



Florida Statewide Agricultural Irrigation Demand

Appendix E – Technical Information



Appendix E – Technical Information

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FSAID Methodology

As required by Florida Statute, metered and reported observations of irrigation water use form the basis for the FSAID estimates of spatially distributed irrigation demand. Water use data is collected each year from the water management districts. Historical water use data extends from 2007 to 2019. For FSAID VIII, the sample size of metered data increased by about 10,000 field-level data points with the incorporation of 2019 calendar year data.

New permits are identified and added to the GIS spatial dataset, using updated permit boundary shapefiles supplied by the districts. Modified CUP permit data is similarly reviewed and GIS values updated as appropriate. Parameter values needed for estimating water demand are assigned to the newly added irrigated fields, including rainfall (assigned by latitude/longitude using a 4 km gridded dataset), evapotranspiration (ET; also assigned by latitude/longitude on a 2km grid), crop, irrigation system, and irrigated acres. Where metered data within a permit reflects multiple fields with multiple crops, water use is apportioned using mean AFSIRS inches/acre by crop. This process does not use the actual irrigation depth values from AFSIRS, rather it uses the ratios of irrigation depths among crops to divide the permit-level water volume totals to fields with different crops within a permit.

Quality control processes are completed before exporting GIS data in tabular format for analytical modeling. The model specification is estimated using Ordinary Least Squares regression analysis to generate coefficients from the actual water use for each field-level variable. Variables include rainfall (assigned by Latitude/Longitude on a 4km grid), ET (assigned by Latitude/Longitude on a 2km grid), the log of net price (crop-specific average farmgate prices less IFAS/UGA average chemical costs), crop choice (Citrus, field crops, vegetables, non-citrus fruits, greenhouse/nursery, potatoes, sod and sugarcane), irrigation system type (gravity/seepage, microspray/microjet, center pivot, traveling gun, drip, container/nursery and impact sprinkler) and location attributes including Water Management District dummies; all input variables are scaled by field-specific irrigated acres. In the current model, about 60,000 water use records throughout the state were used to estimate the effects of these variables on irrigation volumes. The R^2 or statistical “fit” of the model output to actual data is 0.76.

After the model is run on the metered input dataset, the output coefficients are applied to each irrigated field in the ILG (approximately 26,000). The current year irrigation water use estimate is based on rainfall and ET from the year matching the most recent water use data (in this case, 2019).

For projection years, the field level variables are updated to reflect changes in five year increments based on county-level declines or expansions in agricultural acreage, and crop changes indicated by long-run worldwide agricultural price forecasts. Average rain and evapotranspiration (2005-2019) values are used for projections and assigned to each field. If a crop change is indicated in a given period, a new net price is assigned to match the updated crop type. If the crop type does not change, the net price is simply updated to the new period’s value. To simulate future conditions, the coefficients are applied to the updated field level values and aggregated. Water use is then calculated for each irrigated field.

If the water use for a given irrigated field exceeds the prior period’s water use, a portion of the water is retained for assignment to newly added acreage in future periods. In counties with declining acreage,

irrigated fields are selected for deletion based on spatial decision rules, removing the associated acreage and water use from the model.

Model Comparison to Prior Years

Updated field-level metered/reported water usage data from all five Districts was combined into the statistical model. The variables in the prior year model included:

- Water Management District – an indicator value (1 or 0 for each District)
- Rain (annual inches reported for the 2km grid of the field centroid)
- Rain/ET (ET annual inches reported for the field location multiplied by rain annual inches; this treatment allows for estimate of marginal impact of ET when holding rainfall constant)
- Crop indicator and acres of field – Crop categories include:
 - Citrus
 - Field Crops
 - Vegetables (Fresh Market)
 - Fruit (Non-citrus)
 - Greenhouse/Nursery
 - Hay
 - Potatoes
 - Sod
 - Sugarcane
- Crop price, in log form multiplied by the field acres – categories match the crop indicator above. Price is calculated as farm gate price less chemical costs, both on a per acre basis.
- Irrigation system indicator – categories include:
 - Center Pivot (represents 9% of observations)
 - Container nursery (6% of observations)
 - Drip irrigation (17%)
 - Gravity systems (21%)
 - Impact sprinklers (7%)
 - Microspray (39%)
 - Traveling gun (1%)

The updated model includes current year data, but all model function and form are identical to last year. Coefficients reflect a very slight decline in statistical fit. R^2 falls from .76671 to .76443. The South Florida dummy variable, which denotes the origin of 26% of the observations, is not statistically significant with a p-value of 0.60, while in the prior year the p-value was 0.11. Analysis in prior years has found that the irrigation behaviour of SFMWD is very similar to that of SWFWMD irrigation, which covers 50% of the observations, and as such the SFMWD indicator variable adds only minor explanatory value. Similarly, the p-value for SJRWMD is 0.31 for 16% of the records. The SWFWMD indicator remains strong with significance at the 0.02 level. Lastly, the SRWMD variable boasts a p-value of 0.00, a significant improvement in explanatory value from prior years, when the p-value was as high as 0.44.

All other variables are significant to the 1% level, with the exception of the Center Pivot indicator variable, which is not significant at 21%. Given that the model fit is strong and no surprising results emerged, the model will be used without modification for the 2021 update.

Model Input Data and Equation Details

Table E- 1. Statewide Metered Data Records Statistics by Crop

Year	Measure	Citrus	Field Crops	Fruit (Non-citrus)	Greenhouse /Nursery	Hay	Potatoes	Sod	Sugarcane	Vegetables (Fresh Market)	All Crops (n)
2007	Count	536	31	81	155	16	10	26	8	141	1,004
2007	in/yr	13.10	8.78	27.06	30.10	7.22	12.46	15.09	33.42	15.96	14.19
2008	Count	2,198	212	129	1,096	252	127	276	113	1,276	5,679
2008	in/yr	11.25	9.30	29.84	32.20	8.91	15.84	10.98	14.96	18.25	13.04
2009	Count	2,280	187	118	1,109	284	128	236	308	1,379	6,029
2009	in/yr	12.62	8.04	22.88	30.96	9.01	16.28	13.13	9.97	18.93	13.24
2010	Count	684	103	102	154	36	25	29	7	354	1,494
2010	in/yr	13.60	11.07	26.59	30.35	6.91	18.06	16.05	26.84	19.80	15.58
2011	Count	2,385	228	209	1,134	234	139	195	177	1,317	6,018
2011	in/yr	11.79	10.63	24.89	28.67	8.97	15.29	13.17	13.93	17.37	13.30
2012	Count	2,737	290	236	864	249	138	209	246	1,378	6,347
2012	in/yr	12.32	9.27	25.29	28.22	9.56	17.87	12.25	14.96	18.69	13.81
2013	Count	2,542	70	222	701	181	109	163	167	1,167	5,322
2013	in/yr	12.11	6.95	26.22	25.64	9.68	11.96	16.35	17.41	16.67	13.52
2014	Count	2,287	256	251	693	244	61	191	193	1,369	5,545
2014	in/yr	10.41	10.36	25.19	27.63	10.93	14.01	10.46	17.68	15.38	12.61
2015	Count	1,920	503	283	737	257	116	180	365	969	5,330
2015	in/yr	10.76	10.72	27.29	25.38	10.27	13.78	12.57	18.10	15.21	13.40
2016	Count	2,565	402	394	702	255	148	171	312	1,490	6,439
2016	in/yr	11.10	10.02	26.78	30.90	10.98	13.86	10.79	16.40	18.06	13.53
2017	Count	2,938	725	496	824	421	133	212	397	1,541	7,687
2017	in/yr	11.74	10.65	28.02	29.58	11.00	15.17	11.99	20.71	19.59	14.67
2018	Count	2,380	812	847	782	221	165	151	415	1,282	7,055
2018	in/yr	11.66	10.03	26.87	26.85	9.38	14.59	10.22	16.37	16.89	13.44
2019	Count	2,242	859	754	660	288	148	219	393	1,027	6,590
2019	in/yr	11.88	10.93	26.15	30.95	9.96	15.04	11.74	17.68	17.47	14.07
All Years	Count	27,694	4,678	4,122	9,611	2,938	1,447	2,258	3,101	14,690	70,539

Table E- 2. Metered Data Records Statistics by District

WMD	Primary Crop	Total Acres	Total MGD	IN/YR
NWFWMD	Citrus	36	0.02	6.75
NWFWMD	Field Crops	134,015	90.05	9.03
NWFWMD	Fruit (Non-citrus)	33	0.05	19.94
NWFWMD	Greenhouse/Nursery	9,868	28.06	38.22
NWFWMD	Hay	7,837	3.57	6.13
NWFWMD	Potatoes	2,937	5.01	22.93
NWFWMD	Sod	12,407	7.88	8.53
NWFWMD	Vegetables (Fresh Market)	7,084	5.92	11.24
SFWMD	Citrus	1,336,001	1,170.57	11.78
SFWMD	Field Crops	6,493	4.50	9.31
SFWMD	Fruit (Non-citrus)	4,428	7.12	21.62
SFWMD	Greenhouse/Nursery	26,767	60.99	30.63
SFWMD	Hay	377,790	279.30	9.94
SFWMD	Potatoes	23,331	28.86	16.63
SFWMD	Sod	118,496	100.99	11.46
SFWMD	Sugarcane	870,369	1,072.32	16.56
SFWMD	Vegetables (Fresh Market)	570,979	805.06	18.95
SJRWMD	Citrus	92,645	85.92	12.47
SJRWMD	Field Crops	20,713	16.77	10.88
SJRWMD	Fruit (Non-citrus)	9,530	20.06	28.30
SJRWMD	Greenhouse/Nursery	56,625	118.02	28.02
SJRWMD	Hay	99,330	79.25	10.72
SJRWMD	Potatoes	76,283	79.64	14.03
SJRWMD	Sod	58,209	54.64	12.62
SJRWMD	Vegetables (Fresh Market)	46,355	61.83	17.93
SRWMD	Field Crops	206,233	173.40	11.30
SRWMD	Fruit (Non-citrus)	3,059	6.62	29.10
SRWMD	Greenhouse/Nursery	3,351	6.45	25.88
SRWMD	Hay	30,915	23.17	10.07
SRWMD	Potatoes	4,030	5.41	18.05
SRWMD	Sod	703	1.00	19.03
SRWMD	Vegetables (Fresh Market)	26,073	29.14	15.02
SWFWMD	Citrus	1,426,396	1,231.80	11.61
SWFWMD	Field Crops	32,221	18.32	7.64
SWFWMD	Fruit (Non-citrus)	49,195	95.82	26.18
SWFWMD	Greenhouse/Nursery	22,322	42.46	25.57
SWFWMD	Hay	33,762	19.44	7.74
SWFWMD	Potatoes	13,652	15.57	15.33
SWFWMD	Sod	52,045	54.48	14.07
SWFWMD	Vegetables (Fresh Market)	313,319	362.98	15.57
Total		6,185,836	6,272.44	13.63

