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Estimation of the Water Requirement for Beef Production in the United States[1,2]

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ABSTRACT: A static model of developed water use for U.S. cattle production was constructed on a spreadsheet. Water use included that consumed directly by various classes of animals, water applied for irrigation of crops that are consumed by the cattle, water applied to irrigated pasture, and water used to process animals at marketing. Government statistics were consulted for numbers of cattle and crop production. The most recent statistics available for numbers of cattle and crops in individual states were used. On January 1, 1992, a total of 33.8 million beef cows and 5.7 million replacement heifers were in U.S. breeding herds, 12 million animals were on feed, and approximately 28 million animals were fed annually. Thus, the U.S. beef cattle herd produced 6.9 billion kg of boneless beef. Beef cattle directly consumed 760 billion L of water per year. Feedlot cattle were fed various grain and roughage sources corresponding to the regions in which they were fed. Feeds produced in a state were preferentially used by cattle in that state with that state's efficiency; any additional feedstuffs required used water at the national efficiency. Irrigation of crop feedstuffs for beef cattle required 12,991 billion L of water. Irrigated pasture for beef cattle production required an additional 11,243 billion L of water. Carcass processing required 79 billion L of water. The model estimates 3,682 L of developed water per kilogram of boneless meat for beef cattle production in the United States. The model was most sensitive to the dressing percentage and percentage of boneless yield in carcasses of feedlot cattle (62 and 66.7, respectively). A 10% change in either of these parameters resulted in a corresponding 8.6% change in the water required for beef production. A 10% increase in the number of animals on feed resulted in a decrease in the amount of water per kilogram of boneless beef by 5.2%. Changes in irrigated pasture management would also be an effective means of decreasing the water requirement. The water requirement of 3,682 L/kg of boneless beef is much lower than previously suggested.

Key Words: Water Use, Irrigation, Beef Cattle

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Introduction

Several recent publications include estimates of the water requirements for beef production that seem exceptionally high (20,864 L/kg of meat, Robbins, 1987; 20,559 L/kg of boneless beef, Kreith, 1991). These reports are fraught with faulty assumptions and oversimplifications that result from basing estimates on one typical production scenario. A more defendable approach is to quantify all inputs to the production system. Water used for beef cattle can be divided into that drunk by animals, that used for producing feed, and that used for processing the cattle into beef. By far, most of the water consumed is used to grow feed (Oltjen, 1991). Evapotranspiration constitutes a consumptive use of plants for feed production. Further, this water may be supplied by either natural precipitation or irrigation. Application of developed water by irrigation constitutes a direct diversion of water that might have been used for other purposes. Thus, it is important to account for this water and charge it against beef production. The wide diversity of production systems under which beef cattle are raised complicates analysis. Thus, the objective of this research was to quantify the developed water requirements for beef production in the United States, dividing water use into that for drinking, feed production, and processing.

Materials and Methods

A static model depicting beef cattle production in the United States was constructed on a spreadsheet. In the model, all production schemes are represented

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for individual states. The water accounted for is water that is developed and is diverted from possible use by humans. In this respect, natural precipitation that falls on crops is not considered to be developed water. Although data for individual states were used in all calculations, for presentation purposes states are grouped into regions in this paper (Table 1).

Table 1. United States beef production regions

Region	States included
1	WA, OR, ID
2	MT, ND, SD
3	WY, CO, UT
4	NM, TX, OK
5	KS, NE
6	MO, IA, MN, WI, IL, MI, IN, OH, NY, PA
7	CA, AZ, NV
8	Other

