



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 are 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 2018. For FSAID VII, the sample size of metered data increased by about 11,000 permit-level data points with the addition of 2018 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 0.77.

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, 2018). There is also a 2018 water demand estimate based on average rain and ET data inputs to align base year climate inputs with projection year climate inputs.

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 (2005-2018) 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 were 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 8% 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 .77289 to .76672, and the Akaike Criteria (AIC) increases from 16.649 to 16.742 (the latter reflects tightness of fit, with lower numbers better; the formula penalizes additional variables such that two models with the same number of variables would favour the model with the lower AIC). The South Florida dummy variable, which denotes the origin of 26% of the observations, has a borderline statistical significance of 0.11 p-value, while in the prior year the p-value was 0.14. Analysis in prior years has found that the irrigation behaviour of SFMWD is very similar to that of SWFWMD irrigation, and as such the SFWMD indicator variable adds only minor explanatory value. The SRWMD indicator has the same p-value as SFWMD, at 0.11, which is a significant improvement in explanatory value from the prior year, when the p-value was 0.44. As SRWMD

contributed only 2% of the overall observations last year, the weak p-value was consistent, while in the current year SRWMD observations contribute 4%, which is a higher threshold for statistical significance.

All other variables are significant to the 1% level, with the exception of the SFWMD and Center Pivot indicator variables, which are significant to 4% and 6%, respectively. Both variables still show a strong statistical significance.

For the most part, coefficients were close to prior year values. Variables with notable differences include price on field crops, which increased 8% from last year, and show a corresponding 7% increase in water use.

Given that the model fit is strong and no unsurprising results emerged, the model was used without modification for the 2020 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	82	155	16	10	27	8	141	1,006
2007	in/yr	13.10	8.78	26.43	30.10	7.22	12.46	15.30	33.42	15.96	14.20
2008	Count	2,187	215	129	1,088	252	126	276	113	1,276	5,662
2008	in/yr	11.26	8.90	29.84	32.29	8.91	15.86	10.98	14.96	18.25	13.03
2009	Count	2,278	192	119	1,080	287	121	247	285	1,379	5,988
2009	in/yr	12.63	7.79	22.17	32.09	8.92	16.57	12.97	11.47	18.93	13.52
2010	Count	685	108	149	154	36	22	29	7	354	1,544
2010	in/yr	13.67	10.82	23.31	30.35	6.91	20.60	16.05	26.84	19.80	15.61
2011	Count	2,476	242	210	1,124	234	139	196	181	1,262	6,064
2011	in/yr	12.43	10.15	24.77	28.81	8.97	15.29	13.11	14.11	17.19	13.53
2012	Count	2,717	300	239	846	251	140	212	246	1,378	6,329
2012	in/yr	12.40	9.14	24.97	28.56	9.54	17.94	12.16	14.96	18.69	13.83
2013	Count	2,543	69	237	684	182	101	179	167	1,167	5,329
2013	in/yr	12.13	6.30	25.07	26.02	9.66	12.21	15.75	17.41	16.67	13.50
2014	Count	2,254	260	264	691	245	63	198	196	1,347	5,518
2014	in/yr	10.43	10.05	24.97	27.67	10.88	14.15	10.28	18.17	15.20	12.64
2015	Count	1,913	511	285	714	259	107	185	365	969	5,308
2015	in/yr	10.81	10.53	27.18	25.88	9.98	14.86	12.19	18.10	15.21	13.38
2016	Count	2,552	407	394	702	257	149	181	312	1,476	6,430
2016	in/yr	11.13	9.54	26.76	30.90	10.68	14.32	10.15	16.40	17.81	13.41
2017	Count	2,922	738	500	792	422	132	215	397	1,531	7,649
2017	in/yr	11.77	9.96	27.47	30.79	10.98	15.22	12.03	20.71	19.51	14.62
2018	Count	2,385	842	854	772	221	164	151	415	1,281	7,085
2018	in/yr	11.67	9.64	26.71	27.32	9.38	14.64	10.22	16.37	16.88	13.39
All Years	Count	25,448	3,915	3,462	8,802	2,662	1,274	2,096	2,692	13,561	63,912

Table E- 2. Metered Data Records Statistics by District

WMD	Primary Crop	Total Acres	Total MGD	IN/YR
NWFWMD	Field Crops	126,189	82.53	8.79
NWFWMD	Fruit (Non-citrus)	22	0.03	19.21
NWFWMD	Greenhouse/Nursery	9,119	25.97	38.27
NWFWMD	Hay	7,712	3.50	6.10
NWFWMD	Potatoes	2,937	5.01	22.93
NWFWMD	Sod	10,873	7.01	8.66
NWFWMD	Vegetables (Fresh Market)	6,198	5.15	11.17
SFWMD	Citrus	1,238,521	1,097.32	11.91
SFWMD	Field Crops	6,122	4.27	9.38
SFWMD	Fruit (Non-citrus)	4,352	6.90	21.33
SFWMD	Greenhouse/Nursery	23,334	53.74	30.96
SFWMD	Hay	346,238	254.58	9.88
SFWMD	Potatoes	21,208	25.41	16.11
SFWMD	Sod	107,773	90.05	11.23
SFWMD	Sugarcane	746,907	928.12	16.70
SFWMD	Vegetables (Fresh Market)	524,123	738.27	18.93
SJRWMD	Citrus	86,437	81.36	12.65
SJRWMD	Field Crops	19,416	14.80	10.25
SJRWMD	Fruit (Non-citrus)	8,667	18.66	28.94
SJRWMD	Greenhouse/Nursery	51,735	109.95	28.57
SJRWMD	Hay	92,802	72.27	10.47
SJRWMD	Potatoes	64,018	69.22	14.53
SJRWMD	Sod	51,238	49.43	12.97
SJRWMD	Vegetables (Fresh Market)	38,463	49.57	17.32
SRWMD	Field Crops	152,600	121.26	10.68
SRWMD	Fruit (Non-citrus)	2,333	4.58	26.41
SRWMD	Greenhouse/Nursery	2,868	5.31	24.88
SRWMD	Hay	24,587	18.76	10.26
SRWMD	Potatoes	3,388	4.78	18.95
SRWMD	Sod	452	0.59	17.66
SRWMD	Vegetables (Fresh Market)	20,950	24.06	15.44
SWFWMD	Citrus	1,321,680	1,143.06	11.63
SWFWMD	Field Crops	31,552	17.79	7.58
SWFWMD	Fruit (Non-citrus)	42,743	81.37	25.59
SWFWMD	Greenhouse/Nursery	20,049	37.61	25.22
SWFWMD	Hay	31,728	18.29	7.75
SWFWMD	Potatoes	13,144	15.09	15.44
SWFWMD	Sod	49,186	49.69	13.58
SWFWMD	Vegetables (Fresh Market)	292,159	336.71	15.49
Total		5,603,822	5,672	13.61

