# Appendix A

**Suwannee Springs gage record extension**

## USGS gage at Suwannee Springs Record Extension

```
GET DATA
 /TYPE=XLS
 /FILE='P:\1BI300312 USR MFL\12 Engineering\Hydrology\Background Hydrology chapter 2\HSW_USGS_combined_gage
data_SPSS_20210414.xls'
 /SHEET=name 'USGSandHydstra_combined'
 /CELLRANGE=full
 /READNAMES=on
 /ASSUMEDSTRWIDTH=32767.

>Warning.  Command name: GET DATA
>(2101) The column contained no recognized type; defaulting to "Numeric[8,2]"
>* Column 23
DATASET NAME DataSet1 WINDOW=FRONT.
CCF
 /VARIABLES=SuwanneeSprs WhiteSprs
 /NOLOG  /MXCROSS 7.
```

# CCF

[DataSet1]

**Warnings**

| |
|---|
| Some of the missing cases are imbedded within the series. |

**Model Description**

| | | |
|---|---|---|
| Model Name | | MOD_1 |
| Series Name | 1 | SuwanneeSprs |
| | 2 | WhiteSprs |
| Transformation | | None |
| Non-Seasonal Differencing | | 0 |
| Seasonal Differencing | | 0 |
| Length of Seasonal Period | | No periodicity |
| Range of Lags | From | -7 |
| | To | 7 |
| Display and Plot | | All lags |

Applying the model specifications from MOD_1

**Case Processing Summary**

| | | |
|---|---|---|
| Series Length | | 41935 |
| Number of Excluded Cases Due to | User-Missing Value | 0 |
| | System-Missing Value | 3.E4 |
| Number of Valid Cases | | 16025 |
| Number of Computable Zero-Order Correlations After Differencing | | 16025 |

a. Some of the missing values are imbedded within the series.

b. Listwise deletion.

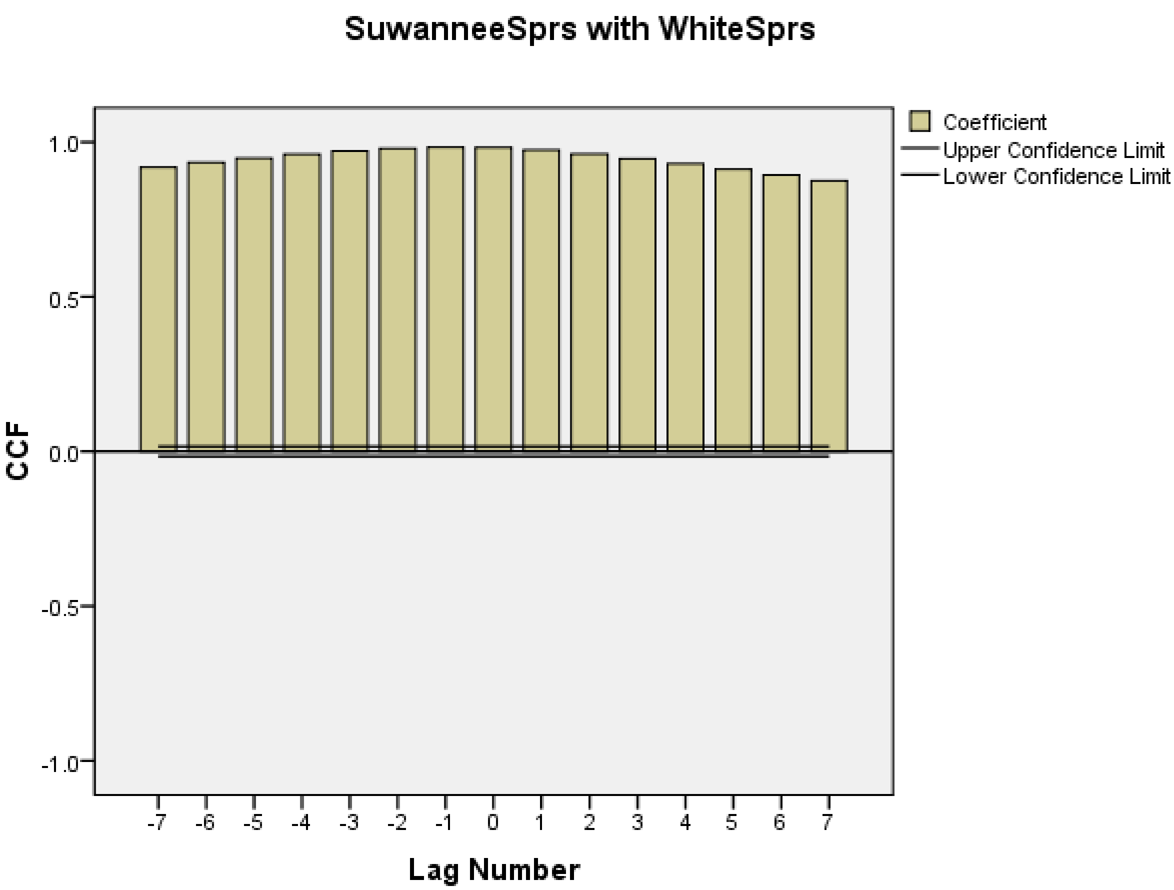
## SuwanneeSprs with WhiteSprs

**Cross Correlations**

Series Pair:SuwanneeSprs with WhiteSprs

| Lag | Cross Correlation | Std. Error[a] |
|---|---|---|
| -7 | .918 | .008 |
| -6 | .934 | .008 |
| -5 | .948 | .008 |
| -4 | .961 | .008 |
| -3 | .971 | .008 |
| -2 | .979 | .008 |
| -1 | .984 | .008 |
| 0 | .983 | .008 |
| 1 | .975 | .008 |
| 2 | .962 | .008 |
| 3 | .946 | .008 |
| 4 | .930 | .008 |
| 5 | .912 | .008 |
| 6 | .894 | .008 |
| 7 | .875 | .008 |

a. Based on the assumption that the series are not cross correlated and that one of the series is white noise.




```
COMPUTE WWs_lag=lag(WhiteSprs).
EXECUTE.
COMPUTE WSs_lag_2=WWs_lag ** 2.
EXECUTE.
COMPUTE WSs_lag_3=WSs_lag ** 3.
EXECUTE.
* Curve Estimation.
TSET NEWVAR=NONE.
CURVEFIT
  /VARIABLES=SuwanneeSprs WITH WSs_lag
  /CONSTANT
  /MODEL=LINEAR QUADRATIC CUBIC
  /PLOT FIT.


SAVE OUTFILE='P:\1BI300312 USR MFL\12 Engineering\Hydrology\Suwannee Springs and Jennings '+
    'Infilling\SuwanneeSprings_Cooks_all_Piecewise20210414.sav'
  /COMPRESSED.
REGRESSION
```

```
/MISSING LISTWISE
/STATISTICS COEFF OUTS R ANOVA COLLIN TOL CHANGE
/CRITERIA=PIN(.05) POUT(.10)
/NOORIGIN
/DEPENDENT SuwanneeSprs
/METHOD=STEPWISE WSs_lag WSs_lag_2 WSs_lag_3
/SCATTERPLOT=(SuwanneeSprs ,*ZPRED) (*ZRESID ,*ZPRED)
/RESIDUALS DURBIN HIST(ZRESID) NORM(ZRESID)
/SAVE PRED COOK RESID.
```

# Regression

[DataSet1] P:\1BI300312 USR MFL\12 Engineering\Hydrology\Suwannee Springs and Jennings Infilling\SuwanneeSprings_Cooks_all_Piecewise20210414.sav

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | WSs_lag | . | Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100). |
| 2 | WSs_lag_3 | . | Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100). |

a. Dependent Variable: SuwanneeSprs

**Model Summary[c]**

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | | | | | Durbin-Watson |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | R Square Change | F Change | df1 | df2 | Sig. F Change | |
| 1 | .984[a] | .968 | .968 | 437.340 | .968 | 485902.130 | 1 | 16024 | .000 | |
| 2 | .990[b] | .980 | .980 | 347.147 | .012 | 9409.075 | 1 | 16023 | .000 | .210 |

a. Predictors: (Constant), WSs_lag

b. Predictors: (Constant), WSs_lag, WSs_lag_3

c. Dependent Variable: SuwanneeSprs

**ANOVA[c]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 9.294E10 | 1 | 9.294E10 | 485902.130 | .000[a] |
| | Residual | 3.065E9 | 16024 | 191266.436 | | |
| | Total | 9.600E10 | 16025 | | | |
| 2 | Regression | 9.407E10 | 2 | 4.704E10 | 390298.003 | .000[b] |
| | Residual | 1.931E9 | 16023 | 120511.337 | | |
| | Total | 9.600E10 | 16025 | | | |

a. Predictors: (Constant), WSs_lag

b. Predictors: (Constant), WSs_lag, WSs_lag_3

c. Dependent Variable: SuwanneeSprs

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 230.227 | 4.063 | | 56.660 | .000 | | |
| | WSs_lag | .951 | .001 | .984 | 697.067 | .000 | 1.000 | 1.000 |
| 2 | (Constant) | 130.097 | 3.386 | | 38.416 | .000 | | |
| | WSs_lag | 1.046 | .001 | 1.082 | 717.848 | .000 | .553 | 1.809 |
| | WSs_lag_3 | -5.326E-10 | .000 | -.146 | -97.000 | .000 | .553 | 1.809 |

a. Dependent Variable: SuwanneeSprs

**Excluded Variables[c]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Tolerance | VIF | Minimum Tolerance |
| 1 | WSs_lag_2 | -.210[a] | -90.570 | .000 | -.582 | .245 | 4.078 | .245 |
| | WSs_lag_3 | -.146[a] | -97.000 | .000 | -.608 | .553 | 1.809 | .553 |
| 2 | WSs_lag_2 | .013[b] | 1.600 | .110 | .013 | .019 | 53.614 | .019 |

a. Predictors in the Model: (Constant), WSs_lag

b. Predictors in the Model: (Constant), WSs_lag, WSs_lag_3

c. Dependent Variable: SuwanneeSprs

**Collinearity Diagnostics[a]**

| Model | Dimension | Eigenvalue | Condition Index | Variance Proportions | | |
|---|---|---|---|---|---|---|
| | | | | (Constant) | WSs_lag | WSs_lag_3 |
| 1 | 1 | 1.526 | 1.000 | .24 | .24 | |
| | 2 | .474 | 1.795 | .76 | .76 | |
| 2 | 1 | 1.892 | 1.000 | .08 | .10 | .09 |
| | 2 | .869 | 1.475 | .45 | .00 | .25 |
| | 3 | .239 | 2.815 | .47 | .90 | .66 |

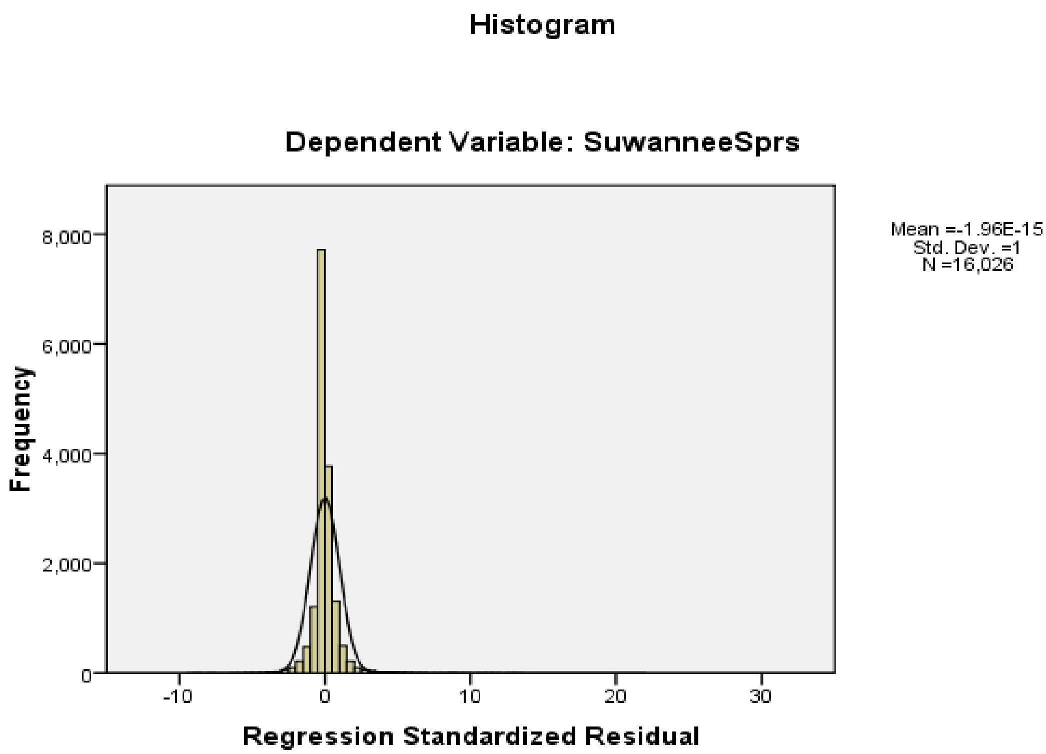
a. Dependent Variable: SuwanneeSprs

**Residuals Statistics[a]**

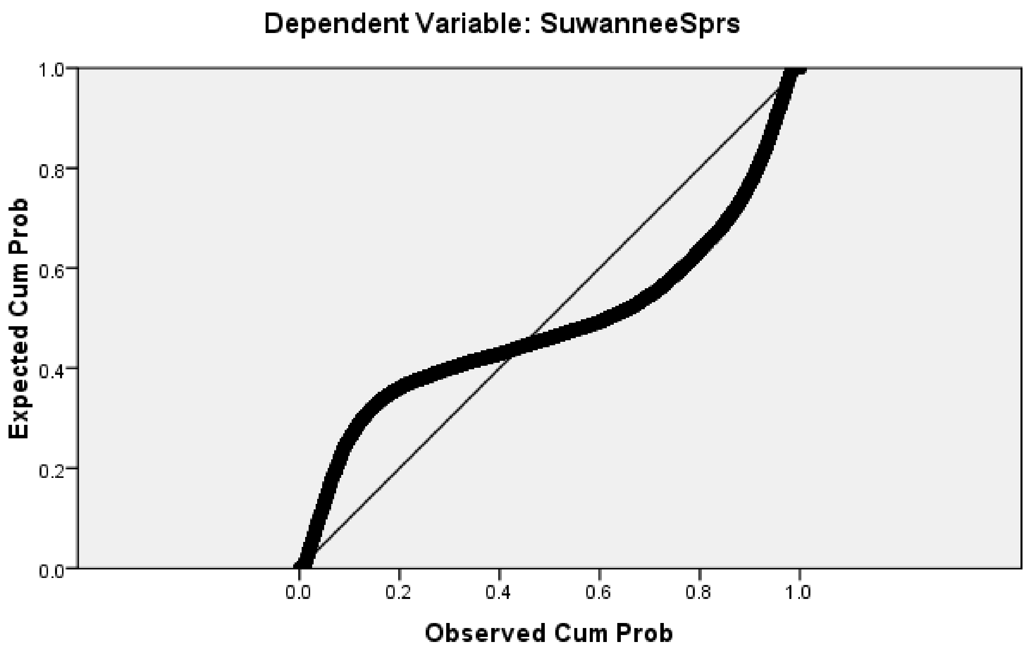
| | Minimum | Maximum | Mean | Std. Deviation | N |
|---|---|---|---|---|---|
| Predicted Value | 133.02 | 17963.95 | 1721.31 | 2422.859 | 16026 |
| Std. Predicted Value | -.656 | 6.704 | .000 | 1.000 | 16026 |
| Standard Error of Predicted Value | 2.765 | 107.021 | 3.722 | 2.950 | 16026 |
| Adjusted Predicted Value | 133.03 | 18007.69 | 1721.34 | 2423.000 | 16026 |
| Residual | -3152.077 | 7502.564 | .000 | 347.126 | 16026 |
| Std. Residual | -9.080 | 21.612 | .000 | 1.000 | 16026 |
| Stud. Residual | -9.094 | 21.613 | .000 | 1.000 | 16026 |
| Deleted Residual | -3161.843 | 7503.041 | -.022 | 347.518 | 16026 |
| Stud. Deleted Residual | -9.117 | 21.934 | .000 | 1.002 | 16026 |
| Mahal. Distance | .017 | 1522.023 | 2.000 | 25.810 | 16026 |
| Cook's Distance | .000 | .360 | .000 | .006 | 16026 |
| Centered Leverage Value | .000 | .095 | .000 | .002 | 16026 |

a. Dependent Variable: SuwanneeSprs

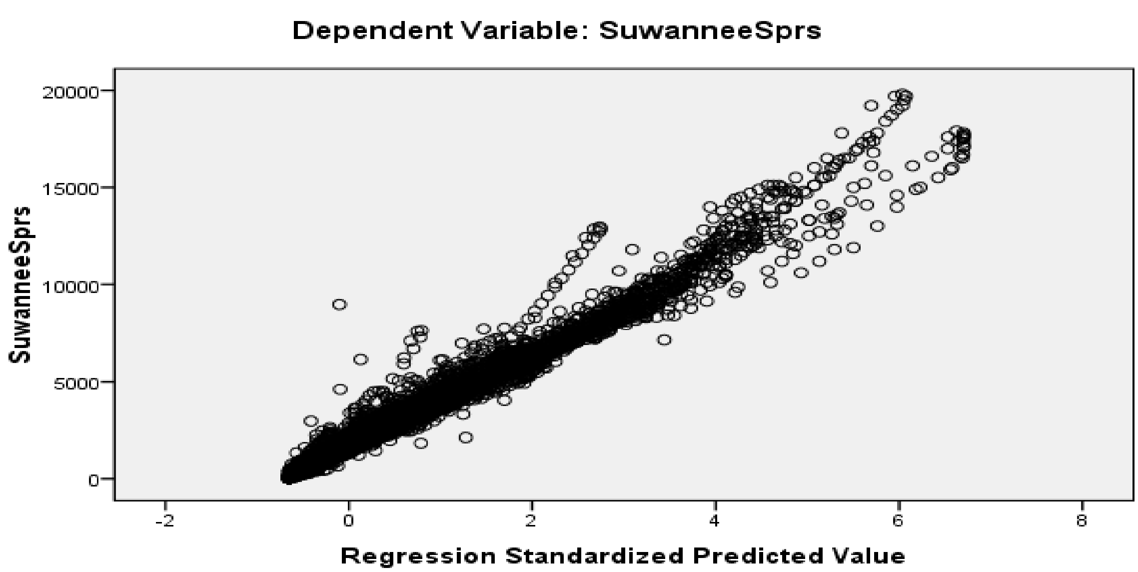
## Charts


Histogram
Dependent Variable: SuwanneeSprs
Mean =-1.96E-15
Std. Dev. =1
N =16,026
Frequency
8,000
6,000
4,000
2,000
0
-10
0
10
20
30
Regression Standardized Residual

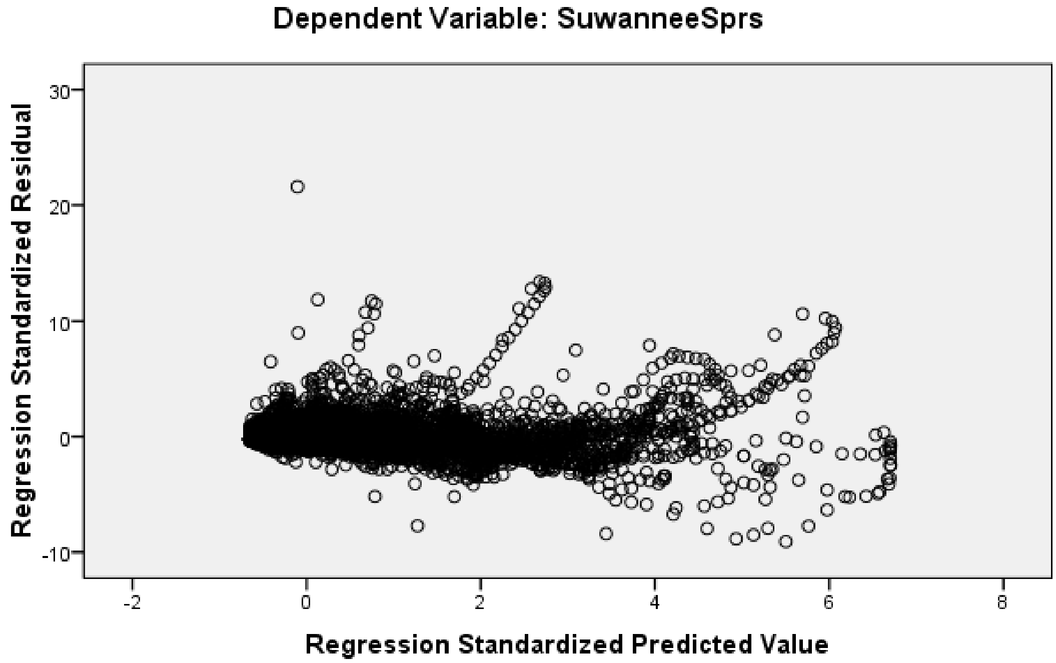
Normal P-P Plot of Regression Standardized Residual




Scatterplot



## Scatterplot




```
USE ALL.
COMPUTE filter_$=(COO_1<.00025).
VARIABLE LABEL filter_$ 'COO_1<.00025 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA COLLIN TOL CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT SuwanneeSprs
  /METHOD=STEPWISE WSs_lag WSs_lag_2 WSs_lag_3
  /SCATTERPLOT=(SuwanneeSprs ,*ZPRED) (*ZRESID ,*ZPRED)
  /RESIDUALS DURBIN HIST(ZRESID) NORM(ZRESID)
  /SAVE PRED COOK RESID.
```

# Regression

[DataSet1] P:\1BI300312 USR MFL\12 Engineering\Hydrology\Suwannee Springs and Jennings Infilling\SuwanneeSprings_Cooks_all_Piecewise20210414.sav

**Variables Entered/Removed[a]**

| Model | Variables Entered | Variables Removed | Method |
|---|---|---|---|
| 1 | WSs_lag | . | Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100). |
| 2 | WSs_lag_2 | . | Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100). |
| 3 | WSs_lag_3 | . | Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100). |

a. Dependent Variable: SuwanneeSprs

**Model Summary[d]**

| | | | | | Change Statistics | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | R Square Change | F Change | df1 | df2 | Sig. F Change | Durbin-Watson |
| 1 | .993[a] | .986 | .986 | 198.305 | .986 | 1096630.836 | 1 | 15206 | .000 | |
| 2 | .994[b] | .988 | .988 | 189.247 | .001 | 1491.451 | 1 | 15205 | .000 | |
| 3 | .994[c] | .988 | .988 | 188.677 | .000 | 93.072 | 1 | 15204 | .000 | .219 |

a. Predictors: (Constant), WSs_lag

b. Predictors: (Constant), WSs_lag, WSs_lag_2

c. Predictors: (Constant), WSs_lag, WSs_lag_2, WSs_lag_3

d. Dependent Variable: SuwanneeSprs

**ANOVA[d]**

| Model | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 1 | Regression | 4.312E10 | 1 | 4.312E10 | 1096630.836 | .000[a] |
| | Residual | 5.980E8 | 15206 | 39324.883 | | |
| | Total | 4.372E10 | 15207 | | | |
| 2 | Regression | 4.318E10 | 2 | 2.159E10 | 602805.539 | .000[b] |
| | Residual | 5.446E8 | 15205 | 35814.448 | | |
| | Total | 4.372E10 | 15207 | | | |
| 3 | Regression | 4.318E10 | 3 | 1.439E10 | 404334.853 | .000[c] |
| | Residual | 5.412E8 | 15204 | 35598.883 | | |
| | Total | 4.372E10 | 15207 | | | |

a. Predictors: (Constant), WSs_lag

b. Predictors: (Constant), WSs_lag, WSs_lag_2

c. Predictors: (Constant), WSs_lag, WSs_lag_2, WSs_lag_3

d. Dependent Variable: SuwanneeSprs

**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Tolerance | VIF |
| 1 | (Constant) | 151.818 | 1.973 | | 76.938 | .000 | | |
| | WSs_lag | 1.012 | .001 | .993 | 1047.201 | .000 | 1.000 | 1.000 |
| 2 | (Constant) | 111.163 | 2.157 | | 51.527 | .000 | | |
| | WSs_lag | 1.081 | .002 | 1.061 | 537.437 | .000 | .210 | 4.757 |
| | WSs_lag_2 | -9.841E-6 | .000 | -.076 | -38.619 | .000 | .210 | 4.757 |
| 3 | (Constant) | 101.171 | 2.387 | | 42.380 | .000 | | |
| | WSs_lag | 1.108 | .003 | 1.087 | 322.265 | .000 | .072 | 13.982 |
| | WSs_lag_2 | -1.845E-5 | .000 | -.143 | -19.887 | .000 | .016 | 63.427 |
| | WSs_lag_3 | 5.749E-10 | .000 | .046 | 9.647 | .000 | .036 | 27.545 |

a. Dependent Variable: SuwanneeSprs

**Excluded Variables[c]**

| Model | | Beta In | t | Sig. | Partial Correlation | Collinearity Statistics | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Tolerance | VIF | Minimum Tolerance |
| 1 | WSs_lag_2 | -.076[a] | -38.619 | .000 | -.299 | .210 | 4.757 | .210 |
| | WSs_lag_3 | -.045[a] | -34.173 | .000 | -.267 | .484 | 2.066 | .484 |
| 2 | WSs_lag_3 | .046[b] | 9.647 | .000 | .078 | .036 | 27.545 | .016 |

a. Predictors in the Model: (Constant), WSs_lag

b. Predictors in the Model: (Constant), WSs_lag, WSs_lag_2

c. Dependent Variable: SuwanneeSprs

**Collinearity Diagnostics[a]**

| Model | Dimension | Eigenvalue | Condition Index | Variance Proportions | | | |
|---|---|---|---|---|---|---|---|
| | | | | (Constant) | WSs_lag | WSs_lag_2 | WSs_lag_3 |
| 1 | 1 | 1.580 | 1.000 | .21 | .21 | | |
| | 2 | .420 | 1.938 | .79 | .79 | | |
| 2 | 1 | 2.196 | 1.000 | .05 | .03 | .03 | |
| | 2 | .724 | 1.741 | .50 | .00 | .07 | |
| | 3 | .080 | 5.248 | .45 | .97 | .90 | |
| 3 | 1 | 2.862 | 1.000 | .01 | .01 | .00 | .00 |
| | 2 | .938 | 1.747 | .32 | .00 | .00 | .01 |
| | 3 | .191 | 3.870 | .35 | .13 | .00 | .06 |
| | 4 | .009 | 18.150 | .31 | .87 | 1.00 | .93 |

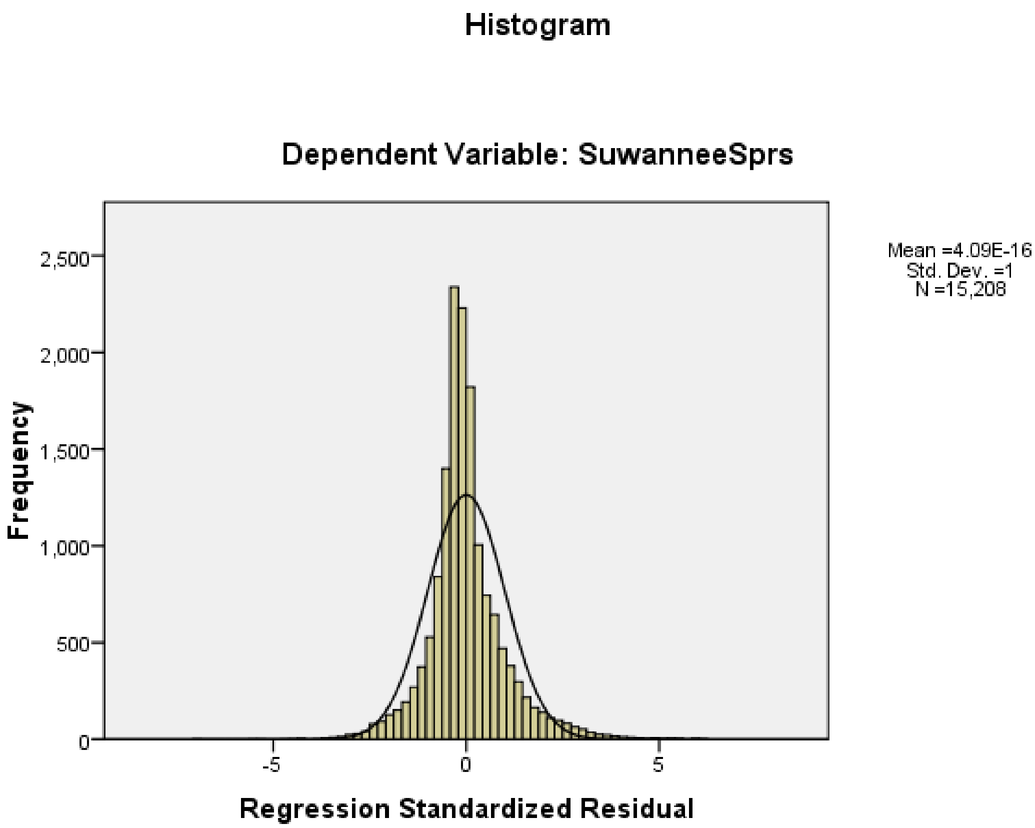
a. Dependent Variable: SuwanneeSprs

**Residuals Statistics[a]**

| | Minimum | Maximum | Mean | Std. Deviation | N |
|---|---|---|---|---|---|
| Predicted Value | 104.27 | 16525.22 | 1349.41 | 1685.108 | 15208 |
| Std. Predicted Value | -.739 | 9.006 | .000 | 1.000 | 15208 |
| Standard Error of Predicted Value | 1.656 | 96.173 | 2.443 | 1.842 | 15208 |
| Adjusted Predicted Value | 104.28 | 16990.40 | 1349.46 | 1685.557 | 15208 |
| Residual | -1325.217 | 1150.662 | .000 | 188.658 | 15208 |
| Std. Residual | -7.024 | 6.099 | .000 | 1.000 | 15208 |
| Stud. Residual | -8.164 | 6.099 | .000 | 1.001 | 15208 |
| Deleted Residual | -1790.398 | 1150.773 | -.049 | 189.097 | 15208 |
| Stud. Deleted Residual | -8.182 | 6.106 | .000 | 1.001 | 15208 |
| Mahal. Distance | .172 | 3950.079 | 3.000 | 43.573 | 15208 |
| Cook's Distance | .000 | 5.849 | .001 | .051 | 15208 |
| Centered Leverage Value | .000 | .260 | .000 | .003 | 15208 |

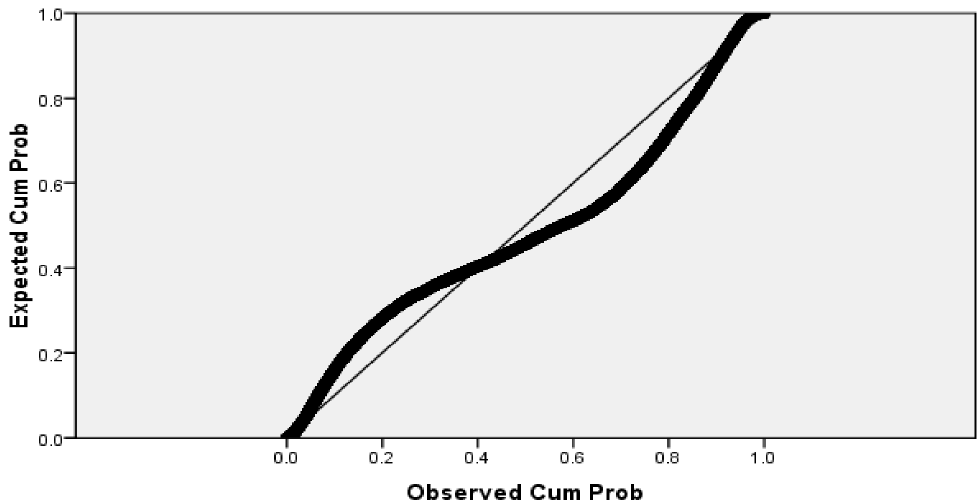
a. Dependent Variable: SuwanneeSprs

## Charts


Histogram
Dependent Variable: SuwanneeSprs
Mean =4.09E-16
Std. Dev. =1
N =15,208
Frequency
2,500
2,000
1,500
1,000
500
0
-5
0
5
Regression Standardized Residual