Direct Consumption

The January 1992 beef cow and replacement heifer inventory was provided by the National Agricultural Statistics Service (USDA, 1992; Table 2). The number of calves was estimated assuming 85 calves weaned per 100 cows per year. Further, one bull per 20 cows and replacement heifers was assumed. Data presented by Winchester and Morris (1956) were used to predict total water intake by class of cattle. These data were fit to regression equations (SAS, 1985) according to the following model: water intake = $b_0 + b_1 \cdot \text{weight} + b_2 \cdot \text{temperature} + b_3 \cdot \text{temperature}^2$. Coefficients for the equations are presented in Table 3. Average annual temperature was calculated for 140 selected weather stations throughout the country based on monthly mean temperatures (Boyer and Savageau, 1989). The average annual temperature for a given state was calculated as the mean for the given weather stations within the state (Table 2). Average weights for cattle are assumed to be 476, 136, 272, and 680 kg for cows, calves, replacement heifers, and bulls, respectively. The yearly predicted total water intake for cows is calculated as the sum 1) of all cows with calves (85% of all cows) times the water consumption for lactating cows for 4 mo of the year, 2) of all cows without calves (15%) times the water consumption for maintenance animals for 4 mo of the year, 3) of all pregnant cows (92%) times the water consumption for pregnant cows for 8 mo of the year, and 4) of all nonpregnant cows (8%) times the water consumption for maintenance cows for 8 mo of the year. Yearly water intake for calves is calculated for 205 d. At the time of weaning, replacement heifers consume water as predicted by the water intake equation for that class of cattle. The rest of the calves either enter the feedlot directly (17%; Henderson and Schwart, 1977) or are stocked for a period of time. Stocker cattle consume water according to the prediction equation for growing calves for a total of 160 d. Calves entering the feedlot consume water as feeders. Bulls and replacement heifers consume water as predicted by the total water consumption equations for their respective classes. Equations predicting water intake represent both water drunk directly by the animal and water contained in the feed. To determine direct water consumption, water in the feed was subtracted from the total water intake predictions. The DMI of all classes of breeding and stocker cattle was estimated as 2% of BW; DMI of calves was estimated to be 2.5% of BW. An average 75% DM of the feedstuffs was used to calculate the amount of water contained in the feed that the animals are consuming. This feedstuff-bound water is then subtracted from the total water intake predictions to give an estimate of the water consumed by drinking (Table 2). Perhaps 75% represents an overestimate of the DM content in the feed; thus, predicted drinking water will be greater than expected.

Water consumed by feedlot animals was estimated to be 37.9 L per animal per day (Winchester and

Table 2. Breeding herd and stocker data

Region[a]	Average annual temp, °C	Inventory (January 1, 1992)		Water from	
		Beef cow	Replacement heifer	Drinking, 10^6 L	Non-pasture irrigated feed, 10^6 L
1	10.6	1,544,000	285,000	25,371	431,550
2	6.8	3,854,000	725,000	58,625	670,358
3	9.2	1,838,000	368,000	29,268	956,927
4	16.2	7,933,000	1,270,000	157,559	133,118
5	11.7	3,085,000	455,000	50,781	330,288
6	9.7	5,421,000	881,000	88,884	165,220
7	16.9	1,426,000	226,000	27,118	953,173
8	13.6	8,733,000	1,537,100	168,883	671,342
Total	—	33,834,000	5,747,100	606,490	4,311,977

[a]See Table 1 for states included in each region.

Table 3. Polynomial coefficients for water intake equations[a]

Animal class[b]	Regression coefficients: Intercept, L	Weight, kg b_1	Temp, °C b_2	Temp^2, °C^2 b_3	R^2
MAIN	−.28	.034	−.38	.030	.93
LACT	37	.0	1.2	.00088	.98
PREG	39	−.034	−.013	.026	.94
WINT	34	−.028	.015	.026	.97
CALV	.90	.067	.0034	.017	.99
BULL	9.5	.038	−.68	.052	.95

[a]Model: Water intake = intercept + b_1·weight + b_2·temperature + b_3·temperature^2.
[b]MAIN = cattle on maintenance rations; LACT = cows nursing calves, first 4 mo after parturition; PREG = mature, pregnant cows; WINT = wintering, pregnant heifers; CALV = growing cattle; BULL = bulls.

Morris, 1956). Rations for feedlot cattle varied by region (Table 1). Dry matter content of the various ration components (NRC, 1984) was used to calculate the water content of the diets. Again, water in the feed was subtracted from total water intake to estimate drinking water.

Feedstuff Production

The Census of Agriculture (United States Department of Commerce, 1987) provided the number of hectares of each crop, irrigated hectares for each crop, and the yield of each crop by state (Tables 4 to 10). Data for individual states have been reported by region in this paper (Table 1).