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

| Ordinary least squares regression Weighting variable = none |
 | Dep. var. = INYRAC Mean = 1192.926837, S.D. = 2163.624476 |
 | Model size: Observations = 63912, Parameters = 31, Deg.Fr.= 63881 |
 | Residuals: Sum of squares= .6976082766E+11, Std.Dev.= 1045.00883 |
 | Fit: R-squared = .766830, Adjusted R-squared = .76672 |
 | Model test: F[30, 63881] = 7002.89, Prob value = .00000 |
 | Diagnostic: Log-L = *****, Restricted(b=0) Log-L = -581501.4670 |
 | LogAmemiyaPrCrt. = 13.904, Akaike Info. Crt.= 16.742 |
 | Autocorrel: Durbin-Watson Statistic = .97506, Rho = .51247 |

Variable	Coefficient	Standard Error	b/St.Er.	P[Z >z]	Mean of X
Constant	(1,279.15)	137.22	(9.32)	-	
SFWMD	(53.56)	33.69	(1.59)	0.11	0.26
SJRWMD	(68.17)	32.42	(2.10)	0.04	0.16
SRWMD	48.59	30.00	1.62	0.11	0.04
SWFWMD	(142.46)	32.38	(4.40)	-	0.50
RAIN	(17.65)	1.86	(9.47)	-	53.90
RAINET	0.33	0.03	10.26	-	2,975.93
CITAC	11.83	0.05	229.10	-	41.41
FIEAC	9.68	0.25	38.73	-	5.26
FRSAC	18.20	0.09	206.41	-	13.80
FRUAC	21.46	0.49	43.37	-	0.91
GREAC	29.81	0.80	37.05	-	1.68
HAYAC	6.88	0.06	121.51	-	7.87
POTAC	14.27	0.31	46.69	-	1.64
SODAC	12.01	0.18	66.17	-	3.43
SUGAC	16.93	0.09	196.26	-	11.69
LNPCIT	122.29	16.26	7.52	-	3.03
LNPFIE	193.51	20.14	9.61	-	0.39
LNPFRS	115.48	13.86	8.33	-	1.91
LNPFRU	132.82	13.88	9.57	-	0.49
LNPGRE	88.33	11.57	7.64	-	1.48
LNPHAY	303.94	23.42	12.98	-	0.22
LNPPOT	140.56	15.06	9.34	-	0.17
LNPSOD	133.69	15.46	8.65	-	0.27
LNPSUG	114.90	16.74	6.86	-	0.32
CPIVOT	83.06	44.46	1.87	0.06	0.08
CONTNUR	416.73	52.32	7.97	-	0.06
GRAVSYS	308.94	42.11	7.34	-	0.21
IMPSPRK	432.70	49.72	8.70	-	0.07
DRIP	227.96	44.61	5.11	-	0.17
MICROS	425.07	49.48	8.59	-	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 47.73 inches, and the recorded average annual ET was 55.24. The estimated net price was \$1,552. A summary of the GIS attribute values for the specified farm are provided in **Figure E- 1**. Applying the coefficients from FSAID VI to this specific farm's GIS attributes produces an estimated 11.35 inches per acre per year.

Figure E- 1. 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)	47.73
RAINET	RainET interaction term (rain times ET)	2,636
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	7.35
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	-1,279.15	-1,279.15
SWFWMD	1	-142.46	-142.46
RAIN	47.73	-17.65	-842.37
RAINET	2,636.26	0.33	867.22
CITAC	95.33	11.83	1,128.00
LNPCIT	7.35	122.29	898.47
MICROS	1	425.07	425.07
ACREIN (Total in Acre Inches per Year)			1,054.77
GALMIL (Total in Millions of Gallons per Year)			28.64
Estimated Inches/Acre/Year (GALMIL/365/95.33 acres*13441.7)			11.06

Table E- 4. Projected Crop Prices and Costs

Primary Crop	Unit	2018	2020	2025	2030	2035	2040	2045
Citrus	Crop Price	\$3,023	\$2,068	\$2,917	\$3,240	\$3,662	\$4,085	\$4,508
	Chem. Cost	\$1,441	\$1,472	\$1,553	\$1,801	\$2,089	\$2,341	\$2,624
Field Crops	Crop Price	\$753	\$763	\$784	\$831	\$882	\$933	\$984
	Chem. Cost	\$224	\$229	\$240	\$269	\$301	\$317	\$333
Vegetables (Fresh Market)	Crop Price	\$5,079	\$5,404	\$5,567	\$6,236	\$6,960	\$7,668	\$8,377
	Chem. Cost	\$1,274	\$1,303	\$1,364	\$1,529	\$1,713	\$1,801	\$1,892
Greenhouse/Nursery	Crop Price	\$68,876	\$70,185	\$71,238	\$74,796	\$75,369	\$79,214	\$83,254
	Chem. Cost	\$2,116	\$2,161	\$2,265	\$2,539	\$2,845	\$2,990	\$3,143
Hay	Crop Price	\$379	\$395	\$401	\$404	\$406	\$408	\$409
	Chem. Cost	\$147	\$151	\$158	\$177	\$198	\$208	\$219
Fruit (Non-citrus)	Crop Price	\$9,000	\$9,398	\$9,600	\$10,611	\$11,965	\$13,150	\$14,336
	Chem. Cost	\$1,537	\$1,583	\$1,680	\$1,948	\$2,259	\$2,532	\$2,838
Potatoes	Crop Price	\$4,014	\$4,072	\$4,127	\$4,446	\$4,727	\$5,025	\$5,324
	Chem. Cost	\$452	\$462	\$484	\$543	\$608	\$639	\$672
Sod	Crop Price	\$4,440	\$4,605	\$4,607	\$4,618	\$4,571	\$4,804	\$5,049
	Chem. Cost	\$738	\$753	\$789	\$884	\$991	\$1,041	\$1,094
Sugarcane	Crop Price	\$2,529	\$2,598	\$2,670	\$3,056	\$3,498	\$4,005	\$4,585
	Chem. Cost	\$213	\$218	\$228	\$256	\$287	\$301	\$317

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 asymmetrical thresholds reflect the right skewness of the water use data (more 0 and small values; mean greater than median). It follows that to represent the mean irrigation demands, a percentile value greater than median would be selected, suggesting asymmetrical thresholds are appropriate.

These ranges (**Table E-5**) 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- 5. 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	3.2	19.8
Fruit (Non-citrus)	12.8	49.4
Greenhouse/Nursery	8.9	62.4
Hay	2.2	23.3
Potatoes	7.8	31.5
Sod	4.0	36.5
Sugarcane	3.5	35.4
Vegetables (Fresh Market)	6.9	34.1

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 2018.

Evapotranspiration

For purposes of assessing sensitivity of the ET variable inputs for the model, an analysis was conducted in a previous FSAID iteration (FSAID 5). The mean ET was calculated by crop, using the model dataset and also using the entire 2016 projection ILG dataset (which was calculated with a 12 year average of ET). **Table E-6** shows the results. Differences will reflect the spatial variation in the model dataset as contrasted with the greater distribution in the larger ILG dataset; overall the difference is within 2.3%.

