NM WRRI Student Water Research Grant Progress Report

Final Report

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Assessment of Water Footprints of New Mexico Major Cops

1. Description of research problem and research objectives.

Many regions in the western US including New Mexico (NM) are suffering from severe water shortages due to climate change impacts such as increased frequency, duration, and severity of drought; and increased number of heatwave events; as well as the need to meet water allocation agreement of interstate water compacts. Such impacts put increased pressure on crop production systems in New Mexico in terms of sustainability and the ability to produce the same (or more) amount of crop with less water. One of the main indicators that can be used to understand and evaluate how crops are adapting to climate change impacts is the water footprint – which refers to the amount of water used to produce one unit of the crop (e.g., how many liters of water is needed to produce one kilogram of alfalfa). Reducing the amount of water needed to produce one unit of crop can reduce its water footprint and ultimately support sustainable water resources efforts. Therefore, to better manage and sustainably use an increasingly limited water supply, there is a need to provide estimates of crop water footprint.

The goal of this project is to assess the water footprint for major crops in New Mexico. The research objectives are: 1) Identify the major crops in New Mexico and the related producing counties in the state using historic crop data; 2) Use the water footprint concept to estimate the different water footprint components which include the green water, blue water, and total water footprint at the county level for the identified major crops; and 3) Assess temporal variation in the water footprint.

2. Description of the methodology employed.

2.1. Identify the crops and counties.

Based on more crop production and more harvested area, four crops were selected for this study under the study area of New Mexico (USDA NASS, 2023). Here, county-wise water footprints were calculated for the crop's wheat, corn, alfalfa hay, and sorghum for the four decades from 1981 to 2020. Crop production, crop yield, counties, and decades are given below:

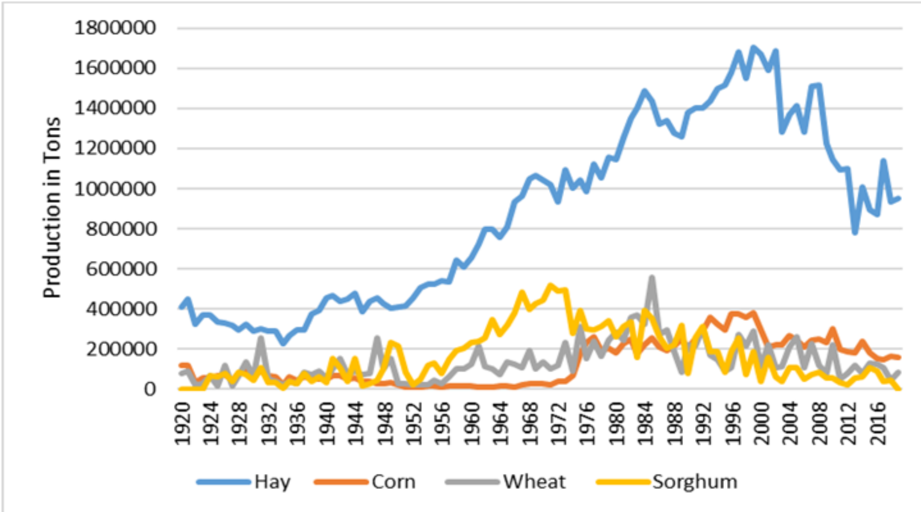


Figure 1: Production of Hay, Corn, Wheat, and Sorghum from 1920 to 2020 in New Mexico.

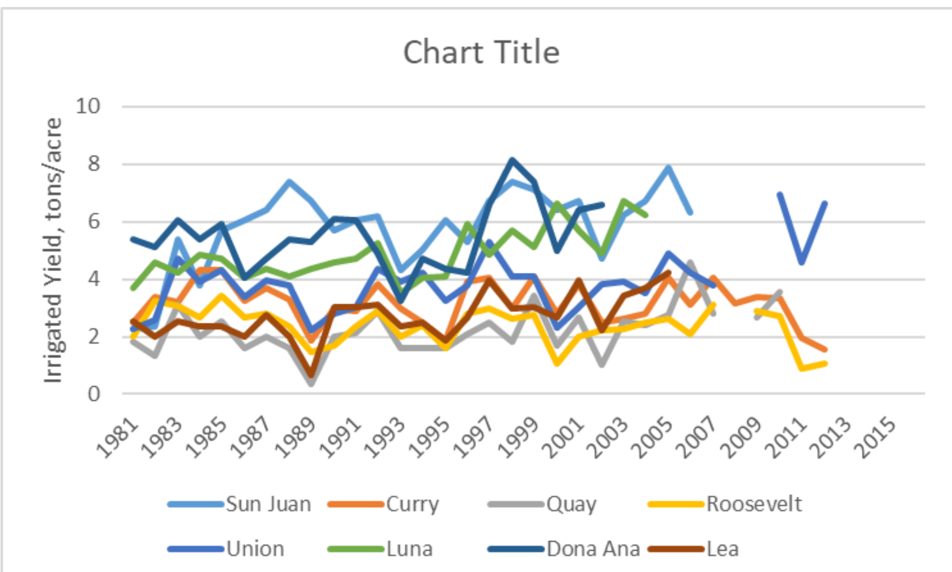


Figure 2: Historical irrigated yield of wheat for the 1981 – 2013 period.

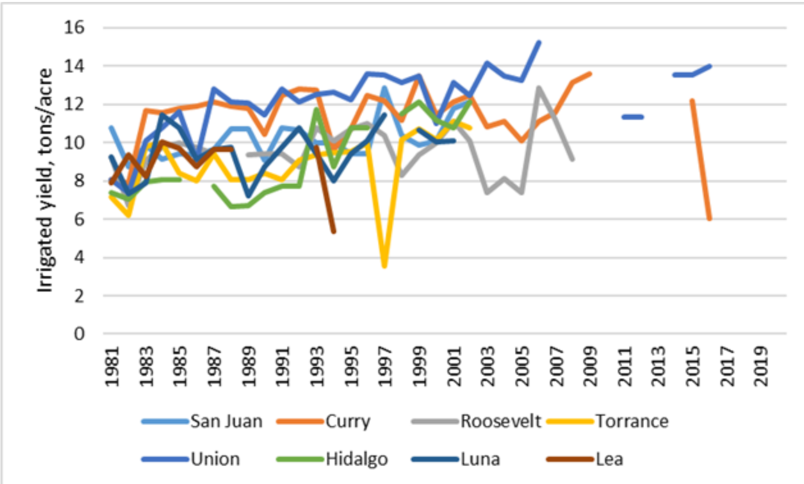


Figure 3: Historical irrigated yield of corn for the 1981 – 2016 period.