Alfalfa, Wheat, Grain Sorghum, Barley, Corn, and Corn Silage. The percentage of total hectares of alfalfa, wheat, grain sorghum, barley, corn, and corn silage irrigated and yield per hectare in each state was calculated (Tables 4, 5, 6, 7, 8, and 9, respectively) by dividing irrigated acres and yield by total acres. The applied water per hectare of irrigated crop was provided by the Census of Agriculture Farm and Ranch Irrigation Survey (United States Department of Commerce, 1988). For any state without an applied water value, the average applied water for all other states was used. Total water applied is the product of the number of irrigated hectares and the applied water per hectare (Tables 4, 5, 6, 7, 8, and 9, respectively, for alfalfa, wheat, grain sorghum, barley, corn, and corn silage). The water use efficiency for the crop grown in each state is the ratio of total water applied to total yield.

Approximately 50% of the irrigated barley in Idaho is used solely for malt production and therefore is not directly available as a feedstuff (McGreevy, personal communication). This anomaly has been included in the model because it seems to represent production practices more adequately.

Irrigated Pasture. The number of hectares of irrigated pasture was provided by the Census of Agriculture (United States Department of Commerce, 1987; Table 10). Irrigated hectares used in wheat for grain production is included in the numbers for Colorado, Kansas, and Texas (15, 50, and 85% of the total surface area reported, respectively). For these three states, the number of irrigated wheat hectares was subtracted from the reported data to give an adjusted number of irrigated pasture hectares. Applied water in each state was calculated as the proportion of water applied to irrigated pasture in

Table 4. United States alfalfa production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, 10^6 kg	Liters of water/kg all alfalfa hay
1	696,990	75.3	6.67	3,500,792	5,578	627.6
2	1,855,898	15.4	5.25	1,504,040	8,124	185.1
3	701,568	80.4	6.18	3,485,465	4,427	787.4
4	277,217	43.2	7.17	858,967	2,093	410.3
5	780,924	23.4	4.39	803,490	5,734	140.1
6	4,203,254	.5	2.25	51,924	28,035	1.9
7	536,936	98.0	11.73	6,175,568	6,915	893.1
8	509,850	1.0	1.72	8,762	2,833	3.1
Total	9,562,638	—	—	16,389,007	63,739	—
Weighted average	—	23.3	7.3	—	—	257.1

[a]See Table 1 for states included in each region.

Table 5. United States wheat production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, 10^6 kg	Liters of water/kg of wheat
1	1,715,450	22.8	4.84	1,891,112	6,801	278.0
2	6,762,988	1.3	3.14	266,830	13,162	20.3
3	1,159,736	8.9	3.90	403,758	2,611	154.6
4	3,332,437	10.6	3.10	1,100,794	6,001	183.4
5	4,306,519	7.0	2.91	878,259	10,065	87.3
6	2,563,887	.8	1.71	37,154	7,761	4.8
7	273,066	78.6	6.94	1,488,347	1,336	1,114.0
8	1,424,975	2.7	1.12	42,965	3,621	11.9
Total	21,539,059	—	—	6,109,218	51,359	—
Weighted average	—	7.0	4.0	—	—	119.0

[a]See Table 1 for states included in each region.

California compared with the water applied to irrigated alfalfa in California (1.164; Department of Water Resources, 1986). An implicit assumption was that this proportion stays relatively constant throughout the United States. However, the majority of the irrigated pasture used in beef production is in the western states. Total water applied is the product of applied water per irrigated hectare and the number of irrigated hectares. Beef specialists were consulted to estimate the percentage of irrigated pasture hectares devoted to beef production (breeding and stocker cattle) within each state. Ninety-five percent was the default value for any state without a specialist's estimate. Water devoted to beef production through irrigated pasture was calculated by multiplying the total water applied to irrigated pasture and the percentage of irrigated pasture used in beef production within each state.

Processing

The water required to process beef carcasses was included. An estimate of the water required during processing the animal from the time it reaches the slaughter facility to the time it has been processed into trimmed, boneless beef was provided by a modern, commercial slaughterhouse (1,533 L/carcass; Roger Hall, Southfield Beef, Fresno, CA, personal communication). This was estimated by dividing the total water entering the facility during a work day by the amount of beef processed during that time. This figure was increased by 50% to ensure that any bias is an overestimation (2,299 L/carcass). Multiplying this figure by the number of animals slaughtered in a year yields 78.5 billion L of water required to process beef.