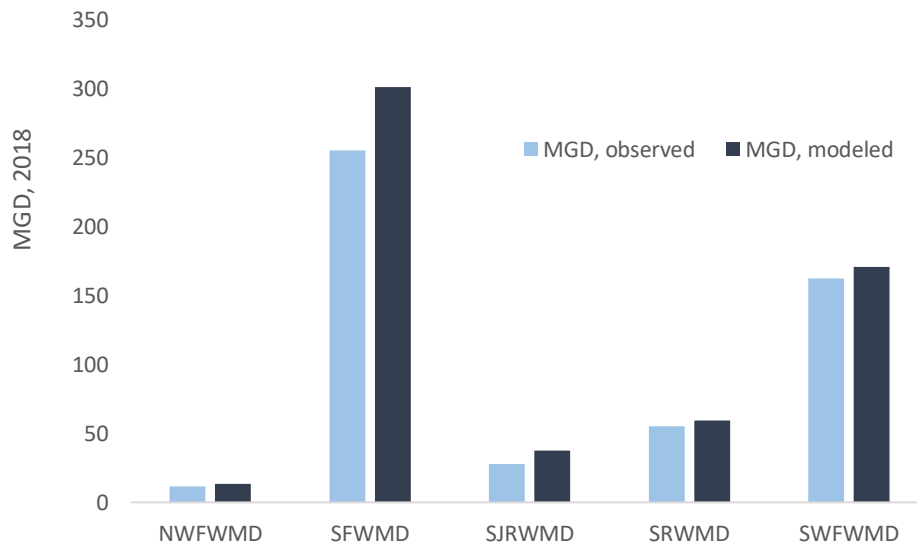
Table E- 6. Difference in Calculations from Model Dataset and Entire 2016 Projection ILG

Statewide	ET (IN/YR)	ET (IN/YR)	Difference
Crop	Metered Dataset	2016 Projection ILG	
Citrus	54.90	55.95	1.9%
Field Crops	49.13	51.34	4.5%
Fruit (Non-citrus)	53.06	54.82	3.3%
Greenhouse/Nursery	51.70	54.73	5.9%
Hay	52.82	53.66	1.6%
Potatoes	51.66	53.86	4.5%
Sod	53.44	55.32	3.5%
Sugarcane	56.75	56.88	0.2%
Vegetables (Fresh Market)	54.72	55.78	1.9%
Total	53.87	54.93	2.0%

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 0.77. **Figure E- 2** shows a comparison of the 2018 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 18 MGD.

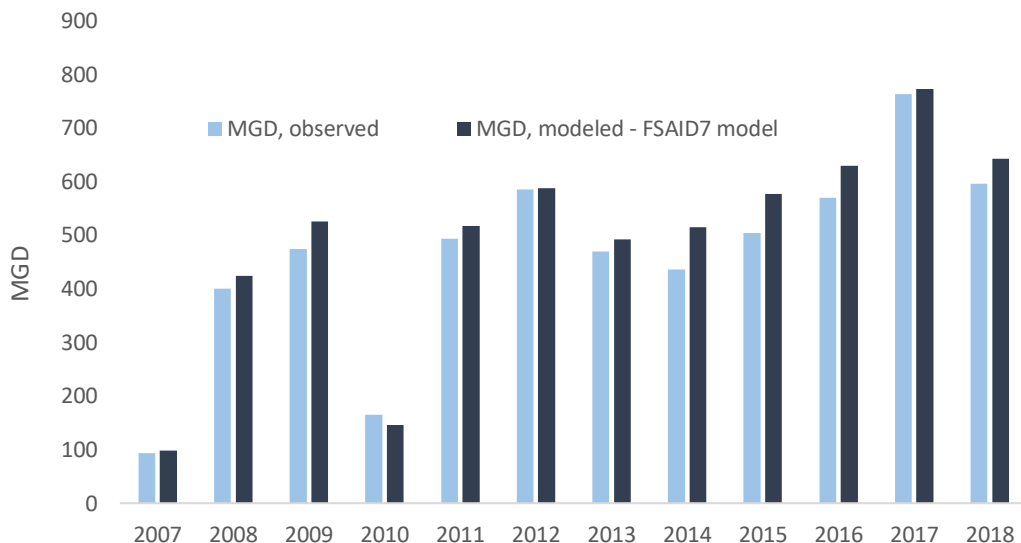
Figure E- 2. Modeled and Measured 2018 MGD



The following figure (**Figure E- 3**) summarizes the FSAID7 modeled values (using the current model form and average 2005-2018 rain and ET data) compared to annual sums for permits with non-zero

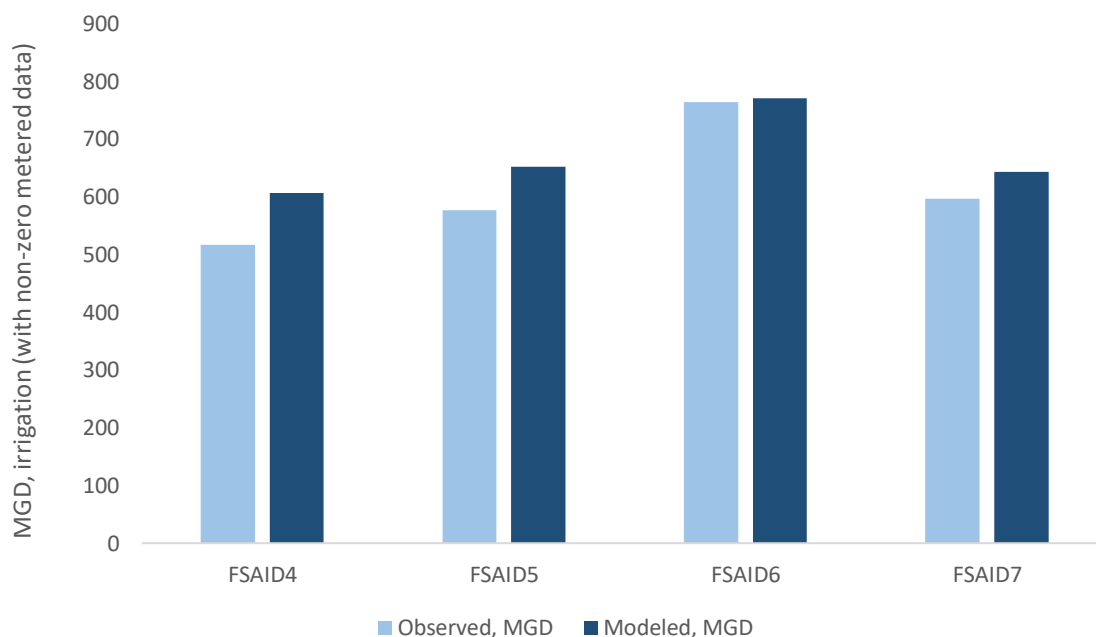
metered/reported water use data in specific years from 2007-2018. This illustrates that the current FSAID model of average irrigation demands can predict yearly totals for recent years with acceptable accuracy.

