituent water, total constituent water loss and losses from each crop and food sector category ($10^6$ kg).

| Crops | Total constituent water | Total constituent water loss (30%) | Field loss (3%) | Processing/ Distribution loss (7%) | Retail/ Consumption loss (20%) |
|---|---|---|---|---|---|
| Potato | 61.1 | 18.34 | 1.83 | 4.40 | 12.11 |
| Blueberry | 60.0 | 18.01 | 1.80 | 4.32 | 11.88 |
| Pumpkins | 7.7 | 2.32 | 0.23 | 0.56 | 1.53 |
| Raspberry | 6.9 | 2.06 | 0.21 | 0.50 | 1.36 |
| Sweet corn | 4.4 | 1.32 | 0.13 | 0.32 | 0.87 |
| Green peas | 1.8 | 0.55 | 0.06 | 0.13 | 0.36 |
| Strawberry | 0.7 | 0.21 | 0.02 | 0.05 | 0.14 |
| Total: | | 42.82 | 4.28 | 10.28 | 28.26 |

processing, transport, retail and consumption, normalized by natural log.

The total values are only estimates based on the latest agricultural production census for the region and also on proxy percentages of food loss. The focus of the study was to provide a relative comparison of the different crops and food sectors.

The crop with the highest annual production was potato (77.07 × $10^6$ kg), followed by blueberry (71.28 × $10^6$ kg) and pumpkin (8.45 × $10^6$ kg). The lowest annual production was strawberry (0.75 × $10^6$ kg). Although the same food loss percentages were used, the extent of losses showed variation in total weight per crop. Considering the seven crops selected for the study, which represented almost one-quarter of the production in the region, the total production loss adds up to over 52 million kilograms, with the losses from the Retail/Consumption level

**Table 9.** Total virtual water, total virtual water loss and losses from each crop and food sector category ($10^6$ kg). Virtual water values for both sprinkler (S) and drip (D) irrigation systems are shown.

| Crops | Total virtual water | | Total virtual water loss (30%) | | Field loss (3%) | | Processing/ Distribution loss (7%) | | Retail/ Consumption loss (20%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S | D | S | D | S | D | S | D | S | D |
| Blueberry | 25,232 | 19,736 | 7570 | 5921 | 757 | 592 | 1817 | 1421 | 4996 | 3908 |
| Potato | 5977 | 4677 | 1793 | 1403 | 179 | 140 | 430 | 337 | 1183 | 926 |
| Raspberry | 2277 | 1783 | 683 | 535 | 68 | 53 | 164 | 128 | 451 | 353 |
| Sweet corn | 1375 | 1076 | 413 | 323 | 41 | 32 | 99 | 77 | 272 | 213 |
| Green peas | 1217 | 953 | 365 | 286 | 37 | 29 | 88 | 69 | 241 | 189 |
| Pumpkins | 1205 | 943 | 361 | 283 | 36 | 28 | 87 | 68 | 239 | 187 |
| Strawberry | 272 | 213 | 82 | 64 | 8 | 6 | 20 | 15 | 54 | 42 |
| | Total: | | 11,267 | 8814 | 1127 | 881 | 2704 | 2115 | 7436 | 5817 |

accounting for almost 35 million kilograms (**Table 4**).

Thus, one-third of the crop production (52 million kg) is not supporting human nutrition. In an area with an increasing population, such as the Lower Fraser Valley, the agricultural sector is under increased pressure to produce even more to compensate for those losses [16].

The drivers of food loss vary among the food sectors. For the production stage, common causes of food losses are poor harvesting equipment, and incorrect handling and storage. As for processing and distribution, food loss may be associated with spilled products, degradation by pests and fungus, inefficient logistics, and poor order forecasting, among others. Final consumers had the highest food losses in Canada, mainly associated with improper storage, excess purchases, misunderstanding of expiration dates and high aesthetically-pleasing food expectations [10] [55]. The economic implications of food wastage along the food supply chain are major, and local losses scale to a national loss of more than $27 billion in Canada [14].

Potato had the highest total energy and protein losses, followed by blueberry. Sweet corn had the third highest energy and protein losses (**Figure 5(b)** and **Figure 5(c)**), with greater values than pumpkin despite showing lower production in total (**Tables 4-6**).

Considering the seven crops selected and the productivity in the LFV, the total energy losses would be enough to meet the daily calorie guidelines of 35,893 males for one year (**Table 5**). The total protein losses would be enough to meet the daily protein guidelines of 33,210 adults for one year (**Table 6**).