Feedlot

The number of cattle and calves on feed (USDA, 1992) was adjusted to provide an estimate of the weighted average number of animals on feed throughout the year by multiplying the number of animals reported on January 1, 1992, by .976 (proportion of animals on feed throughout the year compared with those on feed at the beginning of the year). The total gain, days on feed, and daily gain of all animals on feed throughout the country were assumed to be 195 kg, 148 d, and 1.32 kg/d, respectively. California and

Table 6. United States grain sorghum production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, 10^6 kg	Liters of water/kg of grain sorghum
1	0	0	0	0	0	0
2	74,194	.6	1.32	558	227	2.5
3	77,451	19.0	5.26	77,534	188	413.5
4	1,279,448	18.8	3.65	876,671	4,556	192.4
5	1,902,135	12.0	3.64	828,519	8,358	99.1
6	308,603	4.3	1.83	24,461	1,582	15.5
7	5,268	97.4	8.25	42,327	26	1,645.4
8	302,866	9.0	1.99	54,167	1,146	47.3
Total	3,949,964	—	—	1,904,237	16,083	—
Weighted average	—	13.4	3.6	—	—	118.4

[a]See Table 1 for states included in each region.

Table 7. United States barley production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, 10^6 kg	Liters of water/kg of barley
1	659,177	35.9	2.58	610,708	1,888	323.5
2	2,168,283	4.5	3.32	326,047	5,004	65.2
3	184,916	71.5	5.99	791,853	665	1,190.6
4	11,201	49.2	3.82	21,052	28	750.2
5	57,350	9.8	1.74	9,774	118	83.0
6	416,654	.4	1.40	2,624	1,231	2.1
7	118,836	51.6	5.30	324,775	363	895.9
8	97,954	1.3	.88	1,092	308	3.5
Total	3,714,371	—	—	2,087,924	9,605	—
Weighted average	—	14.6	3.8	—	—	217.4

[a]See Table 1 for states included in each region.

Arizona cattle spent more time in the feedlots with values of 251 kg, 201 d, and 1.25 kg/d for total gain, days on feed, and daily gain, respectively. The latter numbers were obtained from unpublished data for these states. Based on state beef extension specialists' estimates, feedlot rations were formulated by region (see Table 1), as shown in Table 11. Also included in Table 11 is an estimate of the feed:gain ratio for the respective regions. Crops grown in each state were preferentially fed in feedlots in that state. This implies that water required to grow feedstuffs is used at a regional water efficiency. If a state does not produce enough of a crop to provide its feedlots with the required amount of feed, the additional crop needed is fed at the national average water efficiency. Total water required to grow the irrigated feedstuffs fed to feedlot cattle is included in Table 12.

Breeding Stock

After the feed required for feedlots is removed from the respective state's production supply, remaining feed becomes available to the breeding herd and stocker cattle within that state. Again, if an adequate amount of feed is not produced in a state, that additional commodity is assigned the national average water efficiency use. Amounts of feed fed to the breeding herd and stocker cattle are shown in Tables 13 and 14, respectively.

The beef production by the cull cows is calculated by multiplying the number of replacement heifers by the average weight of the cows. The assumption is that the national cow herd stays relatively constant from year to year, so the number of replacements is equal to the number of cows being culled from the cow herd each year. The average weight of the cows is converted to carcass beef by multiplying the live weight by 55%. Carcass weight is multiplied by 66.7% to arrive at boneless beef weight.

Holstein Calves

Because a large amount of the beef produced in the United States originates from Holstein feeder cattle, water required for the growth of Holstein calves is accounted for from the time they leave the dairy (approximately 3 d of age) until the time they are either stocked or enter the feedlot (Table 15).