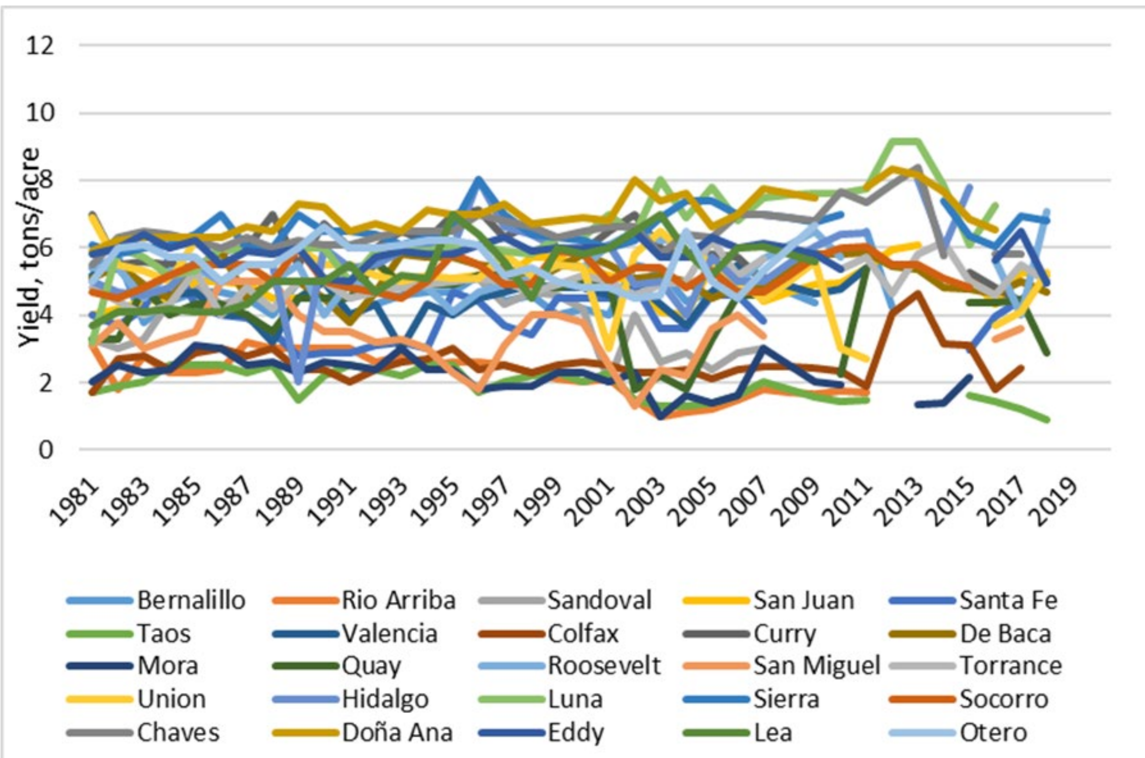


Figure 4: Historical irrigated yield of alfalfa hay for the 1981 – 2019 period.

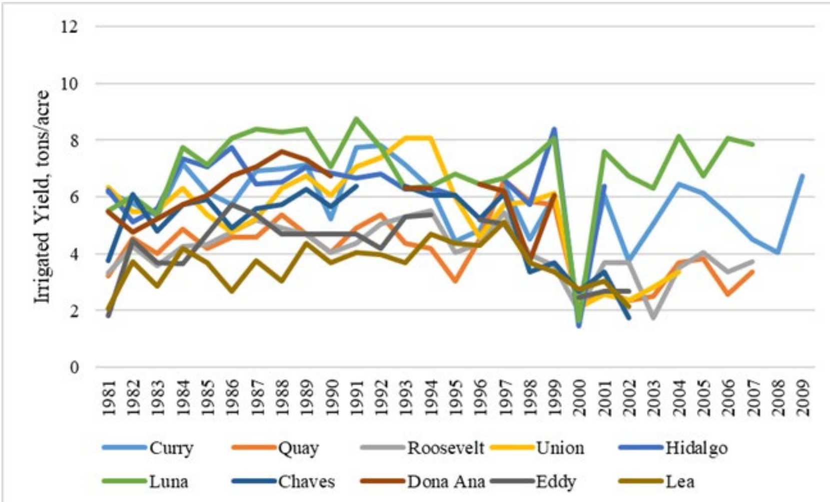


Figure 5: Historical irrigated yield of Sorghum for the 1981 – 2007 period.

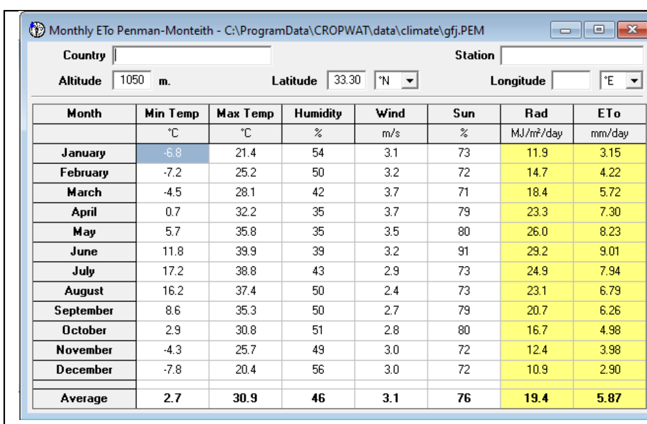
Table 1. The table shows the counties, crops, and decades where the water footprint was calculated.

No	Crop	Counties	Number of Counties	Decades of analysis
1	Sorghum	Curry, Quay, Roosevelt, Union, Hidalgo, Luna, Chaves, Dona Ana, Eddy, Lea	10	1981-1990, 1991-2000, 2001-2010
2	Wheat	San Juan, Curry, Quay, Roosevelt, Union, Luna, Dona Ana, Lea	8	1981-1990, 1991-2000, 2001-2010
3	Alfalfa	Bernalillo, Rio Ariba, Sandoval, San Juan, Valencia, Santa Fe, Taos, Curry, De Baca, Mora, Quay, Roosevelt, San Miguel, Torrance, Union, Hidalgo, Luna, Sierra, Socorro, Chaves, Dona Ana. Eddy, Lea, Otero	24	1981-1990, 1991-2000, 2001-2010, 2011-2020
4	Corn	San Juan, Curry, Roosevelt, Torrance, Union, Hidalgo, Luna	7	1981-1990, 1991-2000

2.2. Estimation of Crop Water Requirement

To estimate the county-wise water footprint for major crops in New Mexico, the water footprint concept as described in Hoekstra et al. (2011) was used. The water footprint components (i.e., green, blue, and grey) can be estimated based on the source of the used to irrigate the crops. The blue water refers to the amount of irrigation water that comes from surface water and ground water sources such as rivers and wells. Green water refers to the amount of water that comes from precipitation and is used for irrigation. The grey water is the water that has been treated and reused. The grey water is not considered in this analysis since there are no crops in New Mexico that are currently being irrigated from treated water sources. The amount of green and blue water requirement (CWR) in this analysis was calculated using a crop water requirement model called the CROPWAT 8.0 (Figure 6) model which was developed by the Food and Agricultural Organization (FAO) [FAO, 2013; FAO, CROPWAT model] (CROPWAT, 2023),. The CWR for the different crops was estimated based on actual evapotranspiration (ET).