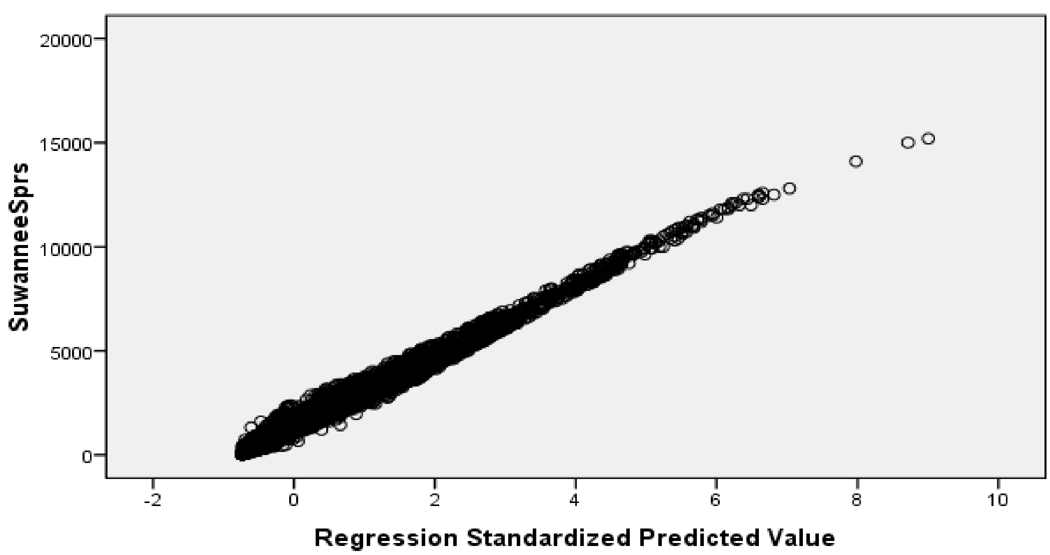
Normal P-P Plot of Regression Standardized Residual

Dependent Variable: SuwanneeSprs

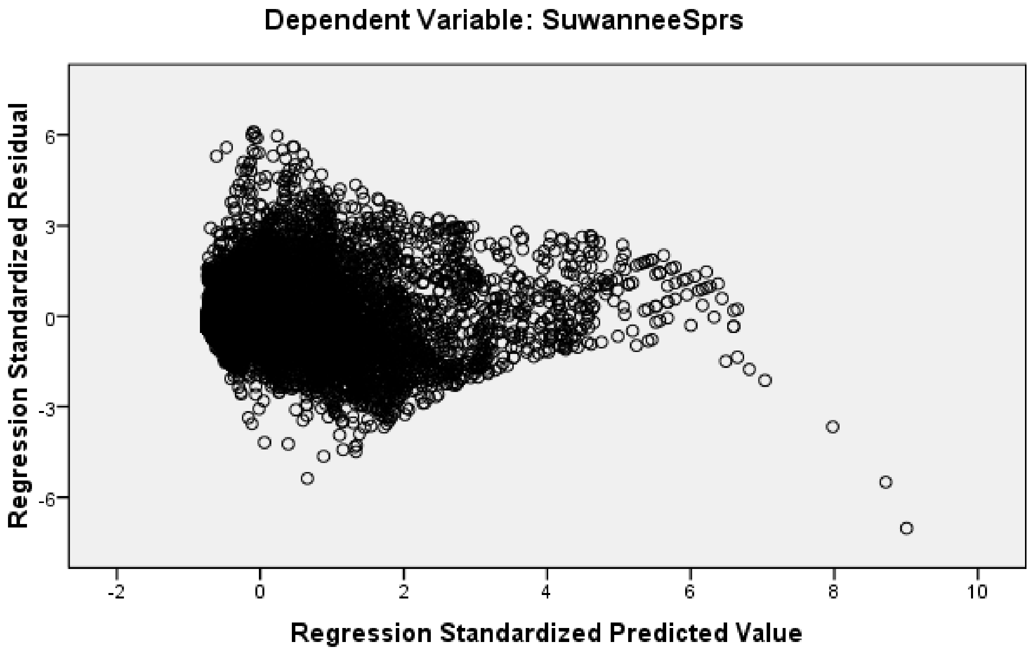



Scatterplot

Dependent Variable: SuwanneeSprs



**Scatterplot**




```
SAVE OUTFILE='P:\1BI300312 USR MFL\12 Engineering\Hydrology\Suwannee Springs and Jennings '+
   'Infilling\SuwanneeSprings_Cooks_all_Piecewise20210414.sav'
  /COMPRESSED.
* NonLinear Regression.
MODEL PROGRAM  b0=25 b1=4 b2=-3 knot2=50 b3=0 knot3=500 b4=-1 knot4=12000.
COMPUTE  PRED_=b0 +b1*WSs_lag + b2*(WSs_lag-knot2)*(WSs_lag>knot2)+ b3*(WSs_lag-knot3)*(WSs_lag>knot3)+
b4*(WSs_lag-knot4)*(WSs_lag>
  knot4).
NLR SuwanneeSprs
  /OUTFILE='C:\Users\kww\AppData\Local\Temp\spss362480\SPSSFNLR.TMP'
  /PRED PRED_
  /SAVE PRED RESID
  /CRITERIA SSCONVERGENCE 1E-8 PCON 1E-8.
```

## Nonlinear Regression Analysis

[DataSet1] P:\1BI300312 USR MFL\12 Engineering\Hydrology\Suwannee Springs and Jennings Infilling\SuwanneeSprings_Cooks_all_Piecewise20210414.sav

**Iteration History[b]**

| Iteration Number[a] | Residual Sum of Squares | Parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | b0 | b1 | b2 | knot2 | b3 | knot3 | b4 | knot4 |
| 1.0 | 6.001E8 | 25.000 | 4.000 | -3.000 | 50.000 | .000 | 500.000 | -1.000 | 12000.000 |
| 1.1 | 5.534E8 | 48.844 | 2.190 | -.863 | 37.266 | -.330 | 500.000 | -.341 | 11698.873 |
| 2.0 | 5.534E8 | 48.844 | 2.190 | -.863 | 37.266 | -.330 | 500.000 | -.341 | 11698.873 |
| 2.1 | 5.593E8 | 44.732 | 2.404 | -1.288 | 33.535 | -.123 | 759.973 | -.328 | 11124.592 |
| 2.2 | 5.593E8 | 44.732 | 2.404 | -1.288 | 33.535 | -.123 | 759.973 | -.328 | 11124.592 |
| 2.3 | 5.593E8 | 44.732 | 2.404 | -1.288 | 33.535 | -.123 | 759.973 | -.328 | 11124.592 |
| 2.4 | 5.585E8 | 46.527 | 2.321 | -1.205 | 35.032 | -.123 | 759.909 | -.328 | 11124.596 |
| 2.5 | 5.430E8 | 50.501 | 2.113 | -.942 | 27.826 | -.178 | 712.762 | -.329 | 11131.438 |
| 3.0 | 5.430E8 | 50.501 | 2.113 | -.942 | 27.826 | -.178 | 712.762 | -.329 | 11131.438 |
| 3.1 | 5.301E8 | 48.332 | 2.200 | -1.091 | 40.280 | -.124 | 1226.482 | -.311 | 11176.994 |
| 4.0 | 5.301E8 | 48.332 | 2.200 | -1.091 | 40.280 | -.124 | 1226.482 | -.311 | 11176.994 |
| 4.1 | 5.188E8 | 46.928 | 2.336 | -1.197 | 29.629 | -.165 | 1507.242 | -.300 | 11411.939 |
| 5.0 | 5.188E8 | 46.928 | 2.336 | -1.197 | 29.629 | -.165 | 1507.242 | -.300 | 11411.939 |
| 5.1 | 5.185E8 | 44.460 | 2.418 | -1.284 | 32.279 | -.162 | 1543.461 | -.304 | 11542.061 |
| 6.0 | 5.185E8 | 44.460 | 2.418 | -1.284 | 32.279 | -.162 | 1543.461 | -.304 | 11542.061 |
| 6.1 | 5.185E8 | 45.338 | 2.363 | -1.229 | 32.703 | -.162 | 1537.759 | -.304 | 11543.687 |
| 7.0 | 5.185E8 | 45.338 | 2.363 | -1.229 | 32.703 | -.162 | 1537.759 | -.304 | 11543.687 |
| 7.1 | 5.185E8 | 45.545 | 2.350 | -1.217 | 32.918 | -.162 | 1538.319 | -.304 | 11543.887 |
| 8.0 | 5.185E8 | 45.545 | 2.350 | -1.217 | 32.918 | -.162 | 1538.319 | -.304 | 11543.887 |
| 8.1 | 5.185E8 | 45.507 | 2.353 | -1.219 | 32.884 | -.162 | 1538.306 | -.304 | 11543.887 |
| 9.0 | 5.185E8 | 45.507 | 2.353 | -1.219 | 32.884 | -.162 | 1538.306 | -.304 | 11543.887 |
| 9.1 | 5.185E8 | 45.447 | 2.358 | -1.224 | 32.795 | -.162 | 1538.258 | -.304 | 11543.887 |
| 10.0 | 5.185E8 | 45.447 | 2.358 | -1.224 | 32.795 | -.162 | 1538.258 | -.304 | 11543.887 |
| 10.1 | 5.185E8 | 45.546 | 2.350 | -1.216 | 32.920 | -.162 | 1538.319 | -.304 | 11543.887 |
| 10.2 | 5.185E8 | 45.462 | 2.354 | -1.221 | 32.876 | -.162 | 1538.320 | -.304 | 11543.887 |
| 10.3 | 5.185E8 | 45.421 | 2.357 | -1.223 | 32.854 | -.162 | 1538.320 | -.304 | 11543.887 |

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 26 model evaluations and 10 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

**Parameter Estimates**

| Parameter | Estimate | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower Bound | Upper Bound |
| b0 | 45.447 | 16.187 | 13.718 | 77.176 |
| b1 | 2.358 | .764 | .860 | 3.856 |
| b2 | -1.224 | .764 | -2.722 | .274 |
| knot2 | 32.795 | 9.480 | 14.213 | 51.377 |
| b3 | -.162 | .005 | -.172 | -.153 |
| knot3 | 1538.258 | 40.889 | 1458.111 | 1618.404 |
| b4 | -.304 | .026 | -.356 | -.252 |
| knot4 | 11543.887 | 174.902 | 11201.059 | 11886.715 |

**Correlations of Parameter Estimates**

| | b0 | b1 | b2 | knot2 | b3 | knot3 | b4 | knot4 |
|---|---|---|---|---|---|---|---|---|
| b0 | 1.000 | -.941 | .941 | .637 | .000 | .000 | .000 | .000 |
| b1 | -.941 | 1.000 | -1.000 | -.848 | .000 | .000 | .000 | .000 |
| b2 | .941 | -1.000 | 1.000 | .847 | -.005 | -.004 | .000 | .000 |
| knot2 | .637 | -.848 | .847 | 1.000 | .168 | .083 | .000 | .000 |
| b3 | .000 | .000 | -.005 | .168 | 1.000 | .492 | -.022 | -.088 |
| knot3 | .000 | .000 | -.004 | .083 | .492 | 1.000 | .030 | .093 |
| b4 | .000 | .000 | .000 | .000 | -.022 | .030 | 1.000 | -.639 |
| knot4 | .000 | .000 | .000 | .000 | -.088 | .093 | -.639 | 1.000 |

**ANOVA[a]**

| Source | Sum of Squares | df | Mean Squares |
|---|---|---|---|
| Regression | 7.090E10 | 8 | 8.862E9 |
| Residual | 5.185E8 | 15200 | 34111.680 |
| Uncorrected Total | 7.142E10 | 15208 | |
| Corrected Total | 4.372E10 | 15207 | |

Dependent variable: SuwanneeSprs

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .988.

```
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## Graph

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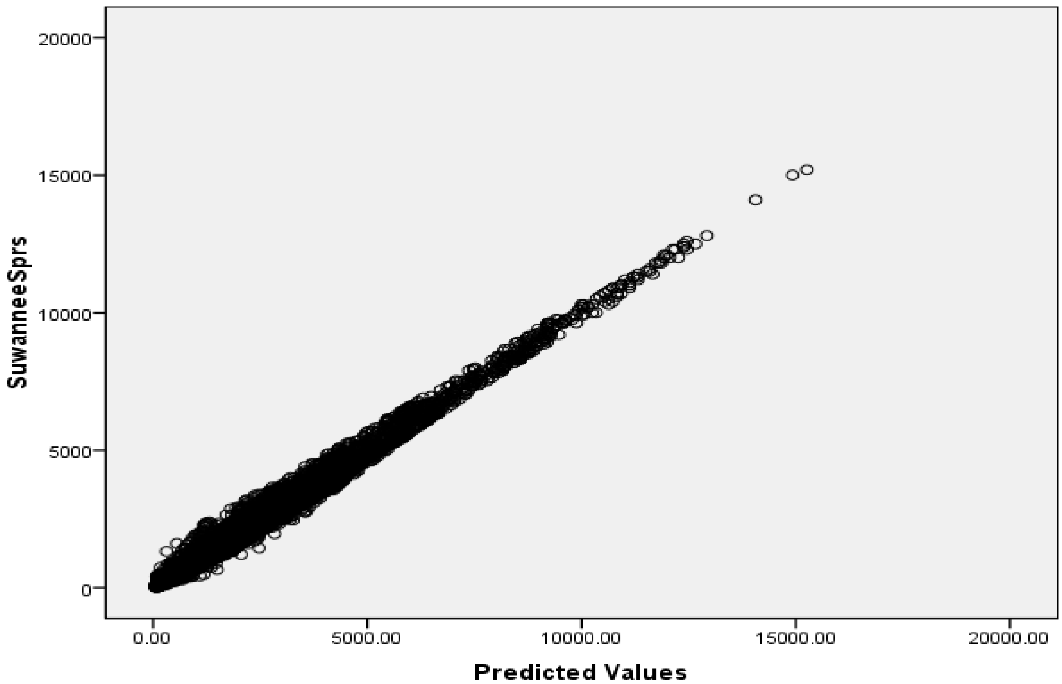


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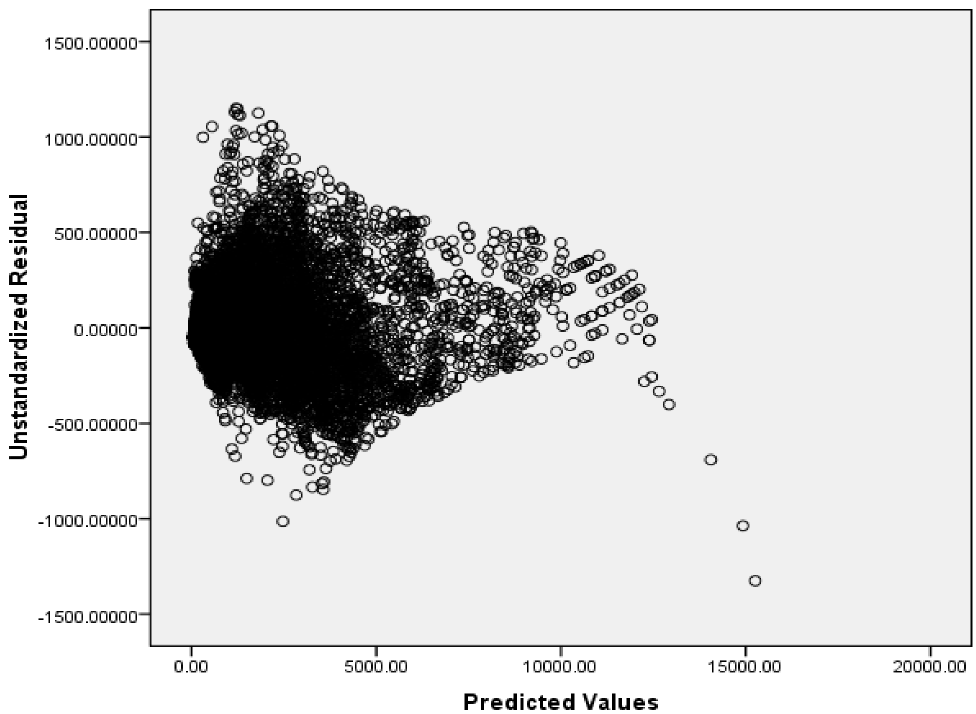


## PPlot

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**Model Description**

| | | |
|---|---|---|
| Model Name | | MOD_3 |
| Series or Sequence | 1 | Residuals |
| Transformation | | None |
| Non-Seasonal Differencing | | 0 |
| Seasonal Differencing | | 0 |
| Length of Seasonal Period | | No periodicity |
| Standardization | | Not applied |
| Distribution | Type | Normal |
| | Location | estimated |
| | Scale | estimated |
| Fractional Rank Estimation Method | | Blom's |
| Rank Assigned to Ties | | Mean rank of tied values |

Applying the model specifications from MOD_3

**Case Processing Summary**

| | | Residuals |
|---|---|---|
| Series or Sequence Length | | 15208 |
| Number of Missing Values in the Plot | User-Missing | 0 |
| | System-Missing | 0 |

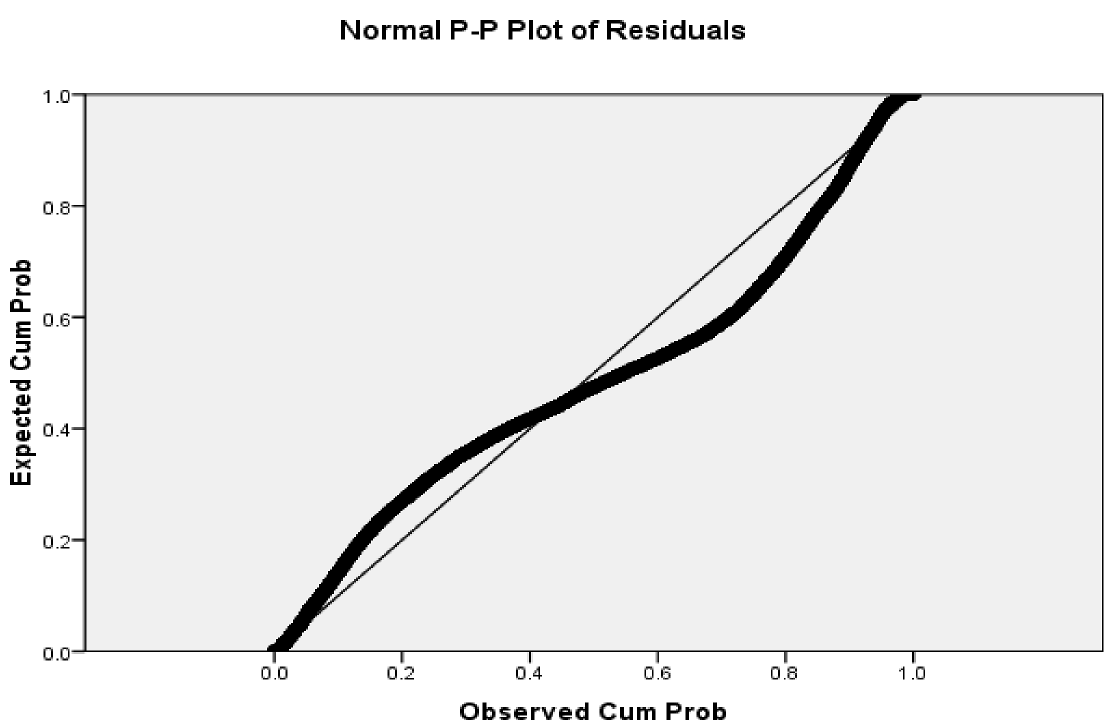
The cases are unweighted.

**Estimated Distribution Parameters**

| | | Residuals |
|---|---|---|
| Normal Distribution | Location | .0004 |
| | Scale | 184.65096 |

The cases are unweighted.

## Residuals




```
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## Graph

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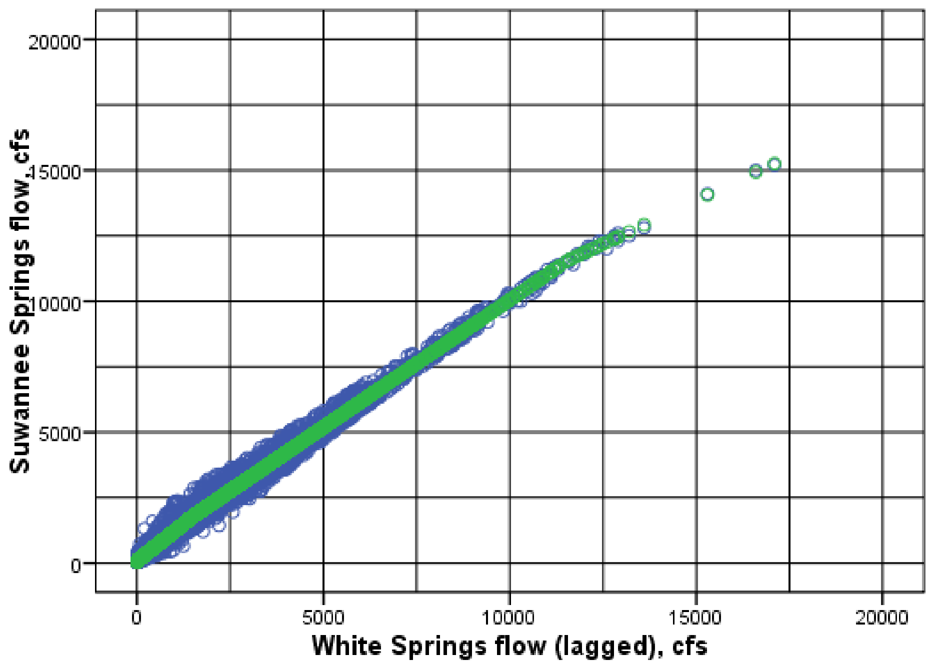


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## Graph

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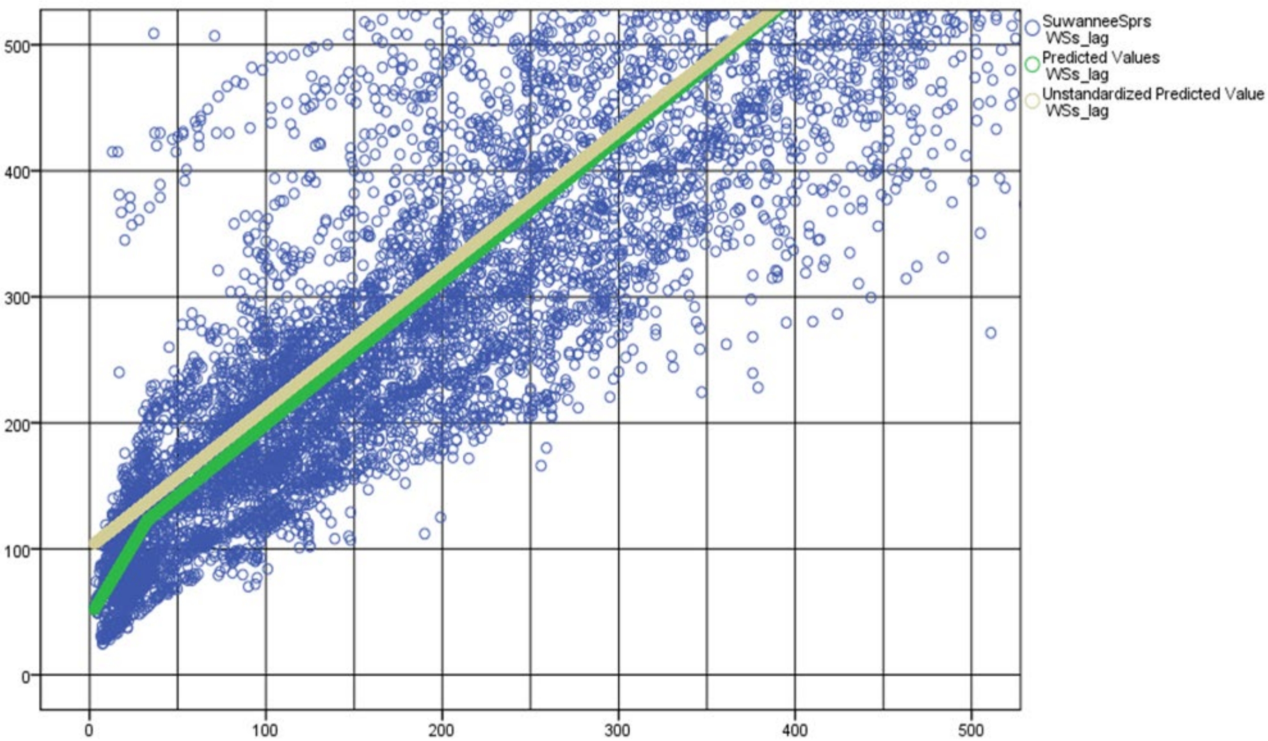

# Appendix B, Part 1

**Water Use Hindcasting**

**(SRWMD 2019)**

# Appendix B, Part 1 – Water Use Hindcasting
Author: SRWMD, 2019

## INTRODUCTION

The purpose of this report is to document the data and methods used in estimating historical groundwater use throughout the North Florida Southeast Georgia Groundwater Model (NFSEG) Domain, including counties in Florida, Georgia, and South Carolina (Figure 1). The hindcasted data is an estimate of historical groundwater use back to 1900. The hindcasted groundwater use estimates were prepared for each county by use type (e.g. agriculture, public supply, industrial). Interpolation between published population and water use estimates as detailed in this section were used to estimate groundwater use on an annual time step. The historical groundwater use estimates form the basis for an evaluation of the impact of historical groundwater use on baseflow groundwater contributions to water bodies within the model domain (see Appendix C).

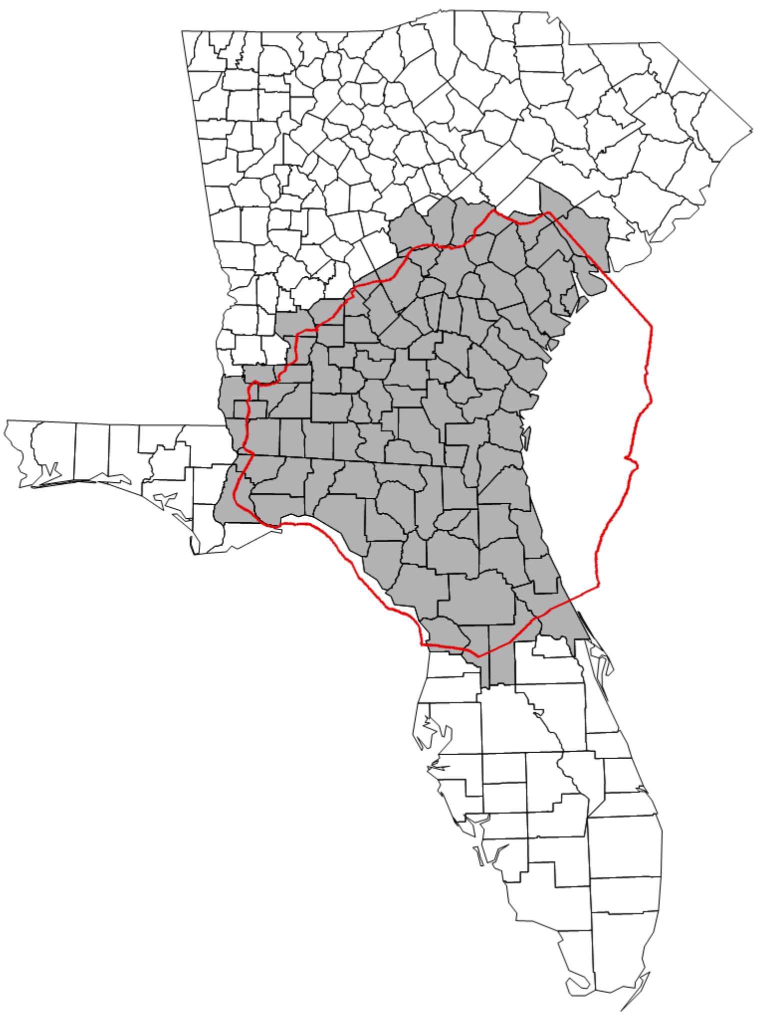

**Figure 1: NFSEG Domain. Counties in gray are included in the effort to estimate historical groundwater use**

## OVERVIEW OF PROCESS

The timeline and data sources used to estimate historical groundwater use by region are summarized in Figure 2. The methods used to estimate historical groundwater use differed by region based on data availability and are provided in detail in the following sections. For each region, water use estimates were prepared for the groundwater use categories summarized in Table 1.

Water use estimates between 1900 and approximately 1960 (Figure 2: gray time periods) were prepared based on historical estimates of population and an estimate of per capita water usage. Historic population data sources are detailed for each region in the following sections. Missing data between published county level population estimates were interpolated in MS Excel using an exponential growth assumption (Excel RATE function) to create annual population estimates. The annual population was multiplied by an estimate of per capita groundwater usage for the categories summarized in Table 1. The per capita water estimates were prepared based on population data and county level groundwater use data summarized by use type from the earliest published groundwater use estimate. In some counties, the timing of initiation of groundwater use within categories or industries could be identified, even though county level estimates were not available. Adjustments made based on historic use data are described in detail for each region and are based on data availability.

Beginning in approximately 1960 (Figure 2: blue, red, purple, and orange time periods) published water use estimates were used to estimate groundwater use by category. Published county level groundwater use estimates were used when available. Missing data between published county level groundwater use were estimated in MS Excel using an exponential growth assumption (Excel RATE function) to create a complete annual groundwater use estimate. Groundwater use was interpolated to produce annual water use estimates. Where available, historical data regarding the initiation of industrial and power generation facilities were used to refine historic water use estimates. For each region, groundwater use was summarized into the categories in Table 1.

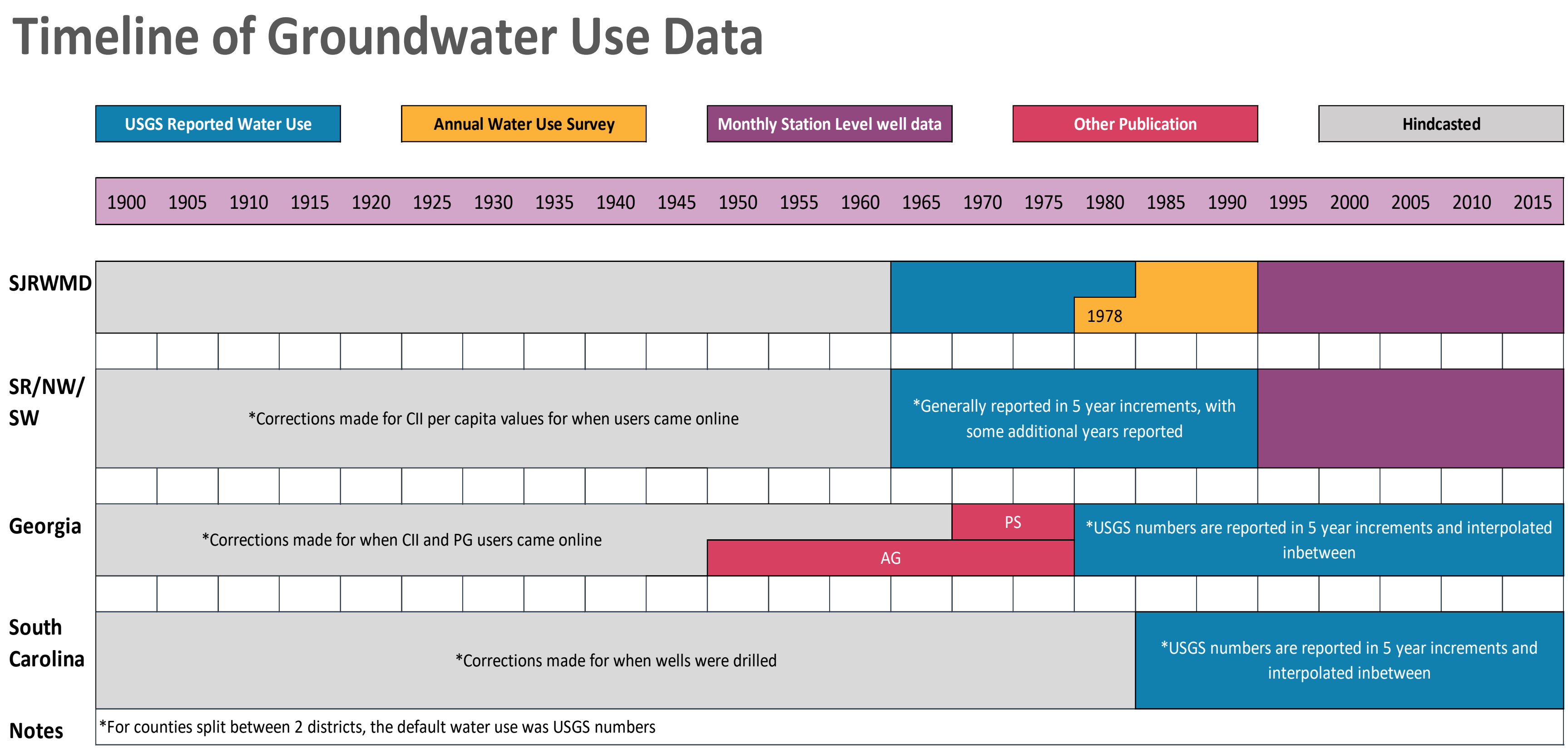


**Figure 2: Timeline of sources and methods used to estimate historic groundwater use**

| Use Type | Abbreviation | Definition |
|---|---|---|
| Public Supply | PS | Large municipal, public, and private systems that supply potable water to the public |
| Domestic Self-Supply | DSS | Domestic water uses generally associated with residential dwellings that are not served by a central public supply utility |
| Agricultural | AG | Irrigation of crops, water used to raise livestock, and other miscellaneous water uses associated with agricultural production |
| Commercial/Industrial/Institutional/ Mining/Dewatering | CII/MD | -Self-Supply from wells<br>-General businesses, office complexes, commercial cooling/heating, etc.<br>-Manufacturing, chemical processing plants, other industrial facilities<br>-Hospitals, assisted living facilities, churches, prisons, schools, etc.<br>-Water associated with extraction, transport, and processing of minerals |
| Power Generation | PG | Water associated with power plant facilities which includes consumptive use of water for steam generation, cooling, and replenishment of cooling reservoirs from self-supply wells |
| Landscape/Recreation/Aesthetics | LRA | Irrigation, maintenance, and operation of golf courses, cemeteries, parks, medians, attractions, etc. from self-supply wells |
| Other (only for Florida) | OTH | Fire protection, environmental |

**Table 1: Abbreviations and Definitions of Water Use Types**

## Partial Counties in NFSEG Domain

For counties that were partially inside the model domain the amount of water use estimated for the 2010 NFSEG model run was summed by county and divided by the amount of water reported from the United States Geological Survey (USGS) in 2010 by county. This ratio was then applied to estimate the amount of water that was attributed to Florida, Georgia, and South Carolina counties that were partially in the model domain. The water use for each category was then multiplied by that ratio for every year of recorded and hindcasted data.