Table 8. United States corn production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, 10^6 kg	Liters of water/kg of corn
1	63,226	98.2	8.18	507,803	613	828.3
2	1,263,336	8.3	3.40	356,016	6,291	56.6
3	301,276	94.6	5.81	1,655,203	2,687	616.0
4	542,621	44.6	5.48	1,327,871	3,483	381.2
5	2,968,223	67.6	3.81	7,644,325	22,693	336.9
6	16,416,691	2.1	2.52	850,220	123,693	6.9
7	68,949	95.8	8.33	550,343	638	861.9
8	2,131,335	6.3	2.31	310,162	10,725	28.9
Total	23,755,656	—	—	13,201,944	170,823	—
Weighted average	—	13.6	4.1	—	—	77.3

[a]See Table 1 for states included in each region.

Table 9. United States corn silage production

Region[a]	Total area, ha	Percentage of area irrigated	Applied water, 10^6 L/ha	Total water, 10^6 L	Total yield, green, 10^6 kg	Liters of water/kg of corn silage
1	45,368	82.6	6.46	242,295	2,104	115.2
2	267,543	8.9	4.99	118,229	5,180	22.8
3	71,279	97.3	6.26	434,084	3,152	137.7
4	43,051	67.8	5.79	169,122	1,677	100.8
5	117,476	52.5	3.37	207,785	4,029	51.6
6	1,260,635	.8	2.00	20,323	39,393	.5
7	81,776	99.2	9.51	770,850	4,118	187.2
8	454,123	3.2	1.92	27,983	13,279	2.1
Total	2,341,252	—	—	1,990,671	72,932	—
Weighted average	—	14.0	6.1	—	—	27.3

[a]See Table 1 for states included in each region.

Table 10. United States irrigated pasture

Region[a]	Total area, ha	Applied water, 10^6 L/ha	Total water, 10^6 L	Percentage irrigated pasture for beef production	Water for beef production, 10^6 L
1	391,847	7.66	3,000,224	88	2,638,717
2	190,936	6.31	1,205,638	80	969,008
3	521,444	6.64	3,463,802	84	2,915,965
4	158,626	3.76	596,537	80	479,793
5	70,902	3.92	278,214	95	264,304
6	11,021	2.45	26,953	83	22,379
7	380,845	13.20	5,025,822	74	3,727,088
8	143,398	2.28	327,038	69	225,353
Total	1,869,018	—	13,924,228	—	11,242,607
Weighted average	—	7.5	—	81	—

[a]See Table 1 for states included in each region.

Nutrients are supplied to the calves in the form of corn, alfalfa, and milk replacer. A typical calf growing ration was used to calculate the feed requirements for the calves. Water required for the feedstuffs was calculated at the national average for each crop due to the small amount of feed that is fed to this class of animal and the difficulty in determining the geographical location of the growing Holstein calves. Direct water consumption per animal was calculated as 10.8 L/d.

The total water consumption by beef cattle in the United States, 25,325,109 million liters, is presented by class of animal in Table 16.

Beef Cattle Production

Calculation of the boneless beef production is shown in Table 17. Beef production is the sum of feedlot cattle growth and cull cow slaughter. The numbers of animals produced in each category is adjusted for dressing percentage for feedlot cattle and cull cows

Table 11. Feedstuffs in feedlot rations

Region[a]	Feed:gain	Percentage dry matter	Alfalfa, %	Corn, %	Wheat, %	Corn silage, %	Sorghum, %	Barley, %
1	6.4	88%	3	10	20	0	0	35
2	6.4	77%	10	40	5	20	0	10
3	6.4	84%	3	65	15	8	0	0
4	6.4	88%	6	40	10	2	17	0
5	6.4	85%	5	60	10	7	0	0
6	7.5	75%	5	50	5	25	0	0
7	6.4	89%	10	33	15	0	0	5
8	7.5	77%	5	40	20	20	0	0

[a]See Table 1 for states included in each region.

Table 12. Feedlot data

Region[a]	Inventory (1/1/92)	Total animals fed/yr	Water consumed by drinking, 10^6 L	Water from irrigated feed, 10^6 L
1	538,000	1,294,981	7,042	550,357
2	445,000	1,071,127	5,610	113,176
3	1,085,000	2,611,624	14,016	1,641,867
4	2,640,000	6,354,551	34,470	2,034,817
5	3,810,000	9,170,773	49,296	3,141,385
6	2,515,000	6,053,673	30,908	57,766
7	649,000	1,178,809	8,520	1,127,064
8	275,000	661,932	3,426	29,149
Total	11,957,000	28,397,470	153,288	8,695,582

[a]See Table 1 for states included in each region.