Table E- 3. Statistical Output and Coefficients of Analytical Model

Ordinary least squares regression				
LHS=INYRAC Mean = 1195.25945				
Standard deviation = 2168.36434				
No. of observations =	70539	DegFreedom	Mean square	
Regression Sum of Squares =	.253560E+12	30	.84520E+10	
Residual Sum of Squares =	.780961E+11	70508	1107620.59001	
Total Sum of Squares =	.331656E+12	70538	4701803.93252	
Standard error of e =	1052.43555	Root MSE	1052.20427	
Fit R-squared =	.76453	R-bar squared	.76443	
Model test F[30, 70508] =	7630.76380	Prob F > F*	.00000	
Variable	Coefficient	Standard Error	P[Z >z]	Mean of X
Constant	(767.20)	112.60	-	
SFWMD	16.70	31.69	0.60	0.26
SJRWMD	(31.28)	30.75	0.31	0.16
SRWMD	97.72	27.69	0.00	0.05
SWFWMD	(68.87)	30.49	0.02	0.50
RAIN	(10.90)	1.65	-	53.99
RAINET	0.21	0.03	-	2,960.17
CITAC	11.75	0.05	-	40.48
FIEAC	10.26	0.23	-	5.67
FRSAC	18.16	0.09	-	13.66
FRUAC	22.27	0.50	-	0.94
GREAC	29.76	0.76	-	1.69
HAYAC	6.75	0.05	-	7.79
POTAC	14.02	0.29	-	1.70
SODAC	11.98	0.17	-	3.43
SUGAC	16.64	0.08	-	12.34
LNPCIT	52.62	12.41	-	2.97
LNPFI	103.48	15.60	-	0.43
LNPF	50.66	10.50	-	1.91
LNPF	67.15	10.52	-	0.54
LNPG	38.26	8.82	-	1.49
LNPH	198.68	17.73	-	0.23
LNPP	72.15	11.72	-	0.18
LNPS	66.17	12.01	-	0.27
LNPS	45.50	12.92	0.00	0.34
CPIV	54.67	43.25	0.21	0.09
CONT	367.98	50.80	-	0.06
GRAV	308.63	41.28	-	0.21
IMPSP	366.94	48.42	-	0.07
DRIP	221.40	43.63	-	0.17
MICROS	370.96	48.22	-	0.39

The econometric model is used to generate coefficients from the metered data records. The coefficients are used to estimate water use for the remaining Florida farms that do not have metered data. The following example is provided to demonstrate the process.

Assume a Citrus farm in DeSoto County in the Southwest Florida Water Management District, with irrigated area of 95.33 acres. The farm has Microspray irrigation, the recorded average annual rainfall was 47.93 inches, and the recorded average annual ET was 54.96. The estimated net price was \$1,472. A summary of the GIS attribute values for the specified farm are provided in **Table E- 4**. Applying the coefficients from FSAID VIII to this specific farm's GIS attributes produces an estimated 11.24 inches per acre per year.

Table E- 4. Application of Analytical Model

GIS Attribute Value for Demonstration Farm		
Name	Variable (all values are for demonstration farm)	Value
ID	Field ID	DeSo_17091
SWFWMD	Indicator of 1 if field is in SWFWMD	1
RAIN	Rainfall (in inches, average annual, per nearest rain station)	47.93
RAINET	RainET interaction term (rain times ET)	2,634.02
CITAC	Indicator of 1 if field is citrus, times acres	95.33
LNPCIT	Indicator of 1 if field is citrus, times the log of citrus Net Price	7.29
MICROS	Indicator of 1 if field irrigation type is Micro Spray	1

Calculation of Farm-level Estimated Water use for GIS assignment

Name	Field-Specific Value	Coefficient	Product
CONSTANT	NA	(767.20)	(767.20)
SWFWMD	1.00	(68.87)	(68.87)
RAIN	47.93	(10.90)	(522.59)
RAINET	2,634.02	0.21	555.17
CITAC	95.33	11.75	1,119.74
LNPCIT	7.29	52.62	383.80
MICROS	1.00	370.96	370.96
ACREIN (Total in Acre Inches per Year)			1,071.02
GALMIL (Total in Millions of Gallons per Year)			29.08
Estimated Inches/Acre/Year (GALMIL/365/95.33 acres*13441.7)			11.24

Table E- 5. Projected Crop Prices and Costs

Primary Crop	Unit	2019	2020	2025	2030	2035	2040	2045
Citrus	Crop Price	\$2,968	\$2,559	\$3,269	\$4,021	\$4,128	\$4,219	\$4,300
	Chem. Cost	\$1,497	\$1,524	\$1,767	\$2,049	\$2,297	\$2,575	\$2,886
Field Crops	Crop Price	\$712	\$759	\$786	\$833	\$900	\$956	\$1,016
	Chem. Cost	\$218	\$222	\$246	\$275	\$290	\$304	\$320
Vegetables (Fresh Market)	Crop Price	\$5,872	\$6,342	\$6,318	\$7,100	\$8,050	\$9,127	\$10,348
	Chem. Cost	\$1,165	\$1,186	\$1,316	\$1,474	\$1,550	\$1,629	\$1,712
Greenhouse/Nursery	Crop Price	\$73,813	\$74,897	\$80,436	\$79,962	\$84,041	\$88,327	\$92,833
	Chem. Cost	\$2,224	\$2,264	\$2,511	\$2,814	\$2,958	\$3,109	\$3,267
Hay	Crop Price	\$412	\$393	\$387	\$390	\$410	\$421	\$433
	Chem. Cost	\$161	\$165	\$185	\$207	\$218	\$229	\$241
Fruit (Non-citrus)	Crop Price	\$8,367	\$9,820	\$9,327	\$10,176	\$11,175	\$12,283	\$13,533
	Chem. Cost	\$1,417	\$1,443	\$1,673	\$1,940	\$2,175	\$2,437	\$2,732
Potatoes	Crop Price	\$4,633	\$4,463	\$4,678	\$5,022	\$5,737	\$6,011	\$6,324
	Chem. Cost	\$384	\$391	\$434	\$486	\$511	\$537	\$564
Sod	Crop Price	\$4,932	\$4,982	\$5,578	\$5,538	\$5,653	\$5,785	\$6,913
	Chem. Cost	\$808	\$826	\$926	\$1,038	\$1,091	\$1,147	\$1,205
Sugarcane	Crop Price	\$2,378	\$2,405	\$2,527	\$2,567	\$2,697	\$2,833	\$2,977
	Chem. Cost	\$186	\$189	\$210	\$235	\$247	\$260	\$273

Sensitivity Analysis

Metered Water Use

Metered or reported water use data was obtained from each Water Management District. Data was cleaned using a number of checks prior to use in the final dataset. Tukey inter-quartile range (IQR) analysis, measurement of the standard deviation from the mean, and tercile analysis were processes used to discover outliers. Tukey analysis uses 1.5 times the IQR from the first and third quartiles to determine the range. The standard deviation methodology uses two standard deviations from the mean to identify potential outliers. In reviewing the reasonableness of irrigation intensities by crop, it was determined that the 25th percentile for the lower bound and the 90th percentile for the upper bound were appropriate to identify thresholds for including metered data for model development. These thresholds reflect the right skewness of the water use data (more 0 and small values; mean greater than median).

These ranges (**Table E-6**) were applied to crop irrigation intensity measures of inches/year for metered measurements of water use and acreage. These variables were chosen over total water use, since outliers for this variable would depend heavily on farm size.

Table E- 6. Crop-specific irrigation in/yr thresholds for including metered data for model calibration

FSAID crop type	25th percentile (in/yr)	90th percentile (in/yr)
Citrus	6.1	21.5
Field Crops	3.6	20.8
Fruit (Non-citrus)	13.5	49.5
Greenhouse/Nursery	8.7	62.4
Hay	2.2	23.3
Potatoes	7.5	31.2
Sod	4.2	36.4
Sugarcane	3.5	34.8
Vegetables (Fresh Market)	6.9	34.6

Rainfall

Because rainfall replaces irrigation water, it is an important component of water demand. Rain gage data was used in the initial FSAID I estimates. However, in some districts, this resulted in very few location-specific measures of precipitation. Starting with FSAID II, NOAA’s Advanced Hydrologic Prediction Service (AHPS) data has been used instead. This set of data is provided in the form of daily point shapefiles for the entire continental USA and Puerto Rico. Within Florida, there are over 12,600 points spaced approximately 3.5 to 4 km apart (point spacing decreases from north to south). The available period of record is from 2005 to 2019.

Crop Changes

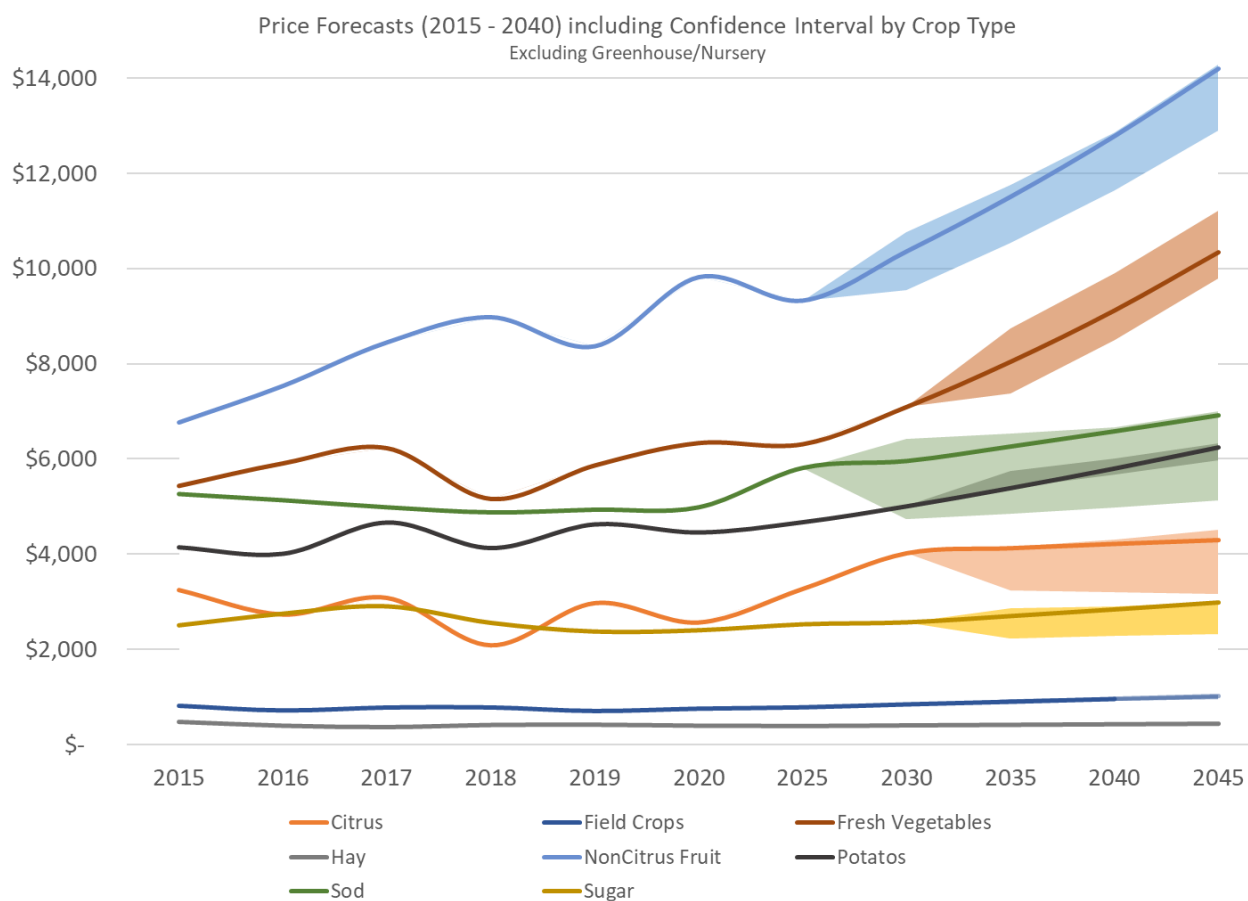
Newly irrigated areas in future projection periods in FSAID are assigned crop types based in part on future predicted net prices and the modelled water demands associated with each crop type. There may be instances of currently irrigated areas on which a crop change would be suggested based on projected net prices in the future. The actual occurrence of crop changes of course depends on producer preference, costs of equipment changes, amount of labor requirements, and other factors. Because crop changes due to price forecasting can shift projected water demand, additional sensitivity analysis was conducted for pricing forecast data. Autoregressive Integrated Moving Average forecast methods, or ARIMA models, were applied to historical forecasts to compare actual outcomes to prior predictions (Ghysels and Marcellino 2018). Autoregressive models predict future values based on past values.