## Data aggregation:

The use categories documented in the USGS water databases for Florida, Georgia, and South Carolina (see References) are as follows:

- State Code
- State Name
- County Code
- County Name
- Year
- Total population of area, in thousands
- Public supply population served by groundwater, in thousands
- Domestic self-supplied groundwater withdrawals, fresh, in million gallons per day (MGD)
- Commercial self-supplied groundwater withdrawals, fresh, in MGD
- Industrial self-supplied groundwater withdrawals, fresh, in MGD
- Total thermoelectric power self-supplied groundwater withdrawals, fresh, in MGD
- Mining self-supplied groundwater withdrawals, fresh, in MGD
- Livestock self-supplied groundwater withdrawals, fresh, in MGD
- Livestock (Animal Specialties) self-supplied groundwater withdrawals, fresh, in MGD
    - Used in South Carolina up until year 2000
- Aquaculture self-supplied groundwater withdrawals, fresh, in MGD
- Irrigation, Crop self-supplied groundwater withdrawals for crops, fresh, in MGD
- Irrigation, Crop self-supplied groundwater withdrawals for crops, fresh, in MGD
    - Used for years 2000 and later

To coincide with the water use categories used in Florida, certain water use types were aggregated together. These categories are as follows:

- PS - Public supply population served by groundwater, in thousands
- DSS - Domestic self-supplied groundwater withdrawals, fresh, in MGD
- AG - Livestock self-supplied groundwater withdrawals, fresh, in MGD, Livestock (Animal Specialties) self-supplied groundwater withdrawals, fresh, in MGD (only in South Carolina), Aquaculture self-supplied groundwater withdrawals, fresh, in MGD, and Irrigation, Crop self-supplied groundwater withdrawals for crops, fresh, in MGD

- CII - Commercial self-supplied groundwater withdrawals, fresh, in MGD, Industrial self-supplied groundwater withdrawals, fresh, in MGD, and Mining self-supplied groundwater withdrawals, fresh, in MGD
- PG - Total thermoelectric power self-supplied groundwater withdrawals, fresh, in MGD
- LRA - Irrigation, Crop self-supplied groundwater withdrawals for crops, fresh, in MGD

Things to note:

- Prior to 2000, water used for golf course irrigation in Georgia was incorporated in the Agricultural irrigation category.

# Groundwater Use Estimates by State:

## Florida:

Population data for all counties in Florida from 1860-1990 in ten-year increments was obtained from the U.S. Census Bureau (Forstall, 1996). The same interpolation approach used for groundwater use was employed between ten-year and five-year population increments to estimate population for in-between years. Hindcasting was completed by multiplying the water use specific GPCD (gallons per capita daily) value by the population for the corresponding year. For example, in Alachua County the 1965 Public Supply water use was 8.60 MGD with a population of 88,092, therefore the per capita value was 98 GPCD. This GPCD was applied to the population of all previous years to calculate the MGD of that given year. For example, in 1950, the population of Alachua County was 57,026 people, the 98 GPCD was then multiplied by the county population and divided by 1,000,000 to get the Public Supply MGD water use value which resulted in 5.57 MGD. The annual hindcasting was completed in Excel.

Historical statewide water use estimates were published by the USGS in 1945, 1950, 1955, 1960, 1965, 1970, 1975, and 1980 for all states in the United States (Guyton 1950, MacKichan 1951, MacKichan 1957, MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972, Murray and Reeves 1977, Solley et al. 1983). The statewide water use estimates used to evaluate whether groundwater estimates produced from the population-based method detailed above were reasonable.

The NFSEG model domain incorporates counties from all or part of four different water management districts throughout the state of Florida. Since the St. Johns River Water Management District (SJRWMD) started estimating water use earlier than the other three, the methodology varies slightly between districts, in order to include the best available estimates of water use. Historical water use in the Suwannee River Water Management District (SRWMD), Northwest Florida Water Management District (NWFWMD), and Southwest Florida Water Management District (SWFWMD) are grouped together because of similar data locations and methods. A monthly timestep of water use was generated for all Florida counties located in the NFSEG model domain. Monthly values were later averaged across the year to obtain an annual timestep.

### St. Johns River Water Management District (SJRWMD):

The USGS publishes county-level water use, for the following types of water use, every 5 years starting in 1965: Public Supply, Domestic Self-Supply, Commercial-Industrial-Mining, Agricultural, Landscape and Recreational Irrigation, and Power Generation. Some interim years are also available in the USGS data between the five-year intervals from 1965-1995 (Historical Water-Use in Florida). The SJRWMD publishes county-level water use by category annually in their Annual Water Use Survey (AWUS), starting in 1978 (SJRWMD 2019). Using these two sources, groundwater use data were aggregated to the county and use type category for every five-year period from 1965 to 1994, and some intervening years between 1965-1994. Missing years for each county and use category were estimated using an exponential growth assumption to create a complete aggregate table. If USGS and AWUS estimates were not equal, published AWUS data were used.

The SJRWMD maintains an estimate of historical water use in a dataset with monthly use and station (i.e., well)-level detail for each well point for the years 1995-2015 for Florida counties in the NFSEG domain. For each station, an evaluation was made to determine if missing data should be gap filled. For each year that has more than 5 months of reported data for a given station, missing months were estimated. To do this, a station's average proportion of water use for each month was determined, using all available data from 1995-2015. The missing month's corresponding average proportion was applied to the annual water use for the year with missing data to develop an estimate of water use for that month. This was done for all stations.

### Suwannee River Water Management District (SRWMD)/Northwest Florida Water Management District (NWFWMD)/Southwest Florida Water Management District (SWFWMD):

The USGS groundwater use data from 1965-1994 was used to estimate groundwater use in counties not located in the SJRWMD (Historical Water-Use in Florida). Groundwater use data was aggregated to the county and use type category for every five-year period from 1965 to 1994, and some intervening years between 1965-1994. Missing years for each county and use category were estimated using an exponential growth assumption. The historical water use database with monthly use and station level detail for each well point from 1995-2015 was used to fill in the remaining years of data.

### Florida Adjustments

Two counties in SRWMD and one county in SJRWMD had large industrial users prior to 1965. The water use attributed to these industrial users was removed from the per capita water use estimate for the CII use category prior to the year the industry came online.

- Taylor County – Buckeye/Foley Cellulose, now known as the Georgia-Pacific Foley Plant, came online in 1954; therefore Taylor county's CII water use category has two different GPCD values that were used for hindcasting ("The History of the Foley Mill"). The first one uses the 1965 per capita value as is with all CII use, including Buckeye water use. The second GPCD value uses the 1965 water use value minus the 1965 Buckeye water use, which creates a smaller GPCD value. The 1965 Buckeye water use value came from USGS paper documents on CII water use. The Buckeye operation came online in 1954; therefore, the first large GPCD was used to estimate 1954-1964 water use for the CII category and the second, smaller GPCD was used to estimate 1900-1953 water use.
- Hamilton County – The PCS Phosphate mine, now known as Nutrien, came online in 1965. Hamilton county's 1965 water use value for the CII category was 10.3 MGD. Prior to 1965, any water use from PCS should not be used in the GPCD value that estimates 1900 - 1964 water use. The reported 10.3 MGD of CII water use was only from the PCS operation, according to USGS paper records on 1965 CII water use ("Suwannee River Mine"). Therefore, the GPCD value for CII prior to 1965 was set to zero.
- Nassau County – Industrial pumping in Fernandina Beach – St. Mary's area was very low prior to 1938, therefore CII water use was set to zero in 1937 and all years prior. Information regarding

this area came from “Impact of Development on Availability and Quality of Ground Water in Eastern Nassau County, Florida, and Southeastern Camden County, Georgia” (Brown, 1984).

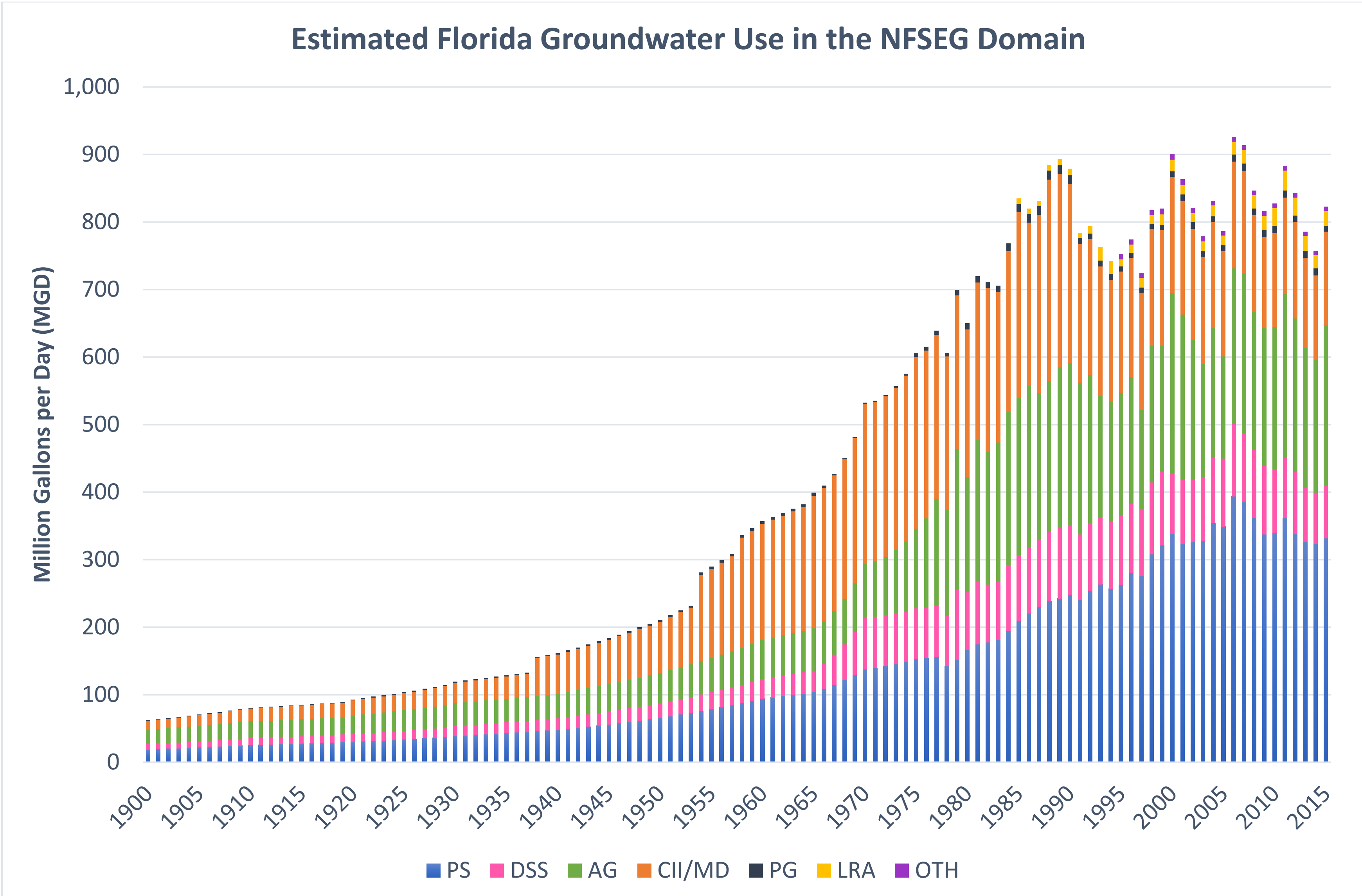


**Figure 3: Estimated groundwater use in the Florida portion of the NFSEG Domain through time by water use category**

## Georgia:

Population for Georgia was obtained from the Georgia Governor's Office of Planning and Budget and was downloaded as an Excel file (Historical Census Data). Data include county level estimates from 1900 through 2000 in ten-year increments. The estimates for in-between years were interpolated using an exponential RATE function in Excel.

County data for each water use category was obtained from the USGS with groundwater use estimates dating back to 1985 ("USGS Water Use Data for Georgia"). Additional county groundwater data for Georgia in 1980 was published in "Water Use in Georgia By County For 1980" (Pierce et al. 1982). County level Public Supply water use estimates were obtained from "Use of water in Georgia, 1970, with projections to 1990" (Carter and Johnson 1974). The GPCD values were calculated for each water use type in each county for the earliest year in which water use data was reported (1970 for Georgia PS, 1980 for all other categories except agriculture, which is described below). The GPCD value was calculated by dividing the groundwater use (in MGD) for each category by the population for that county and multiplying by 1,000,000. For example, in Appling County, Georgia, the 1980 Domestic Self-Supply groundwater use was 1.12 MGD with a population of 15,565, therefore the per capita value was 71.956 GPCD. The calculated GPCD values were held constant dating back to either 1900, or back to the earliest year in which population data was recorded.

Historical statewide water use estimates published by the USGS in 1945, 1950, 1955, 1960, 1965, 1970, 1975, and 1980 for all states in the United States were used to refine agricultural groundwater use estimates in Georgia (Guyton 1950, MacKichan 1951, MacKichan 1957, MacKichan and Kammerer 1961, Murray 1968, Murray and Reeves 1972, Murray and Reeves 1977, Solley et al. 1983). Agricultural irrigation and other agricultural groundwater use was assumed to be zero prior to 1950 in Georgia, based on agricultural irrigation trends and published statewide water use (Harrison and Tyson 1995, and Georgia Water Coalition 2017). Agricultural groundwater use for Georgia was estimated between 1950 and 1980 using statewide groundwater estimates. Statewide estimates of groundwater use by category were published in five-year increments starting in 1945. The agricultural groundwater use for Georgia in 1945 was reported as zero, and as "negligible" in 1950. The total AG groundwater use in Georgia in 1980 was estimated to be 397 MGD. Since agricultural groundwater use in 1950 was said to be "negligible," a value of 0.1 MGD was used (0.1 MGD was used because it is the lowest value that can be input into the Excel equation). This value was then multiplied by the AG groundwater use in each county for the corresponding year and divided by 397 MGD.

### Statewide Georgia AG values from USGS publications:

- 1945 – 0 MGD
- 1950 – "negligible" – assigned as 0.1 MGD
- 1955 – 12 MGD
- 1960 – 21.8 MGD
- 1965 – 19.1 MGD

- 1970 – 37.6 MGD
- 1975 – 33.6 MGD (center pivot irrigation systems introduced)
- 1980 – 397 MGD

The main assumption is that the percent of water use in each individual county compared to the total statewide water use was the same in 1950 as it was in 1980. For example, Appling County had a reported 2.89 MGD of water used for AG in 1980, which represents 0.73 percent of the total agricultural water use in 1980. To estimate water use prior to 1980, the estimated percentage calculated in 1980 was used. Therefore, water use in 1950 for Appling County was estimated to be 0.00073 MGD. Water use was then interpolated between 1950-1955 using the exponential RATE function in Excel. This methodology was applied for every five-year increment from 1950-1980. In 1955, the 1980 percentage for Appling County was multiplied by the statewide estimate of 12 MGD. Water use was then interpolated between 1955-1960.

Adjustments were made for counties in Georgia where the initiation date of CII and PG water use could be estimated. The adjustments made were based on the best estimate of the timing for initiation of groundwater use based on records of when large users came online. The estimated use for the affected use category was set to zero prior to initiation of the identified entity. These adjustments are documented below. adjustments for Power Generation facilities were also made and based on the in-service year (Fanning et al. 1991).

For example, in Charlton County, GA, the Humphreys Mining Company started mining operations in Folkston, GA in 1965. The CII water use for Charlton County was then assumed to be zero prior to when it came online in 1965.

### Georgia Adjustments to CII and PG users:

- Appling – Edwin I. Hatch plant with Georgia Power Company in 1975 (Fanning et al. 1991)
- Bacon – American Protein came online in 1949 (“Tyson Acquires American Proteins, AMPRO Products”)
- Berrien – Propex Operating Company came online in 1968 (Propex)
- Camden – Gilman Paper Company came online in 1940s (“Gilman Paper Company”)
- Charlton – Humphreys Mining Company started mining in 1965 (Fanning et al. 1991)
- Chatham – Savannah Sugar came online in 1917 (Savannah Foods & Industries, Inc.) and Union Camp, (later known as International Paper) in 1920s and 1930s (“Union Camp Corporation”), Riverside Plant with Savannah Electric and Power Company in 1949 (Fanning et al. 1991)
- Clinch – BWAY came online in 1957 (“BWAY CORP”)
- Colquitt – National Beef came online in 1914 (Hall, K. C. 2017)
- Decatur – BASF came online in 1921 (Neshat 2019)
- Dougherty – FL Rock Industries came online in 1965 (“History of Florida Rock & Tank Lines”), Mitchell Plant with Georgia Power Company in 1948 (Fanning et al. 1991)
- Early – Great Southern Paper Company came online in 1963 (“GP Cedar Springs Operations Celebrates Golden Anniversary”)

- Effingham – McIntosh Plant with Savannah Electric and Power Company came online in 1979 (Fanning et al. 1991)
- Evans – Claxton Poultry came online in 1949 (Claxton Poultry Farms)
- Glynn – Pinova Inc. came online in 1911 (Pinova), King and Prince Shrimp in 1924 (King & Prince Seafood), Mead Corporation/Scott Paper in 1937 (The Mead Corporation), and SeaPak Shrimp in 1948 (SeaPak Shrimp & Seafood Co.), McManus Plant with Georgia Power company in 1952 (Fanning et al. 1991)
- Grady – Grace Fertilizer came online in 1954 ("W.R. Grace & Company") and Oil-Dri in the early 1960s (Oil-Dri Corporation of America)
- Jeff Davis – Propex Operating Company came online in 1953 (Propex)
- Laurens – J.P. Stevens came online in 1947 (Thompson)
- Liberty – Interstate Paper (now DS Smith) came online in 1968 ("Interstate Paper: After 40 Years, Business Still Booming")
- Lowndes – Georgia-Pacific came online in 1927 ("Our History - 1920-1949")
- Sumter – McClesky Cotton Company came online 1929 (Bland 2017)
- Thomas – Flowers Foods came online in 1919 ("Our History") and Oil-Dri in the early 1960s (Oil-Dri Corporation of America)
- Ware – CSX Railroad formerly known as Seaboard System Railroad Inc. came online in 1944 ("CSX GATX Rail Corp") and Flanders Provision in 1958 ("Flanders - About Us")
- Washington - Thiele Kaolin Company came online in 1947 ("Thiele Kaolin - About Us")
- Wayne - Rayonier's Cellulose Specialties came online in 1954 ("Company Timeline")
- Worth – Olam Edible Nuts formerly known as Universal Blanchers LLC came online in 1978 ("Universal Blanchers")

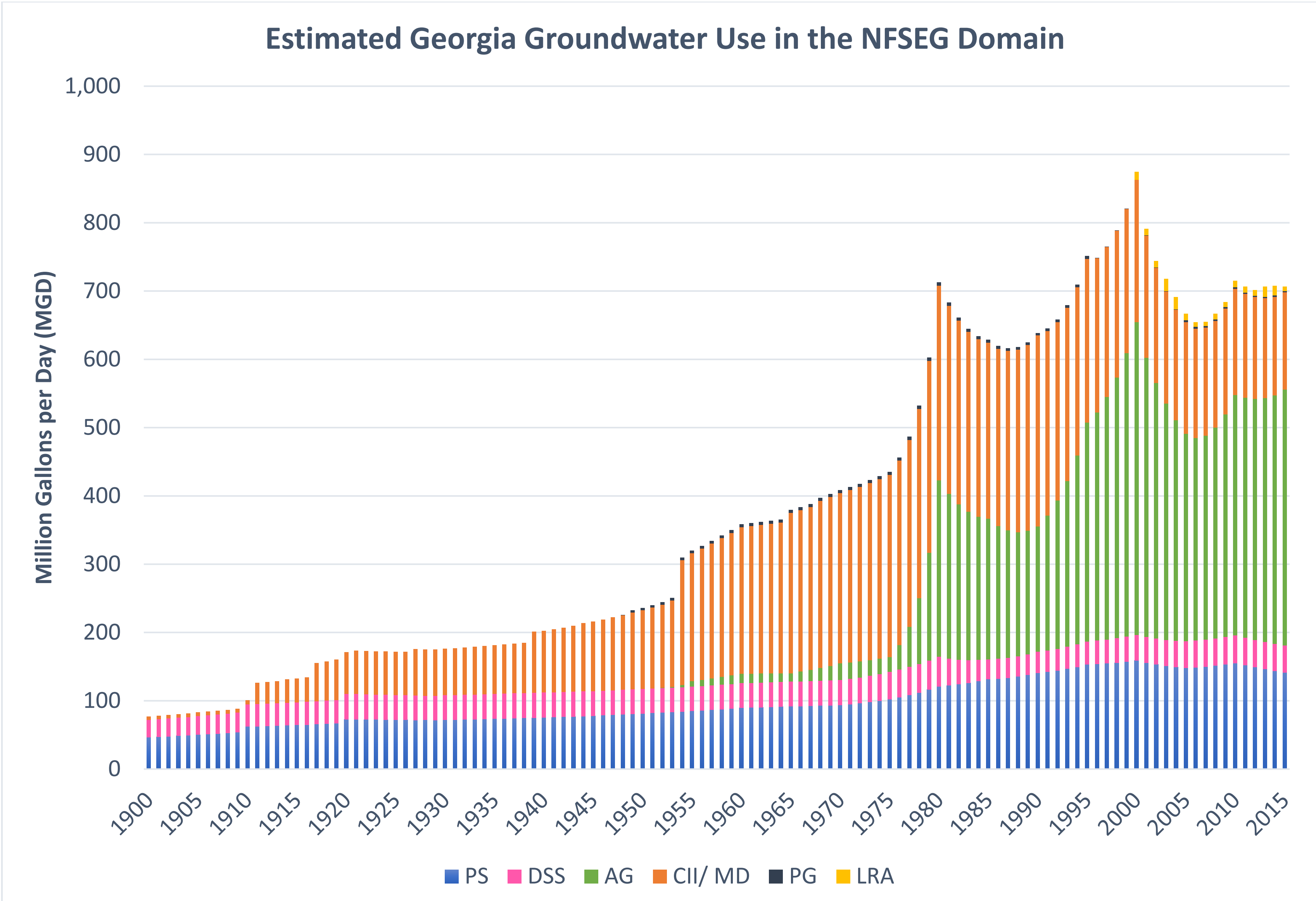


**Figure 4: Estimated groundwater use in the Georgia portion of the groundwater domain through time by water use category**

## South Carolina:

Population data for South Carolina was obtained from the US Census Bureau (Forstall, 1995). Data include county level estimates from 1900 through 2000 in ten-year increments. The estimates for in-between years were interpolated using an exponential RATE function in Excel.

County data for each water use category was obtained from the USGS ("USGS Water Use Data for South Carolina"). Water use estimates dating back to 1985 were used for counties in South Carolina that are in the model domain. The GPCD values were calculated for each water use type in each county for the earliest year in which water use data was reported. The GPCD value was calculated by dividing the estimated groundwater use (in MGD) for each category by the population for that county and multiplying by 1,000,000. The calculated GPCD values were held constant dating back to 1900, or back to the earliest year in which population data was recorded.

Adjustments were made for counties in South Carolina using the Coastal Plain Water Well Inventory (South Carolina Department of Natural Resources). This provided information on when the earliest well was drilled for each water use category. These dates were then used to adjust the water use for each use type in each county.

- South Carolina Adjustments:
- Allendale
  - Earliest DSS well - 1905
  - Earliest AG well – 1950
  - Earliest PS well – 1952
  - Earliest CII well – 1960
- Bamberg
  - Earliest DSS well - 1952
  - Earliest AG well – 1950
  - Earliest PS well – 1938
- Beaufort
  - Earliest DSS well - 1900
  - Earliest AG well – 1955
  - Earliest PS well – 1941
  - Earliest CII well – 1966
- Colleton
  - Earliest DSS well - 1917
  - Earliest AG well – 1955
  - Earliest PS well – 1942
- Hampton
  - Earliest DSS well - 1880
  - Earliest AG well – 1927
  - Earliest PS well – 1898

    - Earliest CII well – 1942
- Jasper
    - Earliest DSS well - 1900
    - Earliest AG well – 1928
    - Earliest PS well – 1941
    - Earliest CII well – 1953

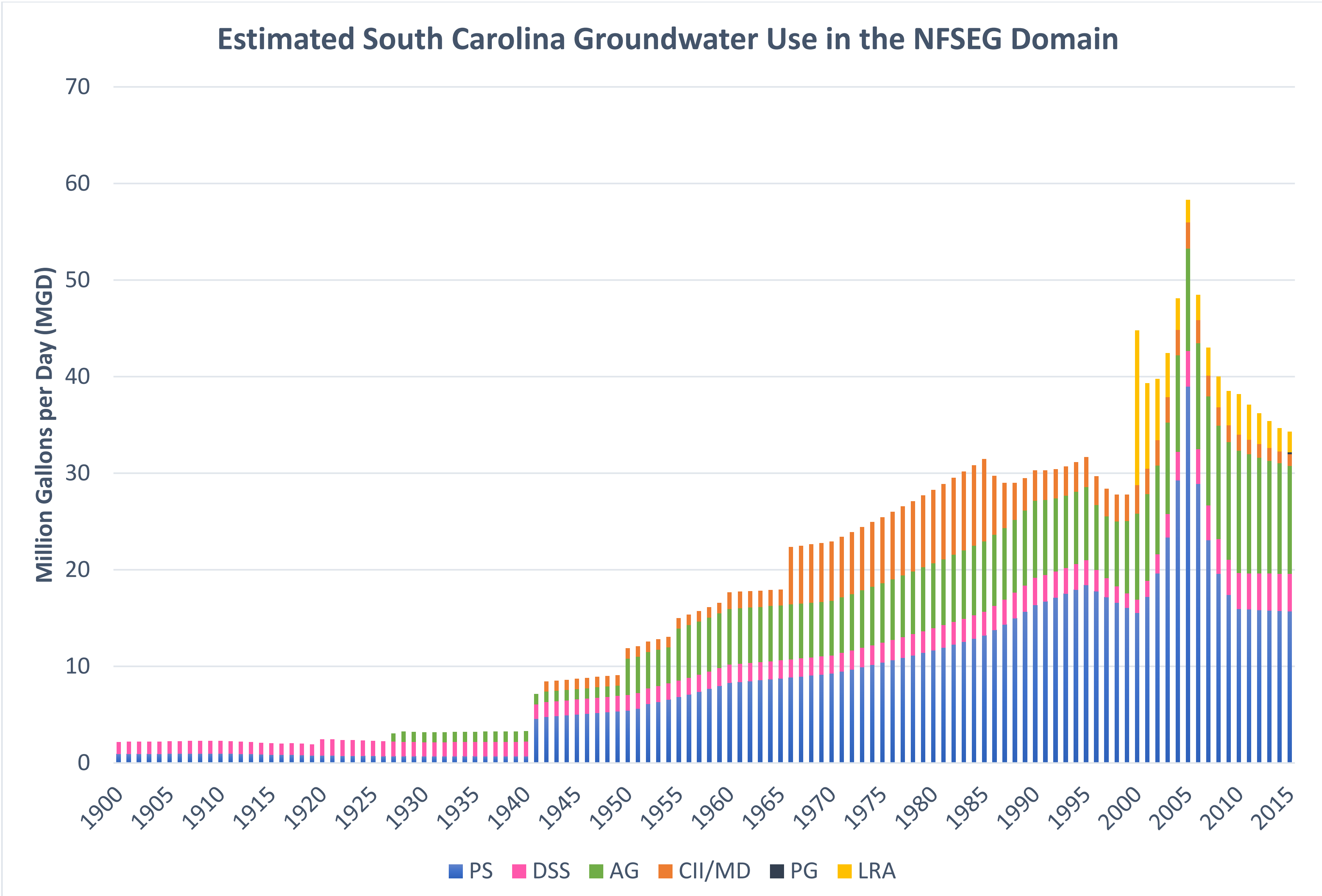


**Figure 5: Estimated groundwater use in the South Carolina portion of the NFSEG domain through time by water use category**

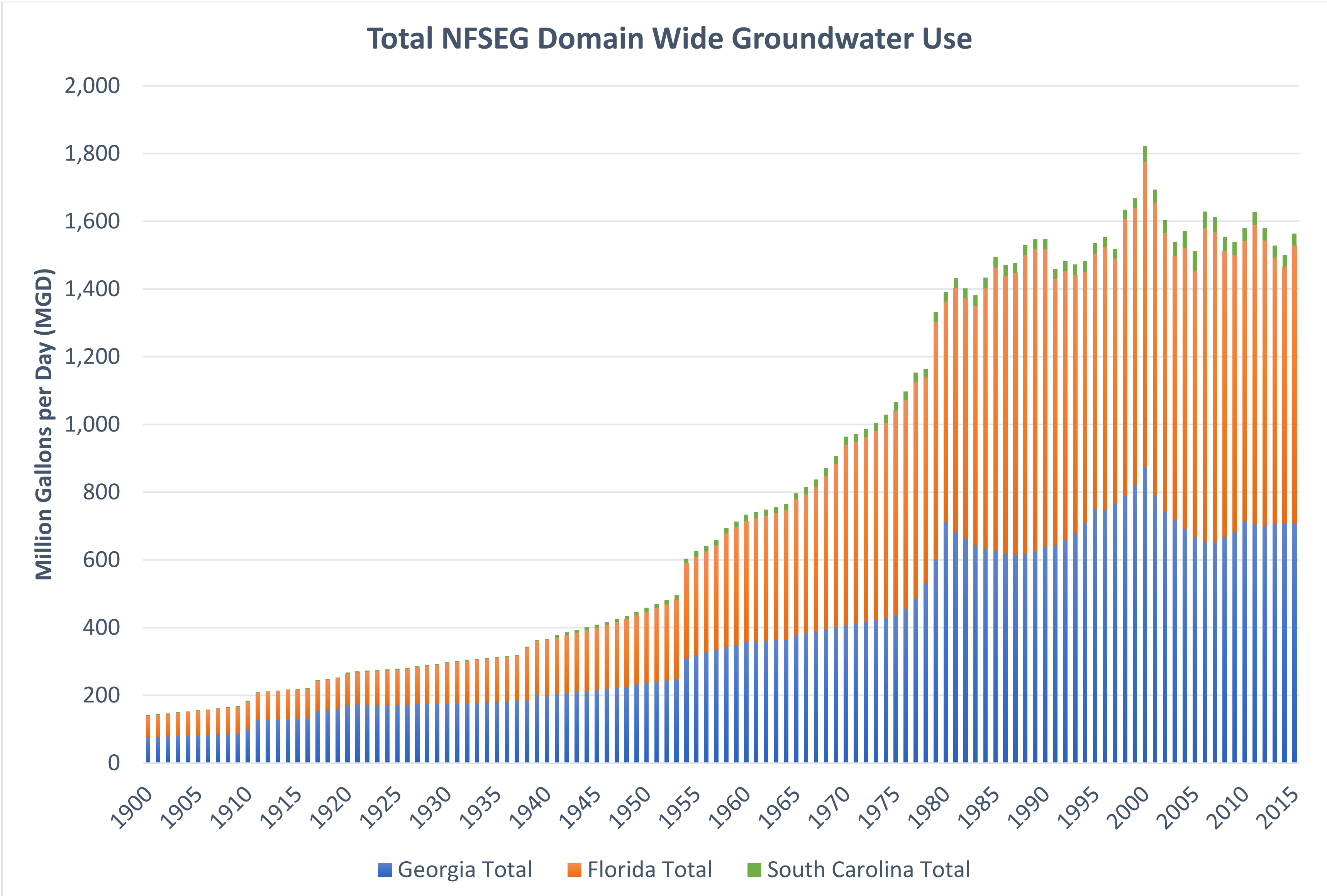


**Figure 6: Hindcasted groundwater use in the NFSEG domain by state**

## • Moving Average Calculation

For each county and use type combination a moving five-year average was calculated. The average was computed based on the current year and the four years preceding that year. For example, the five-year moving average in 1930 included the years 1930, 1929, 1928, 1927, and 1926. This moving average was then calculated for all years starting with 1904. Results for each state, county, and use-type combination in the model domain were then merged into one dataset. Water use-type categories for Georgia and South Carolina were merged into three categories, AG, DSS, and NOT_AG_OR_DSS (this includes PS, CII/MD, PG, and LRA). This was done to coincide with the categories used in the NFSEG model. Results for these estimates are shown for Florida, Georgia, and South Carolina in Figures 7-9. Figure 10 shows the estimated moving average groundwater use broken out by state for the entire model domain. The results of this water use estimation process relative to the single-year estimates for the NFSEG are summarized in Table 2 (Durden et al. 2019).