The CWR based on ET can be calculated using a set of climate and crop data. The required climate data includes minimum temperature, maximum temperature, humidity, wind, and sun hour which are used to calculate reference ET (ET_0) based on the Penman-Monteith equation. In the climate module, after providing local altitude, latitude, and longitude data as well as all climate data like, it calculates the reference evapotranspiration (ET0) by Penman-Monteith equation. Minimum temperature, maximum temperature, and precipitation from NOAA National Centers for Environmental Information (NOAA - NCEI, 2023). Humidity and wind speed were taken from the Power-data access viewer (Power, 2023). The CROPWAT model has a companion tool called CLIMWAT (CLIMWAT, 2023) that allows to acquire and process climate data and it was used in this analysis.



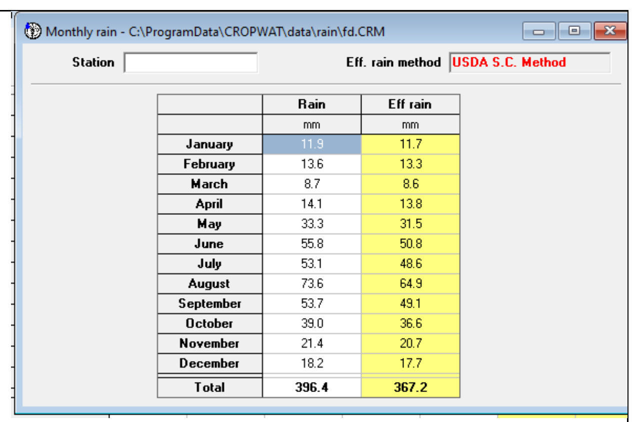
Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\gfj.PEM

Country | Station

Altitude 1050 m. | Latitude 33.30 °N | Longitude °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	%	MJ/m²/day	mm/day
January	-6.8	21.4	54	3.1	73	11.9	3.15
February	-7.2	25.2	50	3.2	72	14.7	4.22
March	-4.5	28.1	42	3.7	71	18.4	5.72
April	0.7	32.2	35	3.7	79	23.3	7.30
May	5.7	35.8	35	3.5	80	26.0	8.23
June	11.8	39.9	39	3.2	91	29.2	9.01
July	17.2	38.8	43	2.9	73	24.9	7.94
August	16.2	37.4	50	2.4	73	23.1	6.79
September	8.6	35.3	50	2.7	79	20.7	6.26
October	2.9	30.8	51	2.8	80	16.7	4.98
November	-4.3	25.7	49	3.0	72	12.4	3.98
December	-7.8	20.4	56	3.0	72	10.9	2.90
Average	2.7	30.9	46	3.1	76	19.4	5.87

Figure 6: ET0 calculation by CROPWAT model



Monthly rain - C:\ProgramData\CROPWAT\data\rain\fd.CRM

Station | Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	11.9	11.7
February	13.6	13.3
March	8.7	8.6
April	14.1	13.8
May	33.3	31.5
June	55.8	50.8
July	53.1	48.6
August	73.6	64.9
September	53.7	49.1
October	39.0	36.6
November	21.4	20.7
December	18.2	17.7
Total	396.4	367.2

Figure 7: Effective rainfall (P_{eff}) calculation by CROPWAT model

In the CROPWAT model, the climate data and crop water requirements calculation were conducted at monthly time scale. Crop yield data for New Mexico over the different counties were available since 1960s while the climate data is available since 1980s both datasets are available until 2020. So, there are four decades of consistent data from 1981 to 2020. To evaluate long-term changes in the water footprint, the analysis was conducted on monthly decadal averages of climate and crop yield data.

Reference evapotranspiration (ET0) and effective rainfall (Peff) were calculated for every four-decade for the selected crops and counties. Local planting and harvesting dates were taken from the United State Department of Agricultural – National Agricultural Statistical Services (USDA NASS). Based on the growing season, four developmental stages: initial, development, mid-season, and late season were divided according to crops growing season information. Other crop growth variables such as crop coefficient (Kc), rooting depth, critical depletion, yield response, and crop height were obtained from the CLIMWAT tool.

Actual ET was calculated following the FAO approach as a fraction of ET0. In other words, by multiplying ET0 by Kc.

$$CWR = ET_c$$

$$ET_c = K_c * ET_0$$

2.3. Estimation of Water Footprint

The total water footprint for a crop is the summation of blue and green water footprint components. In this study, grey water footprint component was not considered.

$$WF = WF_{green} + WF_{blue}$$

where WF, WFgreen, and WFblue are the total, green, and blue water footprint in m^3/ton, respectively.

The WFgreen is estimated by dividing the green crop water use (CWUgreen, m^3/ha), which is based on actual ET from precipitation, by crop yield (Y, ton/ha). The WFblue is estimated by dividing the blue crop water use (CWUblue, m^3/ha), which is based on actual ET from irrigation from surface and groundwater, by crop yield (Y, ton/ha).

$$WF_{green} = CWU_{green}/Y$$

$$WF_{blue} = CWU_{blue}/Y$$

In this analysis, the CWUgreen is calculated every 3 decades for a particular month for the total crop growing period. Total ETgreen is multiplied by a conversion factor of 10 to convert the water depths in millimeters to water volumes per hectare in m3/ha.

$$CWU_{green} = 10 * \sum_{d=1}^{lgp} ET_{green}$$

The CWUblue (m^3/ha) is the irrigation water that is consumed by actual ET (i.e., ETblue)

$$CWU_{blue} = 10 * \sum_{d=1}^{lgp} ET_{blue}$$

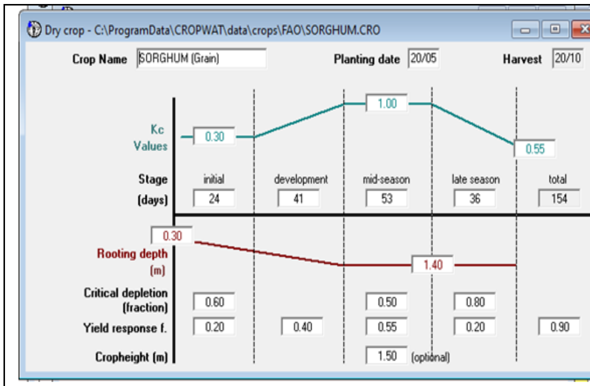
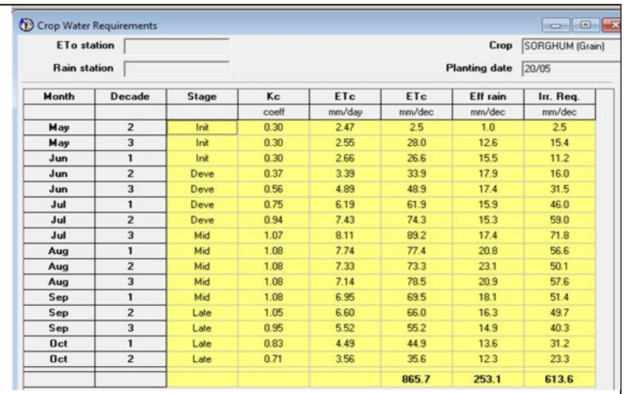