The sensitivity testing used past observed prices and their predicted values based on published models at the time, to create residual values over time and between models. The residuals were then used to predict likely future residuals between the observed and the predicted values. FAPRI forecasts, the primary source for FSAID price data (FAPRI, offer 10-year predictions with their errors embedded into the prediction. Testing methods explored FAPRI’s corrections of future predictions based on their residuals between model years. Ultimately, FAPRI’s predicted values were left as-is and future residuals were modeled based on these values. For crops without a FAPRI 10-year forecast, their past predictions through 2025 were used. For each crop, the absolute values of the 80% confidence intervals of their respective residuals were applied to build confidence intervals around the predicted prices. The confidence intervals were utilized to assess future crop changes; a pertinent example shows that sod

and potato prices have overlapping confidence intervals in the 2025- 2030 period. **Figure E- 1** shows the confidence intervals around each crop type except Greenhouse/Nursery, which is out of scale for purposes of display.

Around 2025 to 2030, the overlapping confidence intervals of sod and potatoes prices suggest there is an elevated chance of possible crop change. For the purposes of testing the model sensitivity to crop changes, a change from sod to potatoes was modelled to estimate realistic irrigation water demand impacts from that crop switch. It was estimated that potentially 25% of sod producers might switch to potatoes around 2030. This represents an acreage change of about 13,000 acres of sod possibly changing to potato production over the 5 years from 2025 to 2030; the associated water demand change by 2045 is about 3 MGD resulting from the sod to potatoes switch. At less than 1% of overall water demand, the crop change was not incorporated into the final model.

Figure E- 1. Confidence Intervals for Pricing Forecasts

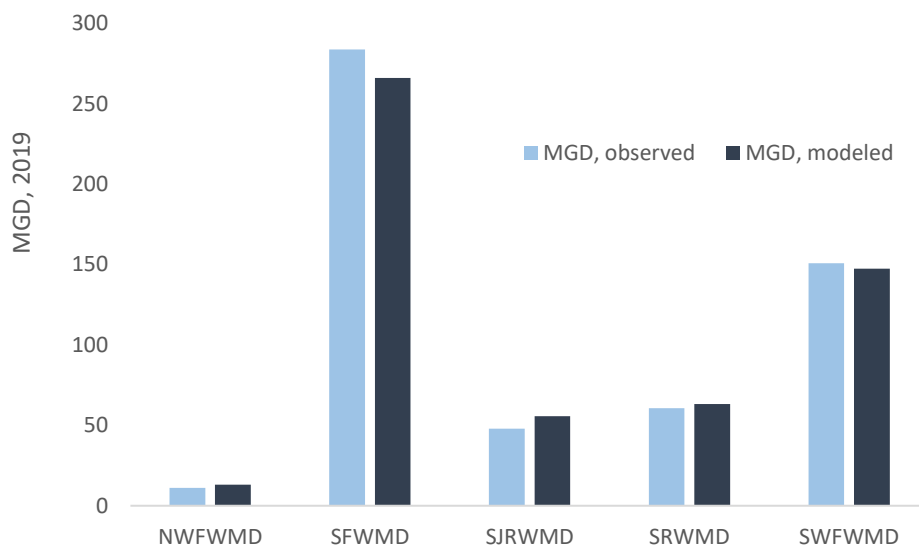


Model Performance

Several performance measures are used to compare the FSAID model results to field-level observations: model R^2 , graphical comparisons of annual and District totals, and scatterplots of permit-level totals. The water use model has an R^2 of about 0.76. **Figure E- 2** shows a comparison of the 2019 reported or metered

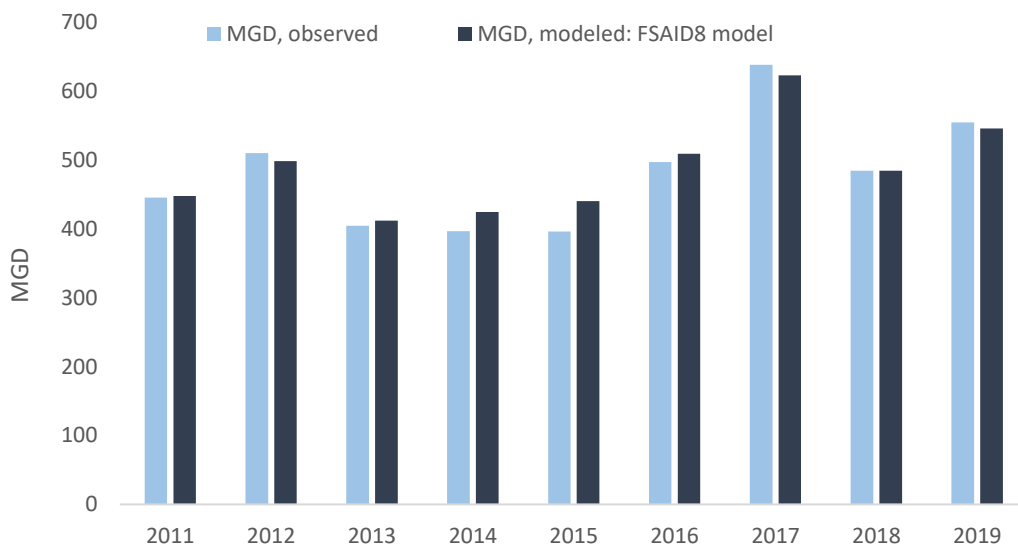
water use compared to the FSAID model estimates for each District. Total differences (modeled – reported) aggregated within each District ranged from 4 to 17 MGD. Note: this does not show the total irrigation water demands, **Figure E- 2** is illustrating only the sums of FSAID model results for permits where we have non-zero metered or reported water use data in 2019.

Figure E- 2. Modeled and measured 2019 MGD

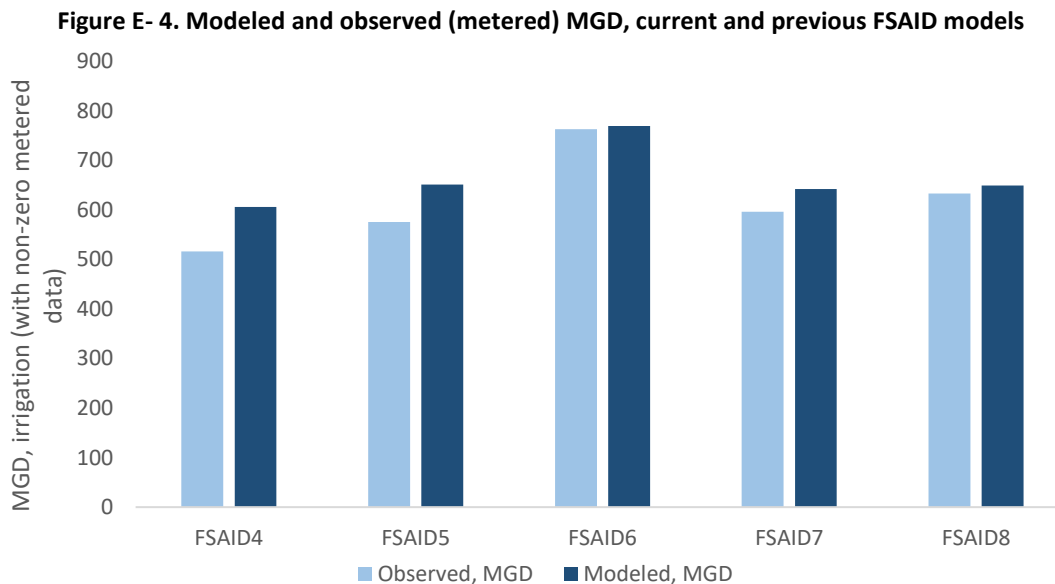


The following figure (**Figure E- 3**) summarizes the FSAID8 modeled values (using the current model form and average 2005-2019 rain and ET data) compared to annual sums for permits with non-zero metered/reported water use data in specific years from 20011-2019. This illustrates that the current FSAID model of average irrigation demands can predict yearly totals for recent years with acceptable accuracy.

Figure E- 3. Modeled (current model) and measured MGD

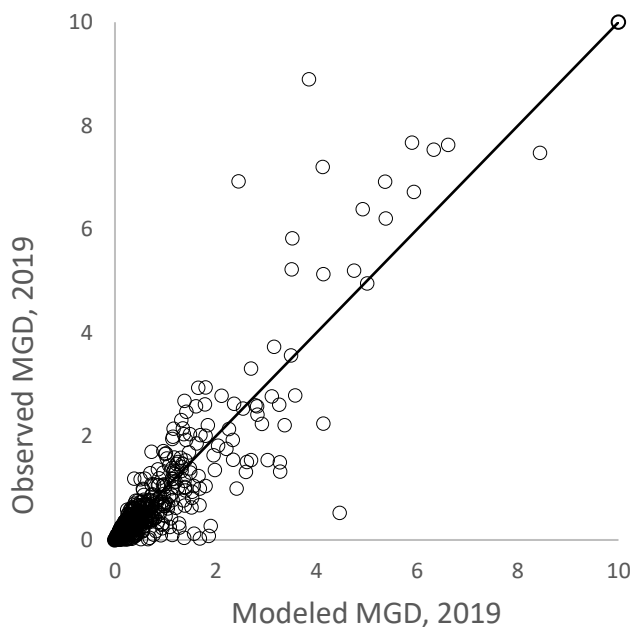


Another graphical assessment of FSAID model performance is the comparison of observed to modeled values for FSAID4 (2017 release), FSAID5 (2018), FSAID6 (2019), FSAID7 (2020), and FSAID8 (2021) models. This shows how the combination of improved model form (different equations) and increase sample size (more input data) has resulted in closer agreement between observed and modeled values (**Figure E- 4**).