| Year | NFSEG Output (MGD) | Hindcasting Output (MGD) | Hindcasting Five-Year Moving Average Output (MGD) |
|---|---|---|---|
| **2001** | 1,568 | 1,694 | 1,659 |
| **2009** | 1,557 | 1,538 | 1,562 |
| **2010** | 1,487 | 1,580 | 1,576 |

**Table 2: Comparison between water use in the NFSEG model, hindcasting, and five-year moving average**

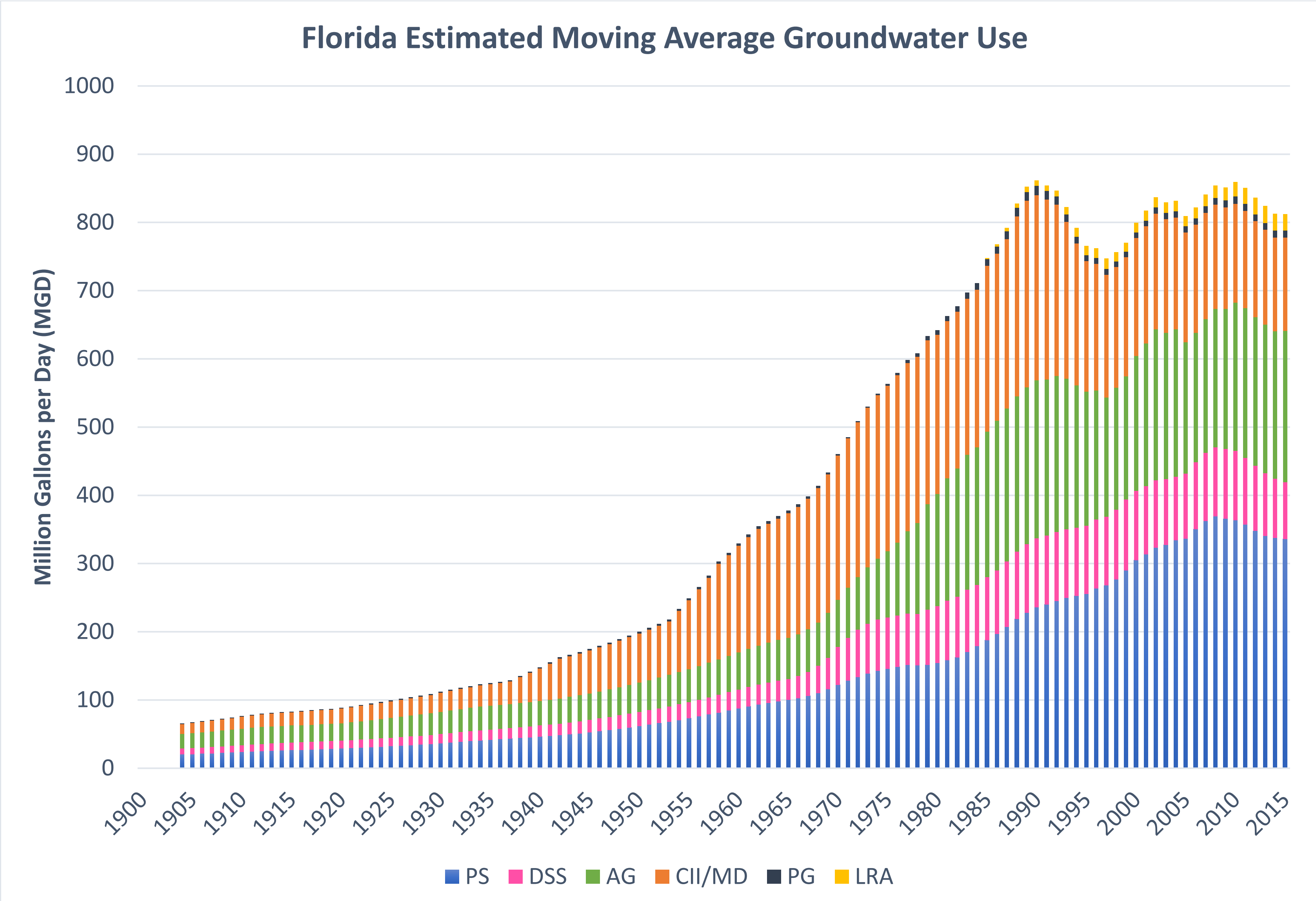


**Figure 7: Estimated moving average groundwater use in Florida by water use category**

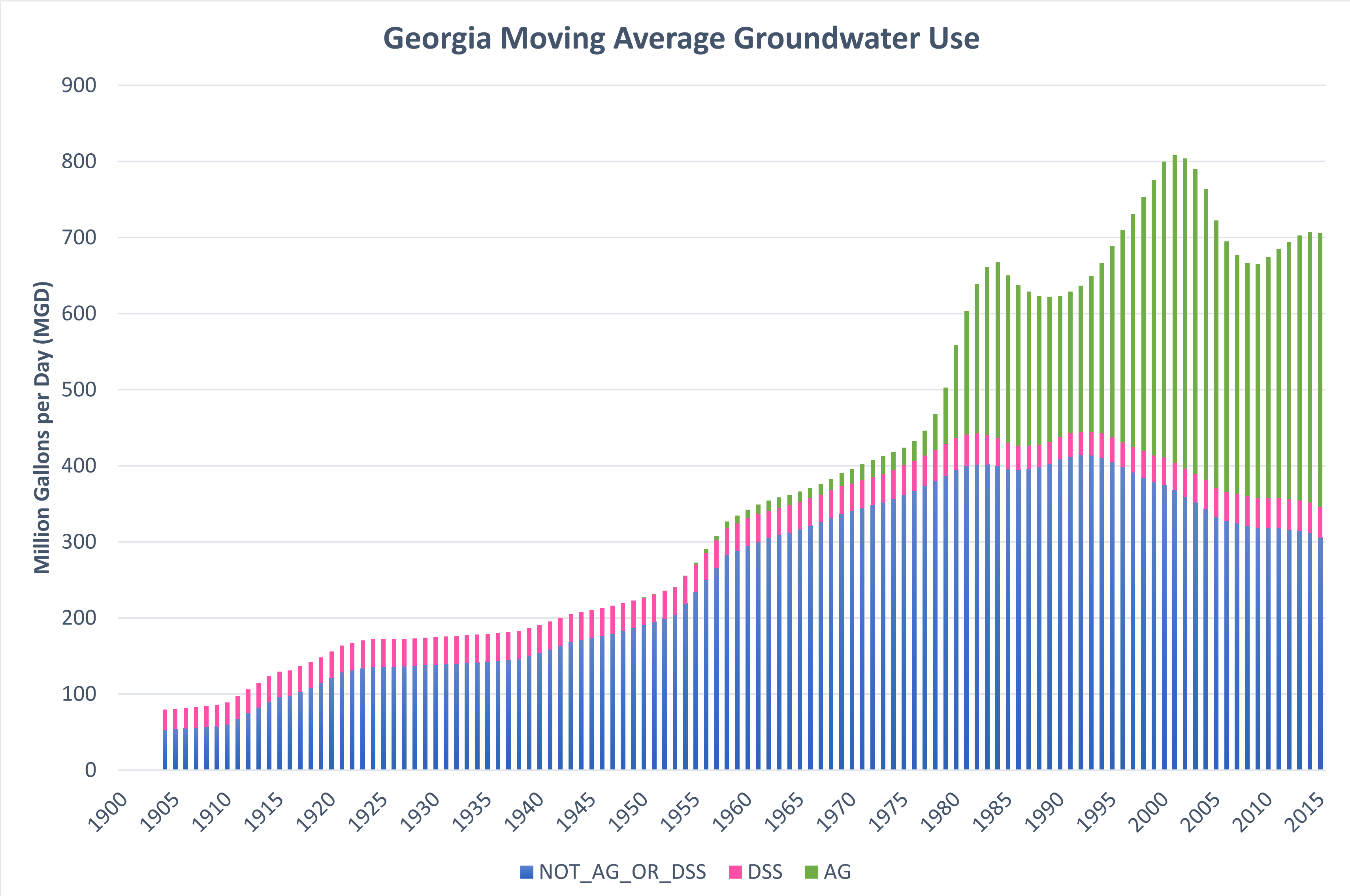


**Figure 8: Estimated moving average groundwater use in Georgia by water use category**

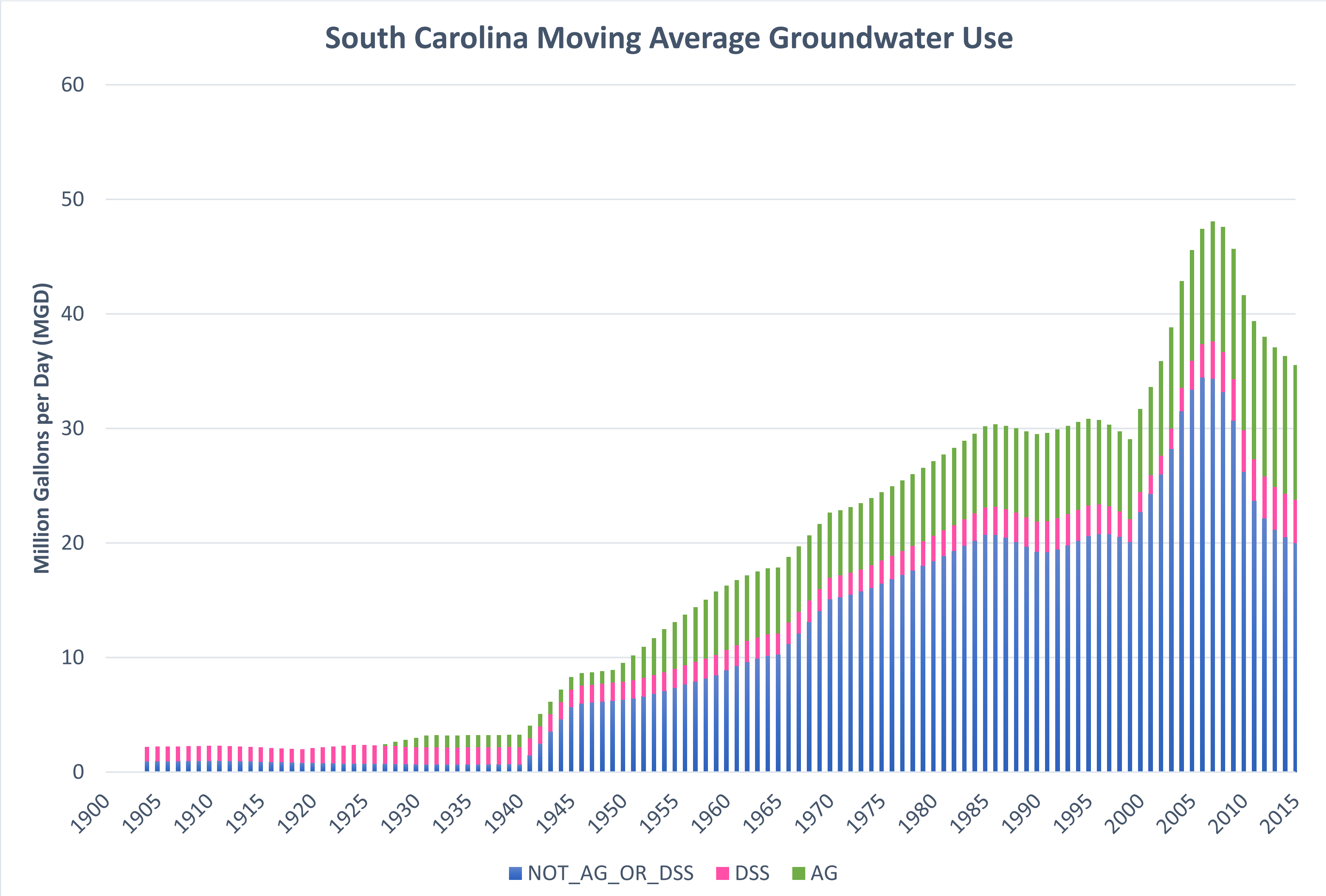


**Figure 9: Estimated moving average groundwater use in South Carolina by water use category**

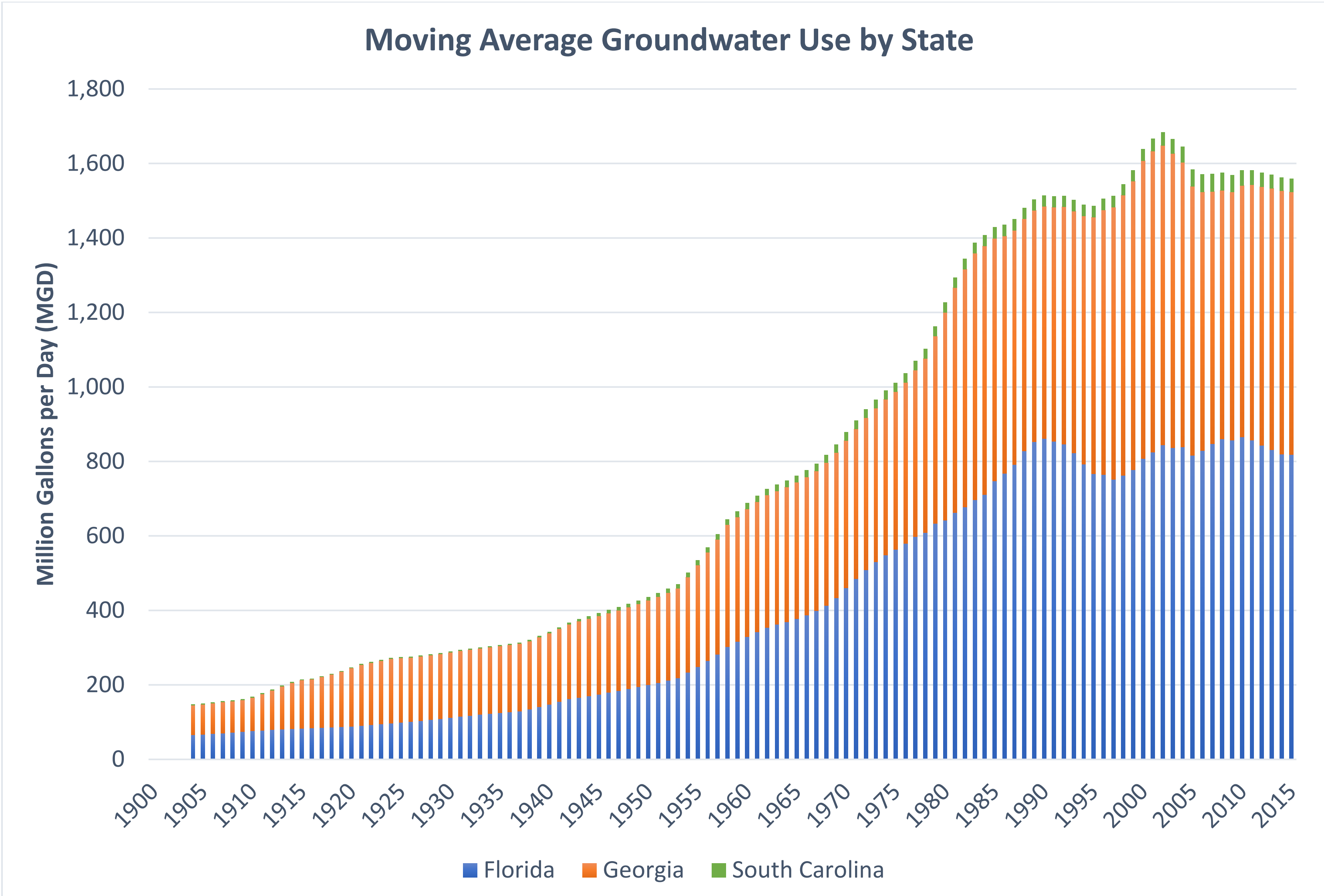


**Figure 10: Estimated moving average groundwater use by state**

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# Appendix B, Part 2

**Injection Wells Hindcasting**

**(SRWMD 2019)**

# Appendix B, Part 2 – Injection Wells Hindcasting
Author: SRWMD, 2019

## Background

Public water utilities operate two wastewater treatment plants (WWTPs) in Gainesville, FL. The discharges from these WWTPs are later returned to the groundwater system. These facilities include the older Main Street facility and the newer Kanapaha facility, both of which are in the SJRWMD portion of the county. The treated wastewater discharged from the Main Street facility goes to Alachua Sink, while treated wastewater from the Kanapaha facility is injected into the aquifer through the Kanapaha well. The University of Florida also operates its own wastewater treatment plant and has two injection wells. Table 1 shows the reclaimed water flows that were estimated for injection wells in the NFSEG model. Figure 1 shows a map of the locations of injection wells.

| Injection wells with reclaimed water flows in NFSEG Domain | Q 2001 million gallons per day | Q 2009 million gallons per day | Q 2010 million gallons per day |
|---|---|---|---|
| **Kanapaha** | **7.83** | **7.46** | **6.94** |
| **Alachua Sink** | **7.04** | **6.37** | **5.76** |
| **University of Florida** | **1.53** | **1.51** | **1.48** |

**Table 1: Injection well reclaimed water flows as estimated in the NFSEG model**

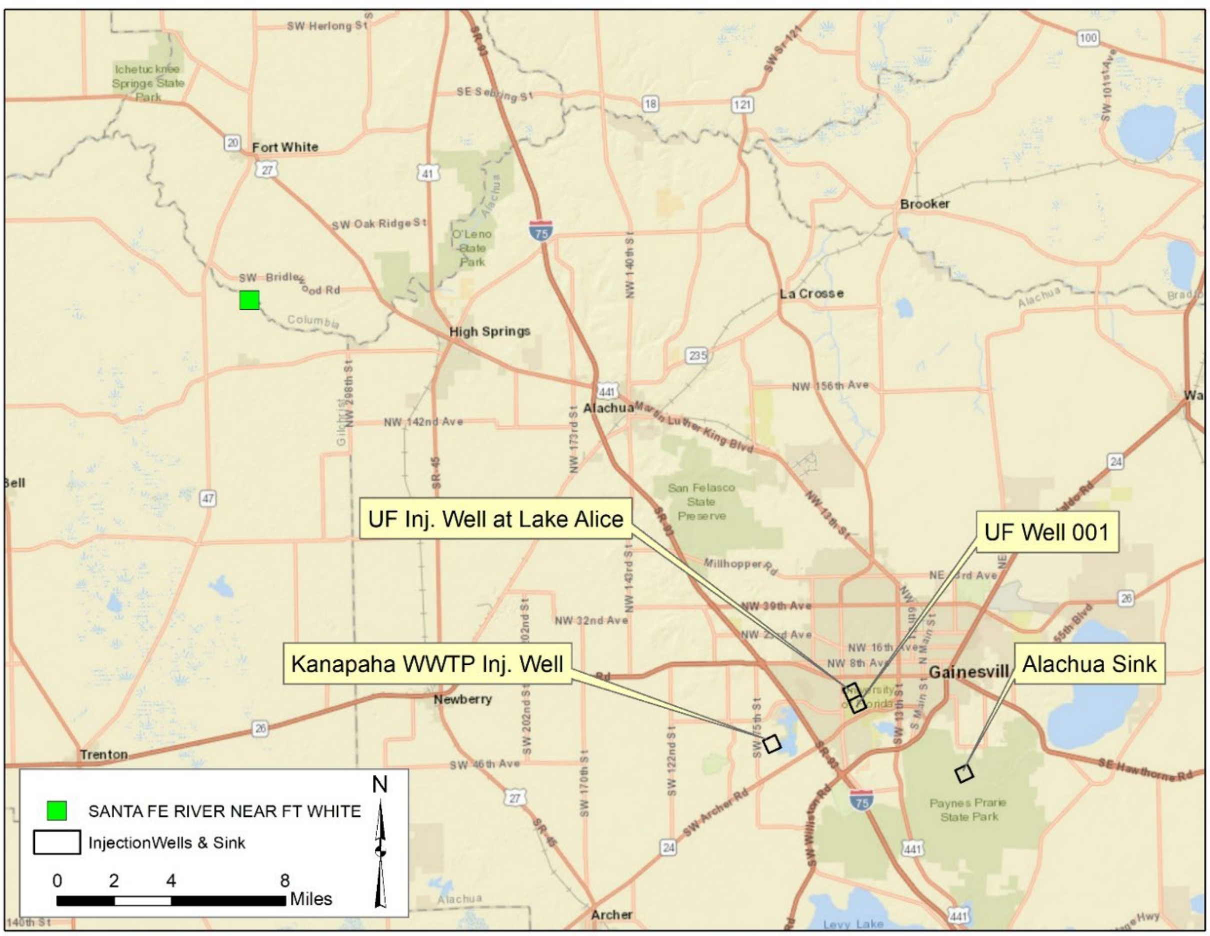


**Figure 1: Map of injection wells located in the NFSEG**

## Murphree Well Field Withdrawal data

The Murphree well field is located in SJRWMD. Withdrawal data was obtained from SJRWMD and includes pumping estimates from 1986-2010. The Murphree withdrawal data was divided by Alachua County Public Supply data for corresponding years to get a ratio of withdrawal to public supply for each year. The ratios of reported years (1986-2010) were averaged together to get an average ratio of 0.90. This ratio was used to hindcast and estimate Murphree withdrawal data going back to 1900 and for 2011-2015.

## Kanapaha

The average estimated flow into the well at Kanapaha from January 1982 through February 1984 was 6.1 mgd (Phelps 1987). This value was used to estimate flow from 1978-1981. The Kanapaha wastewater treatment facility came online in 1977 but no month is stated, therefore it is assumed that it came online halfway through the year and half of the 6.1 mgd was assigned to 1977 ("Kanapaha Water Reclamation Facility History"). Prior to 1977, the injection rate was set to zero because the wastewater treatment plant did not exist, therefore no water was being injected into the Floridan Aquifer.

Jones Edmunds has a time series of injection flows by month for Kanapaha from 1982 through 2012. Injection flows from each month were averaged to get an estimate for the flow in each given year. These numbers are also reported from Gainesville Regional Utilities Historical Wastewater Flow Rates.

Estimates for 2014-2015 were obtained from a SJRWMD file of wastewater treatment and reuse. This included data from 1995-2017.

From the reported data gathered, the average estimate of water injected for the Kanapaha well was 8.42 MGD. Figure 2 shows the estimated flow of reclaimed water into the Kanapaha well.

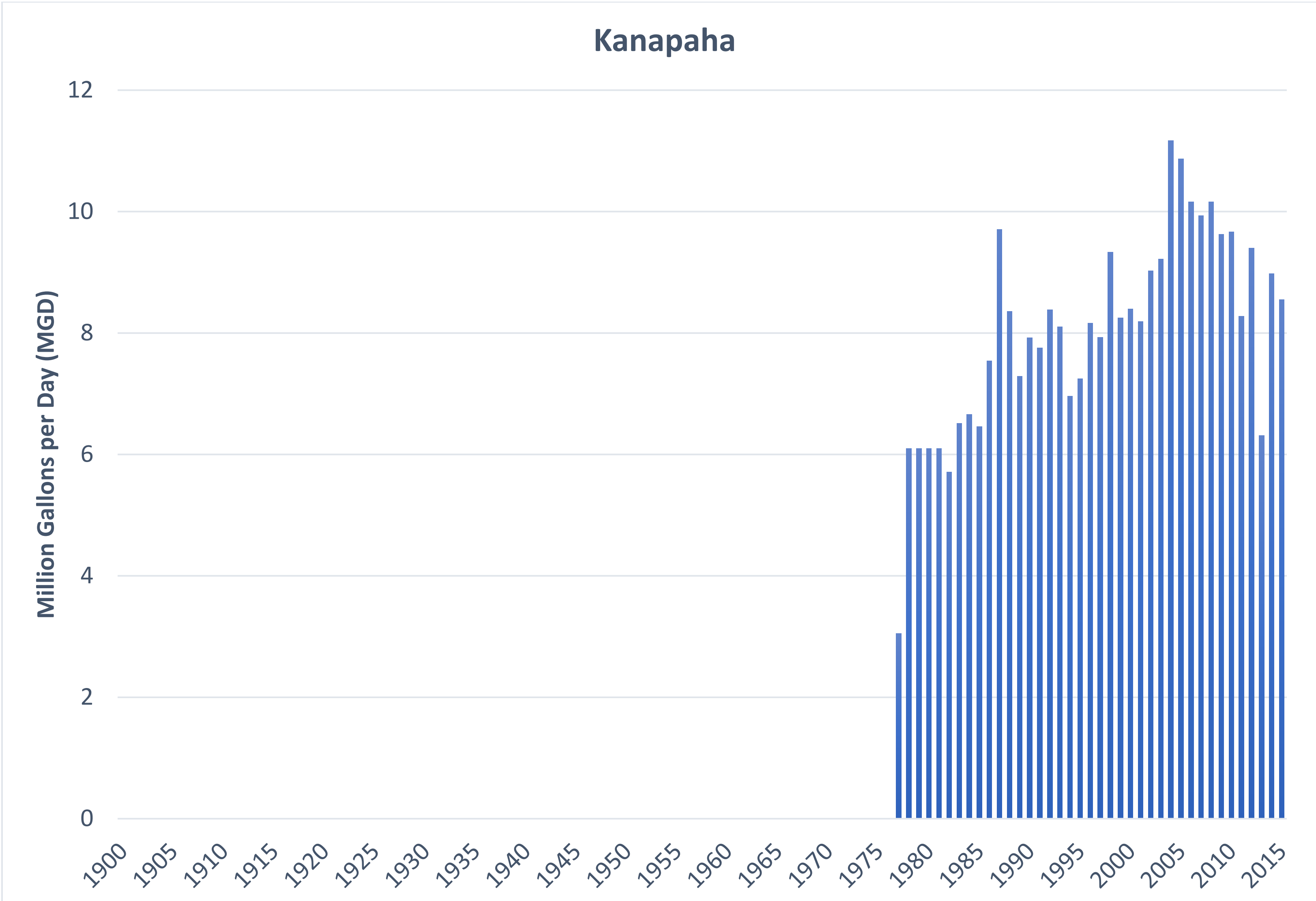


**Figure 2: Estimated Kanapaha injection well flows**

## Alachua Sink

The main assumption regarding Alachua Sink is that all of the wastewater discharging from the Main Street WWTP is making its way to Alachua Sink. Another assumption made is that before the Kanapaha WWTP came online, the volume of treated wastewater being discharged to Alachua Sink included a proportional amount of the Kanapaha flow. The flow from the Main Street WWTP was hindcast back to 1930, when the plant came online ("Main Street Water Reclamation Facility").

From 1982-2012, estimates were obtained from Gainesville Regional Utilities Historical Wastewater Flow Rates as well as the time series from Jones Edmunds. Estimates for 2014-2015 were obtained from SJRWMD file of wastewater treatment and reuse. This included data from 1995-2017. From the reported data gathered, the average of treated wastewater calculated for the Main Street WWTP was 5.82 MGD.

For the years before the Kanapaha WWTP came online, the sum of the average injection of the treated Kanapaha wastewater ($\overline{Q}injection, Kanapaha$) and the Main Street treated wastewater (*Main Street*) was divided by the average withdrawal from the Murphree well field $(\overline{W}Murphree)$ to find ratio *c1*. The value of *c1* is 0.59888.

$$c1 = \frac{\overline{Q}injection, Kanapaha + Main\ Street}{\overline{W}Murphree}$$

Then, the product of ratio *c1* and the average Murphree well field withdrawal ($\overline{W}Murphree$) was subtracted from the average of Alachua County Public Supply ($\hat{Q}Alachua$) to obtain an estimate of injection flow for each year of missing data (1900-1977) (*Pre-Kanapaha*).

$$Pre\ Kanapaha = \hat{Q}Alachua - (c1 \times \overline{W}Murphree)$$

After Kanapaha came online, the same methodology was applied to calculate ratio *c2*, however, the injection flow from Main Street $(\overline{Q}injection, Main\ Street)$ was used, instead of adding in the Kanapaha flow. This value of *c2* is 0.24479.

$$c2 = \frac{\overline{Q}injection, Main\ Street}{\overline{W}Murphree}$$

Thus, the estimated injection (*Post-Kanapaha*) is the ratio *c2* multiplied by the average Murphree well field withdrawal. This was applied for years 1977-1981. The value in 1977 was divided by two, because of the assumption of the Kanapaha WWTP coming online halfway through the year. Injection estimates are available starting in 1982.

$$Post\ Kanapaha = c2 \times \overline{W}Murphree$$

Figure 3 shows the estimated flow into Alachua Sink.

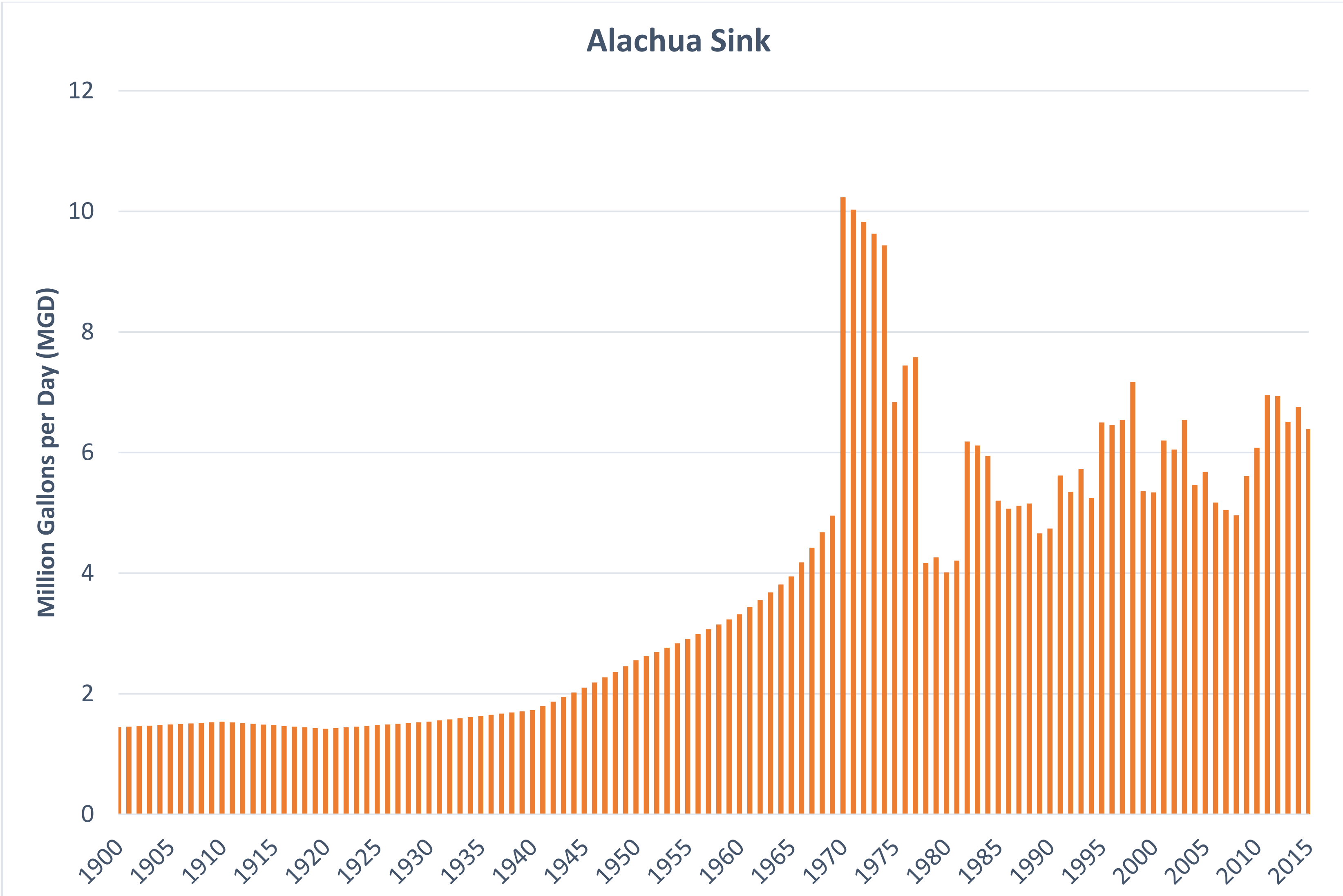


**Figure 3: Estimated flows for Alachua Sink**

## University of Florida

The University of Florida wastewater treatment plant was constructed in 1926. In 1959, two injection wells were installed for lake level control. In 1994, the water reclamation plant (WRP) began operation and in 1995 the effluent from the plant was discharged directly to the R2 (Lake Alice - FLA011322_8285) injection well, leaving the other well, R1 (UF well number 001) to be used only for lake level control.

