Optimal Water Allocation for Agricultural Production in British Columbia

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Introduction

With climate change, the problem of water allocation has become more and more important. Every year, summers in British Columbia become harsher with extreme heat and droughts. It is then of utmost importance to properly allocate the water that is available to us in the most efficient way possible, especially in agriculture, which without proper allocation will lead to unsuccessful harvest seasons and unhealthy livestock. The goal of this report will be to determine optimal allocation of water to different farm types using linear programming during the month of August, with the goal to maximize the overall revenue of the agricultural industry, with the limited quantity of water available.

TYPE OF ANIMAL	DESCRIPTION	US GPD	TYPE OF ANIMAL	DESCRIPTION	US GPD
BEEF			**SWINE** (with wash water)		
cow with calf *	1,300 lb	12	farrow - finish	--	24 / sow
dry cow/mature cow *	1,300 lb	10	farrow - late wean	50 lb	8 / sow
calf *	250 lb	3	farrow - early wean	15 lb	6.5 / sow
feeder – growing **	400-800 lb	6 - 9	feeder	50 - 250 lb	2 / pig
feeder – finishing **	600-1,200 lb	9 - 12	weaner	15 - 50 lb	0.6 / pig
bull	--	12	**POULTRY**		
DAIRY			broiler	per 100	4.2
milking * (with wash water)	holstein	36	roaster/pullet	per 100	4.8
dry cow/replacement	holstein	12	layer	per 100	6.5
calf	to 550 lb	3.5	breeder	per 100	8.5
SHEEP AND GOATS			turkey - grower	per 100	15.5
ewe/doe	--	2.5	turkey - heavy	per 100	19
milking ewe/doe	--	3.5	**OSTRICH**	--	1.2
feeder lamb/kid	--	2	**DEER, LLAMA, ALPACA**	--	2.5
BISON, HORSE, MULE	--	12	**ELK, DONKEY**	--	6

Figure 1: Estimated average daily water consumption for livestock (us gallons per day)

Using data from previous years (Statistics Canada, 2012), the province of British Columbia uses 60 million m^3 of water in the months of July and August. Converting this to gallons gives 15.85 billion gallons.

British Columbia is very agriculturally diverse, with many cattle, poultry as well as fruit and tree farms. The number of farms of each type is as follows:

Farm Types	Number of farms
Total number of farms	15,841
Oilseed and grain farming	419
Vegetable and melon farming	1,077
Fruit and tree nut farming	3,036
Greenhouse, nursery and floriculture production	1,167
Other crop farming	3,021
Cattle ranching and farming	2,776
Hog and pig farming	93
Poultry and egg production	1,266
Sheep and goat farming	636
Other animal production	2,350

Table 1: Quantities of farm by farm type.

(Statistics Canada, 2021b)

Each farm type will require a different amount of water. On top of this, the quantity of water required in each type will also differ, as larger farms will need more water. Using linear programming we can optimize the allocation of water. To do so, we can set an objective function that aims to minimize water usage, while reaching a certain yield level. To do so we will consider the different crop and livestock types, the water requirements for each farm type and the farm size.

The data we will use for crop and livestock water requirements is from the Agriculture Water Demand Model for different regions in BC (Ministry of Agriculture and Lands BC, 2023). As our data for farm types is aggregated by larger groups, but our data for water requirements is more individual, and it is separated by regions in the province, we will have to make calculations to generalize the requirements by group by using weighted averages.

As livestock farms are more sensitive to bad seasons than other agricultural farms, since death or illness of livestock can set back a farmer for several years ahead, we will allocate full water requirements to animal farms. Using a livestock watering fact sheet (Ministry of Agriculture and Lands BC, 2006), and data from the census of agriculture (Statistics Canada, 2021a), we can determine livestock in BC requires 394,373,550 gallons of water in one month. Subtracting this from the 15.85 billion gallons total leaves 15.45 billion gallons for plant farms.

Of these remain farms, we have oilseed and grain, vegetable and melon, fruit and tree nut, greenhouse, nursery and floriculture and finally “other crop” farms.

Agricultural Snapshot of BC

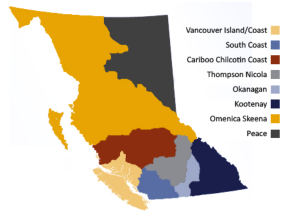

Figure 2: Agricultural Regions of BC (source: Government of BC)

With a surface of 944 735 m^2, British Columbia is the second biggest province in Canada, and the fourth biggest province or territory in the country, behind Nunavut, Quebec and the Northwest Territories. Due to its immense size, the agricultural landscape is very diverse, with many different plants being grown, and livestock being raised. The province's most common livestock are dairy cows, cattle and poultry, and its most commonly produced plant products fruits, vegetables, flows, shrubs and mushrooms.

The Oakanagan-Thompson, which is BC's second largest agricultural region, is known for producing fruit and wine. The Lower Mainland and especially the Fraser Valley is BC's largest producer of livestock, eggs and dairy, while earning the top gross farm receipts (The British Columbia Agriculture in the Classroom Foundation, 2014). Indeed while driving on highway 1 eastbound, it is not uncommon to see, or smell these livestock farms along the road.