Figure 8: Crop module of CROPWAT model



Crop Water Requirements

ETo station

Rain station

Crop: SORGHUM (Grain)

Planting date: 20/05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Init	0.30	2.47	2.5	1.0	2.5
May	3	Init	0.30	2.55	28.0	12.6	15.4
Jun	1	Init	0.30	2.66	26.6	15.5	11.2
Jun	2	Deve	0.37	3.39	33.9	17.9	16.0
Jun	3	Deve	0.56	4.89	48.9	17.4	31.5
Jul	1	Deve	0.75	6.19	61.9	15.9	46.0
Jul	2	Deve	0.94	7.43	74.3	15.3	59.0
Jul	3	Mid	1.07	8.11	89.2	17.4	71.8
Aug	1	Mid	1.08	7.74	77.4	20.8	56.6
Aug	2	Mid	1.08	7.33	73.3	23.1	50.1
Aug	3	Mid	1.08	7.14	78.5	20.9	57.6
Sep	1	Mid	1.08	6.95	69.5	18.1	51.4
Sep	2	Late	1.05	6.60	66.0	16.3	49.7
Sep	3	Late	0.95	5.52	55.2	14.9	40.3
Oct	1	Late	0.83	4.49	44.9	13.6	31.2
Oct	2	Late	0.71	3.56	35.6	12.3	23.3
					865.7	253.1	613.6

Figure 9: Calculation of Irrigation Requirement by CROPWAT model

3. Results, conclusions, recommendations for further research

3.1. Results

The water footprint was calculated for four crops including wheat, corn, alfalfa, and sorghum for the counties shown in Table 1. An example of the historical wheat yield is shown in Figure 5. The results showed that the average green, blue, and total water footprints for wheat for the counties on the east side are 358.82, 1539.21, and 1898.03 m^3/ton while those for the counties on the west side of the state are 136.76, 891.33, and 1028.09 m^3/ton respectively. The average green water footprint for corn for the counties on the east side is 115.34 m^3/ton while that for the counties on the west side of the state is 77.85 m^3/ton. The average blue, and total water footprints for corn for the counties on the south side are 425.23 and 528.63 m^3/ton while those for the counties on the north side of the state are 305.94, and 399.74 m^3/ton respectively. The average green, blue, and total water footprints for alfalfa hay for the higher water footprint value counties (Lea, Quay, San Miguel, Mora, Taos, Rio Arriba, Hidalgo) are 377.34, 753.47, and 1130.80 m^3/ton respectively and the average green, blue, and total water footprints for alfalfa hay for some lower water footprint value counties are 158.73, 539.10, and 697.83 m^3/ton respectively. The average green, blue, and total water footprints for sorghum for the counties on the east side are 231.44, 511.39, and 742.84 m^3/ton while those for the counties on the west side of the state are 120.27, 381.83, and 502.1 m^3/ton respectively. The average, minimal, and maximal values of wheat's total water footprint are 1638 m^3/ton, 656.95, and 3087.60 m^3/ton respectively. The total water footprint of wheat varies between 1300 and 1500 m3/ton for most of the counties. The average, minimal, and maximal values of corn's total water footprint are 448.50 m^3/ton, 332.39 m^3/ton and 574.77 m^3/ton respectively. The total water footprint of corn varies between 400 and 500 m3/ton for most of the counties. The total water footprint of alfalfa hay is 904.94 m^3/ton on average, 507 m^3/ton at its lowest point, and 2178.26 m^3/ton at its highest point. The total water footprint of alfalfa hay varies between 800 and 1000 m3/ton for most of the counties. The water footprint of sorghum is 679 m^3/ton on average, 471.44 m^3/ton at its lowest point, and 1045.17 m^3/ton at its highest point. The total water footprint of sorghum varies between 500 and 600 m3/ton for most of the counties. Therefore, for the four crops, wheat has the highest water footprint, followed by Alfalfa hay, sorghum, and corn.

As the yield varies from county to county and year to year, the amount of water footprint also varies from year to year and county to county. A summary of water footprint components for wheat, corn, alfalfa hay, and sorghum for the respective counties are shown in Figure 10 – 25. There is a clear variation of the water footprint over the different counties.

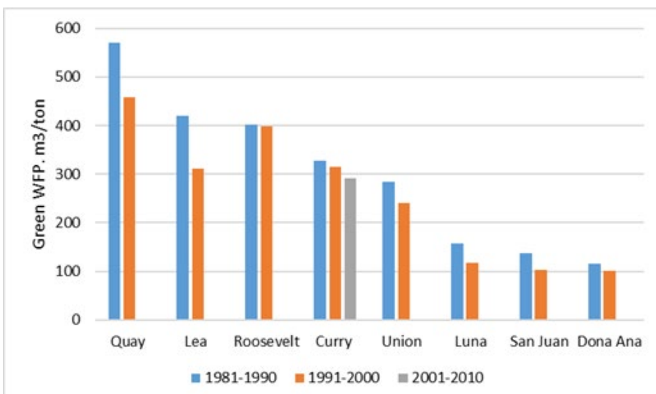


Figure 10: Green water footprint for wheat for eight counties in New Mexico for the 1981 – 2010 period.

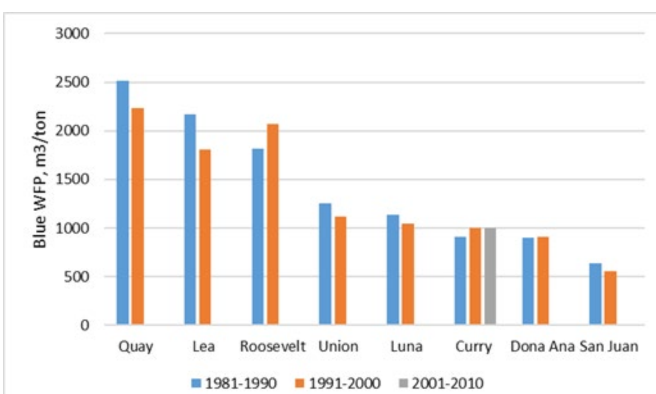


Figure 11: Blue water footprint for wheat for eight counties in New Mexico for the

1981 – 2010 period.

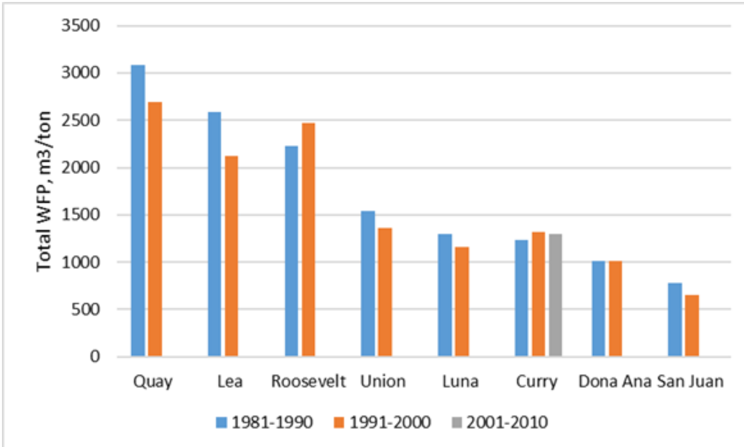


Figure 12: Total water footprint of wheat for eight counties in New Mexico for the 1981 – 2010 period.