Starting in 1995, injection flow rates from the WRP and total flow rates were reported to FDEP. SJRWMD provided a spreadsheet with these numbers (file name “1995 - PRESENT WW TREATMENT AND REUSE MASTER FILE 051518”). The injection flow rates reported from 1995-2015 were assigned to only well R2 because the reclaimed water is injected directly into that well. Well R1 was set to zero for these years.

To estimate the flow through the wells prior to 1995, the average of the total flow reported from FDEP from 1995-2015 was calculated. This average of 1.89 MGD was then divided by the average Murphree Well Field withdrawal for reported years (23.77 MGD) to get a ratio of 0.08. This ratio was then multiplied by the Murphree Well Field withdrawal data back to 1926 and divided equally amongst the R1 and R2 wells. Figure 4 shows the estimated flow into both University of Florida injection wells.

Figure 5 displays the time series for all injection wells where flows were estimated.

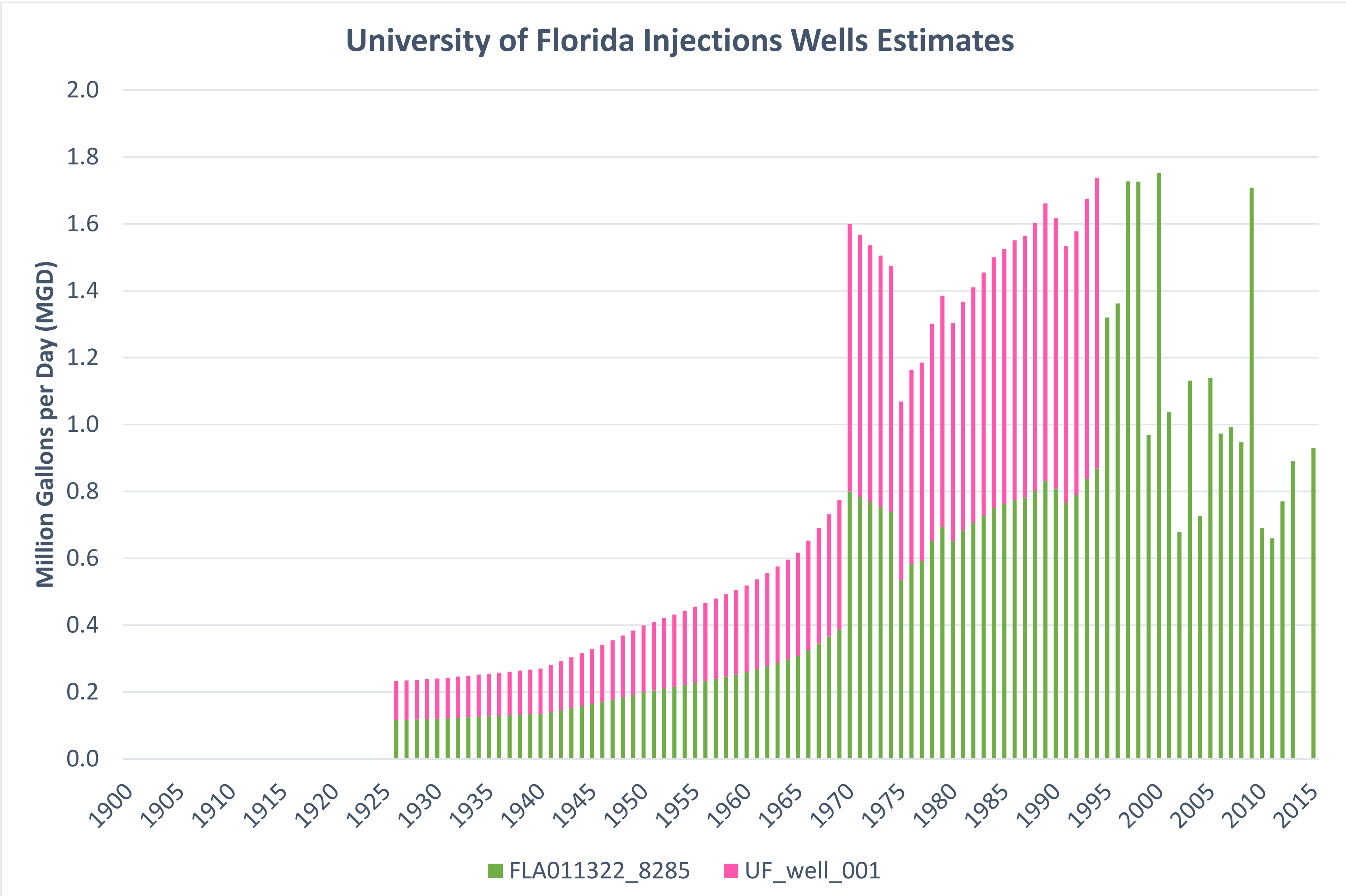


**Figure 4: Estimated flows for University of Florida injection wells**

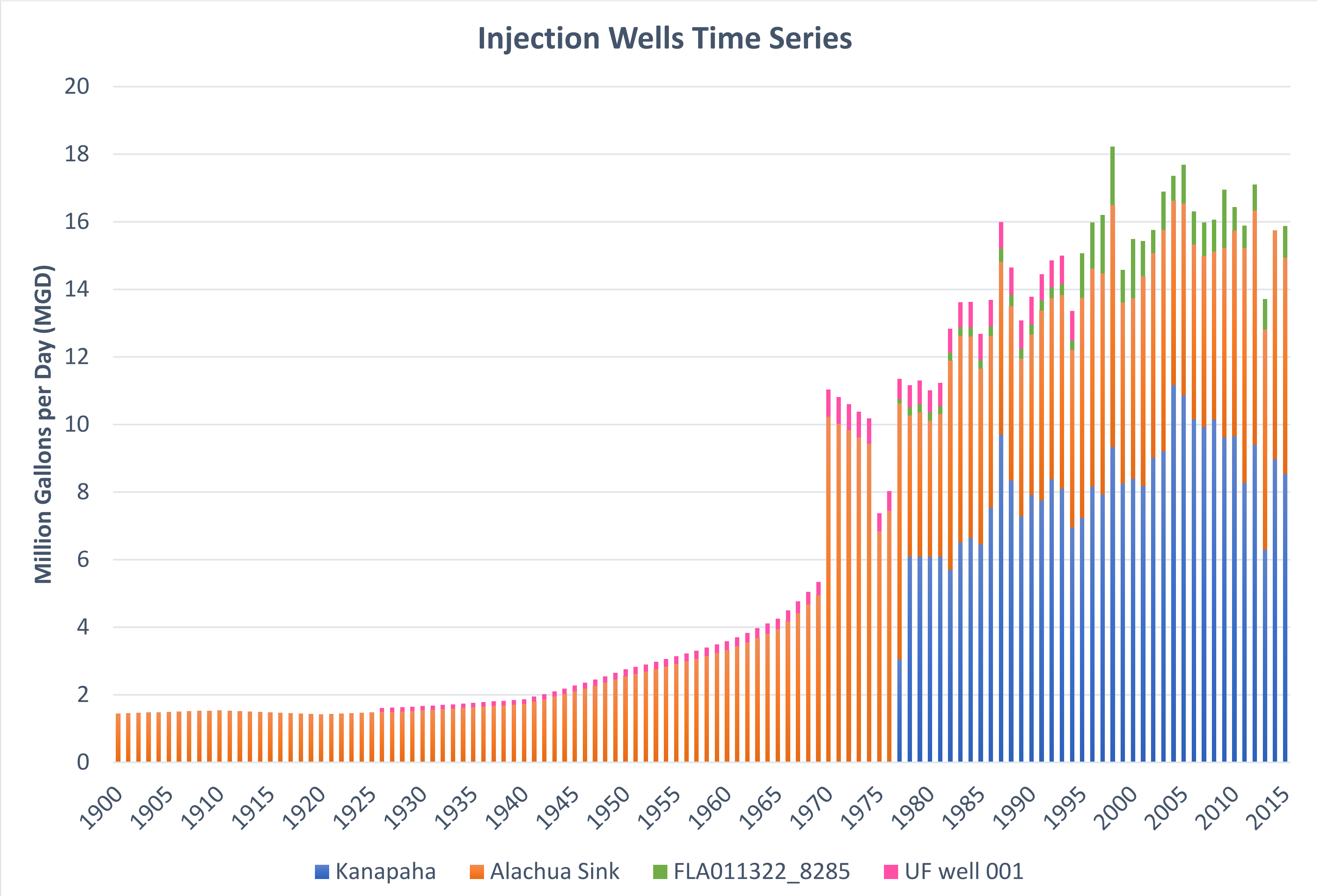


**Figure 5: Estimated injection well flows time series for all wells**

## Moving Average

Lastly, a five-year moving average was calculated from the injection rates for each station. This moving average used the current year, and four years prior to calculate an average that was then applied for the given year. For example, the years used to calculate a five-year moving average for 2015 would include 2011, 2012, 2013, 2014, and 2015. Figures 6-8 show the moving average estimates of injection for the Kanapaha well, Alachua Sink, and University of Florida wells. Figure 9 shows the moving average injection flows for all wells. The results of this injection well flow estimation process relative to the single-year estimates for the NFSEG are summarized in Table 2 (Durden et al. 2019).

| Year | Injection wells reclaimed water flows in NFSEG Domain (MGD) | Hindcasting Output (MGD) | Hindcasting Five-Year Moving Average Output (MGD) |
|---|---|---|---|
| **2001** | 16.40 | 15.42 | 15.98 |
| **2009** | 15.34 | 16.94 | 16.60 |
| **2010** | 14.18 | 16.44 | 16.35 |

**Table 2: Comparison between estimated injection well flows in the NFSEG model, hindcasting, and five-year moving average**

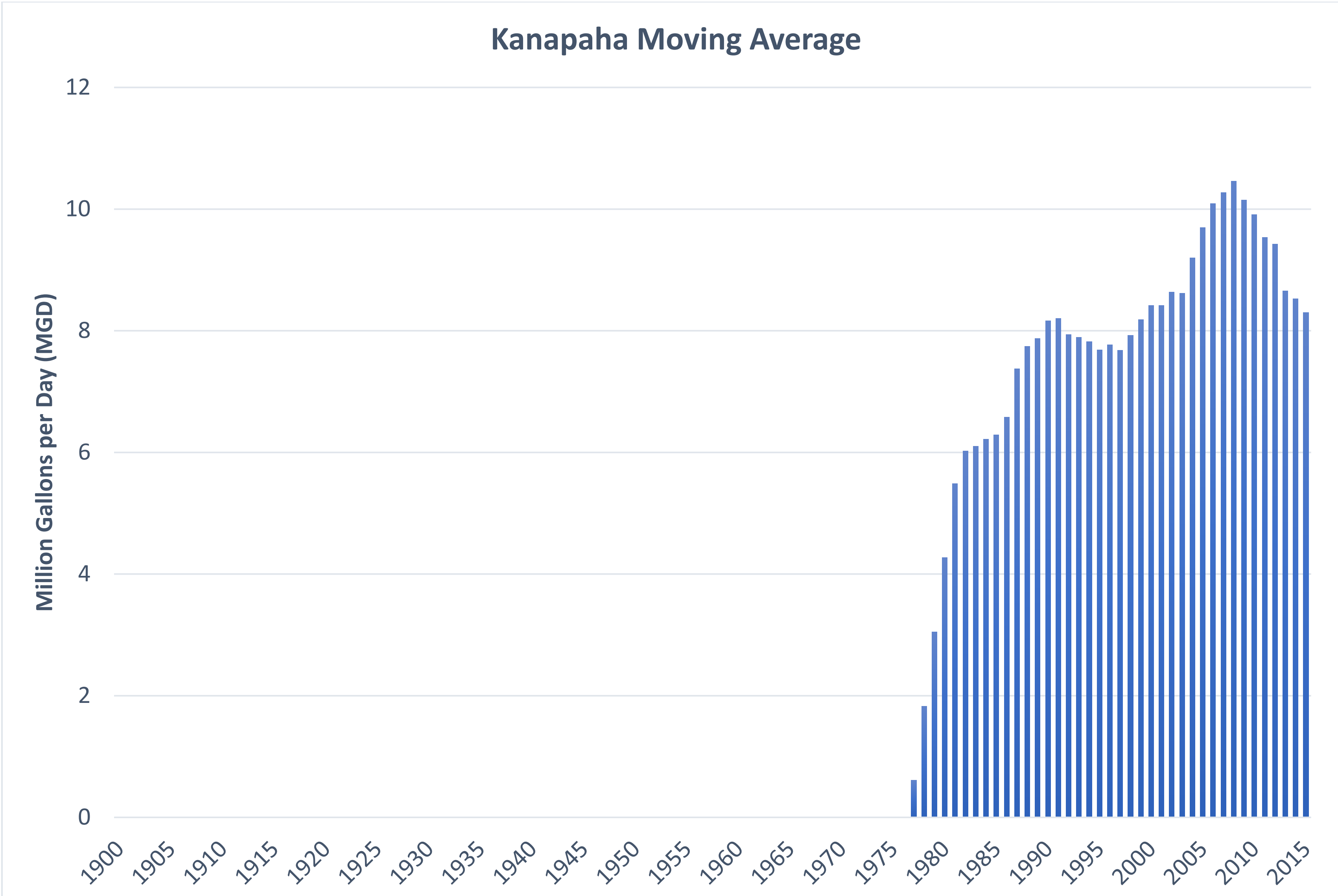


**Figure 6: Moving average time series for Kanapaha injection well**

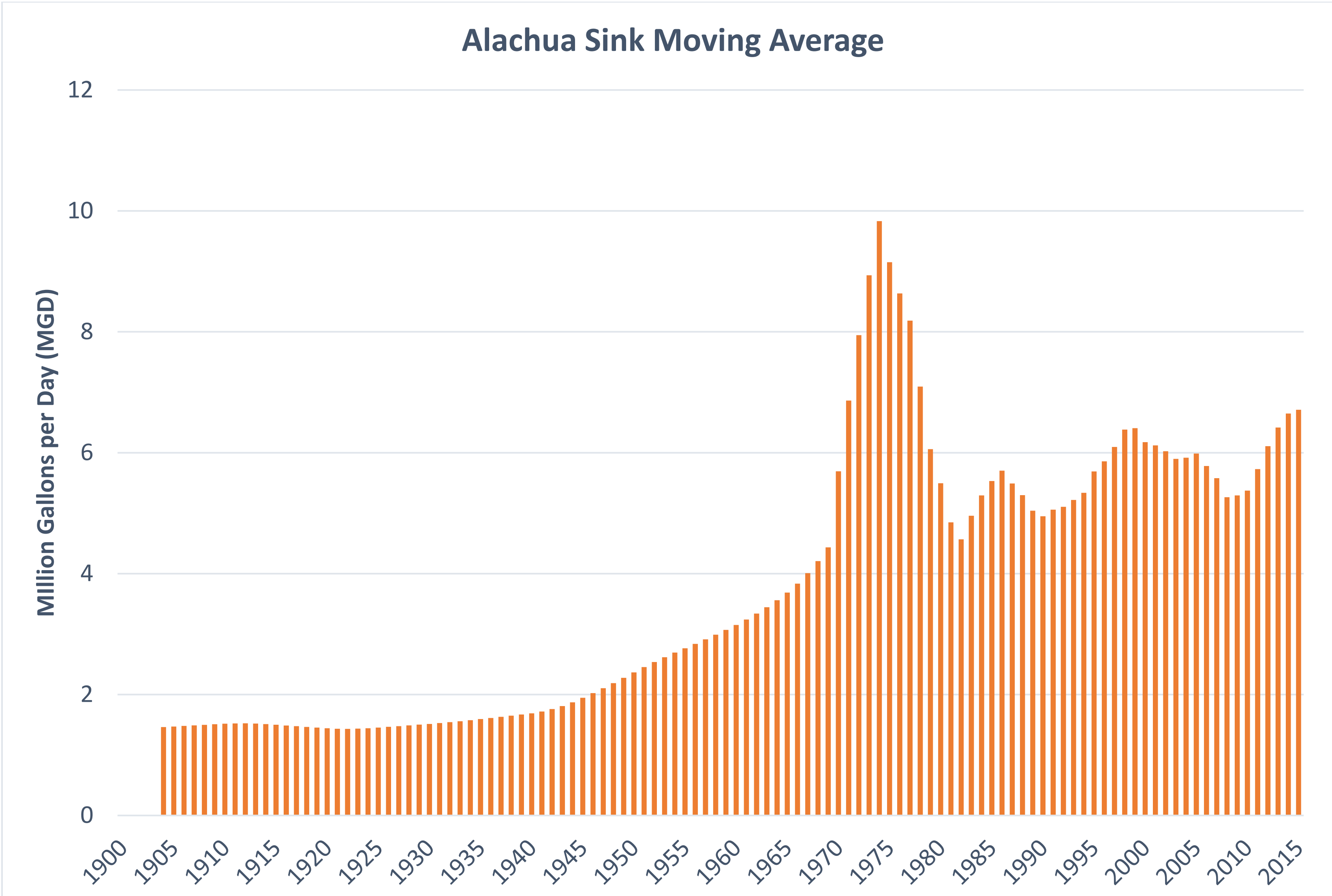


**Figure 7: Moving average time series for Alachua Sink**

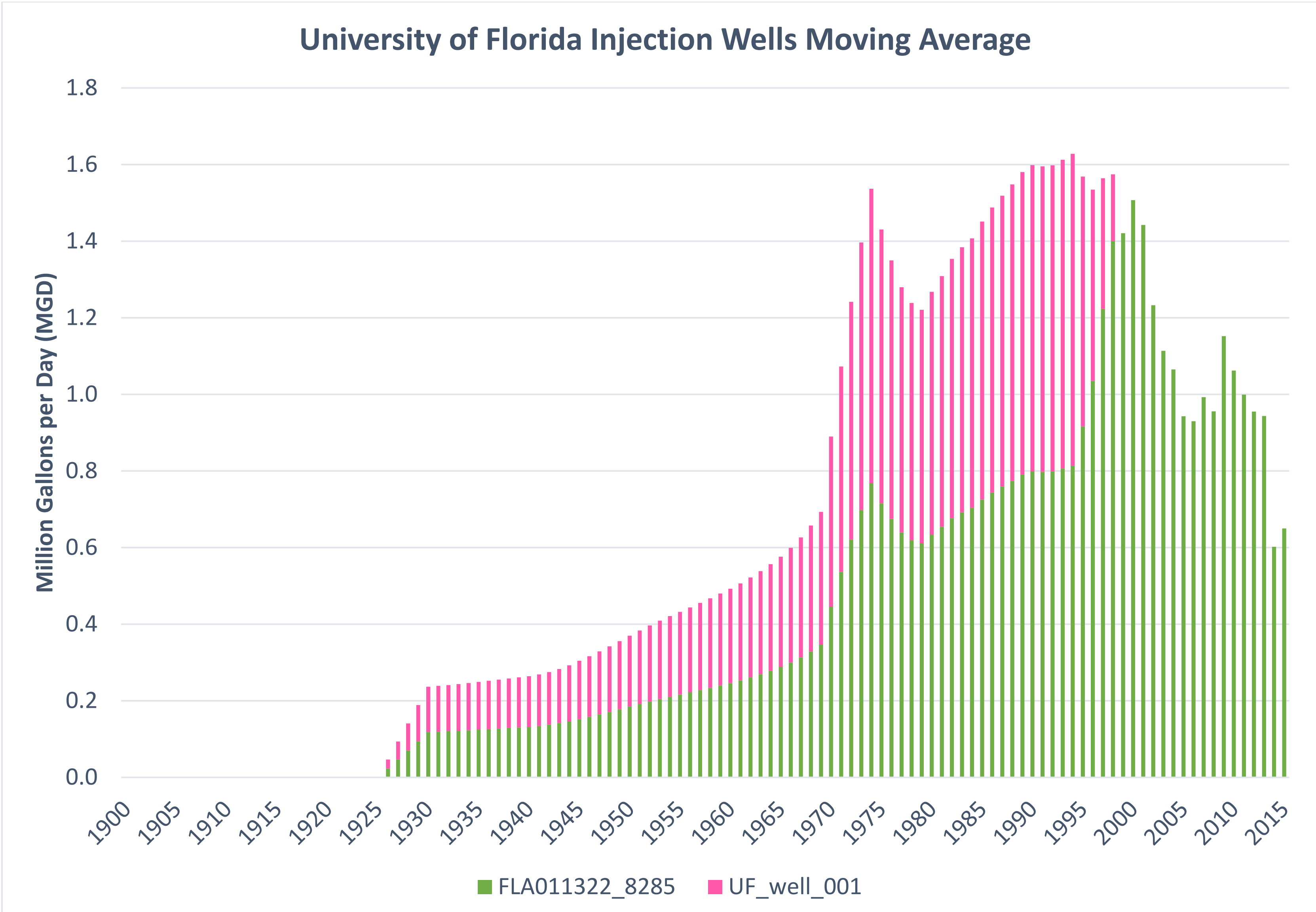


**Figure 8: Moving average time series for University of Florida injection wells**

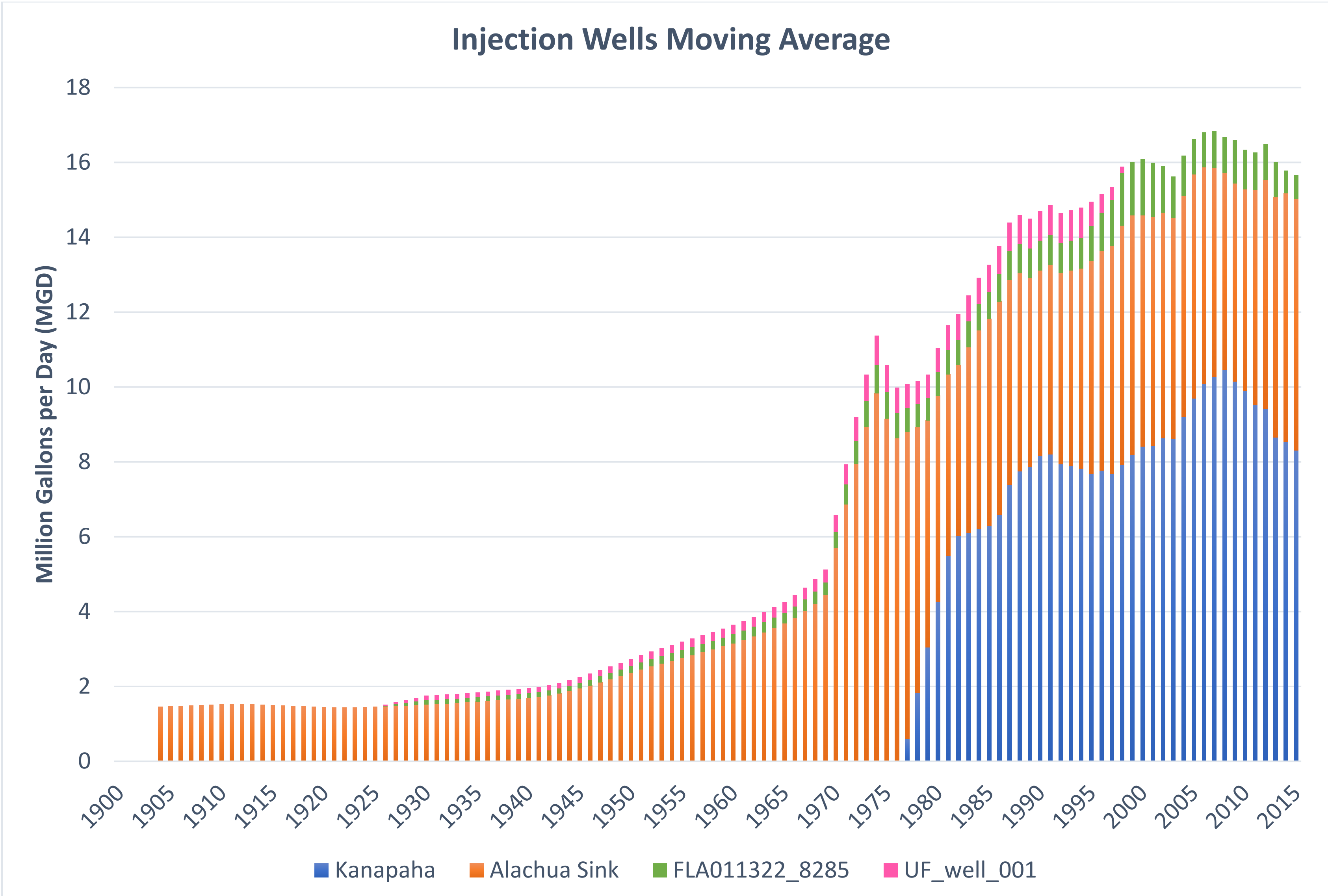


**Figure 9: Moving average time series for all injection wells**

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# Appendix C

**Development of a Reference Timeframe Flow (RTF) Regime for the Minimum Flows and Minimum Water Levels (MFLs) Evaluation of the Upper Suwannee River**

**(SRWMD 2021)**

# Appendix C – Development of a Reference Timeframe Flow (RTF) Regime for the Minimum Flows and Minimum Water Levels (MFLs) Evaluation of the Upper Suwannee River and Priority Springs

Author: SRWMD, 2021

# I. INTRODUCTION

This appendix outlines the process used to develop reference timeframe flow and/or groundwater-head (head) time-series at groundwater monitoring locations, springs and/or stream gage locations using observed and modeled data and an estimated time series of historic groundwater withdrawals (**Appendix B**). For this analysis, a reference timeframe head or flow time-series (referred henceforth as RTF) is defined as an estimate of the historic time-series that would have been observed in the absence of any groundwater withdrawals. In other words, the RTF is a time-series from which any impacts of groundwater withdrawals are removed. The concept of RTF generation is generally based on studies conducted by University of Idaho in the Snake River basin. Development of reference time series relies on utilizing the modeling results from the North Florida Southeast Georgia Groundwater Model, NFSEG (SJRWMD 2019).

The NFSEG model covers an area of 60,000 square miles, encompassing a large area of the Floridan aquifer system in north Florida, Georgia, and South Carolina. The model was developed in MODFLOW-NWT and is setup as a steady- state model representing detailed groundwater system as well as springs and major rivers. The model was calibrated to 2001 and 2009 hydrologic conditions and validated using 2010 conditions (SJRWMD, 2019). The groundwater system in NFSEG is represented using seven layers with Layer 1 representing the surficial aquifer system, Layer 3 representing the Upper Floridan aquifer, and Layers 5 representing deeper segment of the Florida aquifer system. **Figure 1** shows the spatial extent of the NFSEG model domain which is further discretized as 2500 ft by 2500 ft square cells (752 rows and 704 columns). Layer 3 and Layer 5 of the NFSEG model represent the water bearing units of the groundwater system where the majority of the groundwater withdrawal takes place. The surface water hydrology, providing recharge and maximum saturated evapotranspiration inputs to the MODFLOW-NWT model, was simulated using the Hydrological Simulation Program – FORTRAN (HSPF).

The groundwater withdrawals required for the development of RTFs were estimated on a yearly basis for each county in the NFSEG model domain (**Figure 1**) for calendar-years 1900-2015. A subset of these estimates were then used to evaluate changes in groundwater levels and flows in response to changes in groundwater use from 1928 through 2015 – the maximum period of continuous hydrologic record available for long-term analysis on the Upper Suwannee River. The estimated annual groundwater impacts (i.e. reduced flow/ head) were added back to an observed hydrograph of groundwater levels or flows at the site of interest to obtain a synthetic hydrograph representing the variation in groundwater levels or flows at the site in the absence of groundwater withdrawals. These adjusted hydrographs are referred to as reference timeframe flow or head time series. Long-term response of the groundwater system to changes in groundwater use over a long period of time was evaluated through application of the steady state NFSEG groundwater model. The following sections outline the detailed approach that was developed to estimate a RTF for a given monitoring location.

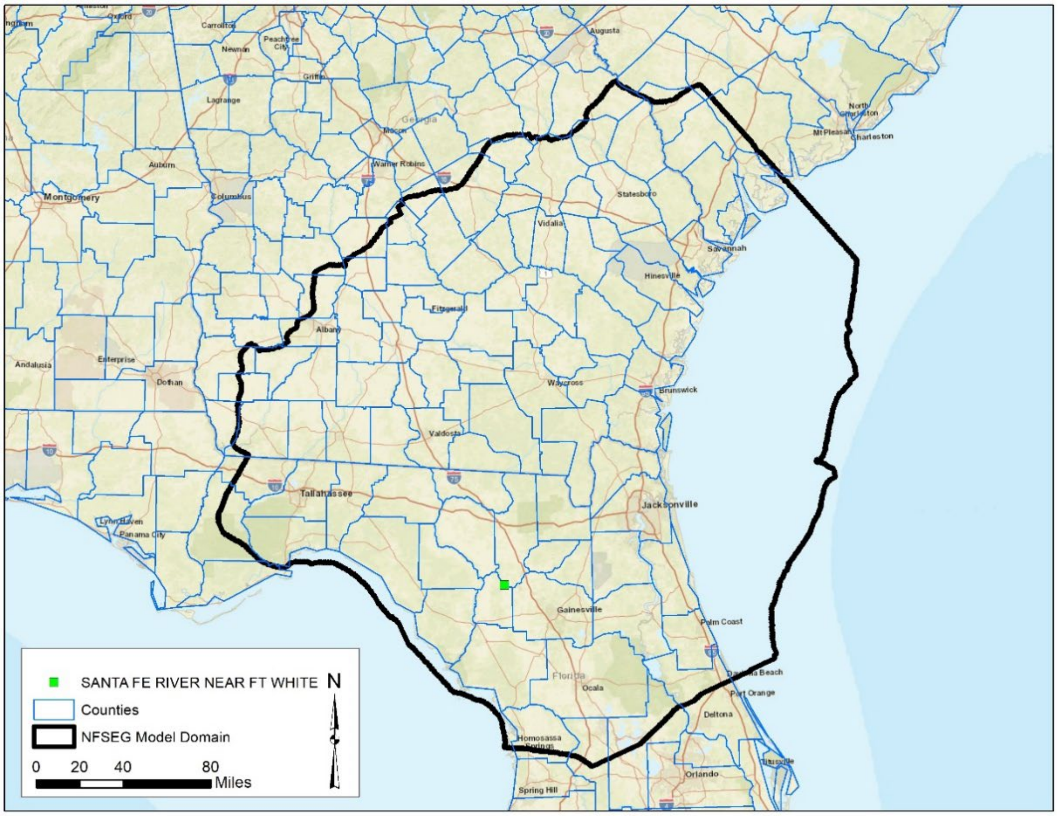


**Figure 1. NFSEG Model Domain**

# II. GENERAL APPROACH

The overall process of generating reference timeframe flow or head time-series for a site of interest entails:

- estimating historic impacts from groundwater withdrawals (as described below) at the site, and then,
- adjusting the observed, historic flow or head time-series at the site by removing the estimated groundwater-withdrawal impacts.

Estimation of impacts of groundwater withdrawals is a multi-step process relying on the results from the 2009-condition run of the NFSEG model. The model results were used to develop quantitative unitized estimates (called sensitivities) of the influence of groundwater withdrawals and/or return flow on the observed groundwater level and flow that can be subsequently be used for hindcasting of the impacts (relying on historic groundwater withdrawal conditions).

- The first step involves estimating the influence of ambient groundwater withdrawals on observed values (head and/or flow) (reduction or increase) at a location of interest (monitoring well, stream gage, or spring)
- The second step involves quantifying changes in flow or head values arising due to influence of "return-flows" (e.g., irrigation or other anthropogenic land-surface applications).
- In the final step, the net change in head and/or flow at the location is derived by aggregating the groundwater withdrawal impacts (generally resulting in lowering of flows and head) and

return flow impacts (generally resulting in increasing of flow and head) and adding to an observed, historic time series of flows or heads at the location of interest.

A key concept utilized in the development of the reference timeframe flow (or head) is “sensitivity”. Sensitivity for a given location of interest (spring/stream gage/groundwater monitoring well) is defined with respect to another place within the watershed (e.g.  public supply withdrawal location) and is quantified as the expected change in the observed flow (or head) values at the location of interest due to a 1 MGD   change in the groundwater withdrawal or 1 cfs change in the return flow at the given place (i.e., public supply withdrawal location). Within the model domain, the locations of interest are identified by a grid cell location. In simple terms, once sensitivity value maps are generated for each cell the expected change in the observed flow (or head) at a location of interest can be directly computed by multiplying the sensitivity values associated with a withdrawal/return-flow cell location with the actual magnitude of the withdrawal or return flow. The expected change is then summed over the model cells. This process can subsequently be expanded to include historical time-series.