Methodology

To calculate the optimal quantities of water for each farm type, much cleaning of the data and reformatting had to be done.

The data from the farm census set farms into groups of farm sizes of 1 acre, 2-10 acres and 11+ acres. This posed a problem as we do not have accurate data on the size of farms and must resort to approximations. As such I used sizes of 1, 5 and 11 to represent these groups. Then, by aggregating the farms by farm type, a total area for each type was estimated. Similarly, the revenue of the farms were in groups of under \$2500, \$2,500 to 4,999, \$5,000 to 9,999, \$10,000 to 24,999, \$25,000 to 49,999, \$50,000 to 99,999, \$100,000 to 249,999, \$250,000 to 499,999 and \$500,000 and over. I elected to use the upper bound of these groups, and \$750,000 as the value for the last group. Then, using data for the average farm revenue and expense by farm type, I was able to use the expense to revenue ratio to calculate a lower bound for the revenue of farm type. The cutoff that was found was typically around 85% of the farm revenue. These lower bounds for revenue represent a value that we should ensure each farm attains on average, as achieving revenue lower than this bound would be a net loss for the farm.

For the water requirements, the BC Agriculture Water Demand Model provided estimates for the demand of plant types in different regions of the province. With most area of BC farms being in the Peace River, Thompson-Oakanagan and Cariboo regions, the water requirement estimates for these regions were prioritized over the other regions. These estimates were given in mm and, using these figures, and multiplying them by the area of the farms, we are able to calculate an estimate for how much volume of water each plant type requires.

By assuming that crop returns are linearly related to the amount of water given to them, a linear decrease in water received will lead to a linear decrease in output produced which in turn will lead to a linear decrease in revenue. Hence a lower boundary for the amount of water each farm type receives was created, based on the same revenue/expense ratios found previously.

A linear programming problem was then set in the following manner:

- The objective function was to maximize revenue, using the formula:

$$z = \sum \frac{H2O}{H2O_{Optimal}} * Revenue_{Optimal}$$

- The constraints were that the total quantity of water must be smaller or equal to 15.45 billion gallons. Furthermore, each farm had to receive a minimum amount of water based on the revenue to expense ratio calculated previously, and the constant returns assumption.

Using the PuLP package in python we can easily set up this linear programming problem and find the optimal value. First three dictionaries were created: The minimum required water dictionary, which gave the minimum amount of water each farm type required to operate and was used for our constraints, then the farm revenue dictionary, which gives the the revenue each farm type receives in receipts under normal conditions and finally the regular water requirements for each farm type. The last two of these dictionaries were used for our objective function.

Findings and discussion

When computing the optimal value with PuLP, we can summarise the findings in the following table:

Farm Type	Quantity of Water (gallons)
Floriculture production	39,852,800.0
Fruit and tree nut farming	165,669,000.0
Mushroom production	14,416,500,000.0
Nursery and tree production	204,991,000.0
Oilseed and grain farming	64,426,200.0
Other crop farming	295,189,000.0
Other food crops grown under cover	1,203,1800.0
Vegetable and melon farming	257,242,000.0

Table 2: Optimal quantity of water allocated to each farm type.

Using these quantities, an optimal revenue of 19,336,281,594.289265 $ was calculated.

Clearly there are some limitations to this analysis. Firstly, this is not accounting for how water will be distributed among the groups themselves. Indeed further linear programming problems can be set to find the "optimal" quantity of water each farm should receive, but this analysis would be ever more complicated as we do not have much information for individual farms.

Secondly, using estimates for gross receipt value, farm area and water requirements was a feasible solution for the categories as a whole as the true values should average out around the estimates but when considering the farms individually, we should be more careful for these values. Similarly, when considering the individual farms, we should account for the soil type, the weather, how much the soil has been used, what irrigation systems are used etc.

It is also evident that there will be diminishing returns as the quantity of water used increases as agriculatural output will not scale infinitely. As such this should be taken into account in this analysis, by using an objective function which models this behavior. However such models are much more complex and outside the scope of my current abilities.

Finally, this allocation of water is made in away to help the economy as a whole, and not individual farms. We can notice this as there is a very uneven distribution as mushroom farms will receive 14.4 billion gallons, whereas floriculture production farms will only receive 39.8 million gallons. Allocating water at such a macroscoping controlling level would require great control over the available water from the government to have the precise allocation calculated. This is not very feasible in an economy like BC's where farmers usually embrace more freedom of operation rather than less.

Conclusion

Despite the limitations of this analysis, I believe a model such as the one I constructed could be very valuable for the economy of British Columbia when encountering dry warm summers. To improve the model I would include more accurate data about farm sizes, revenues and water requirements, as well as a use a more complex objective function to model how the change in quantity of water received by the plants relates to the output of the farm. Furthermore I would consider farms at an individual scale to assess each farm's needs and allocate water more efficiently to each and every one of them.

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