A plot of modeled and metered/reported data by permit for 2019 are shown in **Figure E- 5** with a one-to-one line; this provides a graphical assessment of model performance as seen in the general clustering near the line.

Figure E- 5. Modeled and Measured 2019 MGD Permit Comparison



Climate Risks to Florida Agriculture

Florida's agricultural producers are accustomed to dealing with seasonal and year-to-year variability. Irrigated production mitigates much of the climate risks related to droughts and dry spells, but periods of low rainfall can still have substantial economic impacts by increasing pumping costs. Also, temperature extremes can impact production by directly damaging crops or by affecting pest or disease risks. Elevated temperatures result in increased ET, which may increase irrigation requirements depending on associated rainfall changes. The FSAID model was used here to directly estimate agricultural irrigation demand impacts from ET and rainfall changes in 2045. The datasets and methods used are described in the following section.

Agricultural markets are global; this means that climate changes in Florida are not the only changes that will affect Florida agriculture. For example, if freeze risks are reduced in northern parts of the U.S., this could expand the range of southern highbush blueberries – a crop where Florida has historically held a unique marketing window due to the earliness of harvest. With more areas in the U.S. growing southern highbush, this could drive down prices received by Florida producers. Two possible changes in Florida climate conditions are described below: temperature changes and the related intensification of the hydrologic cycle.

FSAID Modeled Impacts on Agricultural Water Demand

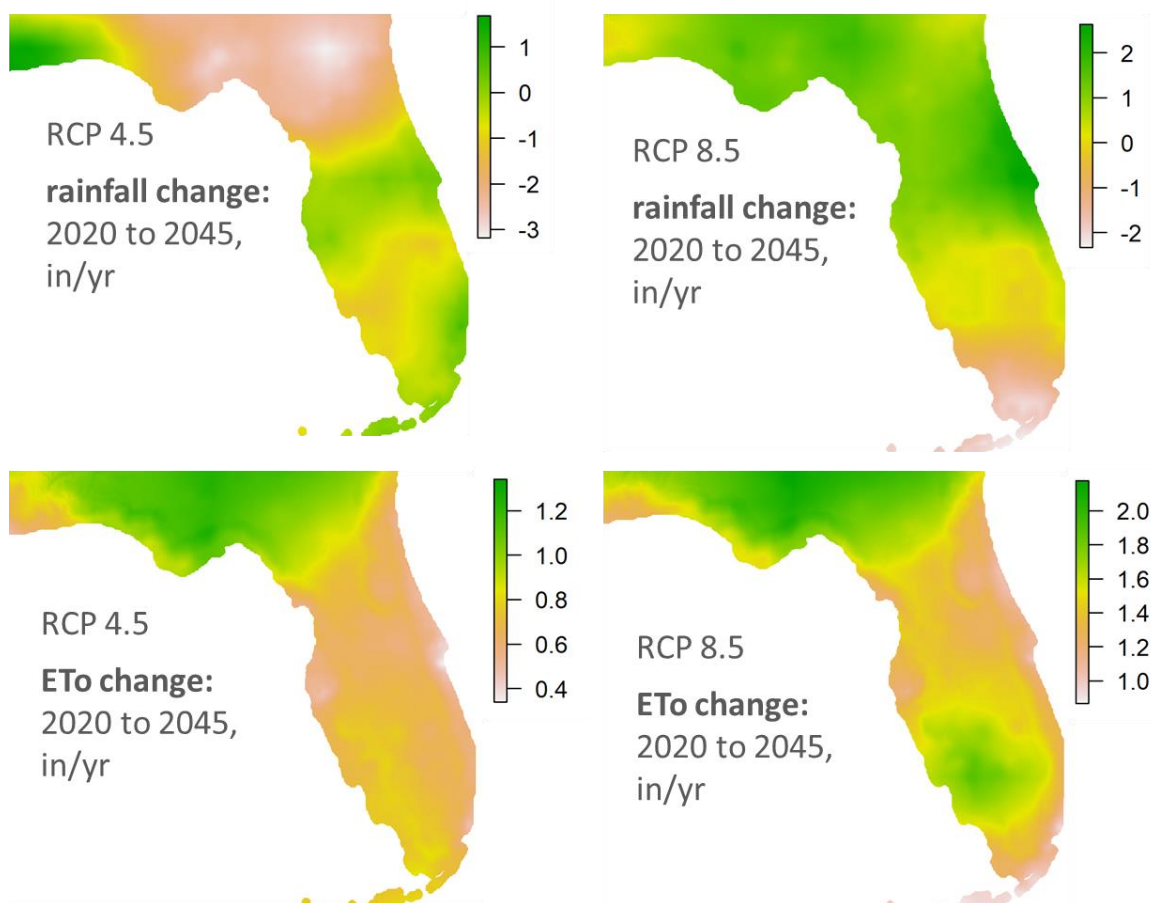
To provide quantitative agricultural irrigation water demand impacts from future climate, the FSAID model was run with rainfall and ET for 2045 from both RCP 4.5 and RCP 8.5. Input data for future climate was retrieved from the NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30). This is a statistically-downscaled version of the results from the Coupled Model Intercomparison Project Phase 5 (CMIP5) [Taylor et al. 2012] used for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). There are 33 different models included in the CMIP5 effort; the ensemble mean (average results across all models) results were used here as there was no compelling evidence in terms of model performance in Florida to select a particular model(s).

The advantage of the NEX-DCP30 version of these model results is that they are bias-corrected and downscaled (to a smaller spatial resolution of about a half mile) based on patterns in historical data. Ensemble mean monthly rainfall from the NEX-DCP30 data were downloaded, subset to Florida, totaled for annual values, and the values were assigned to irrigated areas in Florida based on the grid cell overlapped by the irrigated area. 2020 and 2045 values were retrieved and processed; the 2045 to 2020 differences were added to historical average climate used to FSAID to produce 2045 climate input data for the FSAID model.

The following figures show the spatial variability in ETo and rainfall changes from 2020 to 2045 (**Figure E-6**). The most significant annual rainfall declines show up in RCP 4.5 in north Florida: about 3 in/yr less than current average rainfall in some areas. Other parts of Florida are expected to see slight increases in rainfall in both RCP 4.5 and 8.5, with the exception of south Florida predicted to have slightly less rainfall in RCP 8.5. With both minimum and maximum daily temperatures expected to increase, there are ETo increases – of varying amounts – everywhere in Florida by 2045.

Using FSAID base year 2019 irrigated areas with future modeled climate changes, the FSAID modeled increase in irrigation demand is about 10 MGD statewide for RCP 4.5 and 22 MGD statewide for RCP 8.5, corresponding to about 0.5% and 1% increases, respectively. These projected increases in irrigation water demand resulting from climate changes are in line with values from recent literature (Wang 2016).

Figure E- 6. CMIP5 model mean annual rain and ET changes 2020 to 2045

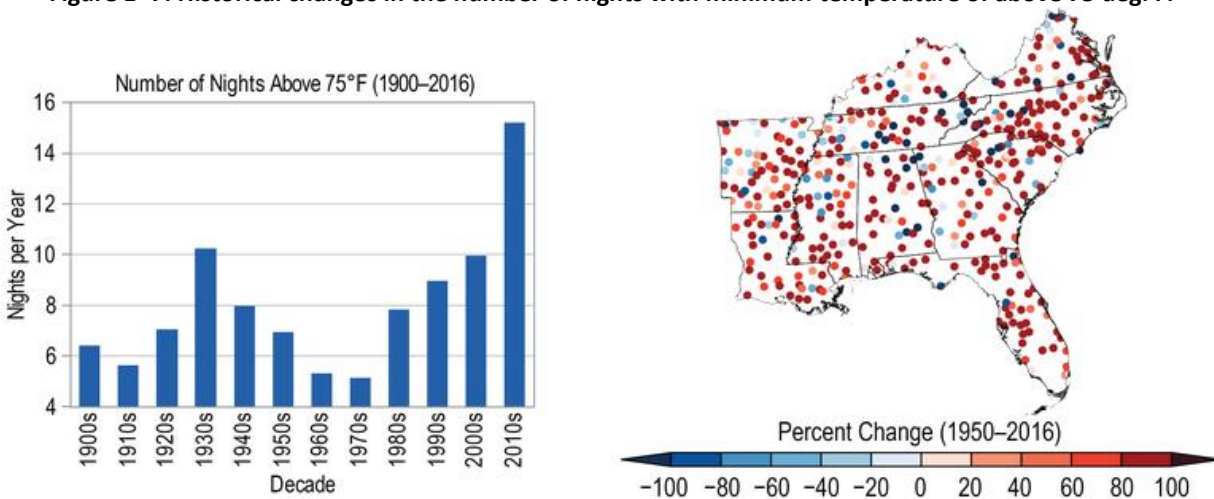


Source: NASA NEX-DCP30 downscaled climate projections

Temperatures

Air temperature affects crop production in numerous ways. Temperatures can impact pest and disease risks; for example, winter freezes can break up pest cycles and/or reduce pest populations. One of the observed historical climate changes in Florida and in most parts of the world is that minimum daily temperatures are increasing faster than maximum temperatures. Elevated nighttime temperatures are generally undesirable for plant growth because respiration losses at night are usually increased with higher temperatures. **Figure E-7** illustrates that since the 1970s the number of nights above 75 deg. F. has been on a steady increase in the Southeast U.S. Also, most stations in Florida show more than a 60% increase in the number of nights about 75 deg. F from 1950-2016. The models of future climate indicate that night time temperatures will continue to rise (**Figure E-8**).

Figure E- 7. Historical changes in the number of nights with minimum temperature of above 75 deg. F.

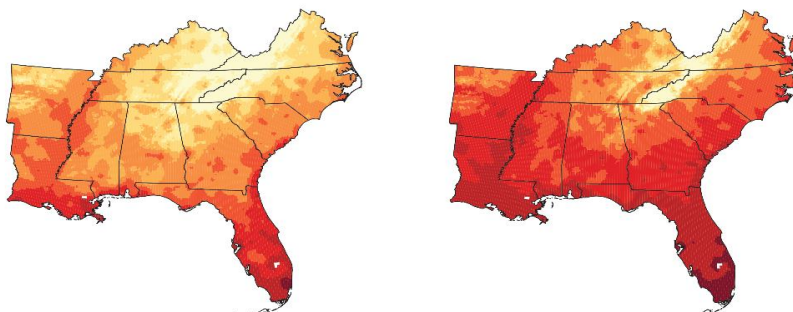


Source: Figure from USGCRP 2018.