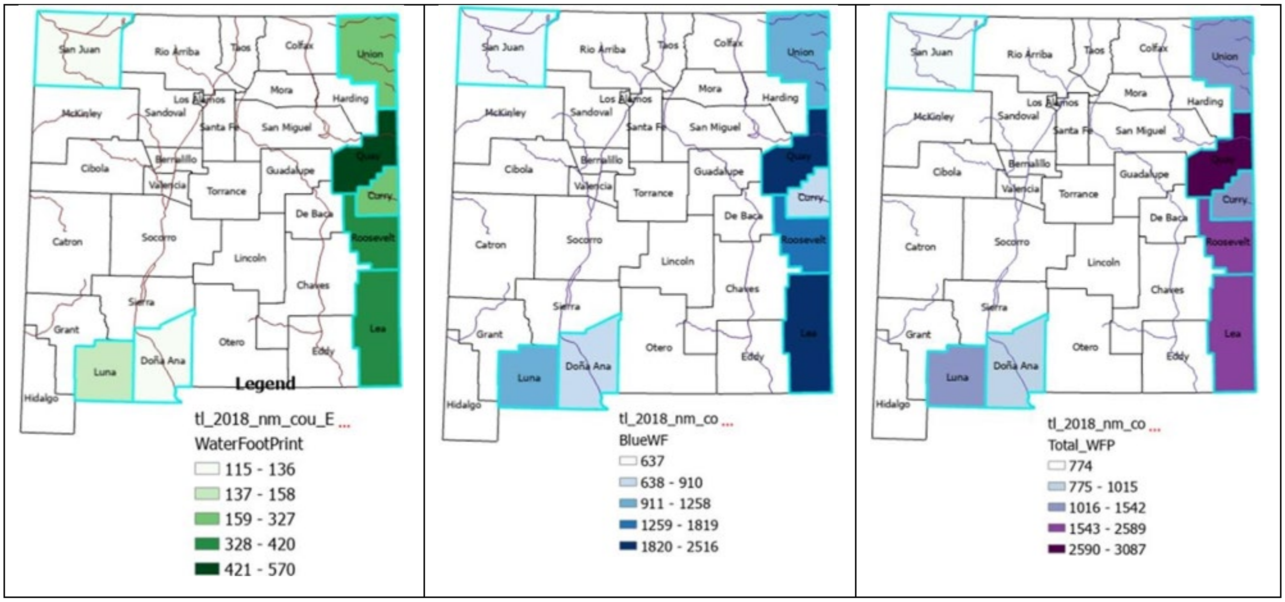


Figure 13: The spatial distribution of green, blue, and total water footprint of wheat over the different counties in New Mexico for the decade 1981 to 1990.

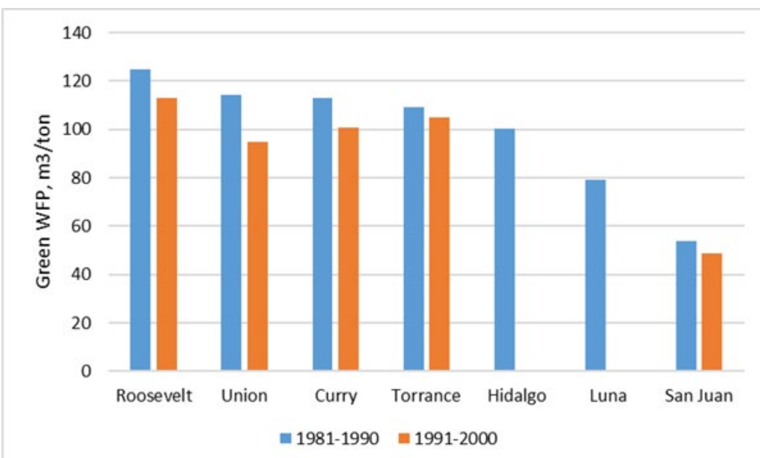


Figure 14: Blue water footprint for corn for seven counties in New Mexico for the 1981 – 2000 period.

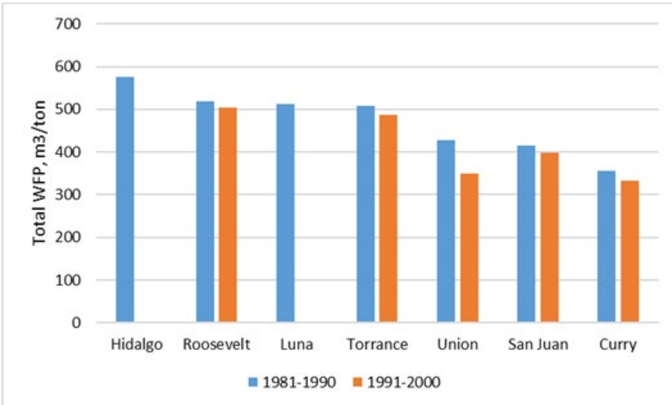


Figure 15: Total water footprint for corn for seven counties in New Mexico for the 1981 – 2000 period.

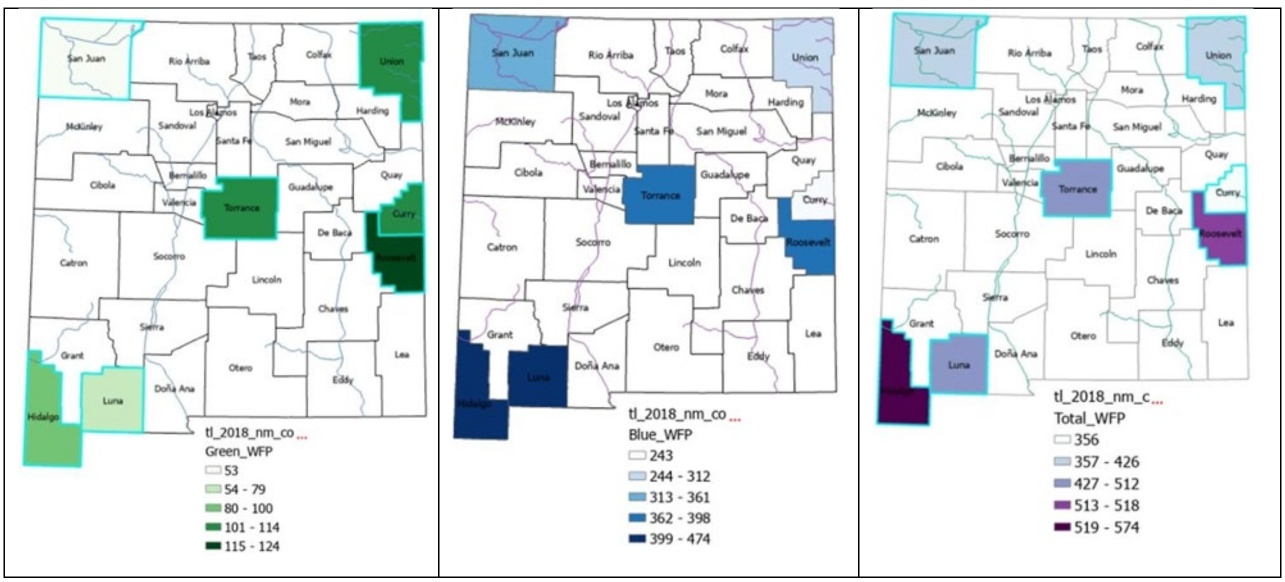


Figure 16: The spatial distribution of green, blue, and total water footprint of corn over the different counties in New Mexico the decade 1981 to 1990.