To help with illustration of the process of the development of RTF time-series, numerical values from the analysis conducted at the USGS gage on Santa Fe River Near Ft. White (USGS Gage ID 02322500, Ft. White gage) will be used as an example. The NFSEG model setup is detailed enough to accurately simulate groundwater flow at the Ft. White gage. The direct groundwater contribution to the river is represented via use of river cells (**Figure 2**) while groundwater contribution from drains and springs are captured via several other model cells (**Figure 3** and **Figure 4**)

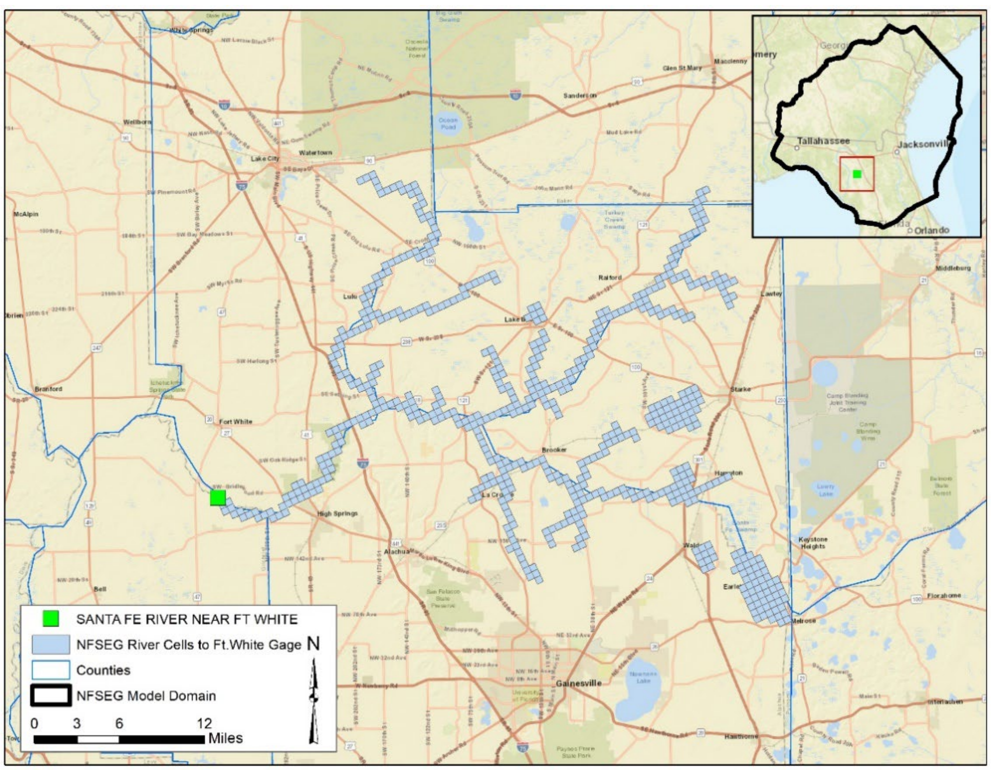


**Figure 2: NFSEG River Cells Contributing to Ft. White Gage**

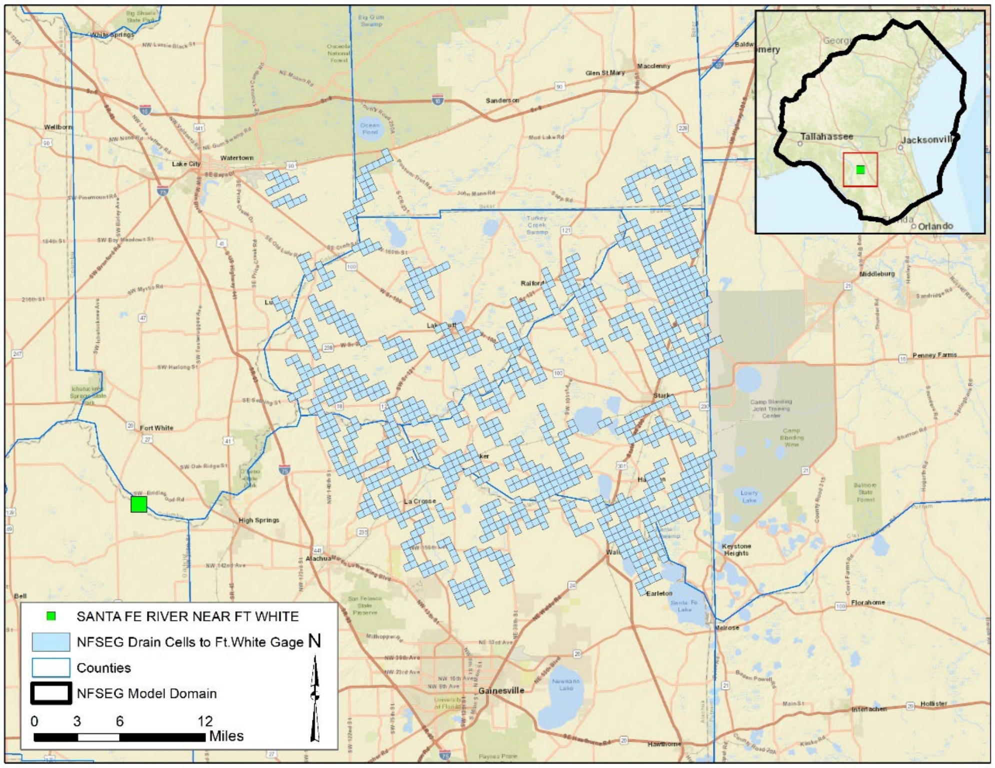


**Figure 3: NFSEG Drain Cells Contributing to Ft. White Gage**

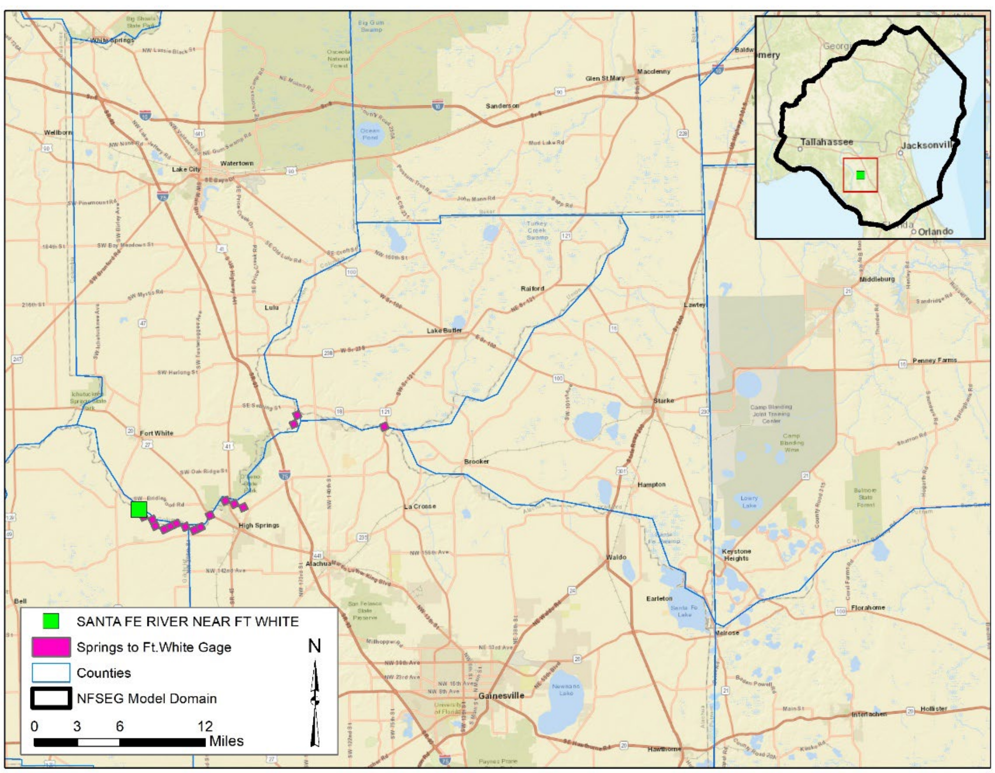


**Figure 4: NFSEG Spring Cells Contributing to Ft. White Gage**

## 2.1 Estimation of Gross Impacts from Groundwater Withdrawals

For the development of RTFs, two different versions of NFSEG model, namely NFSEG v1.1 (Case 007h) and NFSEG v1.1(Case 007h1) were used. NFSEG v1.1(Case 007h) refers to the calibrated model submitted for final peer review. NFSEG v1.1(Case 007h1) refers to the version released for public use in which the groundwater recharge specified in the peer review model was updated to reflect the HSPF-derived recharge (NFSEG Addendum, 2019). Refer to **Section 2.2** for additional details for Case 007h1.

NFSEG v1.1 (Case 007h) formed the basis of the quantifying groundwater impacts for the estimation of the sensitivity values. Groundwater withdrawals in NFSEG model are specified using groundwater wells that either extract water from a single hydrogeologic unit (modeling layer), primarily Layer 3 and Layer 5 (regular wells) or in some cases are screened to allow withdrawals from multiple layers (multi-node wells MNW).

For regular wells, the process of developing sensitivity maps involved running the calibrated steady state NFSEG v 1.1 (2009 conditions, Case 007h) model several times. For each model run, the calibrated base NFSEG model was modified by specifying an additional 1 MGD injection flow at a single model cell in Layer 3. The process was repeated for every active cell in Layer 3 of the NFSEG model. The simulated flow (or head) value at a given location of interest for every model run was compared against the base NFSEG model simulated head or flow value and the difference was assigned as the sensitivity value for the corresponding cell with 1 MGD of added injection rate. This process results in determining sensitivity values at all cells within the model domain (for Layer 3) for the given location of interest. A similar process is subsequently repeated for each individual cell in Layer 5 of the NFSEG model. **Figure 5** shows an example from a selected cell (highlighted red) where an additional 1MGD flow was injected in Layer 3 and as indicated in **Figure 5** the simulated flow at the Ft. White gage increased from 726.779 cfs to 727.682 cfs. The sensitivity value associated with the highlighted cell with a 1 MGD injection in Layer 3, was thus computed as:

$$S = \frac{727.682-726.779}{1} = 0.903\,\frac{cfs}{mgd} = 0.903 \times \frac{86400\times 7.48052}{1e6} = 0.583 \text{ cfs/cfs} \qquad (1)$$

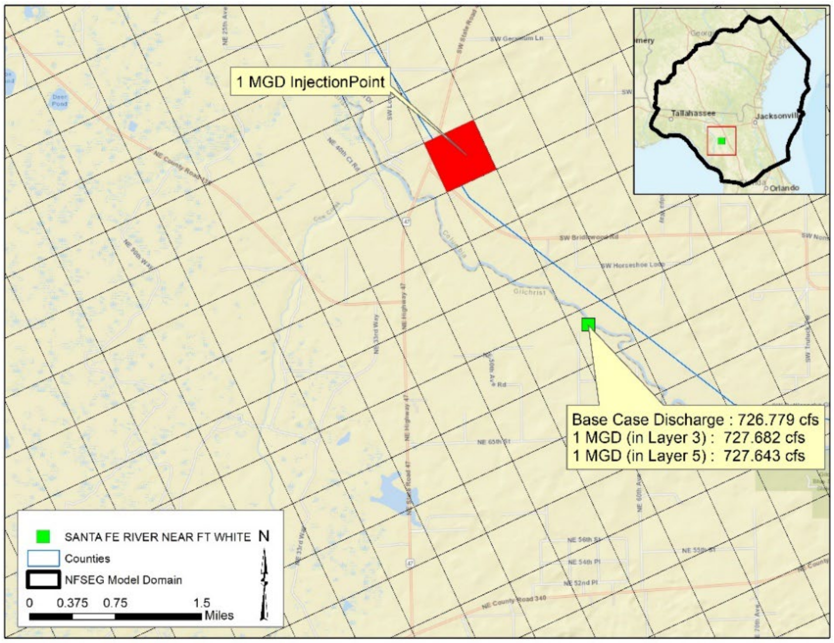


**Figure 5: Selected Location of Additional 1 MGD Injection Flow and Corresponding Changes in the Simulated Flow at Ft. White Gage**

If the same injection of 1 MGD is transferred from Layer 3 to Layer 5 the simulated flow value at the Ft. White gage increases to 727.643 cfs (**Figure 5**) resulting in a sensitivity value of 0.558 (using **Equation 1**). **Figure 6** shows results from a second location where a 1 MGD injection flow in Layer 3 and Layer 5 results in flow increases of 726.812 cfs and 727.049 cfs, respectively, resulting in corresponding sensitivity values of 0.022 and 0.170 (**Figure 7**)

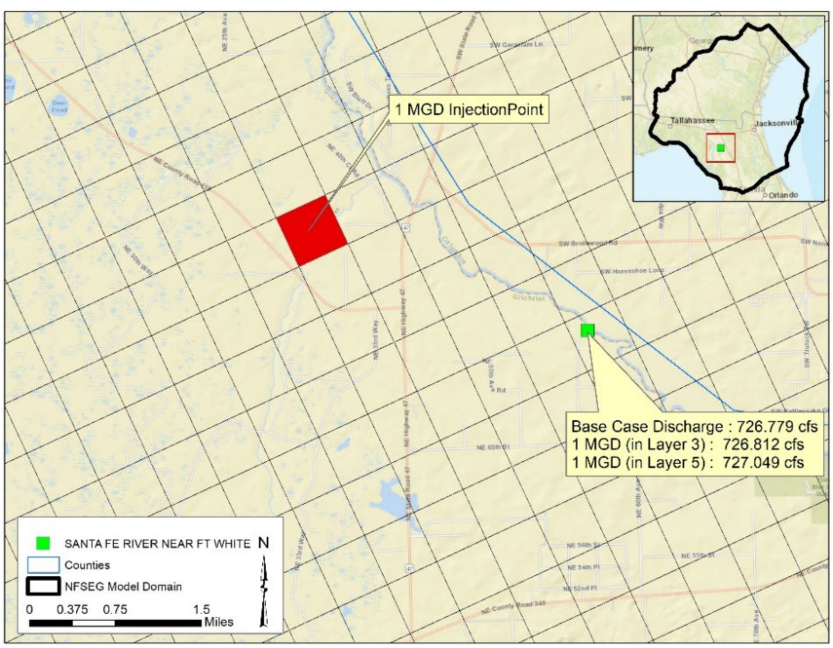


**Figure 6: Second Selected Location of Additional 1 MGD Injection Flow and Corresponding Changes in the Simulated Flow at Ft. White Gage**

This exercise, when conducted for all individual cells in Layer 3 and Layer 5, resulted in spatially distributed sensitivity values that can be mapped to indicate influence (sensitivity) of an individual cell on the Ft. White gage (see **Figure 7** and **Figure 8**). Overall, the model wide sensitivity maps for the Ft. White gage are shown in **Figure 9** and **Figure 10,** showing the local influence of groundwater impacts (higher sensitivity value areas).

<u>**Aggregation of Sensitivity Values based on County and Water-Use Type**</u>

The individual sensitivity values, though accurate and refined, do not lend themselves to long-term hindcasting since they rely on exact withdrawal locations to compute the impact on the gage (or well) of interest, which for historical withdrawals may not be available. Thus, it was decided to aggregate the computed sensitivity values based on unique combinations of County and water-use categories (as used in **Appendix B**). The well package simulated in the NFSEG v1.1 model (representing the 2009 condition) was categorized based on County and Use type (see **Table 1** as an example). The sensitivity values (**Figure 9** and **Figure 10**) from individual cells where withdrawal was specified were multiplied by the corresponding withdrawal rate to compute the expected reduction in flow at Ft. White due to withdrawals. The computed reduction for each combination of given County and use-type was summed to compute the aggregated flow reduction at the Ft. White gage due to a use-type in a County.

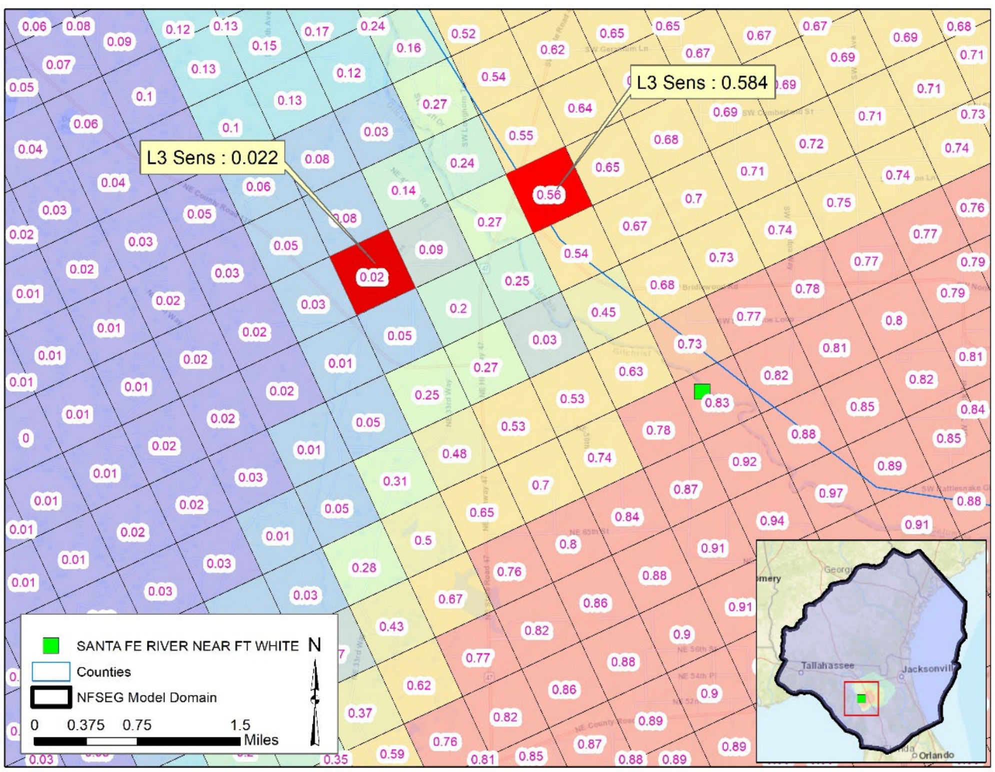


**Figure 7: Zoomed-In Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 3 for the Simulated Flow at Ft. White Gage**

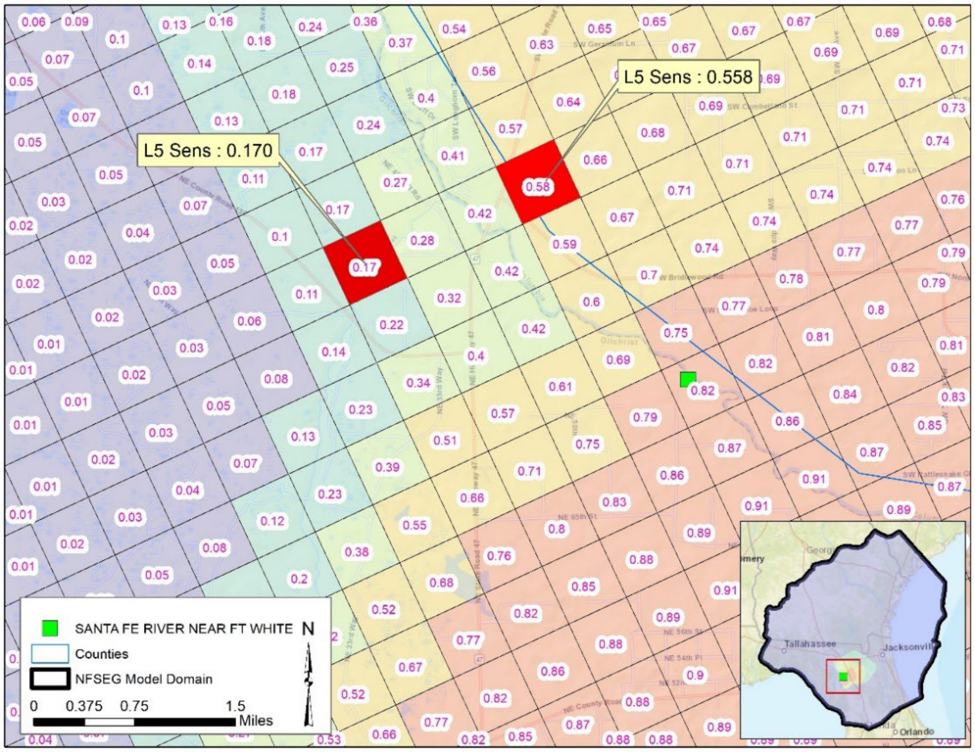


**Figure 8: Zoomed-In Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 5 for the Simulated Flow at Ft. White Gage**

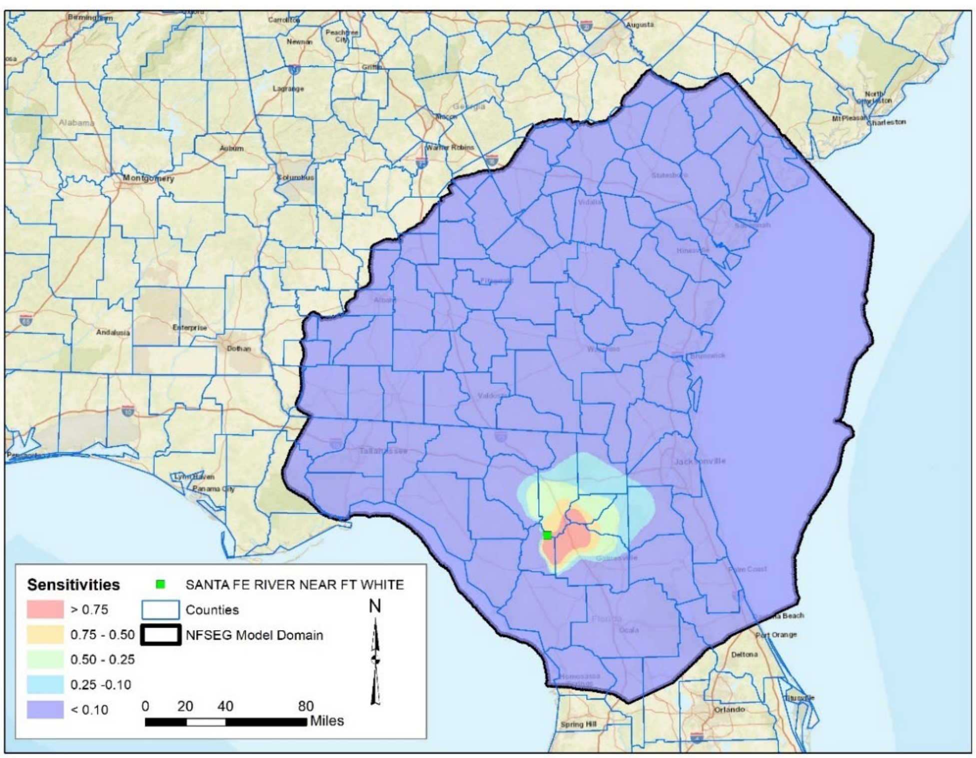


**Figure 9: Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 3 for the Simulated Flow at Ft. White Gage**

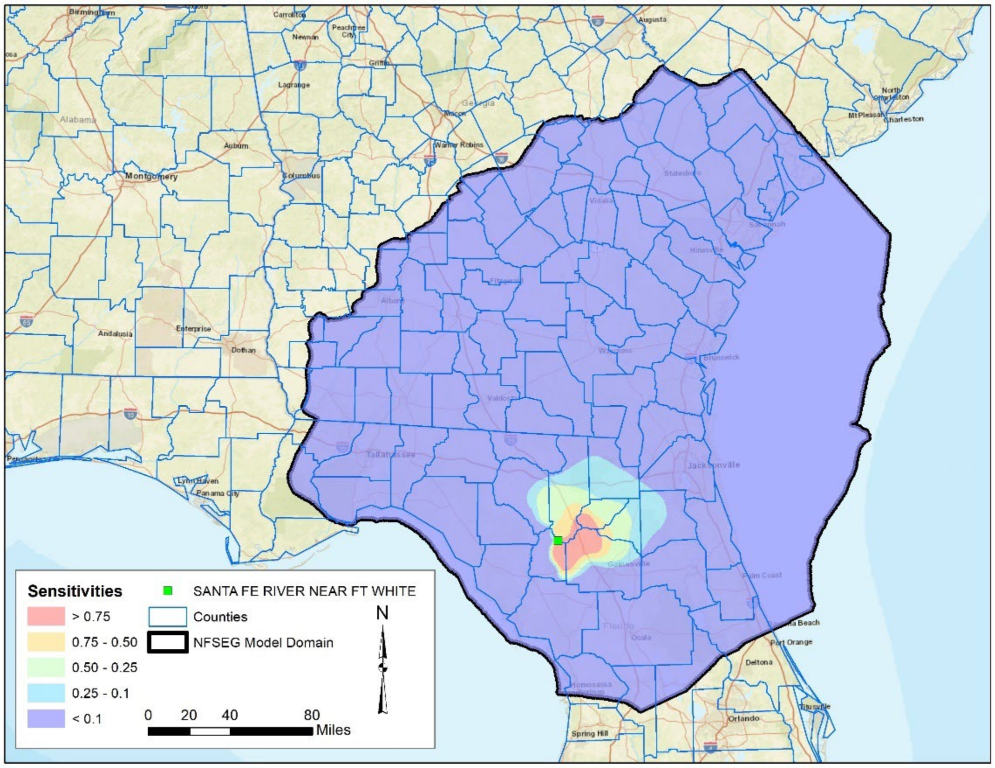


**Figure 10: Sensitivity Map Associated with a Cell-by-Cell 1 MGD Injection Applied to Layer 5 for the Simulated Flow at Ft. White Gage**

| Layer | Row | Column | State | County | Use Type | 2009 Withdrawal (MGD) |
|---|---|---|---|---|---|---|
| 3 | 488 | 162 | FL | Taylor | CII | 4.255 |
| 3 | 488 | 162 | FL | Taylor | CII | 4.255 |
| 3 | 488 | 164 | FL | Taylor | CII | 4.255 |
| 3 | 488 | 164 | FL | Taylor | CII | 4.255 |
| 3 | 489 | 166 | FL | Taylor | CII | 4.255 |
| 5 | 472 | 257 | FL | Hamilton | MD | 3.349 |
| 3 | 398 | 93 | FL | Leon | CII | 3.206 |
| 3 | 398 | 93 | FL | Leon | CII | 3.206 |
| 3 | 398 | 93 | FL | Leon | CII | 3.206 |
| 3 | 510 | 433 | FL | Nassau | CII | 2.809 |
| 5 | 540 | 229 | FL | Suwannee | AG | 0.027* |
| 5 | 570 | 213 | FL | Gilchrist | AG | 0.012* |
| 5 | 585 | 268 | FL | Alachua | LRA | 0.03* |
| 5 | 617 | 294 | FL | Alachua | LRA | 0.01* |

**Table 1. Example of Withdrawal Dataset from 2009 Well Package, Indicating County and Use Type [*Shown in Figure 11]**

**Figure 11** shows selected groundwater withdrawals from Layer 5 in the vicinity of the lower Santa Fe River system. For Alachua County, for example, the two wells for Landscape/Recreation/Aesthetics uses are withdrawing 0.03 MGD and 0.01 MGD, respectively (based on the 2009 well package from NFSEG v1.1 model). The single well sensitivity map (**Figure 10**) indicated sensitivity values at the corresponding withdrawal locations are 0.752 and 0.058, respectively, thus the overall influence of LRA withdrawals from Layer 5 in Alachua County on flow at Ft. White would be

$$\Delta Q = \frac{[(0.752 \times 0.03) + (0.058 \times 0.01)]}{86400 * 7.48052} \times 1e6 = 0.036\ cfs \qquad (2)$$

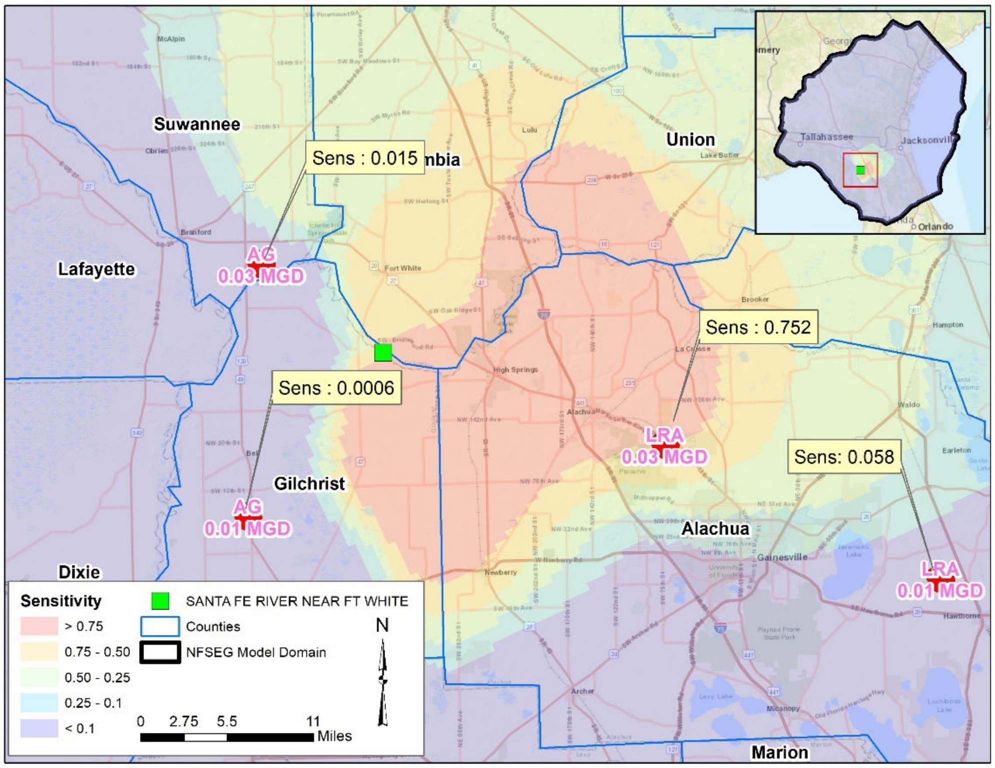


**Figure 11. Selected Groundwater Withdrawal Locations (and Use-Type) in Layer 5. The Withdrawal Quantities are based on 2009 NFSEG v1.1 Well Package**

Similarly, the 2009 AG use type withdrawals in Suwannee and Gilchrist from Layer 5 would result in a reduction of 0.0006 cfs (using **Equation 2**) and 1E-5 cfs, respectively. **Table 2** shows a clip of reduction in flow values at Ft. White gage due to withdrawals associated with a combination of County and use type.

| State | County | Use Type | Model Layer | Flow Reduction Estimates(cfs) |
|---|---|---|---|---|
| FL | Alachua | PS | 3 | 14.9435 |
| FL | Alachua | AG | 3 | 9.0165 |
| FL | Duval | PS | 3 | 3.0295 |
| FL | Nassau | CII | 3 | 2.9802 |
| FL | Alachua | CII | 3 | 2.8905 |
| FL | Alachua | DSS | 3 | 2.8080 |
| FL | Columbia | AG | 3 | 2.6209 |
| FL | Suwannee | AG | 3 | 2.4619 |
| FL | Alachua | LRA | 5* | 0.0361 |
| FL | Suwannee | AG | 5* | 0.0006 |
| FL | Gilchrist | AG | 5* | 1E-5 |

**Table 2. Selected Flow Reduction Estimates (using 2009 withdrawal data) for Ft. White Gage [*Locations are show in Figure 8]**

The flow reduction estimates (**Table 2**) associated with the same use type in a given county, but in different layers, were simply summed to create an aggregated flow reduction table (see **Table 3**) based on County and use-type.

| State | County | Use Type | Number of Locations | Total Withdrawals (MGD) | Flow Reduction Estimates (cfs) |
|---|---|---|---|---|---|
| FL | Baker | CII | 9 | 0.43 | 0.123 |
| FL | Clay | AG | 102 | 0.36 | 0.047 |
| FL | Clay | CII | 29 | 0.30 | 0.032 |
| FL | Clay | LRA | 20 | 0.13 | 0.013 |
| FL | Clay | CII | 29 | 0.30 | 0.032 |
| FL | Clay | PS | 23 | 1.74 | 0.202 |
| FL | Duval | AG | 42 | 0.96 | 0.097 |
| FL | Duval | CII | 71 | 6.01 | 0.571 |
| FL | Duval | LRA | 59 | 0.66 | 0.063 |
| FL | Duval | PS | 92 | 32.15 | 3.029 |
| FL | Lake | AG | 470 | 5.19 | 0.010 |
| FL | Lake | CII | 43 | 1.57 | 0.002 |
| FL | Lake | PS | 191 | 19.64 | 0.033 |
| FL | Marion | AG | 970 | 10.36 | 0.226 |
| FL | Nassau | PS | 22 | 4.94 | 0.471 |
| FL | Putnam | CII | 46 | 2.64 | 0.145 |

**Table 3. Selected Aggregated Flow Reduction Estimates (using 2009 withdrawal data) for Ft. White Gage**

**Table 3** provides a representative table quantifying influence of "regular wells" (a term used for describing wells screened in a single layer) on the flow at Ft. White (2009 average conditions). For groundwater wells of interest, the aforementioned process would result in quantification of influence of "regular wells" on the observed head (delta head).