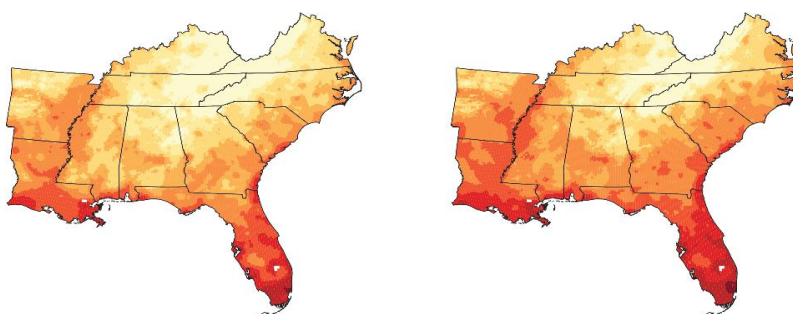
Figure E- 8. Projected number of warm nights (days with minimum temperatures above 75°F) per year in the Southeast for the 2036–2065 period (left) and the 2070–2099 period (right) under a higher scenario (RCP8.5; top row) and a lower scenario (RCP4.5; bottom row).

Mid-21st Century Late 21st Century

Higher Scenario (RCP8.5)



Lower Scenario (RCP4.5)



Number of Nights with a Minimum Temperature Greater than 75°F

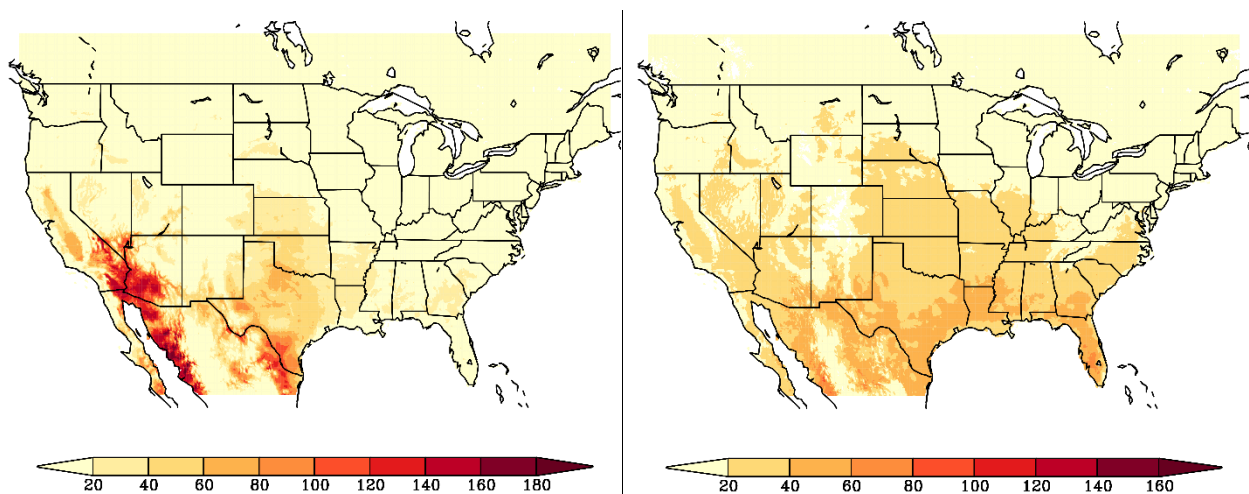


Source: Figure from USGCRP 2018.

Temperature extremes can also affect crop growth and development and water requirements. Maximum daily temperatures have also increased in recent decades and that trend is projected to continue in the coming decades. **Figure E-9** shows that in Florida from 1976-2005 the average annual number of days with temperature > 95 deg. F. was less than 20 per year. The projected number of annual days > 95 deg. F. for the period 2036-2065 increases to between 40 and 60 for most of Florida; this is from models using Representative Concentration Pathway (RCP) 4.5, a somewhat optimistic scenario that projects less drastic climate changes.

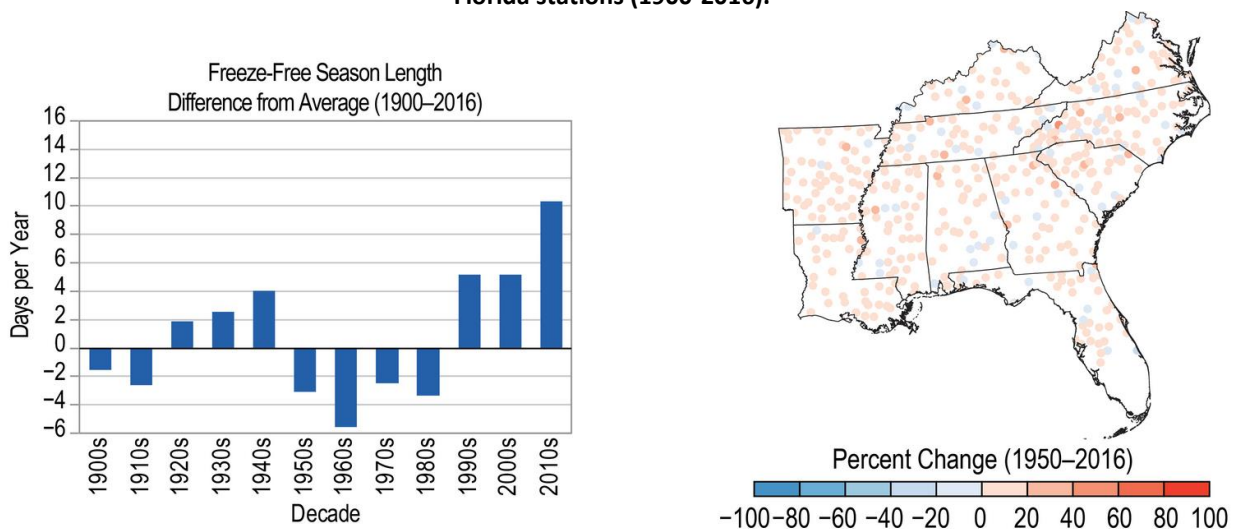
More very hot days will increase crop water requirements and may result in direct heat-related growth or yield reductions. There have also been increases in the length of the freeze-free season, the number of days between first and last days each year with minimum temperature of 32 deg. F. or lower. It can be seen from **Figure E-10** that in recent decades the length of the frost-free season (Southeast U.S. average) has increased by 5 to 10 days per year compared to the 1900-2016 average. Nearly all stations in Florida have seen increases in freeze-free length, and this is projected to continue in coming decades. Fewer freeze days would mean less irrigation demand for cold protection events, but it could also mean increased pest pressure for species whose populations would normally be reduced during freeze events.

Figure E- 9. Annual number of days with temperature > 95 deg F; 1976-2005 (left) compared to 2036-2065 (right); RCP 4.5.



Source: Figure from <https://scenarios.globalchange.gov/loca-viewer/>.

Figure E- 10. Changes in freeze-free season length; note small increases in freeze-free season length for most Florida stations (1900-2016).

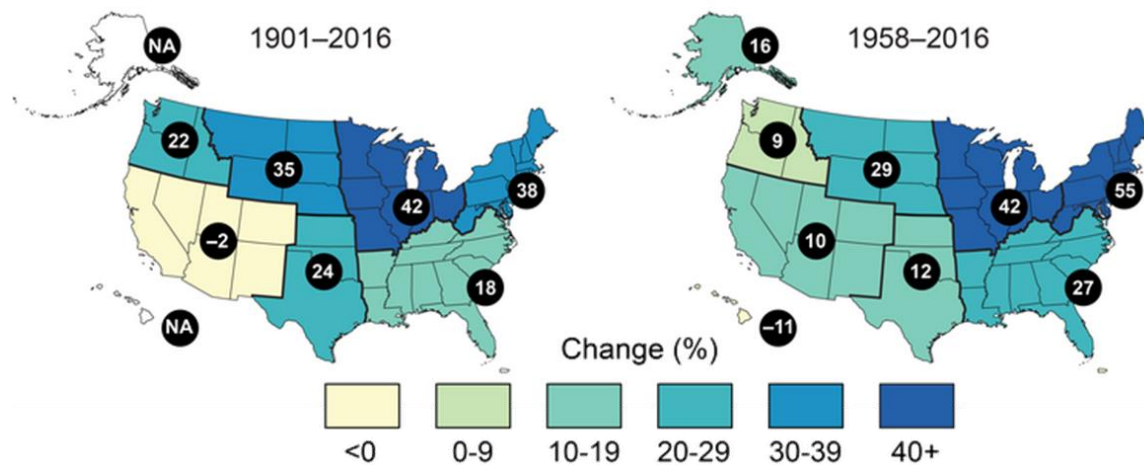


Source: Figure from USGCRP 2018.

Intensification of hydrologic cycle

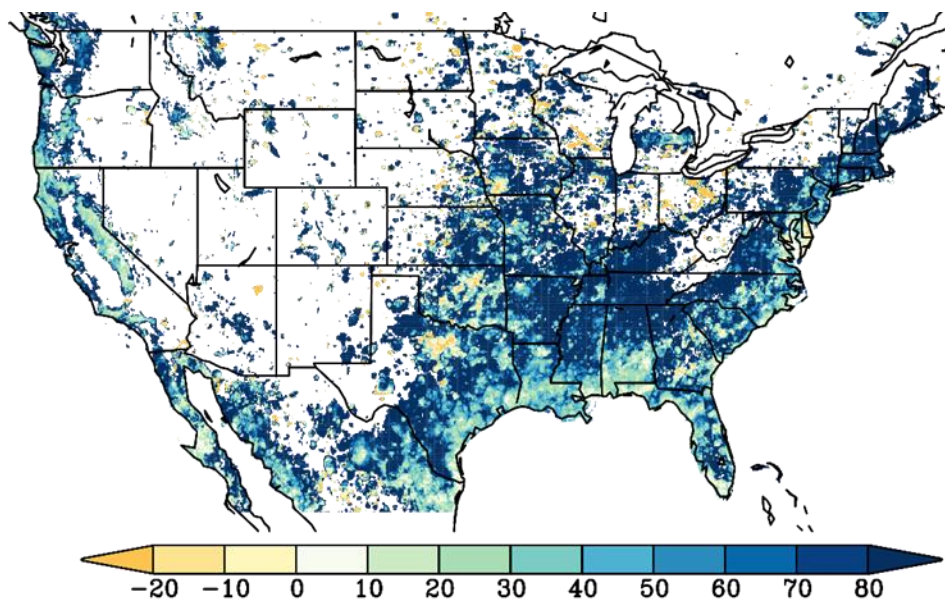
One consequence of warmer air temperatures is that the atmosphere holds more water. The dynamics of moisture convergence during storm formation can result in rainfall becoming more episodic; there may be fewer moderate rain events and more high-intensity rain events (Trenberth 2011). Increasing frequency of big rain events has been observed in Florida (Dourte et al. 2015) and in many areas in the U.S. (USGCRP 2018). Note in the Southeast U.S. there has been a 27% increase in the proportion of total annual rain falling in the top 1% of rain events (from 1958 to 2016), and the Northeast has seen the biggest increases in rain intensity (**Figure E-11**). This trend is projected to continue into the future; models show around a 30 to 60% increase in the annual number of days with more than 4 inches of rainfall in many parts of Florida (**Figure E-12**; 2036-2065 compared to 1976-2005). Some of the potential agricultural outcome of increasing rain intensity: increased soil and nutrient runoff, waterlogging and flooding. In fields that are not well drained, there could be plant damage and yield losses, and there can be significant costs to producers and to the environment if nutrient runoff increases. This likely means increased cost to producers to reapply nutrients and/or to adapt management practices to reduce runoff.