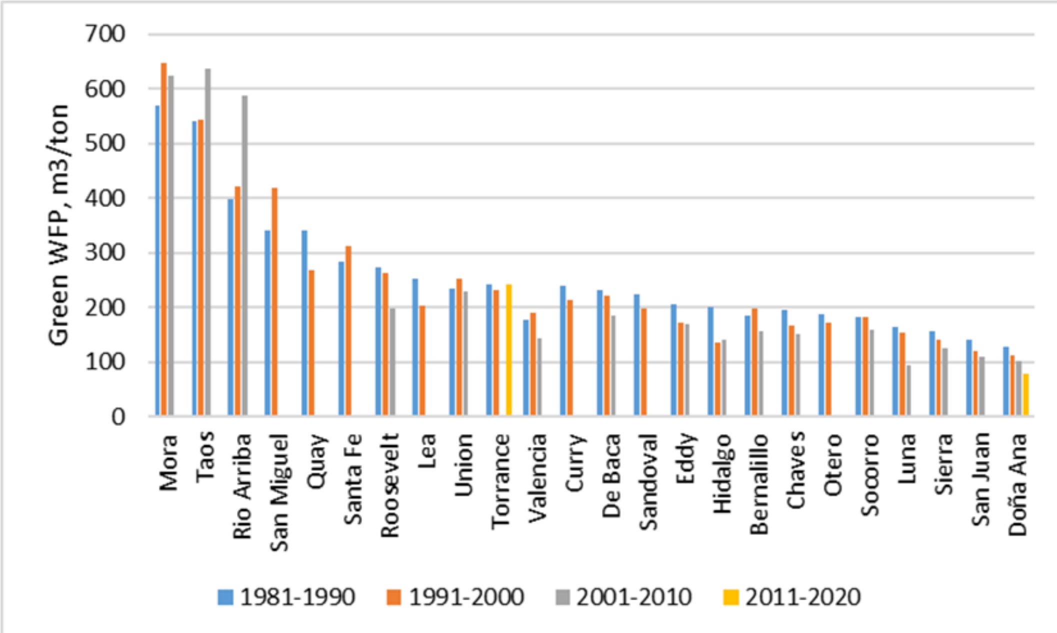


Figure 17: Green water footprint for alfalfa hay for twenty-five counties in New Mexico for the 1981 – 2020 period.

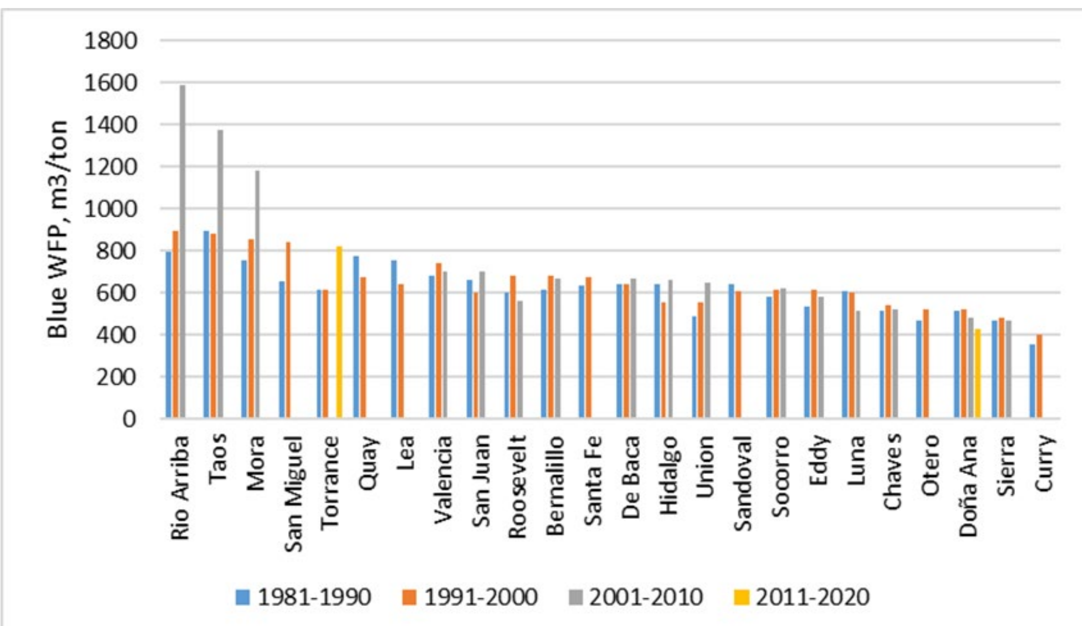


Figure 18: Blue water footprint for alfalfa hay for twenty-five counties in New Mexico for the 1981 – 2020 period.

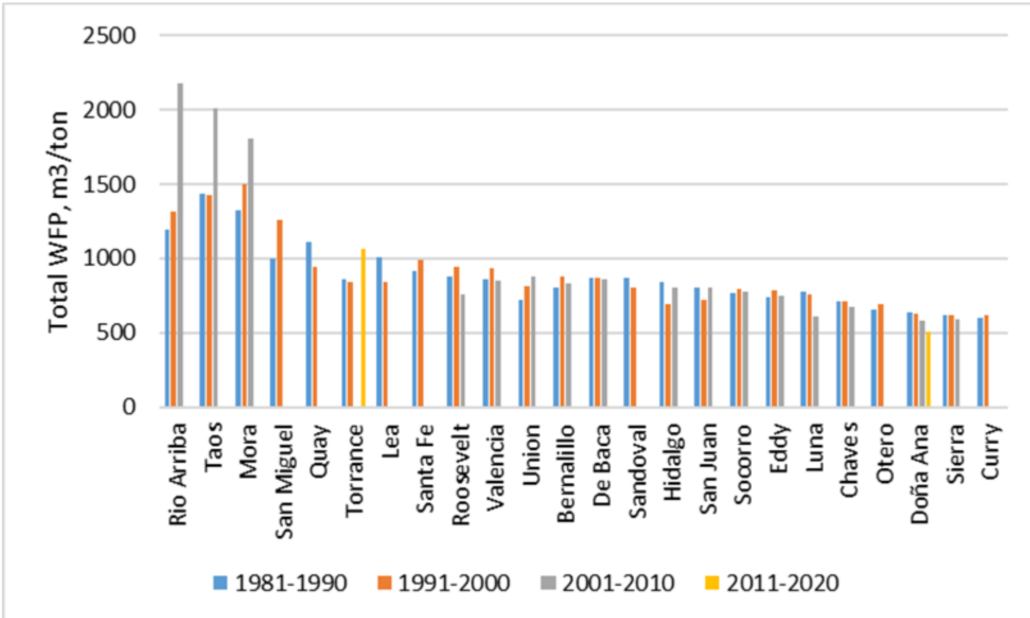


Figure 19: Total water footprint for alfalfa hay for twenty-five counties in New Mexico for the 1981 – 2020 period.