Potato and blueberry had the two highest vitamin C losses, 4.55 and 2.07 metric tons, followed by raspberry with 0.63 metric tons. Although strawberry had the lowest production within the LFV, the loss of Vitamin C is more comparable to the other crops studied (**Figure 5(d)**) as it has the highest Vitamin C content among them (**Table 3**). Considering the seven crops selected and the productivity in the LFV, the total vitamin C losses would be enough to meet the daily guidelines of 244,080 adults for one year (**Table 7**).

Vitamin C is a value-added factor in crops and cannot be alleviated by soil management. Vitamin C is mainly provided to humans by fruits and vegetables, and when this is not enough in the diet, supplements may be required to compensate. However, Vitamin C can be degraded by heat and light; therefore, the waste of crops rich in Vitamin C and that are eaten raw, such as strawberry, raspberry and green peas (**Table 3**) represents the loss of important natural sources of this essential nutrient [56] [57].

Constituent water content is relatively similar for all crops studied (ranging from 0.76 - 0.92 kg water/kg crop) (**Table 3**). Thus, total constituent water losses follow the same crop ranking as the food production in the LFV (**Figure 5(a)**, **Figure 5(e)**). Potato had the highest constituent water losses (18.34 million·kg), followed by blueberry (18.01 million·kg) and pumpkin (2.32 million·kg) (**Table 8**).

Potato had the highest losses for almost all the variables, followed by blueberry. The only exception was virtual water, where blueberry had the highest losses (**Figure 5(f)**, **Figure 5(g)**). Blueberry virtual water loss with sprinkler irrigation was 7570 million kg, while the virtual water loss for potato was 1793 million kg (**Table 9**). This may be explained by blueberry showing higher virtual water per kg of produce (354 kg water/kg blueberry) than potatoes (78 kg water/kg potato) (**Table 3**), which was similar to trends found in other studies [51] [52]. The total agricultural water demand in the region was estimated by previous studies at 128 billion kg of water [39] [58], with blueberry alone accounting for 25 billion kg of water (**Table 9**), *i.e.* 20% of the total region's demand.

As mentioned before, irrigation systems are important for reducing the virtual water of crop production, with sprinkler irrigation showing consistently higher virtual water losses than drip. The high amount of virtual water losses for crops with large harvested areas in the LFV, such as blueberry and potato (**Table 9**), confirm the significance of food loss impacts on water resources from a regional perspective. As this study focused on foods for human consumption, major consumers of water such as forage crops should also be considered in future studies as they also contribute to water demand and local nutrient losses [38]. Thus, the local water impact is potentially much higher than these results estimated.

## 4. Conclusions

Food wastage has numerous implications from socio-economic and political, to environmental and nutritional concerns. This study provides information on the environmental impacts of water losses, both constituent and virtual, in conjunction with caloric energy losses and nutritional value losses at a regional scale. The main goal was to present a regional assessment of the combined effects of food wastage in the Lower Fraser Valley of British Columbia, Canada, and increase the awareness of those effects with comparative estimates for representative crops.

Based on the comparative estimates, Soil Management Groups and texture were not important factors for virtual water demand changes in the region, whereas the seven crops and the two irrigation systems selected showed larger differences. Virtual water losses were higher for sprinkler irrigation, ranging from 82 × $10^6$ kg for strawberry to 7570 × $10^6$ kg for blueberry. Estimates of food losses in kg were highest by the consumer level along the food chain and it was estimated that for the seven crops selected the wasted food would have supplied the protein and caloric energy of over 33,000 and the vitamin C of about 240,000 adult men per year.

The calculation of virtual water is most complex, thus as a comparative estimate, the BC Agricultural Water Calculator provides a useful tool, as it is locally developed and considers the regional climate, soil and landscape. However, the weather is considered constant, and the model does not consider water sources (groundwater, precipitation or surface water), nor agricultural management practices' effects on water demand. The Agriculture Water Demand Model estimates virtual water per hectare, but when yield is taken into consideration, pumpkin and potato which showed high virtual water demands per hectare had the lowest virtual water demands per kg produced. This suggests that virtual water in relation to production would be useful to consider in future studies on food loss. Local productivity and soil management would also likely influence the estimates of energy, protein and Vitamin C for each crop; however, additional data would be needed.