Figure E- 11. Historical % change in the amount of total annual rain falling in the heaviest 1% of rain events.



Source: Figure from USGCRP 2018.

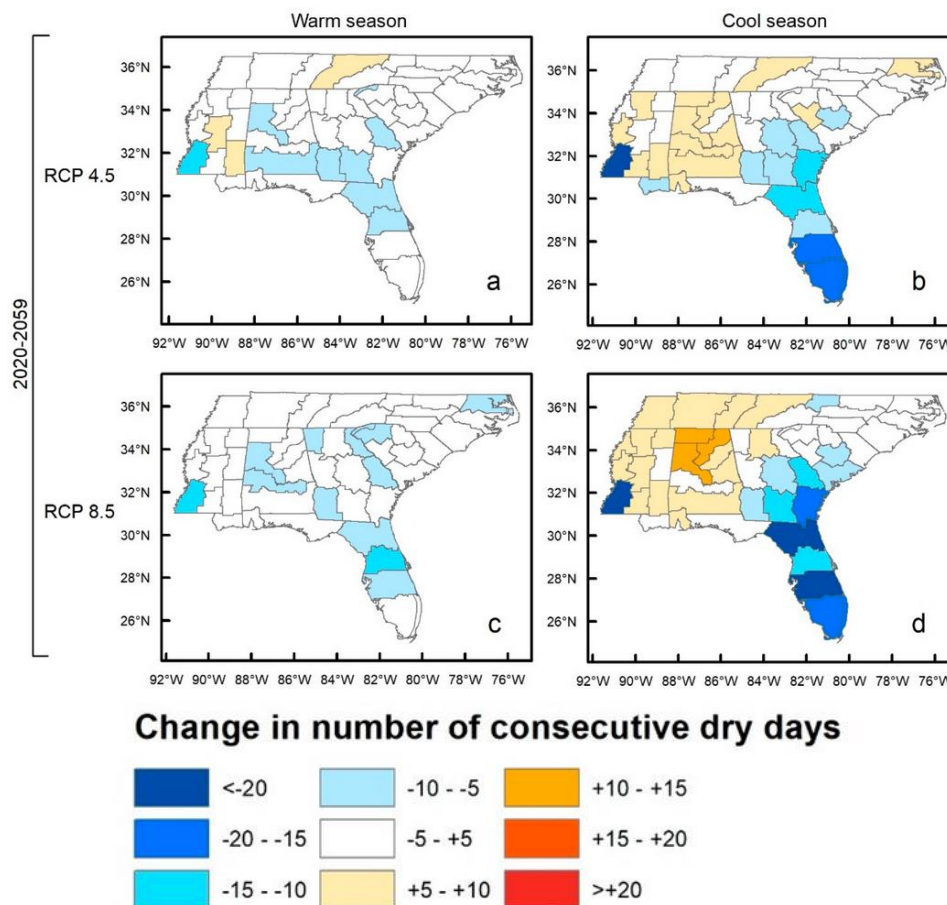
Figure E- 12. Future % change in the annual number of days with > 4 inches of rainfall; 2036-2065 compared to historical (1976-2005).



Source: Figure from <https://scenarios.globalchange.gov/loca-viewer/>.

Concerning drought changes, some climate model projections show that there might actually be a decrease in consecutive dry days (CDD) in Florida in coming decades (Keellings and Engström 2019). The future CDD with a 20-year return period were calculated and averaged across NOAA climate divisions. These CDD projections for 2020-2059 were compared to those from 1950-2005. In Florida, the cool season (November to March, which is typically the dry season) was found to have 20-year return period CDD that had about 10 to 20 fewer CDD (**Figure E-13**). This is potentially a good outcome in terms of increasing water supply recharge in dry parts of the year in the future.

Figure E- 13. Change in number of consecutive dry days with a 20-year return period in warm season (April to October; figures a and c) and cool season (November to March; figures b and d) for the period 2020-2059 compared to 1950-2005 period.



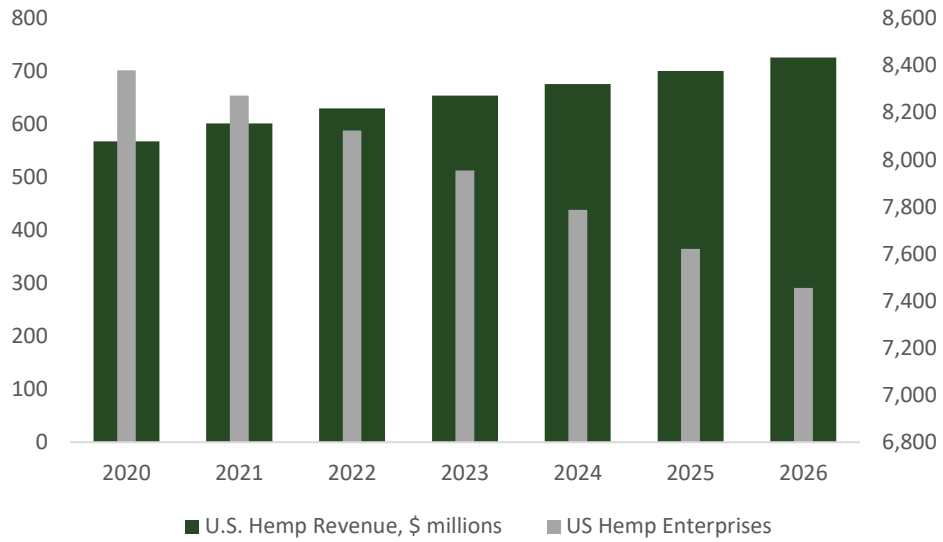
Source: Figure from Keellings and Engström 2019.

Hemp Production Status

Consumer demand for hemp-derived cannabidiol (CBD) oil has increased dramatically in recent years. Presently, hemp growing operations in Florida include only a small number of locations. As with any new product, available acreage and enthusiastic interest is one component of economic viability. Access to processing, distribution networks, and unique security concerns due to the regulated nature of cannabis are prerequisites for a successful supply chain to support viable hemp and/or cannabis production at scale in Florida. While there has been explosive growth in the hemp industry from about 2015 to 2020, there is currently an oversupply of hemp which has put some downward pressure on hemp prices.

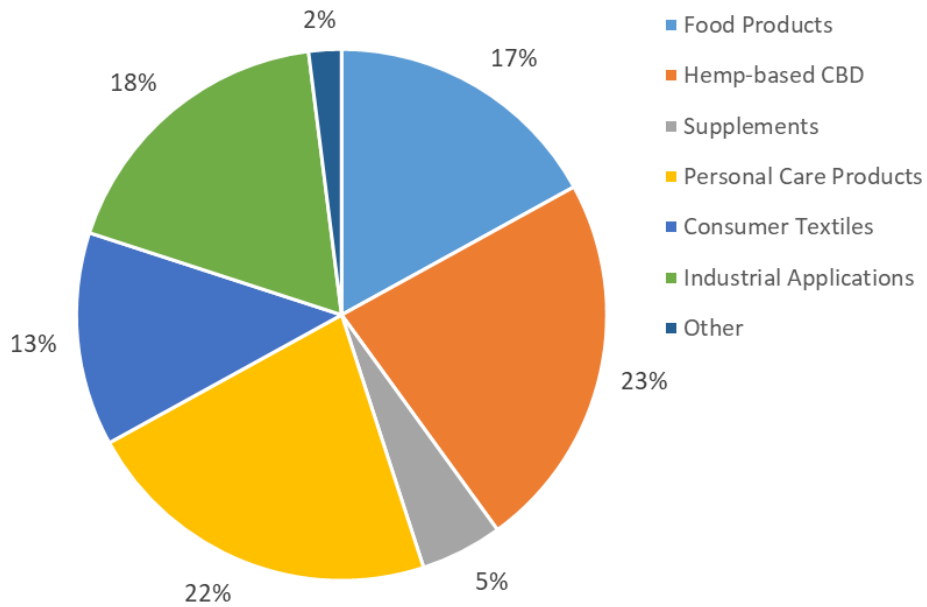
A recent industry report for hemp production (IBISWorld, 2020) shows total hemp revenues in the U.S. increasing by about 5% annually from 2021 to 2026 (See **Figure E-14**), while the number of enterprises declines, as unsuccessful early enterprises leave the industry or are consolidated into large enterprises. Montana, Colorado, Oregon and Kentucky are the leading U.S. states for total hemp acreage, but Kentucky tends to gain a lot of attention for their focus on downstream processing and supply chain sectors.

Figure E- 14. Projected U.S. Hemp Revenue and Enterprises



Source: Hemp Business Today, Farm Bureau

Figure E- 15. Estimated Hemp Product Sales by Category



Source: IBISWorld Hemp Industry Report 2020

There are four main hemp varieties: oilseed/grain, fiber, hybrid (grown for both fiber and seed), and cannabinoids (grown for CBD oil). Hemp production for CBD oil is the most expensive and is potentially the most lucrative if all the testing, marketing, and production challenges are overcome. Anecdotal reports suggest the large majority of early entrants into Florida hemp production are growing for CBD. **Figure E-15** shows recent data reflecting the breakdown of industrial hemp production, which has a broad variety of applications.

Most hemp varieties reportedly need about 25-30 inches of water per year, and are most sensitive to water stress in the first six weeks of production¹. Compared to the statewide average irrigation demands of 12 in/yr for citrus and about 10 in/yr for field crops, which likely represent the most probable crops displaced, hemp irrigation requirements could more closely resemble greenhouse needs if it is fully irrigated. This makes sense, given the highly controlled nature that is anticipated for Florida hemp production.

FDACS has been licensing hemp cultivation through the Florida State Hemp Program since April 2020. Licensing data were used to inform irrigated hemp data included in the ILG. Coordination with FDACS field staff and review of approved harvest areas in 2021 were used to refine the total acreage incorporated into the ILG. Presently irrigated hemp production shows up in the FSAID datasets within the Greenhouse/Nursery crop category, but the FSAID projections have not yet introduced hemp as a separate, future-irrigated crop given the limited acreage currently and the uncertainty around market conditions and production practices in Florida. The FSAID model is heavily dependent of crop-specific water use data, and there is currently very little hemp-specific water use data in Florida. Also, it will likely be several years before it is known what hemp production systems will look like in terms of size, irrigation systems, and open or covered (greenhouse) production. It is expected that future updates to the FSAID projections will include hemp acreage as better data on prices and production costs and water use become available.

International Trade

Florida agriculture is subject to trade agreements and import-export constraints. The U.S.-Mexico-Canada Agreement (USMCA) is arguably the trade agreement with the biggest impact on Florida's irrigated crop production. A recent study estimates that Florida farmers, in particular tomato, strawberry and bell pepper producers, lose up to \$400 million a year as a result of imports from Mexico that are believed to be unfairly subsidized (UF-IFAS, 2019). Legislation is being advanced on a regular basis (for example, the "2019 Defending Domestic Produce Production Act") to allow for market protection for Florida farmers, possibly by creating seasonal limits on Mexican produce import.