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



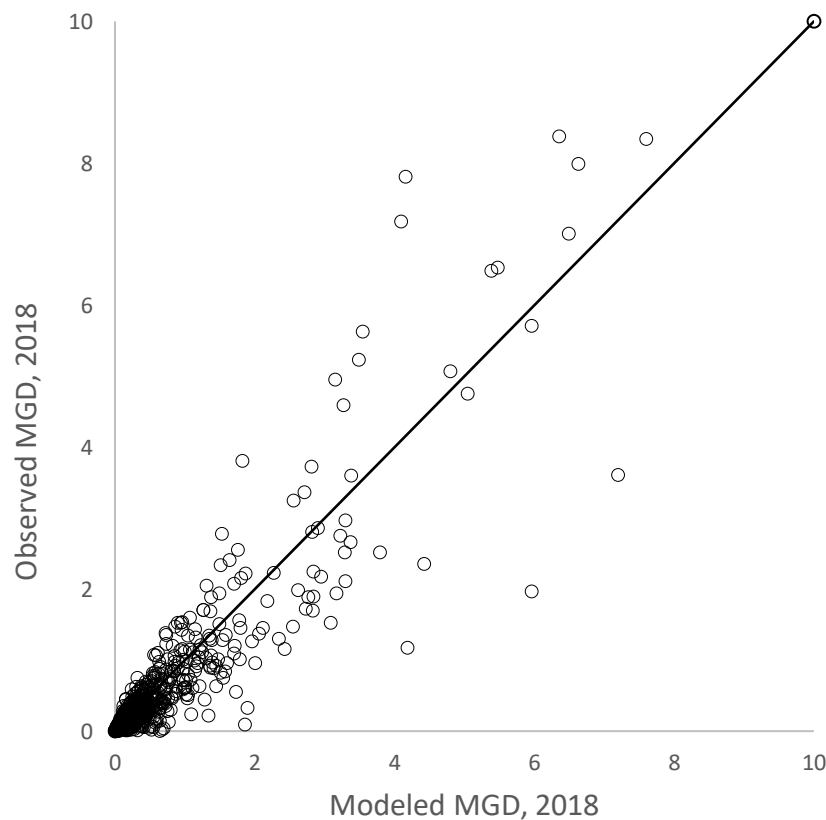
Another graphical assessment of FSAID model performance is the comparison of observed to modeled values for FSAID4 (2017 release), FSAID5 (2018), FSAID6 (2019) models, and FSAID7 (2020) models. This shows how the combination of improved model form (different equations) and increase sample size (more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

Figure E- 4. Modeled and Observed (metered) MGD, current and previous FSAID models



A plot of modeled and metered/reported data by permit for 2018 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 2018 MGD Permit Comparison



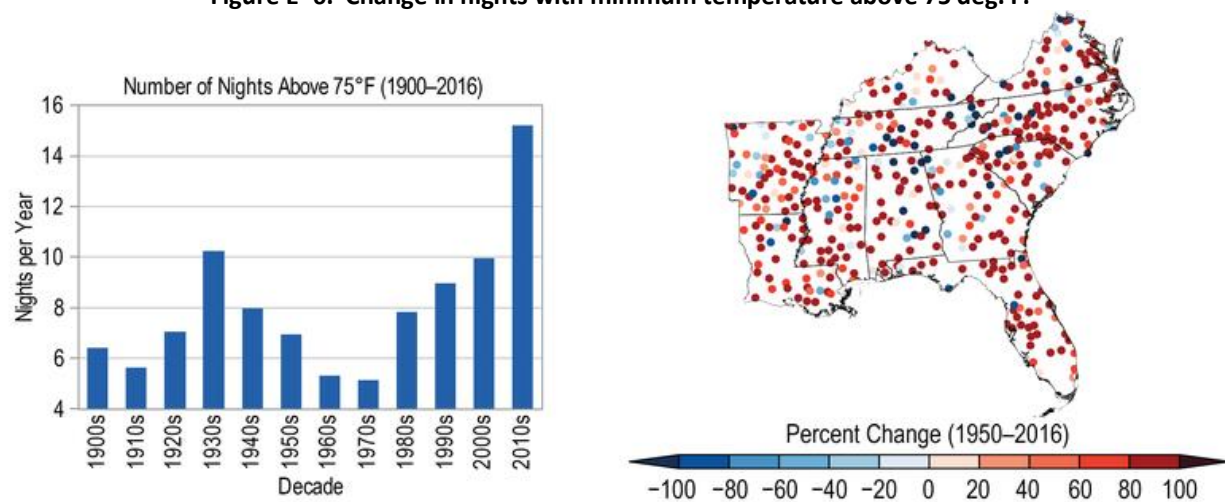
Climate Risks to Florida Agriculture

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. 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.

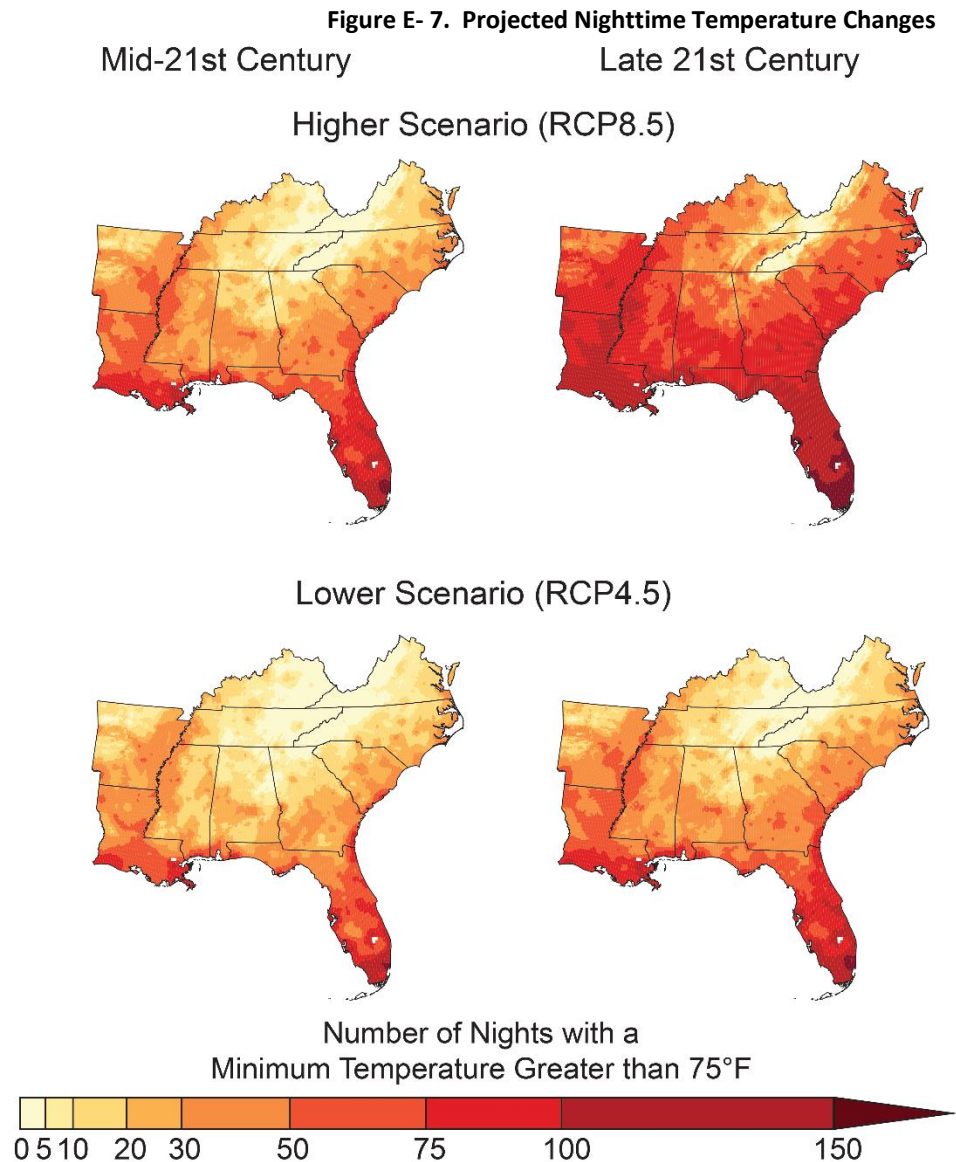
Temperatures

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-6** 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 nighttime temperatures will continue to rise (**Figure E-7**).