The framework presented provides an opportunity to assess the total economic, social and environmental costs of wasted food for both water allocation and human nutrition, using production data from a regional perspective. Further research is needed to determine the regional data for food loss across the different food sectors, as currently there is only data available at the national scale for Canada which was used as a relative estimate of loss in BC districts. To extend the results of this study, there is a need to analyze more crops and Soil Management Groups in the Lower Fraser Valley and at larger scales to better estimate the total impacts of food loss. Local social and economic drivers of crop and agricultural management practices choices, together with drivers of food waste from field to consumption in British Columbia must be assessed to support local water and food policy development.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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## Supplemental Materials

**Table S1.** Soil Parcel ID information, latitude and longitude shown in degrees, minutes and seconds (DMS) and BC Water Calculator outputs.

| Soil Management Group | Soil type | Soil texture | Parcel ID | Latitude, Longitude (DMS) | Growing season (days) | Irrigation season | Climate ID |
|---|---|---|---|---|---|---|---|
| Abbotsford and Ryder | Abbotsford | Silt loam | 002606232 | 49˚01'37.2"N 122˚20'06.0"W | 171 | Apr 15 Oct 02 | 25942048 |
| Abbotsford and Ryder | Keystone | Loam | 002133113 | 49˚11'09.6"N 122˚22'33.6"W | 164 | Apr 22 Oct 02 | 25572040 |
| Berry | Berry | Silty clay loam | 002162504 | 49˚07'22.8"N 122˚35'20.4"W | 171 | Apr 15 Oct 02 | 25732010 |
| Berry | Tunbridge | Silt loam | 011391707 | 49˚10'01.2"N 122˚19'12.0"W | 163 | Apr 23 Oct 02 | 25612048 |
| Fairfield | Henderson | Silty clay loam | 023568232 | 49˚07'01.2"N 122˚04'26.4"W | 172 | Apr 14 Oct 02 | 25662087 |
| Fairfield | Fadden | Silt loam | 011246855 | 49˚07'01.2"N 122˚04'26.4"W | 173 | Apr 13 Oct 02 | 25702085 |
| Grevell | Grevell | Sandy loam | 008428361 | 49˚10'01.2"N 122˚33'39.6"W | 170 | Apr 16 Oct 02 | 25632013 |
| Grevell | Seabird | Sand | 008473978 | 49˚08'13.2"N 122˚13'33.6"W | 173 | Apr 13 Oct 02 | 25672062 |
| Monroe | Matsqui | Silty clay loam | 023081198 | 49˚09'18.0"N 122˚10'08.4"W | 172 | Apr 14 Oct 02 | 25622071 |
| Monroe | Monroe | Silt loam | 011081198 | 49˚07'58.8"N 122˚14'52.8"W | 173 | Apr 13 Oct 02 | 25682059 |
| Whatcom | Milner | Silty clay loam | 026703688 | 49˚08'38.4"N 122˚34'58.8"W | 171 | Apr 15 Oct 02 | 25682010 |
| Whatcom | Durieu | Loam | 013423673 | 49˚15'10.8"N 122˚13'55.2"W | 165 | Apr 21 Oct 02 | 25412060 |

**Table S2.** PCA parameters. Soil texture, % organic carbon, bulk density (Bd), growing season days (Gs), % Sand, % Clay, % Silt, and virtual water demand ($m^3$/ha) for sprinkler (S) and drip (D), grouped by the 6 Soil Management Groups and the 7 crops selected.