However, relative to agricultural production in California and the Midwest, Florida producers are a small share of the market that is affected by USMCA rules. As a result, Florida agriculture (along with Georgia) tends to be less successful in negotiating compromises within the agreement. Seasonality limits have been discussed for several years, but have not progressed sufficiently to protect Florida farmers from apparent unfair competition. If seasonality limits were successful, revenues for some Florida producers

¹ Purdue Hemp Project, Purdue University

could increase significantly. This would result in more stable market conditions and potentially increased irrigation demands in Florida.

Citrus Evaluation

Citrus irrigation is second only to sugarcane in both acreage and in water demand, but it is substantially more volatile due to citrus greening, natural disaster impacts, and competition from Brazil and other major citrus producing regions. Historically a higher share of Florida's citrus tends to be sold as processed than fresh, and processed orange prices have averaged about 66% of fresh orange prices in recent years. However, the 2018 to 2020 data from USDA shows Florida's processed oranges earning about nearly 90% of the prices of fresh oranges per box. This is likely driven by stronger competition from imports (for fresh oranges) and low supplies of processed fruit driving up prices (still affected by Hurricane Irma losses); see **Table E-7**.

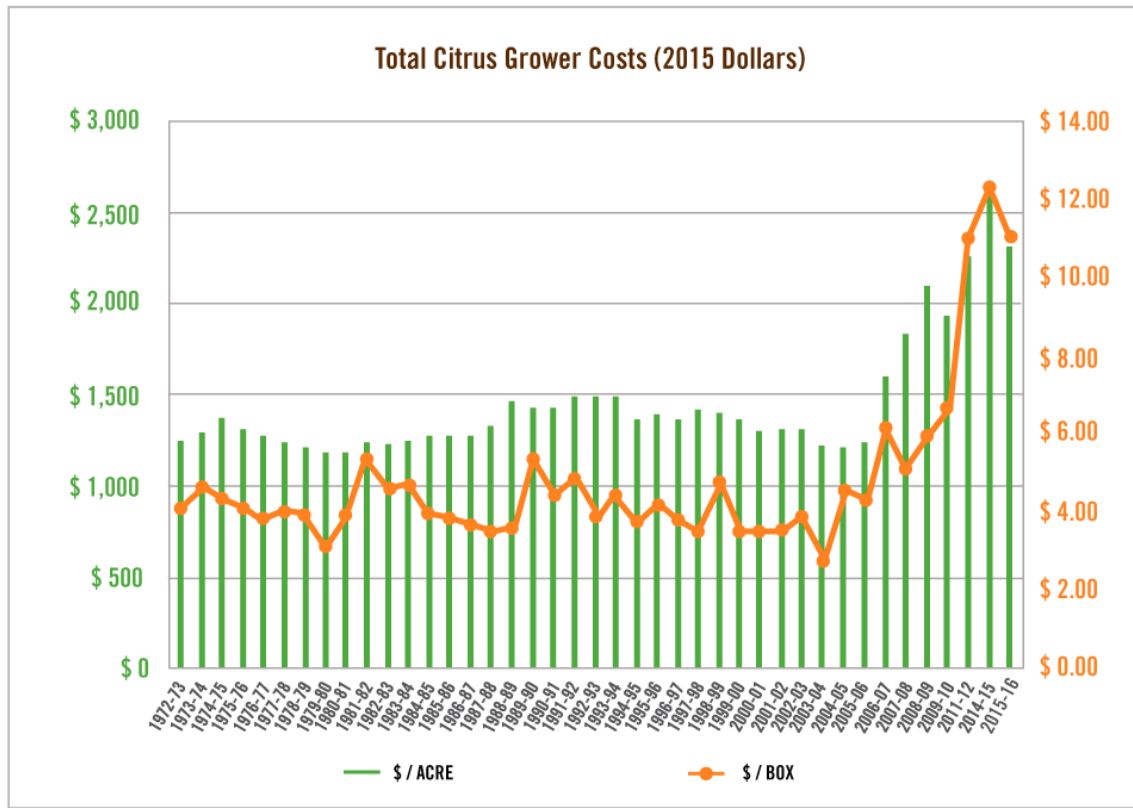
Table E- 7. Fresh vs. Processed Citrus (Oranges, FL) by year

Crop Year	Utilization of Production			Price per Box			Value of Production		
	Fresh (1,000 boxes)	Processed (1,000 boxes)	Total (1,000 boxes)	Fresh (dollars per box)	Processed (dollars per box)	Total (dollars per box)	Fresh (1,000 dollars)	Processed (1,000 dollars)	Total (1,000 dollars)
2012-2013	5,974	127,626	133,600	10.86	7.27	7.43	64,867	927,659	992,526
2013-2014	5,500	99,200	104,700	13.62	9.41	9.63	74,923	933,699	1,008,622
2014-2015	4,970	91,980	96,950	14.39	9.11	9.38	71,507	837,880	909,387
2015-2016	3,930	77,770	81,700	15.14	9.63	9.90	59,484	749,281	808,765
2016-2017	2,841	65,909	68,750	17.51	9.33	9.67	49,759	614,877	664,636
2017-2018	2,759	42,291	45,050	22.95	15.10	15.58	63,307	638,548	701,885
2018-2019	2,737	69,150	71,850	17.71	14.36	14.48	48,467	992,796	1,041,263
2019-2020	3,238	64,062	67,300	13.56	12.85	12.89	43,919	823,285	867,204

Source: USDA Citrus Fruits summary (2020)

Citrus production costs have increased sharply since the onset of greening (around 2006-2007 season) but have leveled off somewhat in recent years as management practices have stabilized. **Figure E-16** provides a graphic timeline of costs per acre which have jumped by 66% since the onset of greening and have stabilized in recent years. The 2018/2019 and 2019/2020 total production costs (processed oranges in southwest region) were \$2,265/acre and \$2,095/acre, respectively. This demonstrates that citrus production costs have stabilized, even though they are well above the pre-greening average.

Figure E- 16. Total citrus production costs 1972-2016



Source: Florida Department of Citrus

Given the issues relating to greening in Florida, and intense foreign competition, there is still significant uncertainty about future citrus production in Florida. The price projection trend for citrus in FSAID was based on the trend in round orange production and prices from 2017/2018 to 2026/2027 from FDOC, adjusted to all citrus prices and extended to 2045. The projections took into account a confidence interval on price forecasts (further detail below), a linear trend on price forecast in the outer years, and an upper bound on overall production. Extensive discussion was held with academic experts in citrus production forecasting, Florida Department of Citrus Chief Economist Marisa Zansler, and producers, resulting in the following components of citrus evaluation:

- Florida Department of Citrus did not update their long-term forecasts of production this year. Existing forecasts of production were based on multiple scenarios that reflect potential changes in replanting rates (50%, 100%, 125% and 255% - the latter considered the “recovery rate”) and yield (184 boxes/acre and 200 boxes/acre); see **Table E-8**. While previously three higher replanting scenarios were reported as “likely”, average replanting in recent years has tracked at the “low” or 50% rate. Hence, 50% replanting rate scenario (192 boxes/acre) was used for projection purposes.

Table E- 8. Florida Department of Citrus Projection Scenarios

Florida Dept of Citrus (DOC) Projection Scenarios (**bold** considered likely scenarios)

Declining Yields@ 100% plant rate

Constant Yields @ 50% plant rate

Constant Yields @ 100% plant rate

Constant Yields @ 125% plant rate

Constant Yields @ 255% plant rate

Increasing Yields @ 50% plant rate

Increasing Yields @ 100% plant rate

Increasing Yields @ 125% plant rate

Increasing Yields @ 255% plant rate

- The long-term accuracy of FDOC price estimates was evaluated. Previous estimates of citrus prices per box were researched; on average, the first three years of forecasts tended to underestimate prices by a few percentage points, while the later years tended to overestimate. In general, repeated forecasts reflected about a 13% overestimate for forecasting periods more than five years out from forecast date.
- The official forecast period for the Department of Citrus extends ten years and reflects price increases of just over 1% per year. Numerous algorithms were tested to extend price forecasts beyond the official forecast period using a variety of trending algorithms. Linear and power trend forecasts tended to most closely track the official forecast trajectories. In the end, based largely on input from Dr. Zansler (who produces the Department of Citrus forecasts), a linear trend was used to extend the forecast to 2045.
- About 260,000 acres are identified as fallow citrus in the current ALG. The vast majority of this land is permitted and could be irrigated at any time, as citrus or as fresh vegetables as a second most likely crop. Using coarse estimates of areas most feasible given transport costs and proximity to distribution facilities, one third of the area could resume production in citrus or fresh vegetables, generating an additional 67 to 102 MGD in demand beyond what is included in current estimates.

Citrus acreage has declined by about 7,000 acres in the ILG from 2018 to 2019 base year. Over the short run, citrus decline is likely to continue, but newer nursery stocks that exhibit more resilience to greening and other pests are beginning to be used in re-plantings such that within 5-7 years, acreage is expected to stabilize. The substantial investments in solutions to greening, through traditional management, breeding, and advanced genomic techniques, are likely to result in some improvements to plants or cultural strategies that should bring about some stability or recovery in citrus acreage and production.

It is expected that in the next several years, there will be information that provides more certainty about the potential recovery of citrus. Based on best-available, current information, the FSAID acreage projections for citrus are about 20,000 acres of decline from the 2019 baseline acreage of 533,000. This is about a 4% decrease in citrus acreage.

FSAID Methodology for Dry-Year Water Demand Estimation

Florida statute requires agricultural demand estimates be developed for use in regional water supply planning to include average year and 1-in-10 year drought demands. In FSAID, the approach is to base the

dry-year estimates on modeled irrigation demand that occurs with a 1-in-10 frequency. This approach reflects the reality that the years of high irrigation demand might correspond to years with normal or above-average rainfall because of the difference in timing of rainfall events and cropping seasons. The relevant water supply planning statute language is as follows:

From Statue 373.709 Regional water supply planning:

“A quantification of the water supply needs for all existing and future reasonable-beneficial uses within the planning horizon. The level-of-certainty planning goal associated with identifying the water supply needs of existing and future reasonable-beneficial uses must be based upon meeting those needs for a 1-in-10-year drought event.”

“Agricultural demand projections used for determining the needs of agricultural self-suppliers must be based upon the best available data. In determining the best available data for agricultural self-supplied water needs, the district shall consider the data indicative of future water supply demands provided by the Department of Agriculture and Consumer Services pursuant to s. 570.93 and agricultural demand projection data and analysis submitted by a local government pursuant to the public workshop described in subsection (1), if the data and analysis support the local government’s comprehensive plan. Any adjustment of or deviation from the data provided by the Department of Agriculture and Consumer Services must be fully described, and the original data must be presented along with the adjusted data”

From Statue 570.93 Department of Agriculture and Consumer Services; agricultural water conservation and agricultural water supply planning:

“Estimates of historic and current water demands must take into account actual metered data as available.”

Estimates of Dry Year Water Demand are calculated using the ratio of dry-to-average 1-in-10 irrigation needs. Based on a statewide batch run of AFSIRS, the 90th percentile irrigation demand by crop was determined. The dry-to-average ratios (by crop by District) used throughout the estimates are shown in **Table E- 9**.