Figure E- 6. Change in nights with minimum temperature above 75 deg. F.



Source: USGCRP 2018

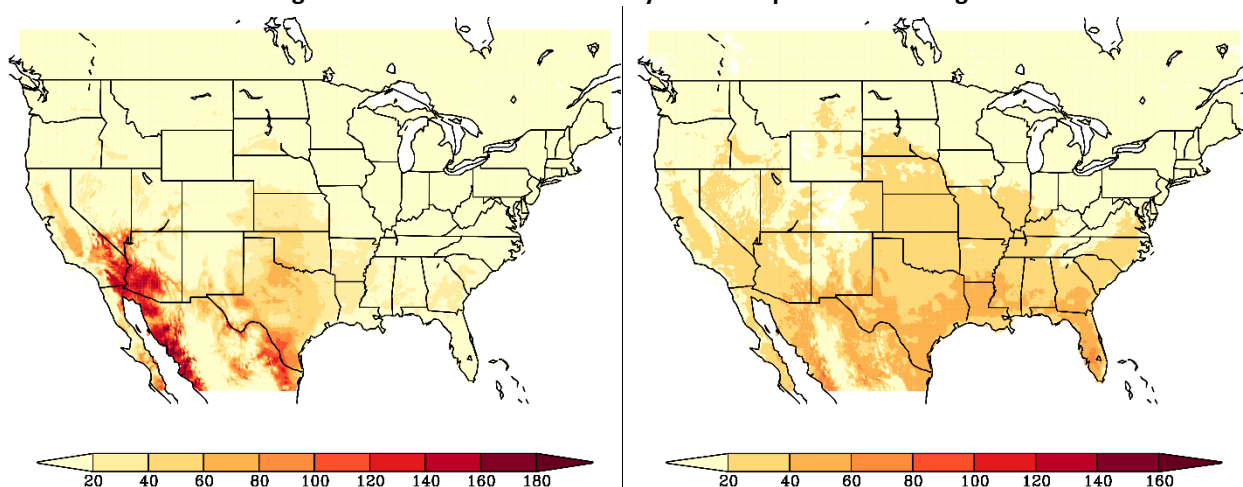


Source: USGCRP 2018 - This figure illustrates the projected number of warm nights (days with minimum temperatures above 75°F) per year in the Southeast for the 2036–2065 period (left) and the 2070–2099 period (right) under a higher scenario (RCP8.5; top row) and a lower scenario (RCP4.5; bottom row).

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-8** 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

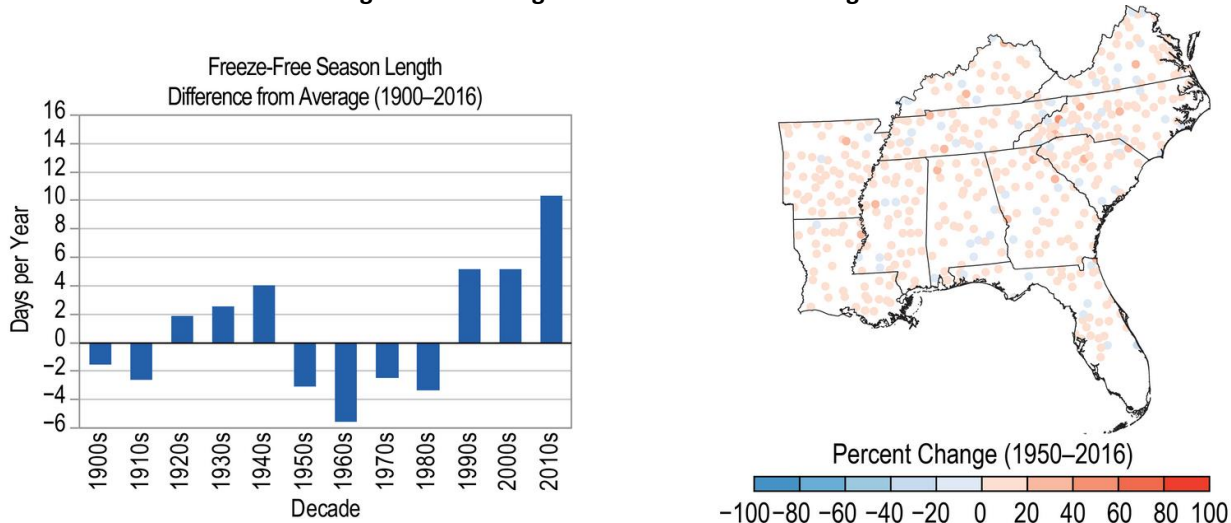
year with minimum temperature of 32 deg. F. or lower. It can be seen from **Figure E-9** that in recent decades the length of the frost-free season (Southeast U.S. average) has increased by 5 to 10 days per year compared to the 1900-2016 average. Nearly all stations in Florida have seen increases in 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- 8. Annual number of days with temperature > 95 deg F



Source: <https://scenarios.globalchange.gov/loca-viewer/> - Annual number of days with temperature > 95 deg F; 1976-2005 (left) compared to 2036-2065 (right); RCP 4.5.

Figure E- 9. Changes in freeze-free season length

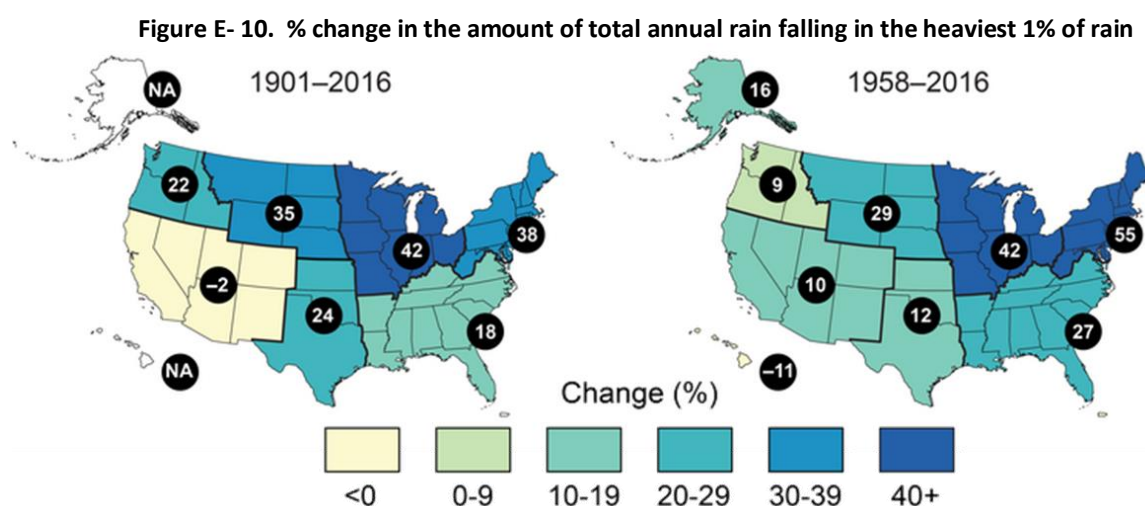


Source: USGCRP 2018 - Changes in freeze-free season length; note small increases in freeze-free season length for most Florida stations (1900-2016).