| Soil Management Group | Soil texture | Org Carbon (%) | Bd | % sand | % silt | % clay | Gs | Blueberry | | Strawberry | | Raspberry | | Potato | | Sweet corn | | Pumpkins | | Green peas | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | S | D | S | D | S | D | S | D | S | D | S | D | S | D |
| Abbotsford/ Ryder | Silt loam | 12.8 | 1.2 | 22 | 67 | 11 | 171 | 2690 | 2110 | 2200 | 1730 | 1920 | 1510 | 2590 | 2030 | 1750 | 1370 | 4020 | 3150 | 2550 | 2000 |
| Abbotsford/ Ryder | Loam | 1.6 | 1.2 | 10 | 45 | 45 | 164 | 2470 | 1930 | 2020 | 1580 | 1760 | 1380 | 2370 | 1860 | 1600 | 1250 | 3690 | 2890 | 2340 | 1830 |
| Abbotsford/ Ryder | Loam | 4.1 | 1.4 | 28 | 67 | 5 | 172 | 2990 | 2340 | 2440 | 1910 | 2130 | 1670 | 2870 | 2250 | 1940 | 1520 | 4460 | 3490 | 2830 | 2220 |
| Abbotsford/ Ryder | Sandy Loam | | | 65 | 25 | 10 | 171 | 3450 | 2700 | 2830 | 2210 | 2470 | 1930 | 3320 | 2600 | 2240 | 1760 | 5160 | 4040 | 3270 | 2560 |
| Abbotsford/ Ryder | Silt loam | | | 23 | 62 | 15 | 164 | 2690 | 1790 | 2200 | 1470 | 1920 | 1280 | 2590 | 1720 | 1750 | 1170 | 4020 | 2680 | 2550 | 1700 |
| Abbotsford/ Ryder | Sandy loam | | | 65 | 25 | 10 | 164 | 2940 | 2300 | 2410 | 1880 | 2100 | 1640 | 2830 | 2210 | 1910 | 1490 | 4390 | 3440 | 2790 | 2180 |
| Berry | Silty clay loam | 4.2 | 1 | 6 | 60 | 34 | 171 | 2600 | 2030 | 2130 | 1660 | 1860 | 1450 | 2500 | 1950 | 1690 | 1320 | 3880 | 3040 | 2460 | 1930 |
| Berry | Silt loam | 9.5 | 1.2 | 25 | 60 | 15 | 163 | 2210 | 1730 | 1810 | 1420 | 1580 | 1240 | 2120 | 1660 | 1440 | 1120 | 3300 | 2580 | 2100 | 1640 |
| Berry | Silt loam | | | 23 | 62 | 15 | 171 | 2630 | 2060 | 2150 | 1680 | 1880 | 1470 | 2530 | 1980 | 1710 | 1340 | 3930 | 3070 | 2490 | 1950 |
| Berry | Sandy loam | | | 65 | 25 | 10 | 163 | 2830 | 2220 | 2320 | 1810 | 2020 | 1580 | 2720 | 2130 | 1840 | 1440 | 4230 | 3310 | 2690 | 2100 |
| Berry | Clay loam | | | 33 | 33 | 34 | 171 | 2710 | 2110 | 2220 | 1730 | 1940 | 1510 | 2600 | 2030 | 1760 | 1370 | 4050 | 3150 | 2570 | 2000 |
| Berry | Clay loam | | | 33 | 33 | 34 | 163 | 2270 | 1770 | 1860 | 1450 | 1620 | 1270 | 2180 | 1710 | 1470 | 1150 | 3390 | 2650 | 2150 | 1680 |
| Fairfield | Silty clay loam | 5 | 1.04 | 5 | 63 | 32 | 172 | 2700 | 2110 | 2210 | 1730 | 1930 | 1510 | 2600 | 2030 | 1750 | 1370 | 4030 | 3160 | 2560 | 2000 |
| Fairfield | Silt loam | 8.2 | 1.04 | 10 | 65 | 25 | 173 | 2760 | 2160 | 2260 | 1770 | 1970 | 1540 | 2650 | 2080 | 1790 | 1400 | 4120 | 3230 | 2620 | 2050 |
| Fairfield | Silt loam | | | 23 | 62 | 15 | 172 | 2740 | 2150 | 2250 | 1760 | 1960 | 1530 | 2640 | 2060 | 1780 | 1390 | 4100 | 3210 | 2600 | 2040 |
| Fairfield | Silty clay loam | | | 10 | 56 | 34 | 173 | 2730 | 2130 | 2230 | 1740 | 1950 | 1520 | 2620 | 2050 | 1770 | 1380 | 4070 | 3180 | 2580 | 2020 |
| Fairfield | Clay loam | | | 33 | 33 | 34 | 172 | 2810 | 2200 | 2300 | 1800 | 2010 | 1570 | 2700 | 2120 | 1830 | 1430 | 4200 | 3290 | 2670 | 2090 |
| Fairfield | Clay loam | | | 33 | 33 | 34 | 173 | 2830 | 2220 | 2320 | 1810 | 2020 | 1580 | 2720 | 2130 | 1840 | 1440 | 4230 | 3310 | 2680 | 2100 |
| Grevell | Sandy loam | 1 | 1.35 | 65 | 25 | 10 | 170 | 3410 | 2670 | 2790 | 2180 | 2440 | 1910 | 3280 | 2560 | 2210 | 1730 | 5090 | 3990 | 3230 | 2530 |
| Grevell | Sand | 0.2 | 1.55 | 90 | 5 | 5 | 173 | 3920 | 3070 | 3210 | 2510 | 2800 | 2190 | 3770 | 2950 | 2550 | 1990 | 5860 | 4590 | 3720 | 2910 |
| Grevell | Sand | | | 90 | 5 | 5 | 170 | 3960 | 3100 | 3240 | 2530 | 2830 | 2210 | 3800 | 2980 | 2570 | 2010 | 5910 | 4620 | 3750 | 2930 |
| Grevell | Loamy sand | | | 81 | 12 | 7 | 173 | 3720 | 2910 | 3040 | 2380 | 2660 | 2080 | 3580 | 2800 | 2420 | 1890 | 5560 | 4350 | 3530 | 2760 |
| Grevell | Sandy loam | | | 65 | 25 | 10 | 173 | 3380 | 2650 | 2770 | 2170 | 2420 | 1890 | 3250 | 2540 | 2200 | 1720 | 5050 | 3950 | 3210 | 2510 |
| Grevell | Loamy sand | | | 81 | 12 | 7 | 170 | 3750 | 2940 | 3070 | 2400 | 2680 | 2100 | 2680 | 2820 | 2440 | 1910 | 5600 | 4380 | 3560 | 2780 |
| Monroe | Silty clay loam | 3.5 | 1.12 | 90 | 60 | 31 | 172 | 2660 | 2080 | 2170 | 1700 | 1900 | 1490 | 2550 | 2000 | 1730 | 1350 | 3970 | 3100 | 2520 | 1970 |
| Monroe | Silt loam | 2.8 | 1.14 | 5 | 70 | 25 | 173 | 2650 | 2070 | 2170 | 1700 | 1890 | 1480 | 2550 | 1990 | 1720 | 1350 | 3960 | 3100 | 2510 | 1970 |
| Monroe | Silt loam | | | 23 | 62 | 15 | 172 | 2690 | 2110 | 2200 | 1720 | 1920 | 1500 | 2590 | 2020 | 1750 | 1370 | 4020 | 3150 | 2550 | 2000 |
| Monroe | Sandy Loam | | | 65 | 25 | 10 | 173 | 3400 | 2660 | 2780 | 2180 | 2430 | 1900 | 3270 | 2560 | 2210 | 1730 | 5080 | 3970 | 3220 | 2520 |
| Monroe | Loam | | | 43 | 38 | 19 | 173 | 2860 | 2230 | 2340 | 1830 | 2040 | 1600 | 2740 | 2150 | 1850 | 1450 | 4260 | 3340 | 2710 | 2120 |