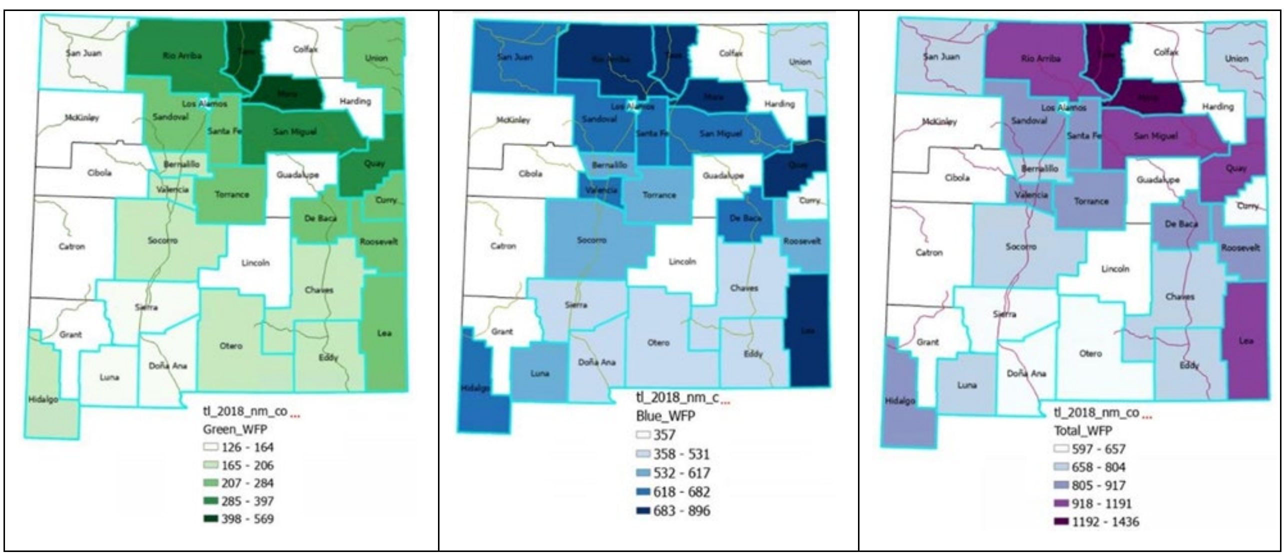


Figure 20: The spatial distribution of green, blue, and total water footprint of Alfalfa Hay over the different counties in New Mexico the decade 1981 to 1990.

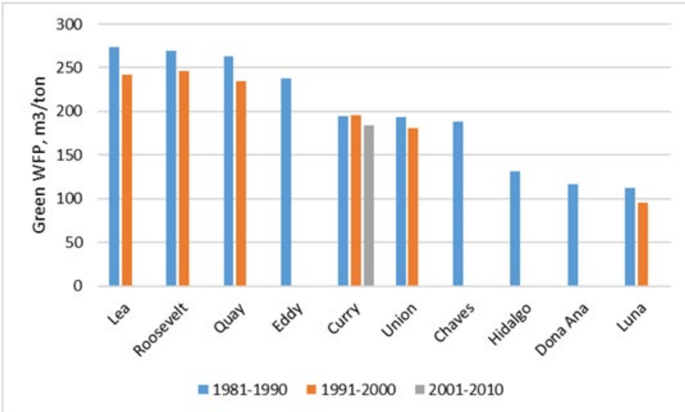


Figure 21: Green water footprint for Sorghum for ten counties in New Mexico for the 1981 – 2010 period.

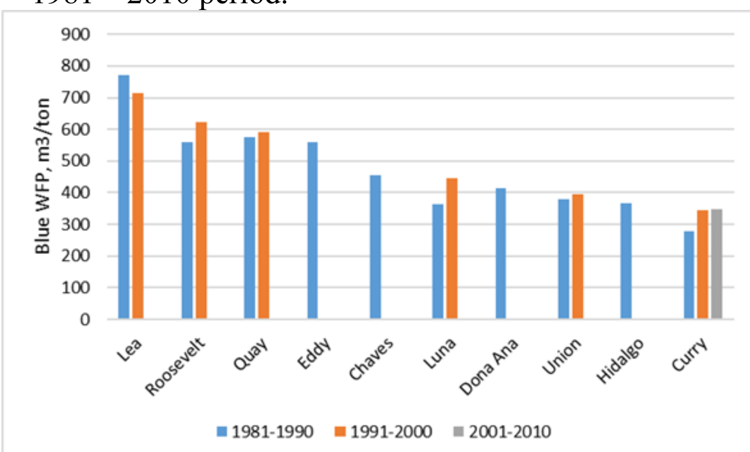


Figure 22: Blue water footprint for Sorghum for ten counties in New Mexico for the 1981 – 2010 period.

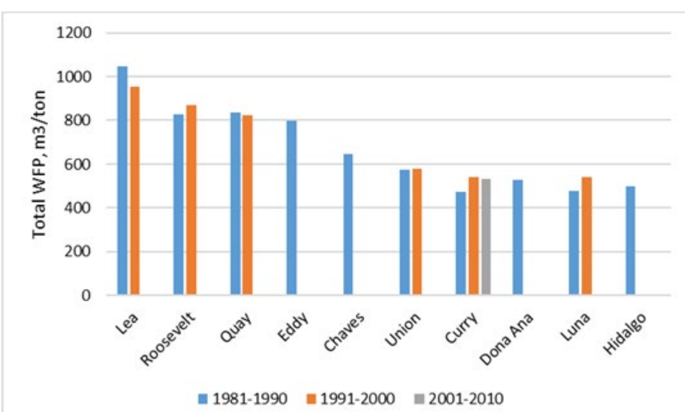


Figure 23: Total water footprint for Sorghum for ten counties in New Mexico for the 1981 – 2010 period.