Intensification of hydrologic cycle

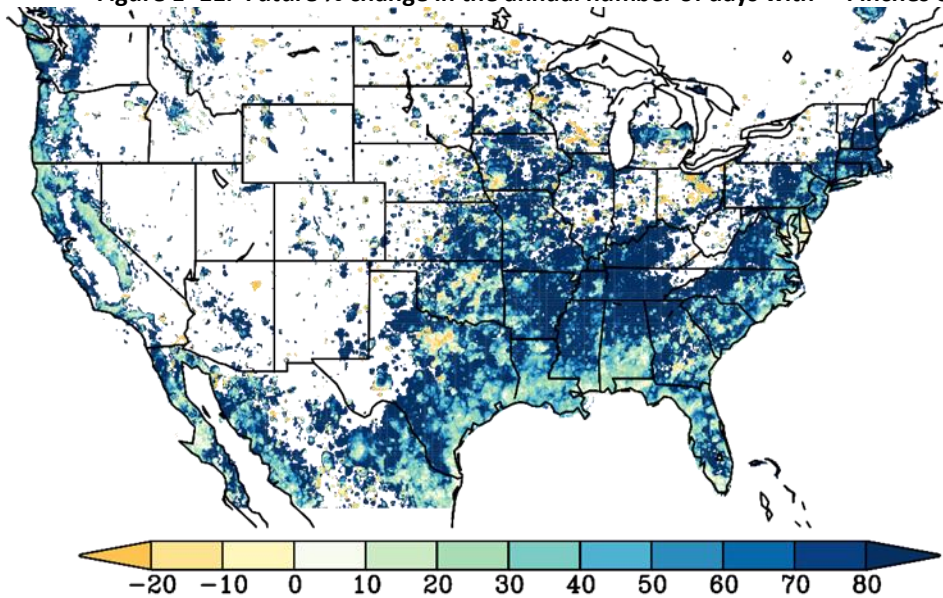
One consequence of warmer air temperatures is that the atmosphere holds more water. The dynamics of moisture convergence during storm formation can result in rainfall becoming more episodic; there

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-10**). 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-11**; 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.



Source: USGCRP - Historical % change in the amount of total annual rain falling in the heaviest 1% of rain events.

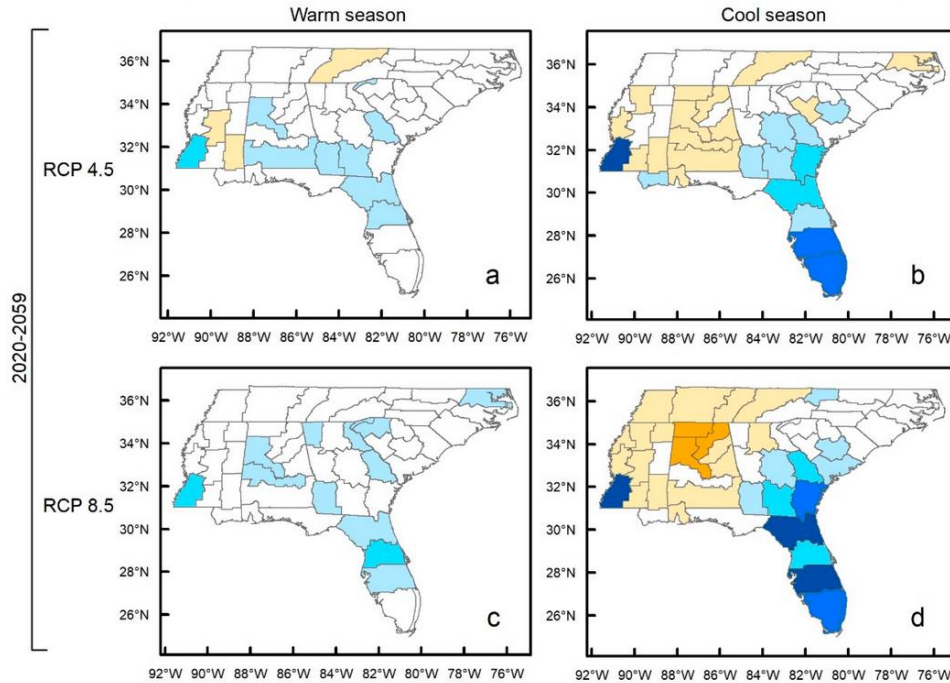
Figure E- 11. Future % change in the annual number of days with > 4 inches of rainfall



Source: <https://scenarios.globalchange.gov/loca-viewer/> - Future % change in the annual number of days with > 4 inches of rainfall; 2036-2065 compared to historical (1976-2005).

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-12**). This is potentially a good outcome in terms of increasing water supply recharge in dry parts of the year in the future. However, there is not consensus on the projections of total annual rainfall in Florida in future periods. For example, Misra et al. 2019 project rainfall reductions over peninsular Florida based on downscaled climate models; this is contrast to slight rainfall increases in the projections used by USGCRP 2018.

Figure E- 12. Change in number of consecutive dry days with a 20-year return period



Change in number of consecutive dry days



Source: Keellings and Engström 2019 - 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.

Findings

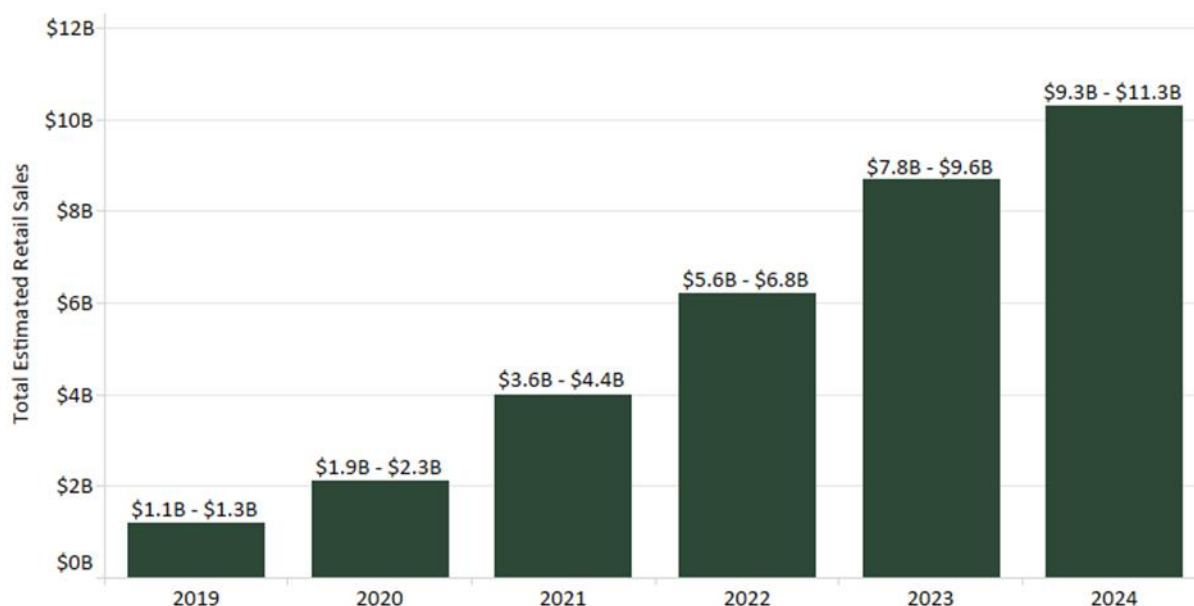
Within the current report, sensitivity analysis has been conducted with alternative rainfall and ET scenarios, but not alternative climate future conditions using the scenarios included in this section. In future FSAID update, alternative climate future conditions will be integrated into the sensitivity analysis. Doing so will allow District planners and policymakers better information regarding the upper and lower bounds of water demand, under different future climate conditions.