As mentioned earlier, NFSEG v1.1 represents the groundwater withdrawals using regular wells screened in a single layer (simulated using MODFLOW well package) and multi-node wells (MNW, simulated using MODFLOW MNW2 package) that are screened in multiple layers. **Table 4** lists the sixteen MNW wells that were specified in the NFSEG v1.1 model. Calculation of sensitivity values and subsequent determination of impacts due to flow reduction at a gage or observation well of interest was achieved by selectively turning off MNW wells of a given county and use type and noting the resulting increases in simulated flow (or head) at the gage (or observation well) of interest. For instance, in one model run only withdrawals associated with CII wells in Baker county were turned off, leaving all other specified withdrawals as-is. For the second model run, AG withdrawals in Clay County were turned off and the process repeated for the next county until all remaining counties are completed. **Table 4** shows the calibrated simulated base flow at the Ft. White gage and the simulated flows associated with turning off the corresponding set of wells. In Clay County, for example, AG MNW withdrawals (2009 conditions) were 0.21 MGD. Switching them off resulted in the flow increase of 0.023 cfs (= 726.802-726.779). Similarly, by switching off the 0.12 MGD withdrawals associated with CII wells in Clay County, the simulated flow at Ft. White gage increased by 0.0205 cfs (726.800 – 726.779). **Figure 12** shows the location of Clay County with the example withdrawals and their impacts on the Ft. White gage.

| State | County | Use Type | Total Withdrawals (MGD) | Base Q (cfs) | Scenario Q (cfs) | Del Q (cfs) |
|---|---|---|---|---|---|---|
| FL | Baker | CII | 0.29 | 726.779 | 726.840 | 0.061 |
| FL | Clay | AG | 0.21 | 726.779 | 726.802 | 0.023 |
| FL | Clay | CII | 0.12 | 726.779 | 726.800 | 0.021 |
| FL | Clay | LRA | 0.49 | 726.779 | 726.834 | 0.055 |
| FL | Clay | CII | 0.44 | 726.779 | 726.841 | 0.062 |
| FL | Clay | PS | 12.01 | 726.779 | 728.093 | 1.314 |
| FL | Duval | AG | 0.01 | 726.779 | 726.779 | 0.000 |
| FL | Duval | CII | 14.05 | 726.779 | 728.216 | 1.437 |
| FL | Duval | LRA | 0.76 | 726.779 | 726.852 | 0.073 |
| FL | Duval | PS | 84.63 | 726.779 | 735.338 | 8.559 |
| FL | Lake | AG | 0.42 | 726.779 | 726.782 | 0.003 |
| FL | Lake | CII | 0.13 | 726.779 | 726.780 | 0.001 |
| FL | Lake | PS | 3.28 | 726.779 | 726.784 | 0.005 |
| FL | Marion | AG | 0.11 | 726.779 | 726.780 | 0.001 |
| FL | Nassau | PS | 2.31 | 726.779 | 727.000 | 0.221 |
| FL | Putnam | CII | 0.07 | 726.779 | 726.784 | 0.005 |

**Table 4. All MNW Wells Specified in NFSEG v1.1 and Computed Flow Change Reduction at the Ft. White Gage when each is turned off in the model.**

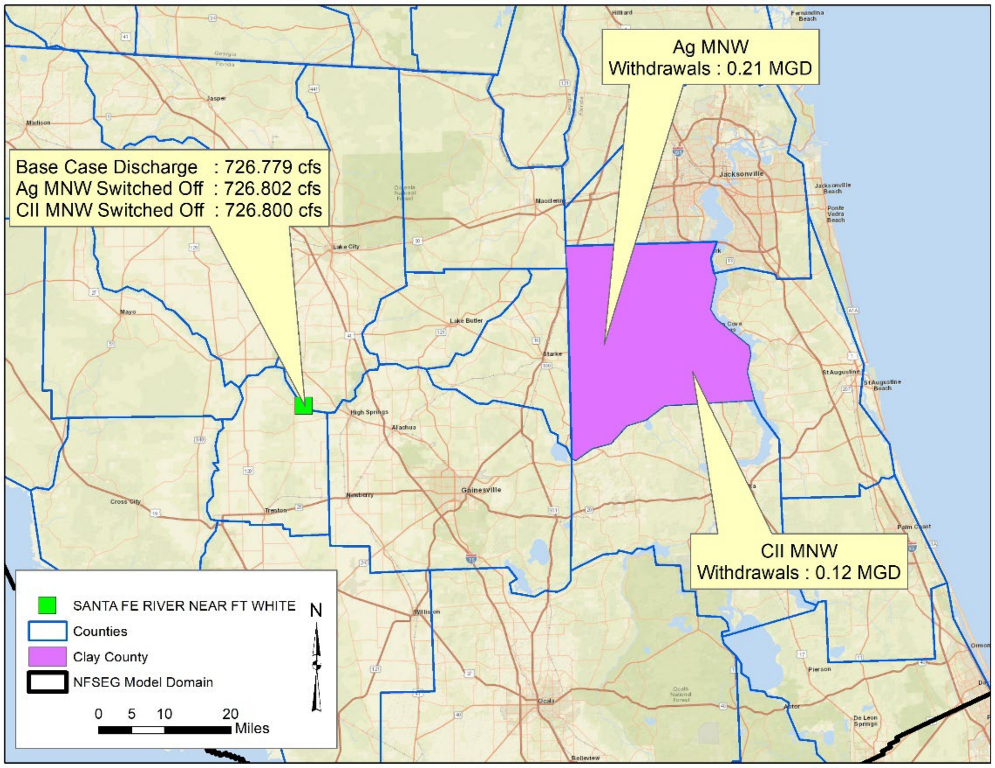


**Figure 12. Clay County AG and CII MNW Wells and their impacts on the Ft. White gage**

For long-term hindcasting it would be impractical to differentiate between an MNW and a regular well, hence composite groundwater withdrawal effective sensitivity estimates based on County and Use-type were developed. Estimated reductions in flow (or head) from regular and MNW wells for a given County and Use-type combination can be added and then divided by the total MNW and regular flow withdrawal values to develop effective sensitivity values for groundwater withdrawal for the combination of County and use-type. For Ft. White gage, **Table 5** aggregates results from regular wells (**Table 3**) and MNW wells (**Table 4)** and computes total flow reduction and effective sensitivity to groundwater withdrawals associated with a combination of county and use-type. As an example, for Baker County CII wells, the total withdrawal (2009 condition) from regular wells was 0.43 MGD and the corresponding flow reduction at Ft. White gage was 0.12 cfs. For the same county and Use-type combination of MNW wells the total withdrawal was 0.29 MGD and the corresponding reduction at Ft. White gage was 0.061 cfs. Combining them results in a total flow reduction of 0.181 cfs for a total withdrawal of 0.72 MGD (= 1.114 cfs). Thus, the effective sensitivity value would be 0.164 cfs/cfs (=0.181/1.114). The other effective sensitivity values can be calculated in a similar way. It should be noted that for counties and use-types that did not have MNW wells the effective sensitivity could simply be computed by assuming MNW withdrawals and associated flow reduction to be zero. **Figure 13** shows the effective sensitivity map for Public Supply Wells. Similar effective sensitivity datasets were developed for all possible combinations of county and use-type.

| County | Use Type | Reg. Wells Withdrawals (MGD) | Delta Q (cfs, Reg. Wells) | MNW Wells Withdrawals (MGD) | Delta Q (cfs, MNW Wells) | Total Withdrawals (MGD) | Effective Sensitivity (cfs/cfs) |
|---|---|---|---|---|---|---|---|
| Baker | CII | 0.43 | 0.12 | 0.29 | 0.061 | 0.72 | 0.164 |
| Clay | AG | 0.36 | 0.05 | 0.21 | 0.023 | 0.57 | 0.080 |
| Clay | CII | 0.30 | 0.03 | 0.12 | 0.021 | 0.43 | 0.080 |
| Clay | LRA | 0.13 | 0.01 | 0.49 | 0.055 | 0.62 | 0.071 |
| Clay | CII | 0.30 | 0.03 | 0.44 | 0.062 | 0.74 | 0.082 |
| Clay | PS | 1.74 | 0.20 | 12.01 | 1.314 | 13.75 | 0.071 |
| Duval | AG | 0.96 | 0.10 | 0.01 | -0.001 | 0.96 | 0.064 |
| Duval | CII | 6.01 | 0.57 | 14.05 | 1.437 | 20.06 | 0.065 |
| Duval | LRA | 0.66 | 0.06 | 0.76 | 0.073 | 1.42 | 0.062 |
| Duval | PS | 32.15 | 3.03 | 84.63 | 8.559 | 116.79 | 0.064 |
| Lake | AG | 5.19 | 0.01 | 0.42 | 0.003 | 5.61 | 0.002 |
| Lake | CII | 1.57 | 0.00 | 0.13 | 0.001 | 1.70 | 0.001 |
| Lake | PS | 19.64 | 0.03 | 3.28 | 0.005 | 22.91 | 0.001 |
| Marion | AG | 10.36 | 0.23 | 0.11 | 0.001 | 10.47 | 0.014 |

**Table 5. Aggregated Withdrawals and Flow-Reduction Estimates for Regular and MNW wells**

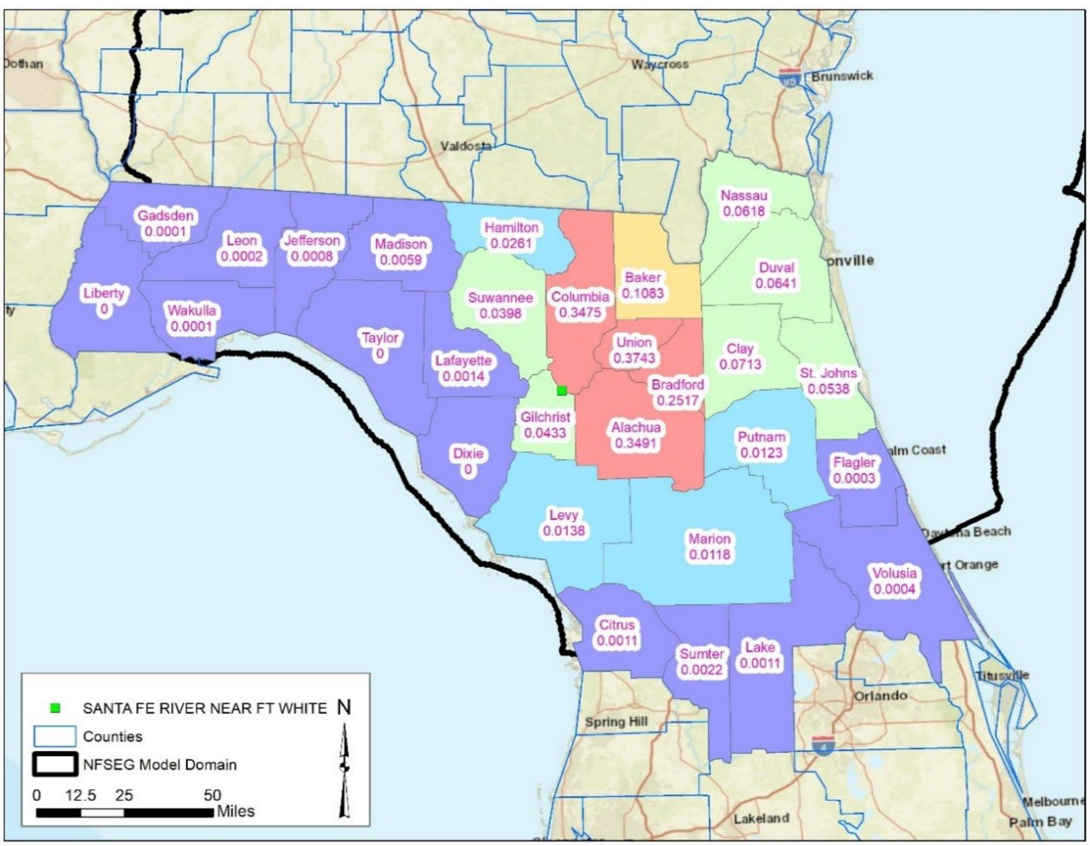


**Figure 13. Effective Sensitivities at the Ft. White Gage for PS Withdrawals for Different Florida Counties**

Historic changes in flow or head were estimated by repeating the following two operations for each year in the historic period. In the first operation, the incremental impact from groundwater withdrawals associated with a given combination of county and use-type was first estimated by multiplying the total groundwater withdrawals in that year for that combination of county and use-type by the effective sensitivity values (ratio of flow or head change per unit change in groundwater withdrawal) associated with that combination of county and use-type. In the second operation, an estimate of the total impact of groundwater withdrawals during that year was computed by adding together the incremental impacts estimated for that year for all of the county and use-type combinations computed in the previous step. The effective sensitivity values were obtained using the methodology described above, while the county-level and use-type specific historic water use time series development is described in **Appendix B**. An assumption underlying the application of the water use hindcasting process (**Appendix B**) to the generation of RTFs is that the well location distribution in 2009 and individual well withdrawals relative to the county total for that use type, are representative for a given use type, through time, in that county. For example, the number of agricultural wells since 1900 are assumed to be in the same locations as the present day (2009). The total water use, by year, estimated for each county and water use-type combination was distributed within each county to the same use-type wells represented in the 2009 well package, but scaled based on the proportional within-county use-type withdrawals.

From a physical standpoint, impacts due to changes in the groundwater withdrawals are not instantaneous, but rather take time to manifest (as a flow or head change) at a given gage of interest. To account for this delay in the responses observed at a gage, the historic withdrawal time-series was smoothed using a 5-year antecedent rolling mean. The smoothed withdrawal time-series was subsequently used to convert the effective sensitivity values into changes in flow (or head). **Figure 14** shows the cumulative groundwater withdrawals estimated for the NFSEG model domain

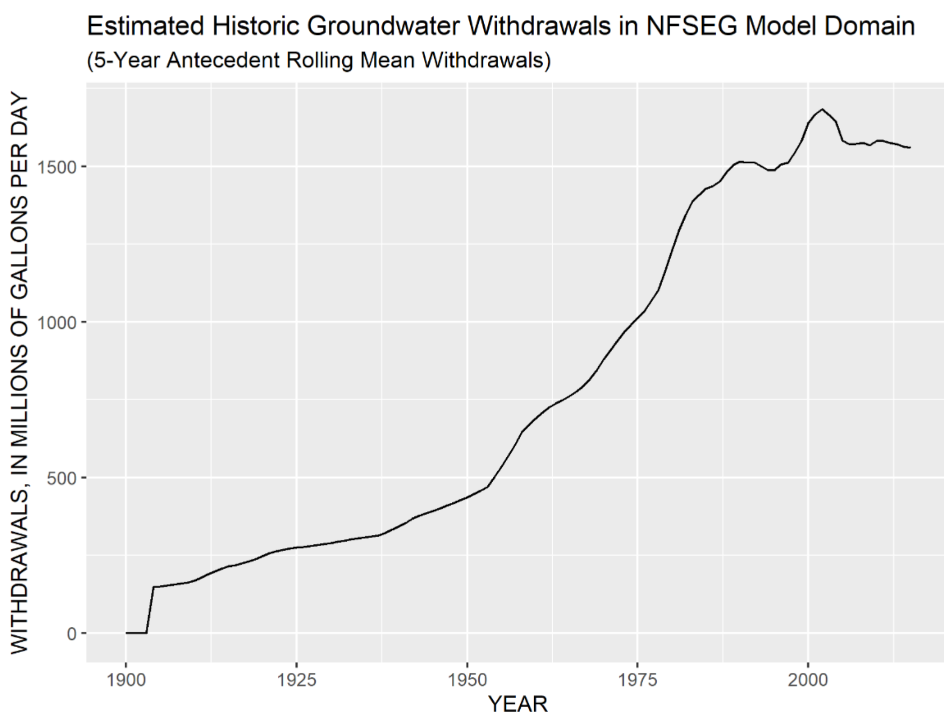


**Figure 14. Estimated Historic Groundwater Withdrawals shown as 5-Year Antecedent Rolling Average Values**

**Table 6** shows records of smoothed groundwater withdrawals for selected County and use-type (to match **Table 5**) for an example year of 2001. Additionally, **Table 6** also lists the computed effective sensitives with respect to Ft. White gage (see **Table 5**) for the listed combination of counties and use-type. From **Table 6** it can be noted that by multiplying (and keeping the units consistent) smoothed withdrawal for 2001 with effective sensitivity, net impact on the flow at Ft. White can be computed. As an example, for Baker County the CII wells had a total withdrawal of 0.83 MGD which (using an effective sensitivity of 0.164 cfs/cfs) would result in a net 0.21 cfs reduction in the observed flow. Addition of all such "Delta Q" for all combination of County and use-type would result in the total impact of groundwater withdrawals at the Ft. White gage for 2001. Repeating this process for all the years would develop a flow reduction time-series which would indicate the impacts of groundwater withdrawals on the Ft. White gage. **Figure 15** shows the time estimated flow reduction time-series at Ft. White gage.

| State | County | Use Type | 2001 Smoothed Withdrawals (MGD) | Effective Sensitivity (cfs/cfs) | Delta Q (cfs) |
|---|---|---|---|---|---|
| FL | Baker | CII | 0.83 | 0.164 | 0.21 |
| FL | Clay | AG | 0.94 | 0.080 | 0.12 |
| FL | Clay | CII | 3.83 | 0.080 | 0.47 |
| FL | Clay | LRA | 0.06 | 0.071 | 0.01 |
| FL | Clay | CII | 3.83 | 0.082 | 0.48 |
| FL | Clay | PS | 13.42 | 0.071 | 1.48 |
| FL | Duval | AG | 0.99 | 0.064 | 0.10 |
| FL | Duval | CII | 21.40 | 0.065 | 2.14 |
| FL | Duval | LRA | 0.71 | 0.062 | 0.07 |
| FL | Duval | PS | 105.94 | 0.064 | 10.51 |
| FL | Lake | AG | 8.23 | 0.002 | 0.02 |
| FL | Lake | CII | 2.93 | 0.001 | 0.00 |
| FL | Lake | PS | 15.15 | 0.001 | 0.03 |
| FL | Marion | AG | 7.60 | 0.014 | 0.16 |

**Table 6. Sample Estimate of Flow Impacts on Ft. White Gage due to Groundwater Withdrawals associated with Different Combination of County and Use -Type**

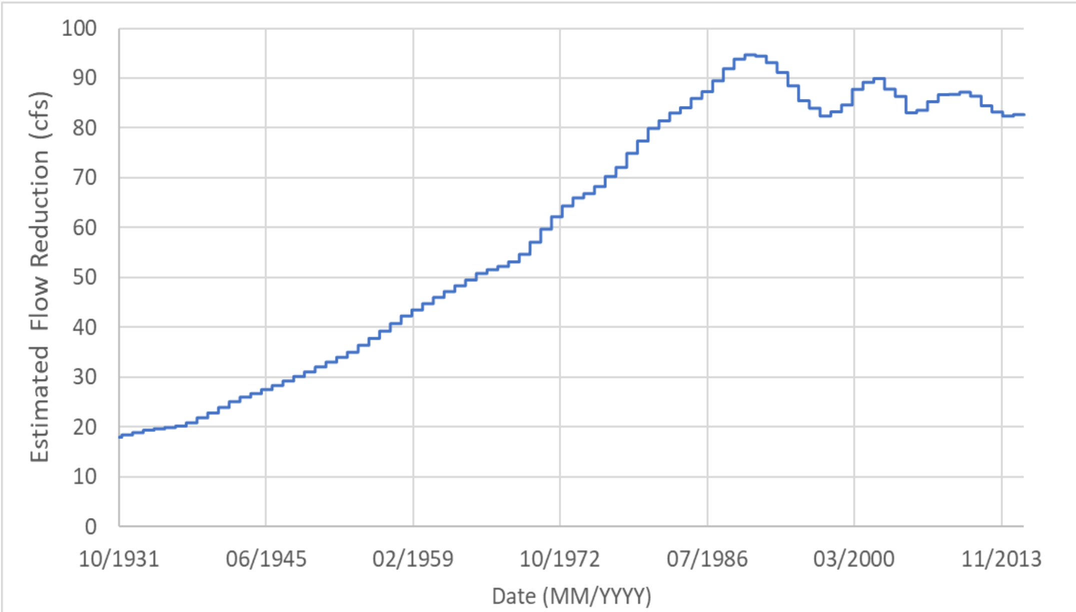

**Figure 15. Estimated Flow Reductions over time at Ft. White Gage due to groundwater withdrawals**

## 2.2 Estimate of Flow and Head Changes due to Return Flows

To estimate mitigating impacts of the return flows from irrigation or other anthropogenic applications of water at or near the land surface, a series of model runs (one for each county within the NFSEG model domain) using NFSEG v1.1(Case 007h1) was executed. Each of these model runs were set up by creating a new MODFLOW recharge file in which the return flow component of recharge for calendar-year 2009 was removed for the given county. County-level sensitivities to return flows, with respect to a gage (or well) of interest, were then calculated by (1) subtracting the simulated head or flow from the base calibrated model at the location of interest from the corresponding simulated head or flow from the model run in which the return flow was removed for that county, and (2) dividing this head or flow difference by the magnitude of the return flow for that county. **Figure 16** shows the results from the simulations conducted to estimate return flow sensitivities.

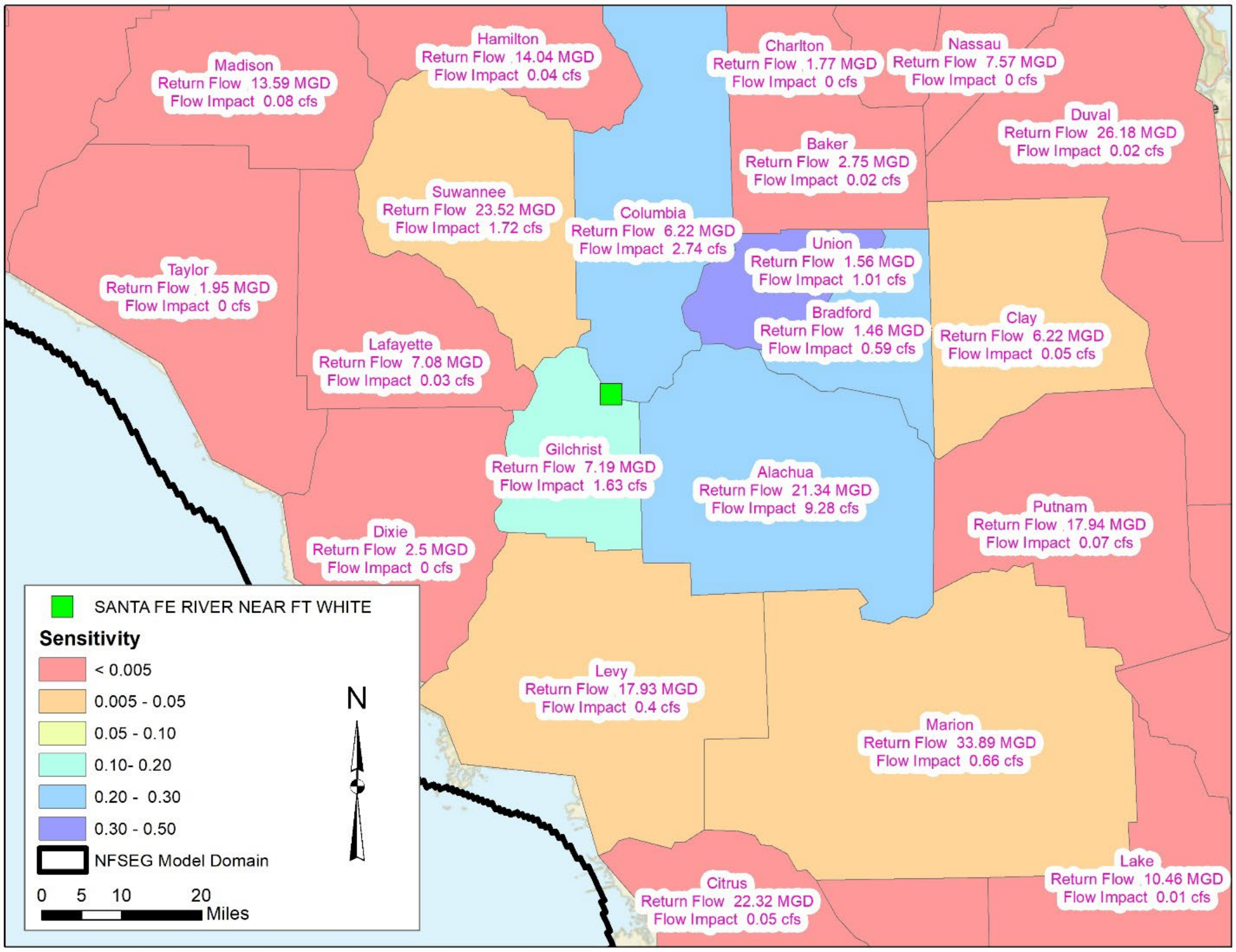


**Figure 16. Model Results from Return Flow Sensitivity runs for Ft. White Gage**

From **Figure 16** for Gilchrist County, as an example, the computed return flow was 7.19 MGD and turning that flow off resulted in a flow decrease of 1.63 cfs at the Ft. White Gage. Using **Equation 1** the return flow sensitivity for Gilchrist county would be 0.146. Similarly, for Columbia County the return flow was 6.22 MGD, which when switched off resulted in a flow decrease of 2.74 cfs at the Ft. White gage, and a sensitivity value of 0.285. **Figure 17** shows the estimated sensitivity values for Ft. White gage with respect to return flow for all counties within the NFSEG model domain.

An important aspect to note is that the groundwater sensitivities were computed using NFSEG v1.1(Case 007h) model, while return flow sensitivities were computed using NFSEG v1.1 (Case 007h1) model. From the application of the NFSEG model for the purpose of computing sensitivity values, and eventually developing a reference timeframe flow (or head) time-series, this is not expected to influence the results of the analysis. The NFSEG base model results comparison for groundwater withdrawal sensitivity calculations use the Case 007h base calibrated model while the return flow sensitivity calculations use the Case 007h1 base calibrated model. Since the methodology relies on the differences in the simulated flows (or heads) which are further unitized (per MGD or per cfs), the absolute values of flows and stages are no longer relevant.

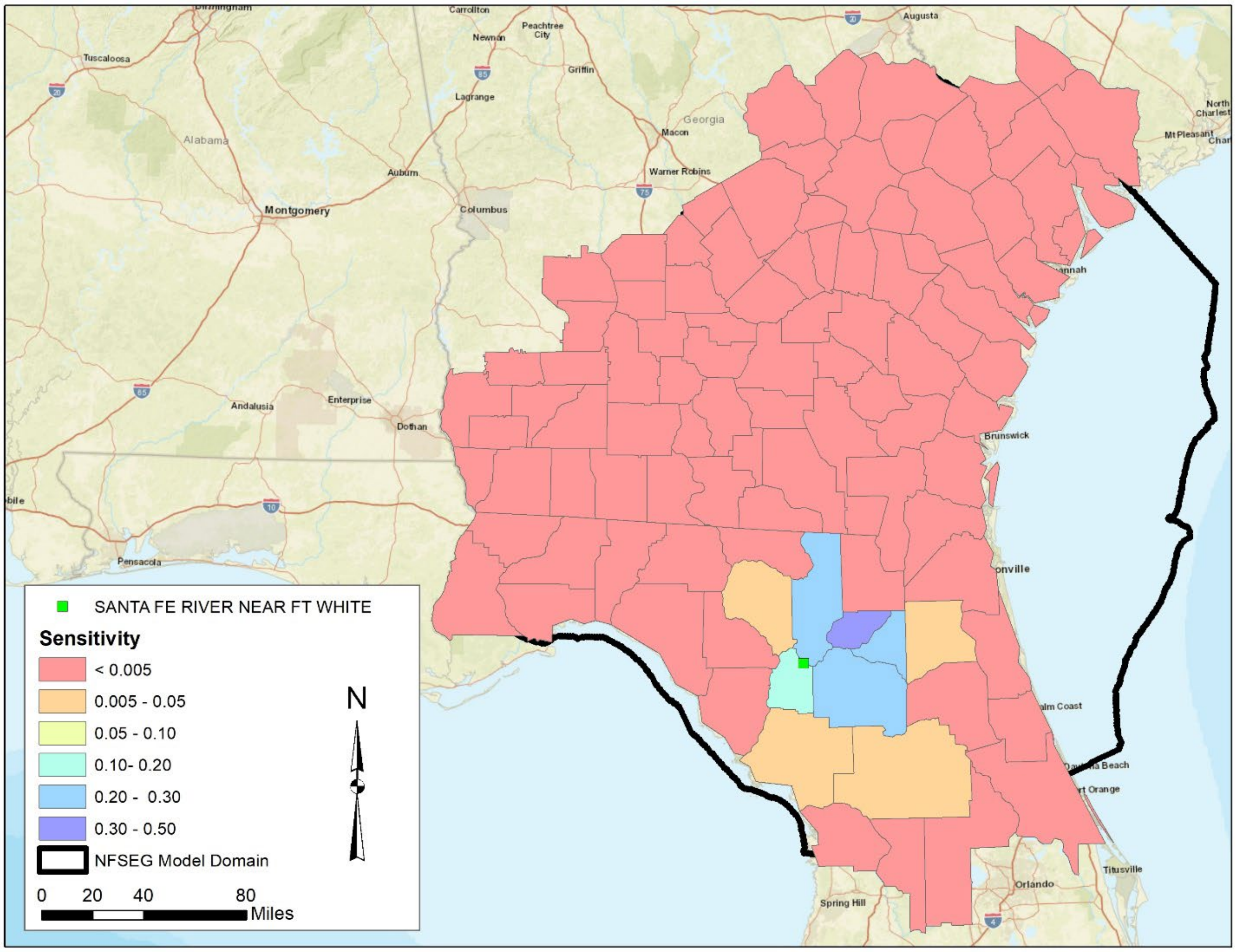


**Figure 17. County-Level Return Flow Sensitivity for Ft. White Gage**

To develop historic return flow time-series that can be subsequently used to estimate the mitigating impact of return-flow on the gage (or well) of interest a two-step process was followed. In the first step, the ratio of calendar-year 2009 total return flow to calendar-year 2009 total withdrawals for agricultural, commercial-industrial-institutional, domestic self-supplied, landscape and recreation, and public supply uses was computed for each county assumed to contribute to return flow impacts. In the second step, the change in return flow in each year of the historic period was estimated for each of these counties by multiplying the ratio computed in the first step by the total withdrawals in that year and in that county for the uses described in the first step.