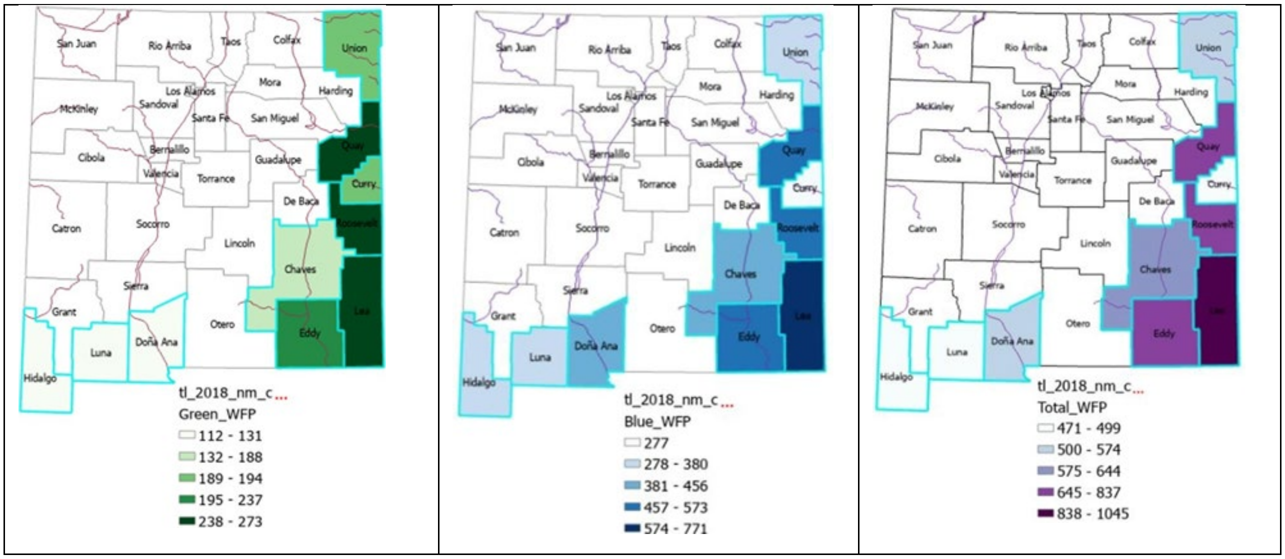


Figure 24: The spatial distribution of green, blue, and total water footprint of Sorghum over the different counties in New Mexico the decade 1981 to 1990.

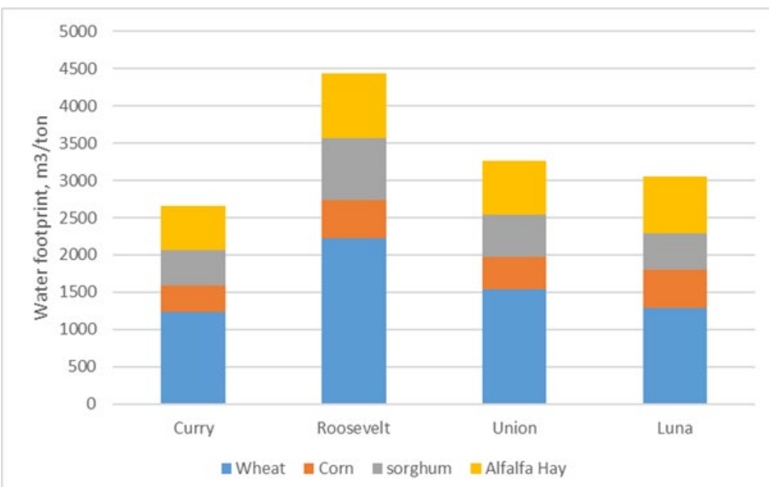


Fig. 25. Water footprint of four crops for the common counties for the decade 1981 to 1990.

3.2. Conclusions

Based on this analysis it appeared that for the same crop there is a spatial variation in the water footprint over the different counties. Several reasons can explain this variation including regional climate variability, crop management, and water management practices. Identifying the specific reasons or factors for such variation needs further analysis. Additionally, the amount of blue water footprints and green water footprints may vary from year to year and county to county depending on the precipitation. More precipitation can reduce the blue water footprint, while less precipitation can increase the blue water footprint. Crop seasonal performance and characteristics are another important factor. For example, increased ET due to an increase in air temperature can result in increased water footprint. Also, higher crop yields can result in decreased water footprint and vice versa.

3.3. Recommendations for further research

Based on these preliminary findings, there is a need for more research to identify the main factors that can reduce water footprints. These factors may include variable precipitation; rising temperature; and crop management practices such as irrigation methods, use of fertilizers, crop varieties among others. The two main goals are to reduce the amount of water used to grow crops can help in reducing water footprints. Similarly, increasing crop yield can help in reducing crop water footprints. Evaluating the effects of climate change is important as it can provide some guidance on how to develop practices that allow to reduce crop water footprints.

4. Benefits to Stakeholders from the Research Results.

This study will provide information about an important indicator related to the agricultural water use which accounts to almost 80% of the water use in New Mexico. The water footprints can be considered as a performance metrics for farmers and irrigation district on how effectively water is used in crop production. Farmers can use this metric to identify which irrigation methods and other farming practices can reduce water footprints. Irrigation districts such as the Elephant Butte Irrigation District (EBID) in southern New Mexico can use this metric as part of its effort in developing more sustainable agricultural water use in the region. Other state agencies such as the Office of State Engineer can benefit from the information provided by the water footprints metric. In General, the findings of this study will benefit farmers, water management agencies, policymakers in New Mexico and the southwestern US.

5. Describe how you have spent your grant funds.

The grant funds were used to cover graduate assistance along with fringes with a total of $4,238.55 and $24.57, respectively; and professional development activities that include attending the 2023 Water for Food Global Conference in Lincoln, Nebraska with airfare of $418.40, registration fees of $400; and an online seminar for about $50. The total of these expenses is $5,131.52.

6. List presentations you have made related to the project.

Title of the Presentation	Class	Date
Assessment of water footprint for alfalfa hay, corn, wheat, and sorghum of New Mexico	Seminar (AGRO-590-M01)	February 25, 2022
Assessment of water footprint for alfalfa hay, corn, wheat, and sorghum of New Mexico	MS Thesis	18 July, 2023

7. List of publications

I am planning to present my research at the following professional conferences. I have submitted my MS thesis document in ProQuest.

- Begum, M. and Geli, H. M. E., Evaluation of water footprints over New Mexico at county level from 1981 to 2022, The American Geophysical Union, December 11 – 15, 2024, San Francisco, CA. (The abstract submission is not open yet)
- Begum, M. and Geli, H. M. E., Water footprints for Major Crops in New Mexico for the 1981 -2022 Period, The New Mexico Annual Water Conference, October 2024, Las Cruces, NM. (The abstract submission is not open yet)

8. List any other students or faculty members who have assisted you with your project.

My main advisor Dr. Geli mentored me during my research and provided scientific and technical support. I have received some technical support from another graduate student Kidane Amar Abib who completed his MS in Water Science and Management.

9. Provide special recognition awards or notable achievements as a result of the research including any publicity such as newspaper articles, or similar.

Not available at this time.

10. Degree completion and future career plans.

I have completed my MS degree in summer 2023. I have earned CGPA 3.79 (out of 4) in my MS degree. I have applied for phd at NMSU. In the future, I hope to work as an agricultural engineer in New Mexico.

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