Table E- 9. Dry to Average Year Ratio

Primary Crop	NWFWMD	SFWMD	SJRWMD	SRWMD	SWFWMD	Statewide
Citrus	1.5	1.43	1.58	1.47	1.5	1.5
Field Crops	1.39	1.32	1.48	1.27	1.29	1.35
Fruit (Non-citrus)	1.6	1.17	1.44	1.41	1.3	1.31
Greenhouse/Nursery	1.17	1.1	1.14	1.13	1.1	1.13
Hay	1.72	1.36	1.64	1.36	1.37	1.46
Potatoes	1.45	1.23	1.53	1.45	1.31	1.45
Sod	1.34	1.18	1.31	1.2	1.17	1.22
Sugarcane	1.38	1.38	1.2	1.38	1.38	1.38
Vegetables (Fresh Market)	1.45	1.23	1.34	1.31	1.29	1.28
Statewide overall						1.34

Irrigation Efficiency Improvements

The efficiency of an irrigation system describes the relationship between the amount of irrigation water retained in crop root zones and the total amount of water withdrawn from a source for irrigation. Improvements to irrigation efficiency are generally the result of the following changes:

- Management or scheduling improvements (possibly resulting from implementation of soil moisture sensors or weather stations or other monitoring equipment)
- Equipment change to irrigation equipment that reduces non-beneficial water use
- Equipment maintenance and upgrades that improve uniformity and/or efficiency (resulting from nozzle replacement, adding pressure regulators, or other equipment improvements)

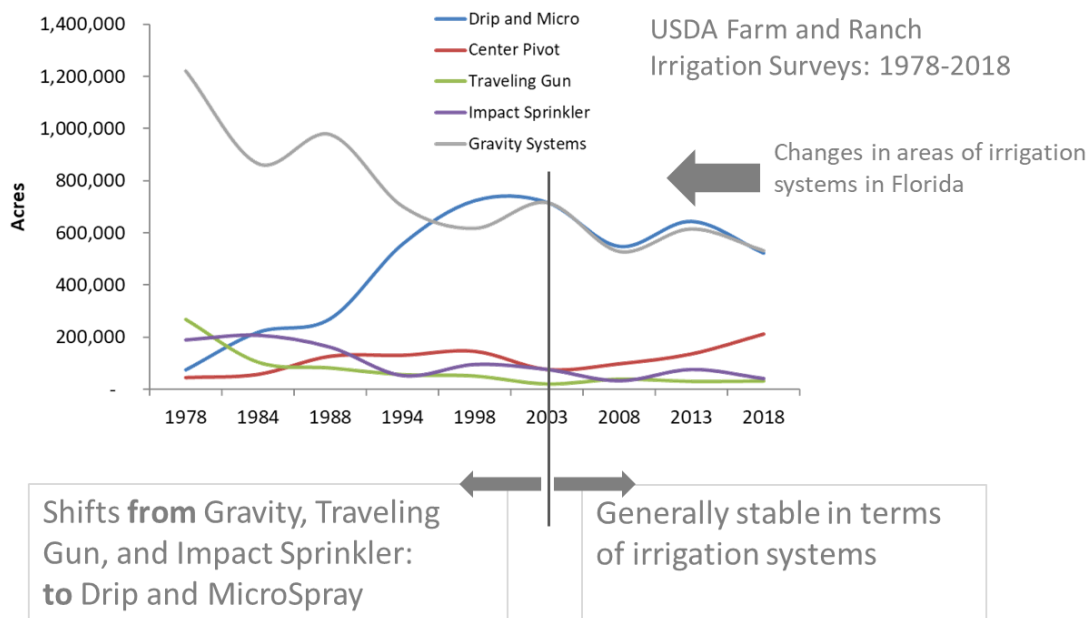
One option for estimating future improvements in irrigation efficiency requires estimating the field-level improvements in efficiency and estimating the number of fields or farms that are expected to achieve those efficiency improvements. The advantage of this approach is that it can be linked to on-farm data where irrigation efficiency improvements have been made in the past. However, a challenge with this approach is estimating the numbers of farms that can be expected to realize similar efficiency improvements in the future.

The approach used in FSAID relies on historical trends in Florida irrigation efficiency in agriculture to predict future improvements. The Farm and Ranch Irrigation Surveys (FRIS) of the USDA were utilized as the data source for statewide irrigated area and total volume of water applied. The FRIS data are a subset of USDA's Ag Census; producers are required by law to respond to the Ag Census (Title 7 USC 2204(g) Public Law 105-113). FRIS data used in FSAID to estimate irrigation efficiency improvements are based on Florida producers' self-reported water use volumes and irrigated area. A main advantage of this method is that it avoids the uncertainty of estimating at the field level exactly what type of management change would be made and how many farms or fields would be expected to make that change. It also recognizes the equipment and management changes made by producers which happen outside of any particular conservation initiative.

The time series of the FRIS-derived ratio of irrigation water volume applied to irrigated area was used to develop two exponential functions of efficiency improvements, where water per area is used as a proxy for efficiency. The function derived from the more recent FRIS data (2003-2018) is assumed to be representative of efficiency improvements resulting mostly from management/scheduling changes.

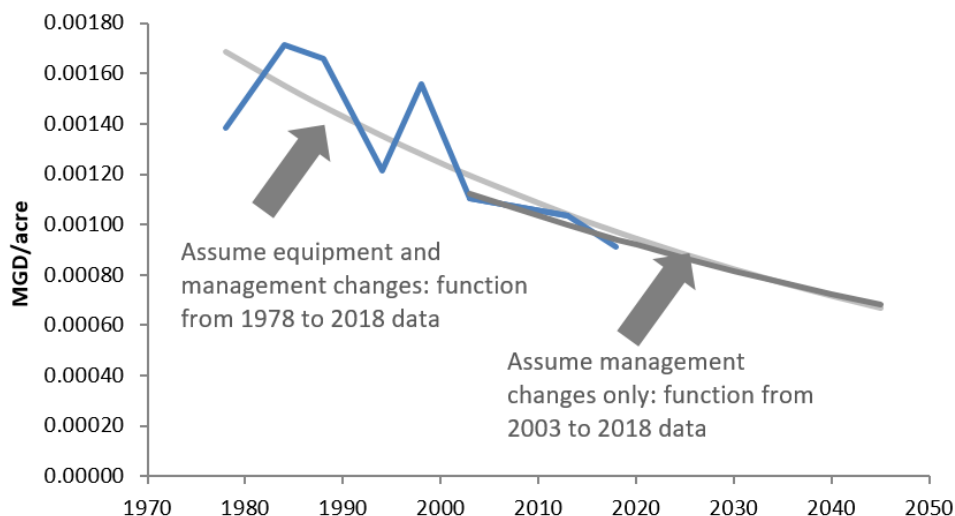
The exponential function derived from the entire time series (1978-2018) is used to represent the combined impacts of irrigation system equipment changes and management improvements. **Figure E- 17** illustrates the shift in types of irrigation equipment. It can be seen that there is a sizeable shift from gravity systems to drip and micro-spray systems. There appears to be relative stability in the equipment trends beginning with the 2003 FRIS.

Figure E- 17. Shift in Types of Irrigation Equipment



Both FRIS-derived efficiency improvement functions are used in the FSAID estimates (**Figure E- 18**). The approach of using two functions allows for less efficiency improvements to be projected in the coming decades for newly irrigated fields or for existing irrigated fields that have drip or micro-spray systems. It is assumed that newly irrigated fields or fields with drip or micro-spray systems would achieve efficiency improvements largely resulting from management improvements.

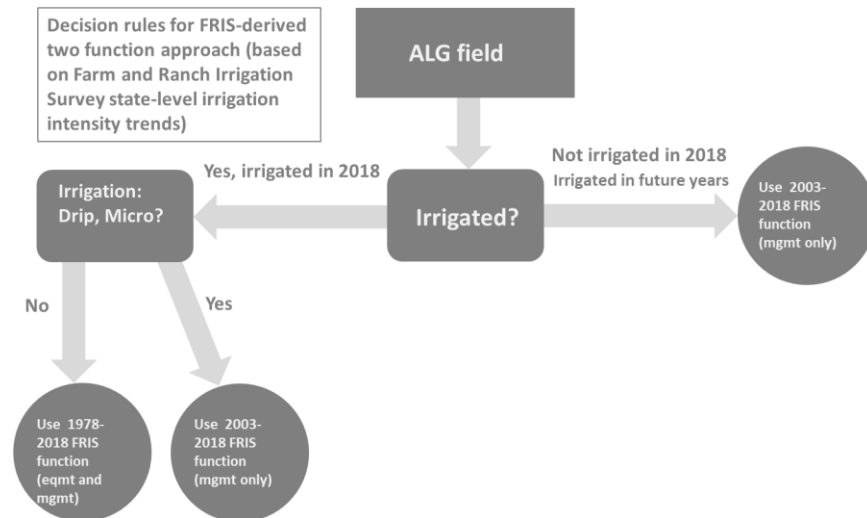
Figure E- 18. FRIS Data of Irrigation Amount (MGD) Per Irrigated Acre



Other fields (that are not new, or have not yet upgraded their equipment) could be expected to achieve efficiency improvements of a larger amount resulting from combinations of equipment and management improvements; this is represented by the exponential function built from the entire FRIS time series of water applied per irrigated area. A diagram of these decision rules is illustrated by **Figure E- 19**. It should

be noted that the use of exponential trends in conservation results in slopes that are flattening in the future periods (see **Figure E- 18**). Also, as the 1978-2018 FRIS trend dips below the management-only trend in 2035 (FRIS data 2003-2018), the 2003-2018 trend is used for all irrigated areas from 2035 onward.

Figure E- 19. Methodology for Applying FRIS-Derived Efficiency Improvement Functions



Limits on irrigation efficiency are defined using the metered/reported irrigation data. The median irrigation intensity (in/year) by crop type, based on all 2007-2019 metered/reported water use data, was used to constrain additional efficiency improvements at the field level if the irrigation intensity dropped below the median value (**Table E-10**). This means that for an individual Field Crop field, for example, if the irrigation rate decreases below 8.5 in/yr as a result of the conservation trend, then no further irrigation conservation would be estimated for that field. For citrus, the average irrigation intensity (11.9 in/yr) from the historical data, rather than the median, was used to constrain efficiency improvements. This was done to reflect the potentially higher irrigation rates in new citrus fields resulting from greater planting densities. Similarly, for fresh vegetable crop types, the average intensity (16 in/yr) was used to limit irrigation efficiency improvements in order to accommodate the likely crop rotation intensification (more crops per year in some fields) that will happen within that crop type.

Table E- 10. Median Metered Irrigation Intensity Reported by Crop, 2007-2019

Primary Crop	in/year
Citrus	11.9 (10.2 median)
Field Crops	8.5
Fruit (Non-citrus)	22.5
Greenhouse/Nursery	20.8
Hay	8.6
Potatoes	12.1
Sod	7.9
Sugarcane	16.2
Vegetables (Fresh Market)	16.3 (13.2 median)

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