(62 and 55, respectively) and boneless beef percentage of carcass (66.7 for both categories). Based on January 1, 1992, inventories, the total beef production in the United States is 6.9 billion kg of boneless beef.

Sensitivity Analysis

Model sensitivity to various parameters was determined by increasing and then decreasing the parameter by 10% and noting the overall change in the water requirement for beef production (Table 18).

Results and Discussion

The model predicts that 3,682 L of water are required to produce a kilogram of boneless beef under current beef production systems employed in the United States. This compares to previous estimates of 20,864 L/kg of meat and 20,559 L/kg of boneless beef (Robbins, 1987; Kreith, 1991). Water consumed by the breeding herd and stocker cattle, in the feedlot, and by the dairy calves is shown in Table 16.

The model is particularly sensitive to the number assumed for dressing percentage and boneless yield of beef carcasses (Table 18). It is also sensitive to water

Table 13. Feedstuffs fed to cows and bulls per year (kg)

Region[a]	Alfalfa	Corn	Wheat	Corn silage
1	227	0	14	0
2	454	50	0	181
3	454	0	0	0
4	45	14	0	0
5	263	73	0	408
6	227	23	23	907
7	454	23	23	0
8	454	23	23	227

[a]See Table 1 for states included in each region.

Table 14. Feedstuffs fed to stockers per year (kg)

Region[a]	Alfalfa	Corn	Wheat	Corn silage
1	227	0	0	0
2	136	91	0	680
3	227	0	0	0
4	0	0	0	0
5	0	91	0	454
6	0	91	0	1,361
7	227	0	0	0
8	0	0	0	0

[a]See Table 1 for states included in each region.

Table 15. Holstein calves

Item	Amount
Holstein calves entering feedlot per year	5,385,670
Daily water consumption, L/animal	12.9
Daily water intake of cattle from feed, L/animal	2.1
Daily water intake from drinking, L/animal	10.8
Total yearly water intake from drinking, 10^6 L	4,663
Days on feed	80
Daily feed/animal	
Corn, kg	.91
Alfalfa, kg	1.81
Feed consumed, per animal during growth period	
Milk replacer, L	159
Corn, kg	73
Alfalfa, kg	145
Yearly consumption	
Corn, 10^6 kg	391
Alfalfa, 10^6 kg	782
Water required to grow feed	
Corn, 10^6 L	30,208
Alfalfa, 10^6 L	201,004
Water required for milk replacer, 10^6 L/yr	771
Total water to grow Holstein calves, 10^6 L	236,645

Table 16. Water consumption by beef cattle in the United States

Form of consumption	Water consumed, 10^6 L
Water consumed directly by breeding herd and stockers	606,490
Irrigated feed for breeding herd and stockers	4,311,977
Irrigated pasture for breeding herd and stockers	11,242,607
Water consumed in feedlot	153,288
Water used for processing animal	78,520
Water used for feed in feedlot	8,695,582
Water consumed for Holstein calf growth (prefeedlot)	236,645
Total	25,325,109

Table 17. Beef cattle production in the United States

Item	Feedlot cattle	Cull cows
No. of animals	28,397,470	5,747,100
Average body wt, kg	500	476
Dressing percentage	62.0%	55.0%
Carcass beef, kg/animal	310	262
Boneless beef (% of carcass)	66.7%	66.7%
Boneless beef, kg/animal	207	175
Total beef production, kg	5,873,301,157	1,004,135,490

applied to and hectares of irrigated pasture. It is moderately sensitive to animal performance. All other parameters assumed in the model make less than a 2% difference in water use per kilogram of boneless beef produced. The model was most sensitive to the dressing percentage and percentage of boneless yield in carcasses of feedlot cattle (62 and 66.7, respectively). A 10% change in either of these parameters resulted in a corresponding 8.6% change in the water required for beef production. A 10% increase in the number of animals on feed resulted in a decrease in the liters of water per kilogram of boneless beef by 5.2%. This inverse relationship is due to the increased beef production from those animals relative to the water required for that gain. Changes in the irrigated pasture management would be an effective means of decreasing the water requirement.