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. In the spring of 2020, FDACS began accepting applications for Hemp Cultivation Licenses through the Florida State Hemp Program. The licensing process will govern the varieties grown, field containment, transportation, and other aspects of production. It is anticipated that numerous producers will apply for licenses, but it will likely be several years before there is substantial hemp acreage.

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. Bio-energy projects and bio-ag research in Florida lost momentum for lack of investment in the supply chain and subsequent lack of interest by investors. Research published by Hemp Business Factbook has estimated that the national market for hemp-derived CBD oil will increase from about \$2B/year in 2020 to about \$10B by 2024 (See **Figure E-13**). Montana, Colorado, Oregon and Kentucky lead the states in acreage of production, but Kentucky tends to gain a lot of attention for their focus on downstream processing and supply chain sectors.

Figure E- 13. Estimated Annual Hemp Retail Sales



Source: 2019 Hemp Business Factbook

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Source: 2019 Hemp Business Factbook

Figure E- 14. Estimated Hemp Product Sales by Category

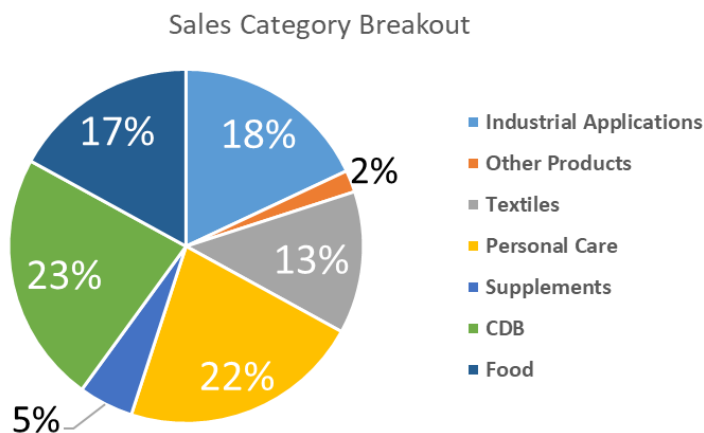


Figure E-14 shows recent data reflecting the breakdown of industrial hemp production, which has a broad variety of applications. Based on reported industry revenues and acreage, the average revenue per acre totaled about \$10,500 in 2017, with profits ranging from \$130 to \$730 per acre, which would compete favorably with many Florida crops. A high degree of red tape, large expanses of land and ready access to seed (which

is currently in shortage) and processing facilities will accompany successful operations. The state has about 261,000 acres of fallow citrus currently, and substantial agricultural acreage vulnerable to residential or commercial land use change. This suggests that if hemp production is demonstrated to be profitable in Florida, there will likely be sufficient available agricultural lands to support it.

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 just under 10 in/yr for field crops, which likely represent the most probably displaced crops, 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.

The FSAID projections have not yet introduced hemp as a 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.

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. Annual average citrus prices are published and forecast by USDA, but at the state level, only historical pricing is provided. Historically a higher share of Florida's citrus tends to be sold as processed than fresh and processed fruit prices have averaged about 66% of national prices for the past ten years. However, the most recent USDA data available shows that Florida's processed citrus earned \$9.79 per box, while fresh earned \$20.72 per box, a 47% ratio. The decline in ratio appears to be more related to the increase in fresh fruit prices than a drop in processed prices; see **Table E-7**.

¹ Purdue Hemp Project, Purdue University

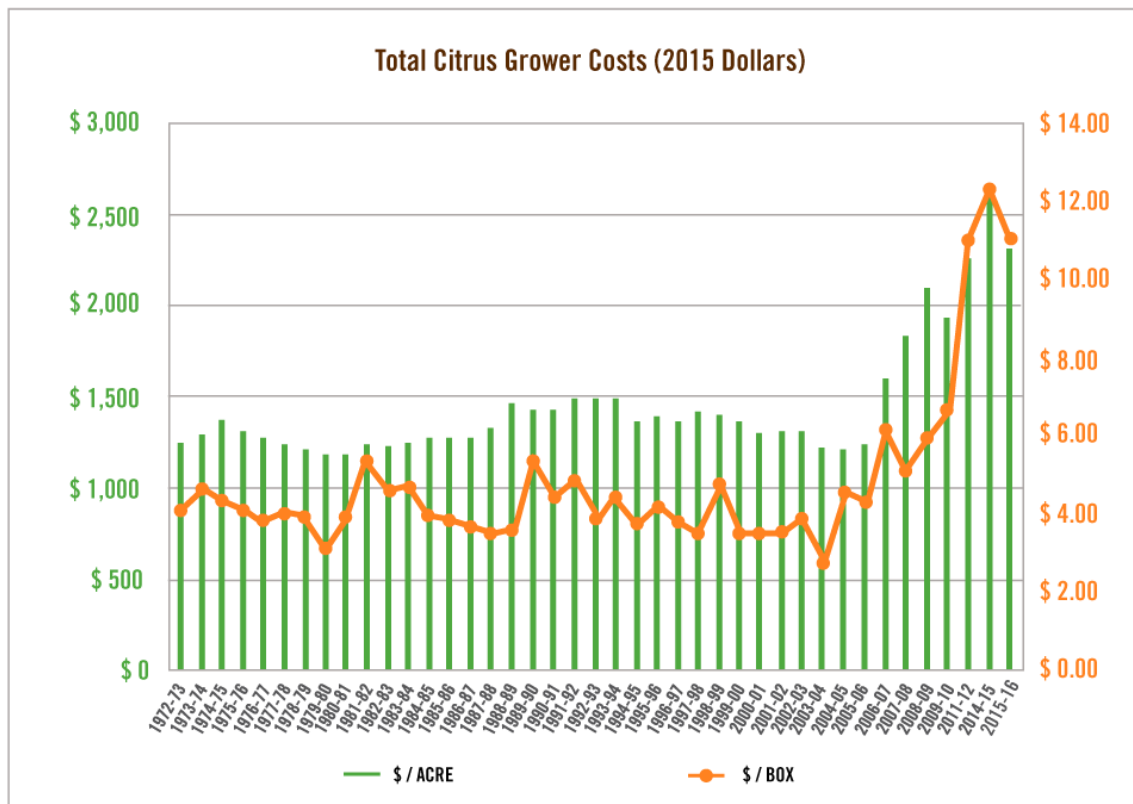
Table E- 7. Fresh vs. Processed Citrus by year

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	2,762	42,188	44,950	20.72	9.79	10.46	57,229	413,021	470,177

Source: USDA

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-15** provides a graphic timeline of costs per acre which have jumped by 66% since the onset of greening and have stabilized in recent years.