**Continued**

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monroe | Silty clay loam | | | 10 | 56 | 34 | 173 | 2620 | 2050 | 2140 | 1680 | 1870 | 1460 | 2520 | 1970 | 1700 | 1330 | 3910 | 3060 | 2480 | 1940 |
| Monroe | Sandy Loam | | | 65 | 25 | 10 | 172 | 3450 | 2540 | 2820 | 2080 | 2460 | 1810 | 3320 | 2440 | 2240 | 1650 | 5150 | 3790 | 3270 | 2410 |
| Monroe | Loam | | | 43 | 38 | 19 | 172 | 2900 | 2270 | 2370 | 1860 | 2070 | 1620 | 2790 | 2180 | 1880 | 1470 | 4330 | 3390 | 2750 | 2150 |
| Whatcom | Silty clay loam | 5 | 1 | 8 | 54 | 38 | 171 | 2630 | 2060 | 2150 | 1680 | 1880 | 1470 | 2530 | 1980 | 1710 | 1340 | 3930 | 3070 | 2490 | 1950 |
| Whatcom | Loam | 3.5 | 0.71 | 49 | 43 | 8 | 165 | 2260 | 1760 | 1850 | 1440 | 1610 | 1260 | 2170 | 1700 | 1460 | 1150 | 3370 | 2640 | 2140 | 1670 |
| Whatcom | Loam | | | 43 | 38 | 19 | 171 | 2870 | 2250 | 2350 | 1840 | 2050 | 1600 | 2760 | 2160 | 1860 | 1460 | 4290 | 3350 | 2720 | 2130 |
| Whatcom | Silt loam | | | 23 | 62 | 15 | 165 | 2090 | 1640 | 1710 | 1340 | 1500 | 1170 | 2010 | 1570 | 1360 | 1060 | 3130 | 2450 | 1990 | 1550 |
| Whatcom | Silty clay loam | | | 10 | 56 | 34 | 165 | 2070 | 1620 | 1690 | 1320 | 1480 | 1160 | 1990 | 1550 | 1340 | 1050 | 3090 | 2420 | 1960 | 1530 |
| Whatcom | Silt loam | | | 23 | 62 | 15 | 171 | 2670 | 2090 | 2180 | 1710 | 1900 | 1490 | 2560 | 2000 | 1730 | 1350 | 3980 | 3110 | 2530 | 1980 |