The model takes into account all the water that is applied to irrigated feedstuff crops and irrigated pasture. This total water is then used to calculate the water use efficiency for each crop by state and any feed that is fed to cattle is assigned that water use efficiency. However, 10 to 20% of the water that is applied to crops during irrigation runs off the fields and returns to water sources such as irrigation ditches, reservoirs, or streams (Richard Pruitt, personal communication). This water is then available for human consumption again and is considered developed water. Incorporating a 15% runoff factor for irrigated pasture results in a decreased water requirement of 245 L/kg of boneless beef, or 6.7% of the total water required for beef production. Doing the same

Table 18. Model sensitivity to parameter changes

Parameter	Parameter initial value	Effect of 10% parameter change[a]	
		%	L/kg
Dressing percentage for feedlot cattle	62%	8.60	316.6
Percentage boneless yield in carcass (feedlot animals)	66.7%	8.60	316.6
Animals on feed	11,957,000	5.24	192.9
Total water applied to irrigated pasture, m^3	1.39×10^{10}	4.44	163.5
Irrigation water for beef pasture, L	1.12×10^{13}	4.44	163.5
Area of irrigated pasture, ha	1,869,018	4.44	163.5
Total gain for animals on feed (average), kg	197	2.74	100.7
Feed:gain	6.68	2.74	100.7
Days on feed	150	2.72	100.2
Area of irrigated corn (grain), ha	3,238,765	2.55	93.8
Applied water on irrigated corn, L	1.32×10^{13}	2.55	93.8
Percentage grain in feedlot rations		2.40	88.4
Corn yield, kg	1.71×10^{11}	1.86	68.5
Alfalfa yield, kg	6.37×10^{10}	1.83	67.4
Area of irrigated alfalfa, ha	2,232,305	1.73	63.8
Applied water on irrigated alfalfa, L	1.64×10^{13}	1.73	63.8
No. of replacement heifers	5,747,100	1.65	60.6
Average cow weight, kg	476	1.52	55.8
Dressing percentage for cull cows	55.0%	1.46	53.7
Percentage boneless yield in carcass (cull cows)	66.7%	1.46	53.7
No. of beef cows	33,834,000	1.46	53.6
Water intake by breeding herd and stockers	6.06×10^{11}	.24	8.8
Dry matter in feed for breeding herd, %	75.0%	.09	3.4
Holstein calf growth, L	2.37×10^{11}	.09	3.4
Cow:bull ratio	20:1	.09	3.1
Water consumed in the feedlot, L	1.53×10^{11}	.06	2.2
Percentage calves weaned	85%	.04	1.4
Water used for processing animal, L	7.85×10^{10}	.03	1.1
Dry matter intake for cows, bulls, and replacement heifers (% BW)	2.0%	.02	.76
Average calf wt, kg	136	.02	.68
Average replacement heifer wt, kg	272	.01	.44
Average bull wt, kg	680	.01	.22
Dry matter intake for calves (% BW)	2.5%	.00	.10

[a]Change from 3,682 L of water required/kg of boneless beef.

with all irrigated hectares on which crops are grown results in decreasing the requirement by 283 L of water/kg of boneless beef, or 7.7% of the total water required for beef production. Considering a 15% runoff of applied water for both irrigated pasture and feedstuff crops, the adjusted water requirement for beef would be 3,151 L/kg of boneless beef. This is 529 L (14.4%) less than when runoff water is not considered.

Finally, in certain regions, much of the beef consumed is shipped in from other parts of the country, and the direct effect of changing beef consumption in one region may have little or no effect on water use for beef cattle in that region.

The latest statistics available were used in this model; there is no base year for which this project has been standardized. This approach has been taken because data are not available for one complete year. Further, assumptions have been conservative, so any bias is reflected as an overestimation of water required for beef production.

Implications

The water requirement found here of 3,682 L per kg of boneless beef is much lower than previously suggested. Irrigation is the major cost of water in U.S. beef production. Further, irrigated pasture is a major contributor to the total water cost for beef production in the United States. More intensive irrigation practices or decreased use may provide the most plausible alternatives to reduce the water required for beef production. Sensitivity analysis suggests that errors in the model would not produce large changes in the water requirements for beef production.

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