Figure E- 15. 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 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.
- More than 250,000 acres are identified as abandoned citrus in the current year 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 immediately 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 10,000 acres in the ILG from 2017 to 2018 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 replantings 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 2018 baseline acreage of 540,000. 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	NFWMD	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)

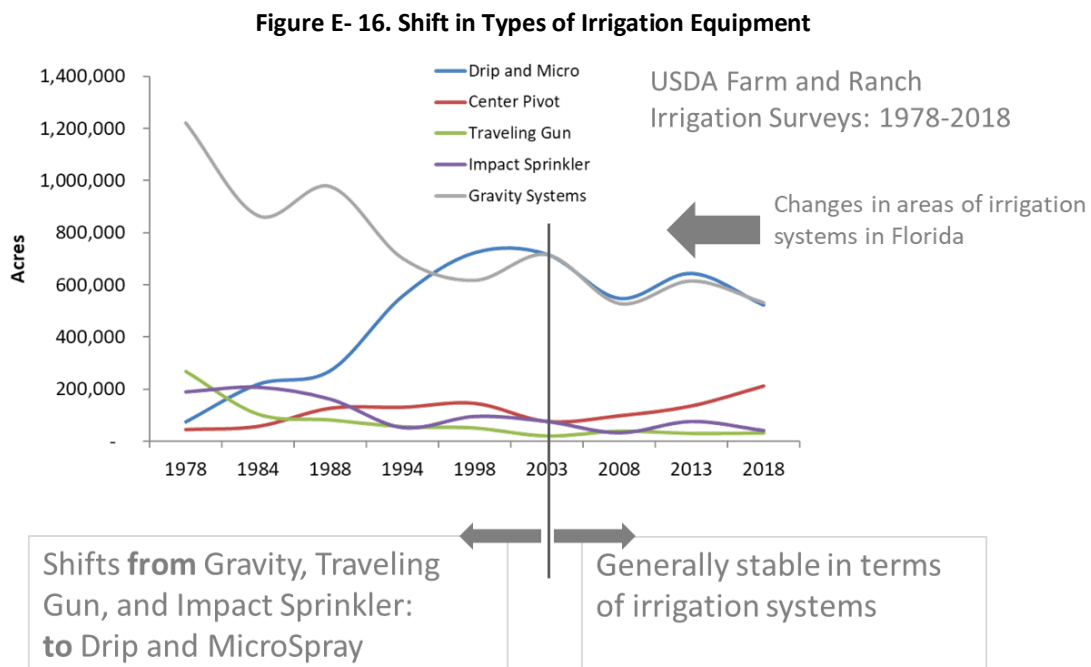
One option for estimating future improvements in irrigation efficiency requires estimating the field-level improvements in efficiency and estimating the number of fields or farms that are expected to achieve those efficiency improvements. The advantage of this approach is that it can be linked to on-farm 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.

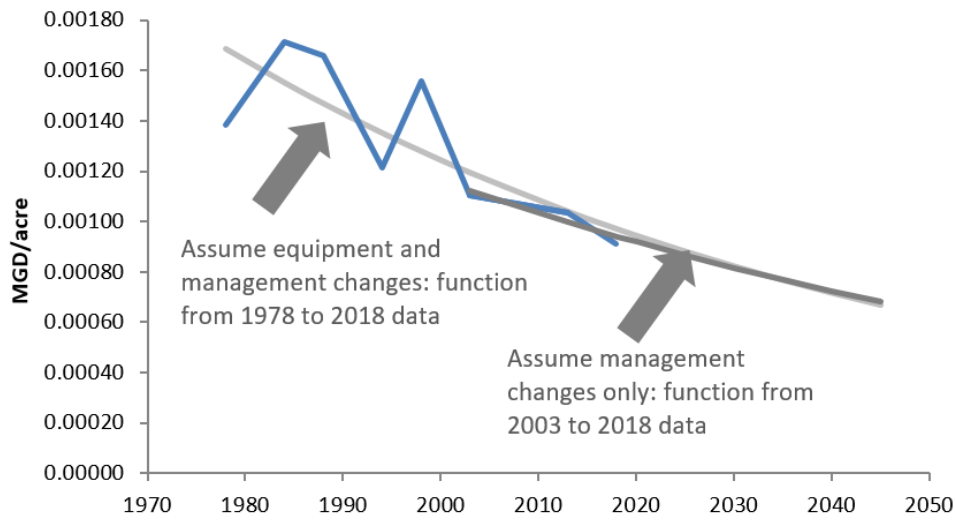
The time series of the FRIS-derived ratio of irrigation water volume applied to irrigated area was used to develop two exponential functions of efficiency improvements, where water per area is used as a proxy for efficiency. The function derived from the more recent FRIS data (2003-2018) is assumed to 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- 16** 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.



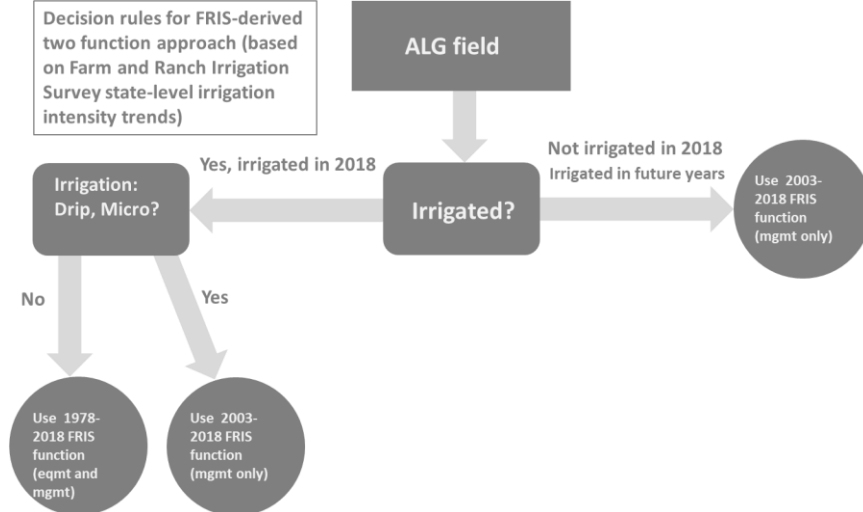
Both FRIS-derived efficiency improvement functions are used in the FSAID estimates (**Figure E- 17**). The approach of using two functions allows for less efficiency improvements to be projected in the coming decades for newly irrigated fields or for existing irrigated fields that have drip or micro-spray 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- 17. 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- 18**. 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- 17**). 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- 18. 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 2007-2018 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 sod field, for example, if the irrigation rate decreases below 7.7 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 (12 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, 2007-2018

Primary Crop	in/year
Citrus	11.9 (10.1 median)
Field Crops	7.8
Fruit (Non-citrus)	21.6
Greenhouse/Nursery	21.1
Hay	8.5
Potatoes	12.3
Sod	7.7
Sugarcane	16.5
Vegetables (Fresh Market)	16.1 (13.0 median)

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