**Table 7** shows an example for the estimate of groundwater withdrawals from CII, DSS, AG, and LRA for selected counties of interest (see **Figure 16**) and corresponding return flow values for 2009. The ratio of return flow values and groundwater withdrawals is computed by simply dividing the two terms. For example, for Taylor County the groundwater withdrawal for 2009 was 43.5 MGD which the return flow was 1.95 resulting in a ratio of 0.045 (=1.95/43.5). Also listed in **Table 7** is the return flow sensitivity values computed previously (**Figure 16).**

| County | 2009 GW Withdrawals (MGD) | 2009 Return Flow (MGD) | Ratio | Return Flow Sensitivity |
|---|---|---|---|---|
| Madison | 17.850 | 13.600 | 0.762 | 0.0040 |
| Taylor | 43.525 | 1.947 | 0.045 | 0.0000 |
| Lafayette | 9.031 | 7.081 | 0.784 | 0.0026 |
| Dixie | 2.731 | 2.503 | 0.916 | 0.0001 |
| Levy | 23.289 | 17.946 | 0.771 | 0.0143 |
| Gilchrist | 9.929 | 7.198 | 0.725 | 0.1466 |
| Citrus | 28.518 | 22.331 | 0.783 | 0.0013 |
| Marion | 60.103 | 33.913 | 0.564 | 0.0127 |
| Lake | 34.879 | 10.470 | 0.300 | 0.0004 |
| Putnam | 29.290 | 17.953 | 0.613 | 0.0026 |
| Clay | 20.084 | 6.221 | 0.310 | 0.0056 |
| Duval | 151.888 | 26.198 | 0.172 | 0.0005 |
| Nassau | 47.139 | 7.573 | 0.161 | 0.0001 |
| Columbia | 11.539 | 6.228 | 0.540 | 0.2850 |
| Alachua | 49.062 | 21.354 | 0.435 | 0.2810 |
| Union | 2.349 | 1.559 | 0.663 | 0.4191 |
| Bradford | 6.097 | 1.462 | 0.240 | 0.2593 |
| Suwannee | 36.615 | 23.534 | 0.643 | 0.0473 |
| Hamilton | 40.748 | 14.053 | 0.345 | 0.0018 |

**Table 7. Groundwater Withdrawals and Return Flow Estimates for Selected Counties for 2009**

**Table 8** shows application of return flow ratio and sensitivity values utilizing the historical smoothed groundwater withdrawal data (for 2001 as an example). The ratio for individual counties computed in **Table 7** can be used to convert the smoothed groundwater withdrawal values to return flow values for corresponding counties (only selected counties shown in **Table 8**). For example, for Lafayette county the 2001 smoothed groundwater withdrawal is 8.51 MGD and the ratio of return flow to groundwater withdrawal is 0.784 resulting in the 2001 estimate of return flow to be 6.67 MGD (=0.784 x 8.51). Using the previously computed return flow sensitivity of 0.0026 the increase in flow at Ft. White gage would be 0.027 cfs due to return flow from Lafayette County for 2001. Similarly, return flow impacts from all counties can be added up to determine the return flow impacts at Ft. White gage for 2001. Similar exercises can be conducted for all historical years to develop a return flow impact time-series for the gage (or well) of interest. **Figure 18** shows the time-series of estimate flow increase as Ft. White gage due to return flow impacts.

| County | 2001 Smoothed GW Withdrawals (MGD) | Ratio | 2001 Return Flow (MGD) | Return Flow Sensitivity | Delta Q (cfs) |
|---|---|---|---|---|---|
| Madison | 16.089 | 0.762 | 12.258 | 0.0040 | 0.075 |
| Taylor | 49.274 | 0.045 | 2.204 | 0.0000 | 0.000 |
| Lafayette | 8.511 | 0.784 | 6.674 | 0.0026 | 0.027 |
| Dixie | 3.788 | 0.916 | 3.471 | 0.0001 | 0.001 |
| Levy | 27.774 | 0.771 | 21.402 | 0.0143 | 0.474 |
| Gilchrist | 10.113 | 0.725 | 7.332 | 0.1466 | 1.662 |
| Citrus | 24.272 | 0.783 | 19.006 | 0.0013 | 0.039 |
| Marion | 59.960 | 0.564 | 33.833 | 0.0127 | 0.663 |
| Lake | 27.883 | 0.300 | 8.370 | 0.0004 | 0.006 |
| Putnam | 45.159 | 0.613 | 27.679 | 0.0026 | 0.112 |
| Clay | 22.014 | 0.310 | 6.819 | 0.0056 | 0.059 |
| Duval | 141.236 | 0.172 | 24.361 | 0.0005 | 0.020 |
| Nassau | 45.230 | 0.161 | 7.266 | 0.0001 | 0.001 |
| Columbia | 11.568 | 0.540 | 6.243 | 0.2850 | 2.753 |
| Alachua | 45.857 | 0.435 | 19.959 | 0.2810 | 8.678 |
| Union | 2.474 | 0.663 | 1.641 | 0.4191 | 1.064 |
| Bradford | 6.796 | 0.240 | 1.629 | 0.2593 | 0.654 |
| Suwannee | 33.143 | 0.643 | 21.302 | 0.0473 | 1.560 |
| Hamilton | 43.094 | 0.345 | 14.862 | 0.0018 | 0.041 |

**Table 8. Sample Estimate of Flow Impacts (positive) on Ft. White Gage due to Return Flows associated with Selected Counties**

NFSEG v1.1 has multiple sources of groundwater inflow that have a potential to positively impact a given gage or well of interest. These sources include deep injection wells, as well as drainage wells and natural sink features that receive treated wastewater discharges. To estimate the impact of these features on flow (or head), the point groundwater sensitivity values for a "regular well" with respect to a given gage of interest for Layer 3 and Layer 5 are manually queried from the previously developed sensitivity maps (see example **Figure 9** and **Figure 10**). The queried sensitivity value is multiplied by the historic flow injection time-series for each of the features to estimate their positive influence (i.e. increase in flow or stages) on the gage (or well) of interest.

Note that the historic time series of annual injection rates for these features are based on data from reported values of treated wastewater discharges, when available. Estimation of missing historic treated wastewater discharged to Alachua Sink and injection wells at Lake Alice in Gainesville, Florida was required for some periods, and was accomplished by calculating ratios of reported wastewater discharges and reported or estimated concurrent withdrawals at the Murphree Wellfield in Gainesville. These ratios were then multiplied by reported or estimated historic withdrawals from the Murphree Wellfield for periods when reported wastewater discharge data were not available. (see Appendix B, Part 2 – Injection Wells Hindcasting, for more information).

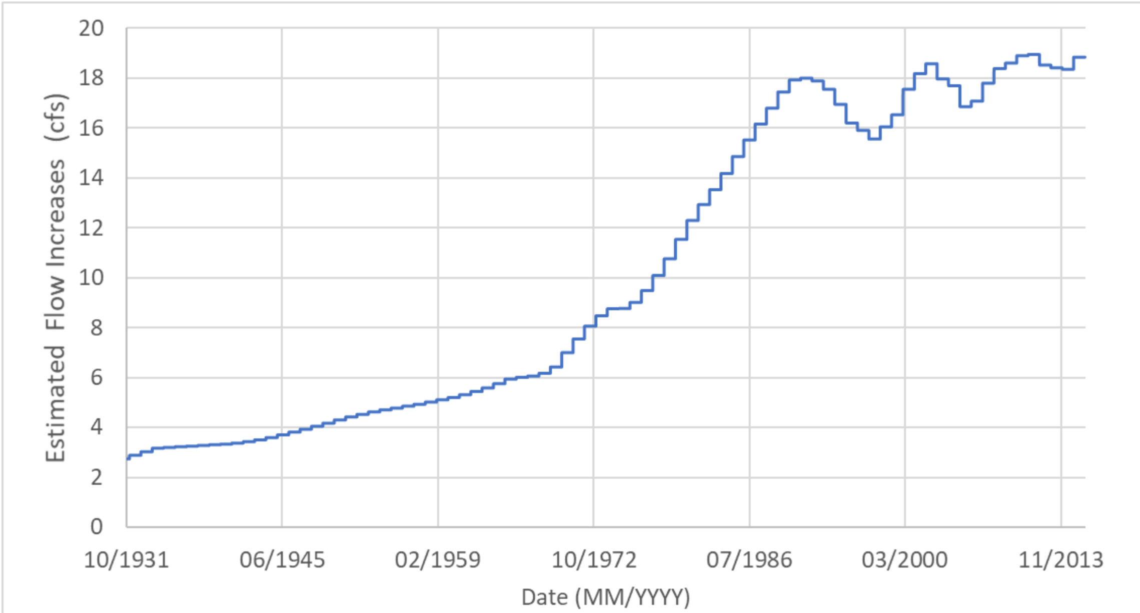


**Figure 18. Estimated Flow Increases at Ft. White Gage due to Return Flows**

**Figure 19** shows an example figure for Ft. White gage indicating different injection wells and their corresponding "regular" well sensitivity values based on the model layer that the injection wells are screened in. For instance, Kanapaha well is screened in Layer 5 and its point sensitivity value is 0.046. Multiplication of 0.046 with the historic injection time-series for Kanapaha well results in the impact time-series for Ft. White gage. When results from all injection wells are added, the resultant time-series represents overall impact of the injection wells on a given gage of interest. **Figure 20** shows historic combined time-series of the influence of all four injection wells on the Ft. White gage.

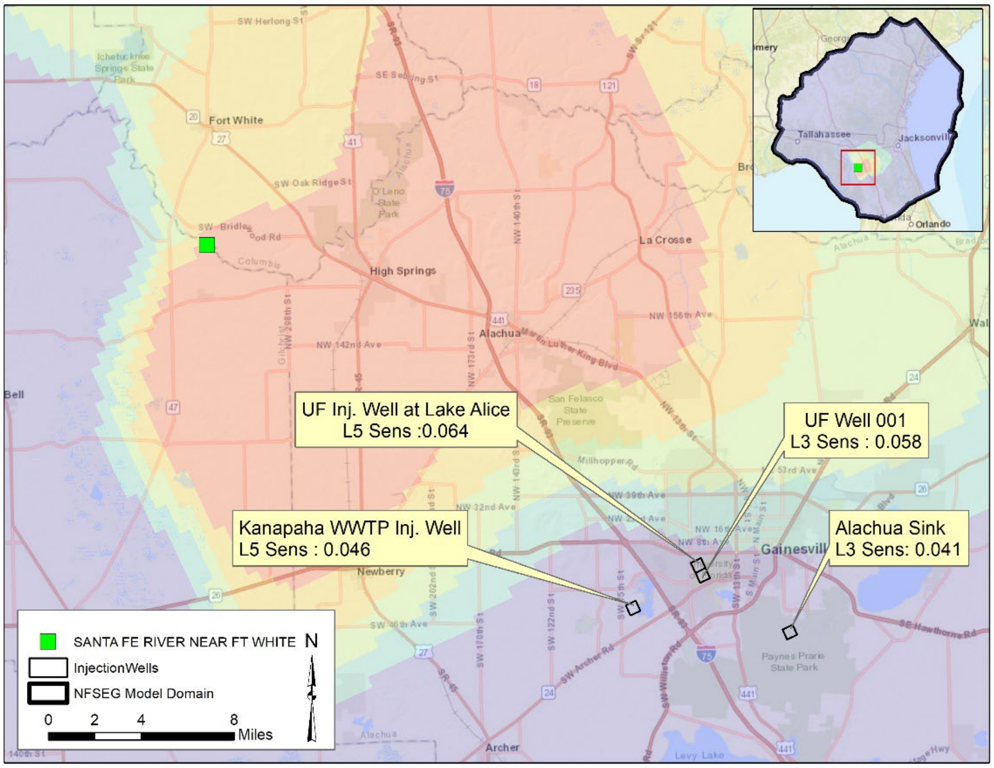


Figure 19. Deep Injections Wells and Corresponding Sensitivity Values

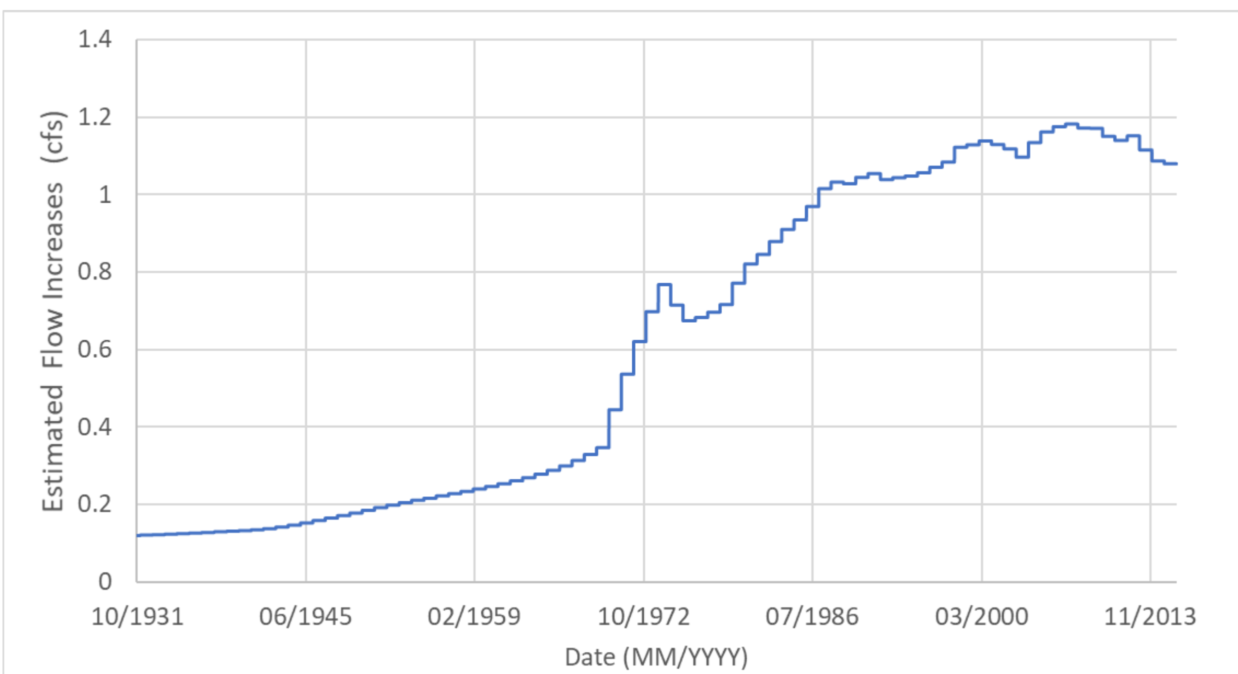


Figure 20. Flow Impact Time Series due to Deep Injection Wells at Ft. White Gage

## 2.3 Estimating Net Flow and Head Changes

Net impacts are defined in this report as the difference between the estimated impacts from groundwater withdrawals (associated with a given time step) on flows or head at a location of interest, after accounting for the offsetting impacts of near surface applications and deep injection returns from groundwater withdrawals. These net impacts were calculated for each time step by subtracting the total offsetting impacts of near surface and deep injection returns at that time step from the previously estimated gross groundwater withdrawal impacts. Recall that the latter is computed as the sum of estimated total gross impacts from regular well and MNW withdrawals. This resulted in a time series of estimated historic net impacts on flows or head at the given location of interest.

For Ft. White gage this essentially translates into subtracting the time-series shown in **Figure 18** and **Figure 20** from the groundwater withdrawal time-series shown in **Figure 15**. **Figure 21** shows the adjusted flow reduction time-series for Ft. White gage. These are the overall flow adjustments that indicate the influence of anthropogenic groundwater withdrawals and injections.

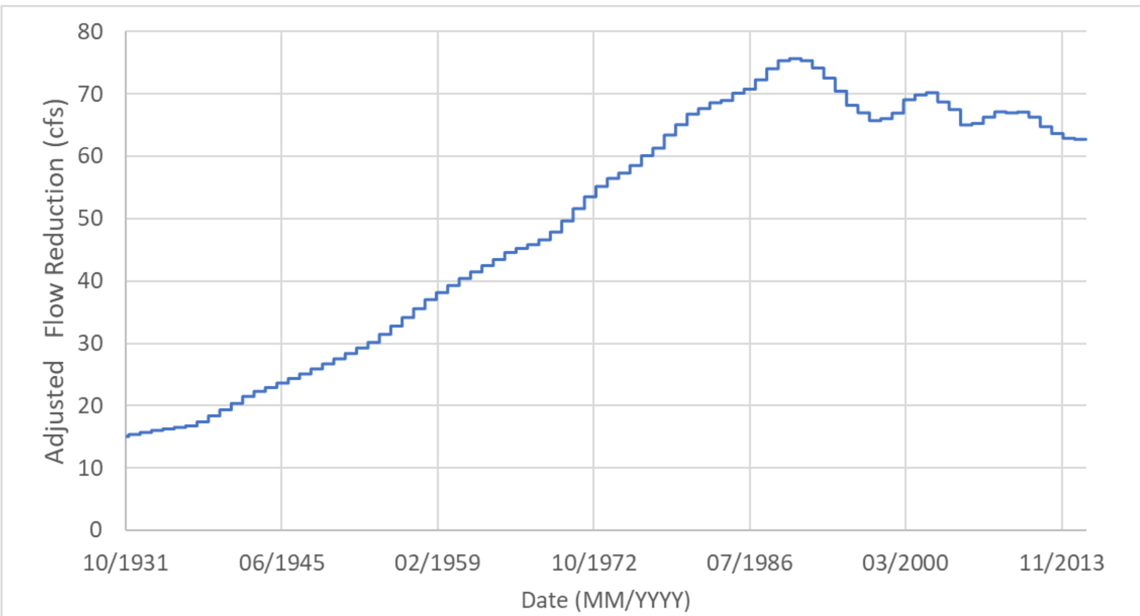


**Figure 21. Adjusted Flow Reductions for Ft. White Gage**

## 2.4 Development of Reference Timeframe Flow or Head Time-Series

Once the adjusted flow reduction time-series is generated (e.g., **Figure 21**) the reference timeframe flow or head time-series can be simply developed by adding the adjusted flow reduction values from the observed time series. An important factor to note is that the adjusted flow reduction time-series developed above is not dependent on the period of record for the actual observed data. For instance, if the available flow data at a given gage starts from 1/1/1960, then the adjusted flow reduction factors computed from 1/1/1960 can be used to adjust observed flow (or head) time-series to the reference timeframe flow or head time-series. The values from 1930s thru 1950s can be ignored.

# Appendix D

## HEC-RAS Model Review

Introduction

The development, calibration, validation, and demonstration of the USR HEC-RAS model is described in detail in a final report (EAS, 2013). HSW evaluated the prior work by EAS by assessing the quality of the calibration and the constructed HEC-RAS models. The concept of calibrating the HEC-RAS model for unsteady flows over a 14-year period (October 1, 1997 to October 1, 2011), verifying it in space (9 new stage measurement locations) and time for the period September 1, 2011 to September 1, 2012), and then using the "calibrated" and "verified" hydraulics (Manning's n roughness coefficients and intermediate flow apportionment along the rivers) to simulate the water-surface profiles over a wide range of steady flows is a sound approach to determine the relations between flows and depths throughout the river system.

Three specific items deemed critical to the application of the models were evaluated:

- Validity of the calibrated values of Manning's roughness coefficient, n
- calibration and verification of the transient model
- boundary condition of the Steady-state model downstream at Ellaville

Manning's n values

Based on field observations on the roughness of the river bottom and vegetation growth conditions on the riverbank, EAS staff realized that using a single Manning's n coefficient in the main channel was not adequate to represent the varied roughness of the river bottom in each cross-section. Therefore, for most of the cross-sections of the HEC-RAS model, a smaller Manning's n value was assigned to the river bottom where no vegetation exists, and a greater Manning's n was used at the left and right remaining portions of the main channel (Table 1). The higher Manning's n values for the riverbanks (0.06-0.065) are only slightly greater than those for the vegetation-free portion of the main channel (typically between 0.03 and 0.04). The substantially higher Manning's n values prescribed for the overbank (floodplain) reflect forest cover. The approach is sound and achieved excellent simulation results. Further, the Manning's n values for the main channel, riverbanks, and overbank areas (Table 1) are characteristic of typical river studies throughout the U.S. and Florida (e.g., see INTERA (2012) for the Lower Santa Fe and Ichetucknee Rivers.

Transient model calibration and verification

The purpose of calibrating and verifying the HEC-RAS transient model was to show that HEC-RAS can properly simulate the relations between flow and stage (water-surface elevation, and, by inference, depth) for the Upper Suwannee River. If the transient model is reasonably calibrated and verified, then the application of the HEC-RAS model to steady flows should yield accurate associations between flow and water-surface elevation, and a reliable MFL analysis can be completed.

The time series plots comparing measured and simulated stages show very good agreement between measured and simulated values for all locations and nearly all time periods (EAS, 2013). The assessment of the unsteady HEC-RAS model is strengthened by HSW's independent assessment of "goodness of fit" statistics and the comparison of these statistics to commonly accepted standards for model calibration and verification.

One of the more powerful measures of "goodness of fit" is the coefficient of model-fit efficiency, $E$, defined by Nash & Sutcliffe (1970) as follows (eq. 1):

$$E = \frac{\sum_{i=1}^{n}(Q_{mi} - \overline{Q_m})^2 - (Q_{mi} - Q_{si})^2}{\sum_{i=1}^{n}(Q_{mi} - \overline{Q_m})^2}$$

**Table 1. Variations in Manning's n in the calibrated HEC-RAS model for the Upper Suwannee River for the main channel, riverbank, and overbank areas.**

| Reach | River Miles | Main | Riverbank | Overbank |
|---|---|---|---|---|
| Florida-Georgia Stateline to White Springs | 206.71-197.93 | 0.03-0.05 | 0.05-0.055 | 0.30 |
| " " | 196.896-195.72 | 0.035-0.06 | 0.055 | 0.30 |
| " " | 195.71-176.15 | 0.025-0.05 | 0.065 | 0.30 |
| " " | 176.1-171.14* | 0.03-0.08 | 0.065 | 0.30 |
| " " | 171.13-168.84 | 0.035-0.04 | 0.06 | 0.30 |
| White Springs to Alapaha Rise Run | 168.81-135.59** | 0.03-0.06 | 0.06 | 0.30 |
| Alapaha Rise Run to Withlacoochee River | 135.01-128.08 | 0.035-0.045 | 0.06 | 0.30 |
| Withlacoochee River to Ellaville | 127.51-127.49 | 0.035 | 0.06 | 0.30 |

* In this stretch, the main channel had two or three subsections with different Manning's n values for these subsections for 18 of the 24 cross sections with the portion with the lowest resistance being either 0.03 or 0.04 and the highest being in the range of 0.06 to 0.075 (i.e., higher than the value for the riverbanks).

** The majority of the Manning's n values for the main channel in this reach were between 0.03 and 0.04 with only a few values of 0.06.

where $Q_{mi}$ = the measured discharge at time, $i$, $\overline{Q_m}$ = the average measured discharge, $Q_{si}$ = the simulated discharge at time, $i$, and $n$ = the number of measured discharge values. Moriasi et al. (2007) proposed the following criteria for model evaluation based on $E$: $E \geq 0.75$ –Very Good, $0.75 > E \geq 0.65$ – Good, and $0.65 > E \geq 0.5$ – Satisfactory. These criteria are for a monthly evaluation and Engel et al. (2007) noted typically, model simulations are poorer for shorter time steps than for longer time steps (e.g., daily versus monthly or yearly). These criteria commonly are used to assess the quality of watershed models for continuous simulation of streamflow.

The fraction of simulated daily depths meeting at least the very good (within 10%), good (within 15%), and fair (within 25%) criteria are listed in Table 2, and it also includes the Nash-Sutcliffe, E, for the daily water depths for the three main USGS calibration gages over the entire period of simulation (i.e., October 1, 1997, to September 1, 2012).

**Table 2. Fraction of simulated daily water depths within 10, 15, and 25% of the measured daily water depth and the Nash-Sutcliffe coefficient (E) of model-fit efficiency for the daily water depths for the entire simulation period of October 1, 1997, to September 1, 2012.**

| Gage | <10% | <15% | <25% | E |
|---|---|---|---|---|
| Suwannee River near Benton, FL | 0.923 | 0.988 | 0.996 | 0.997 |
| Suwannee River at White Springs, FL | 0.977 | 0.998 | 1.000 | 0.993 |
| Suwannee River at Suwannee Springs, FL | 0.786 | 0.918 | 0.993 | 0.989 |

All three long-term gaging sites show excellent agreement between measured and simulated water depths with E greater than 0.98. Further, for Benton and White Springs more than 90% of the simulated depths within 10% of the measured depth, and for Suwannee Springs more than 90% of the simulated depths are within 15% of the measured depth.

The impressive results for the long-term gaging stations are strongly affected by the HEC-RAS incremental flow procedure used by EAS that matches observed flows at those locations. Thus, SRWMD installed and maintained eight continuous-recording, stage-monitoring gages during the period September 1, 2011, to September 1, 2012, for additional model testing at non-calibration locations. Comparisons also were made at the SRWMD long-term stage gage at Nobles Ferry, FL, during this period (Table 3). The combined results for the long- and short-term gaging stations were deemed suitable for using the hydraulic parameters derived from transient model calibration to a steady-state model used to evaluate WRV metrics.

**Table3. Fraction of simulated daily water depths within 10, 15, and 25% of the measured daily water depth and the Nash-Sutcliffe coefficient (E) of model-fit efficiency for the daily water depths for the model testing simulation period of September 1, 2011, to September 1, 2012, at the continuous stage gages installed by the SRWMD.**

| Gage | <10% | <15% | <25% | E |
|---|---|---|---|---|
| Suwannee River below Florida/Georgia State Line | 0.971 | 1.000 | | 0.991 |
| Suwannee River at Big Shoals, FL | 1.000 | | | 0.843 |
| Suwannee River at Little Shoals, FL | 1.000 | | | 0.980 |
| Suwannee River at State Route 136 | 0.971 | 0.982 | 0.994 | 0.964 |
| Suwannee River at Blue Sink, FL | 0.705 | 0.804 | 0.969 | 0.961 |
| Suwannee River at Woods Ferry, FL | 0.568 | 0.721 | 0.986 | 0.932 |
| Suwannee River at Mattair, FL | 1.000 | | | 0.981 |
| Suwannee River at Holton Camp, FL | 0.948 | 0.978 | 1.000 | 0.980 |
| Suwannee River at Nobles Ferry, FL | 0.957 | 1.000 | | 0.941 |

<u>Steady-state model downstream boundary condition at Ellaville</u>

For the current MFLs evaluation, the latest USGS defined flow rating curve for the Suwannee River at Ellaville, FL (USGS 02319500) adopted June 12, 2021, was applied to determine the known water-surface elevation as a function of the selected RTF flows in steady state HEC-RAS model. The USGS defined flow-rating curves for 2013 and 2021 for the Ellaville gage were compared (Figure 1). For flows higher than 2000 cfs, the difference in stage between the two curves is very small (less than 0.1 ft). Therefore, the flow profiles for flows greater than the 80% exceedance probability should be minimally affected by this change in the downstream boundary condition compared to the original steady-state HEC-RAS model flow analysis (EAS, 2013).

HSW evaluated the sensitivity of the difference in boundary condition at Ellaville by comparing computed and USGS defined rating curves at Suwannee Springs, FL. These results indicate a substantial improvement compared to those reported earlier (EAS, 2013) . In the earlier verification, the two ratings began to diverge by more than 0.5 ft (the target for good verification) at the 40% exceedance flow of 1,030 cfs (in that analysis), whereas in the current study the rating curves do not diverge by more than 0.5 ft until the 15% exceedance flow of 3,800 cfs. Thus, the computed rating yields a good match of the USGS defined rating curve for 85% of the flow range at Suwannee Springs.

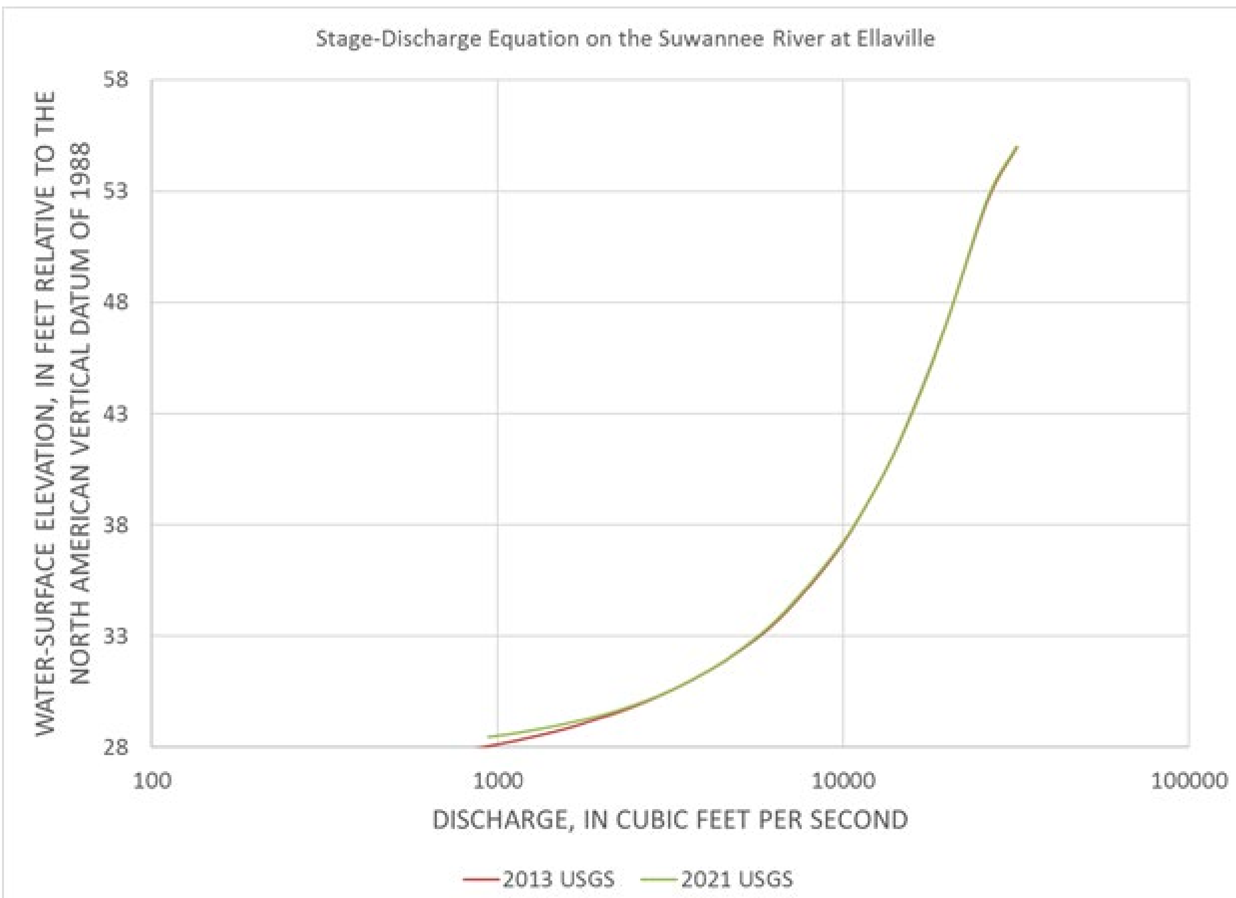


**Figure 1. USGS defined flow rating curves from 2013 and 2021 on the Suwannee River at Ellaville, FL (USGS 02319500)**

**Table 4. Steady HEC-RAS verification at USGS 02315550 at Suwannee Springs, FL [River Station (RS) 150.32]**

| Flow scenario ID | Percent time indicated flow is exceeded | Flow (cfs) | Verification Targets (USGS defined rating curve stage (ft NAVD88) | Model results stage (ft NAVD88) | Difference (ft) |
|---|---|---|---|---|---|
| 1 | 99.9% | 76.48 | 35.47 | 35.26 | -0.21 |
| 2 | 99.8% | 80.68 | 35.52 | 35.32 | -0.20 |
| 3 | 99.5% | 88.46 | 35.62 | 35.42 | -0.20 |
| 4 | 99% | 96.31 | 35.73 | 35.51 | -0.22 |
| 5 | 98% | 108.10 | 35.88 | 35.64 | -0.24 |
| 6 | 95% | 132.27 | 36.18 | 35.88 | -0.30 |
| 7 | 90% | 177.68 | 36.62 | 36.27 | -0.35 |
| 8 | 85% | 223.06 | 36.94 | 36.65 | -0.29 |
| 9 | 80% | 269.24 | 37.24 | 36.97 | -0.27 |
| 10 | 70% | 395.16 | 37.97 | 37.75 | -0.22 |
| 11 | 60% | 590.09 | 38.94 | 38.79 | -0.15 |
| 12 | 50% | 879.72 | 40.20 | 40.07 | -0.13 |
| 13 | 40% | 1312.85 | 41.87 | 41.78 | -0.09 |
| 14 | 30% | 1968.78 | 44.07 | 44.19 | 0.12 |
| 15 | 20% | 3049.51 | 47.18 | 47.53 | 0.35 |
| 16 | 15% | 3800.45 | 49.10 | 49.61 | **0.51** |
| 17 | 10% | 4959.90 | 51.82 | 52.33 | **0.51** |
| 18 | 5% | 7271.90 | 56.36 | 57.10 | **0.74** |
| 19 | 2% | 9974.02 | 60.78 | 62.77 | **1.99** |
| 20 | 1% | 12451.48 | 64.39 | 65.94 | **1.55** |

The poorer agreement between the USGS defined and computed rating curves at Suwannee Springs in the earlier analysis was attributed to the effects of Tropical Storm Debby in 2012 on the defined rating curve (EAS, 2013). As shown in Figure 5-16 (EAS, 2013), the USGS defined rating after Tropical Storm Debby estimated higher flows for stages greater than about 41 ft NAVD88 than found for the majority of field measurements of flow at Suwannee Springs up to that time.

The current USGS defined rating came into use on December 5, 2016, and it is compared to the computed rating curve and the historical USGS flow measurements (Figure 2.). As can be seen, the current defined USGS defined rating curve has moved back into the center of the historical flow measurements at Suwannee Springs, and both the computed and defined rating curves show good agreement with the historical flow measurements. Both comparisons (Table 4 and Figure 2) indicate a good verification of the HEC-RAS steady flow model used in the current MFLs assessment.

<u>Steady RTF model development and application</u>

Only the hydrologic boundary conditions were modified in the steady-state model developed by EAS to conform with RTF flows for evaluating WRVs. Channel and floodplain geometric data were not modified. Proportional longitudinal flow changes determined by EAS (EAS, 2013) and implemented in the EAS steady-state model were not changed. Flow-proportioning coefficients between gaged locations (i.e., subreach endpoints) were developed by HSW using the EAS steady-state model flow-change tables. The only exception to this proportioning approach was for the stretch between the Florida-Georgia state line and the Benton gage for the extreme-low flow with exceedance probabilities of 99.9% and 99.8% where the RTF flow at Benton was applied to the entire stretch, as was done in the original steady-state HEC-RAS model (EAS, 2013). RTF flow duration curves for the endpoint long-term gaging stations were then used to select 20 steady-state RTF model simulations spanning the wide range in hydrologic conditions considered in the WRV evaluation (Table 5).

HEC-RAS output was processed to characterize associations among hydraulic characteristics such as flow, water-surface elevation, depths, top width, wetted perimeter, and velocity at cross-sections. Low flow scenarios then were used to analyze water resource values associated with low flow conditions, such as recreation and fish passage. Bankfull and higher flow scenarios were used to evaluate channel geomorphology and floodplain habitat.

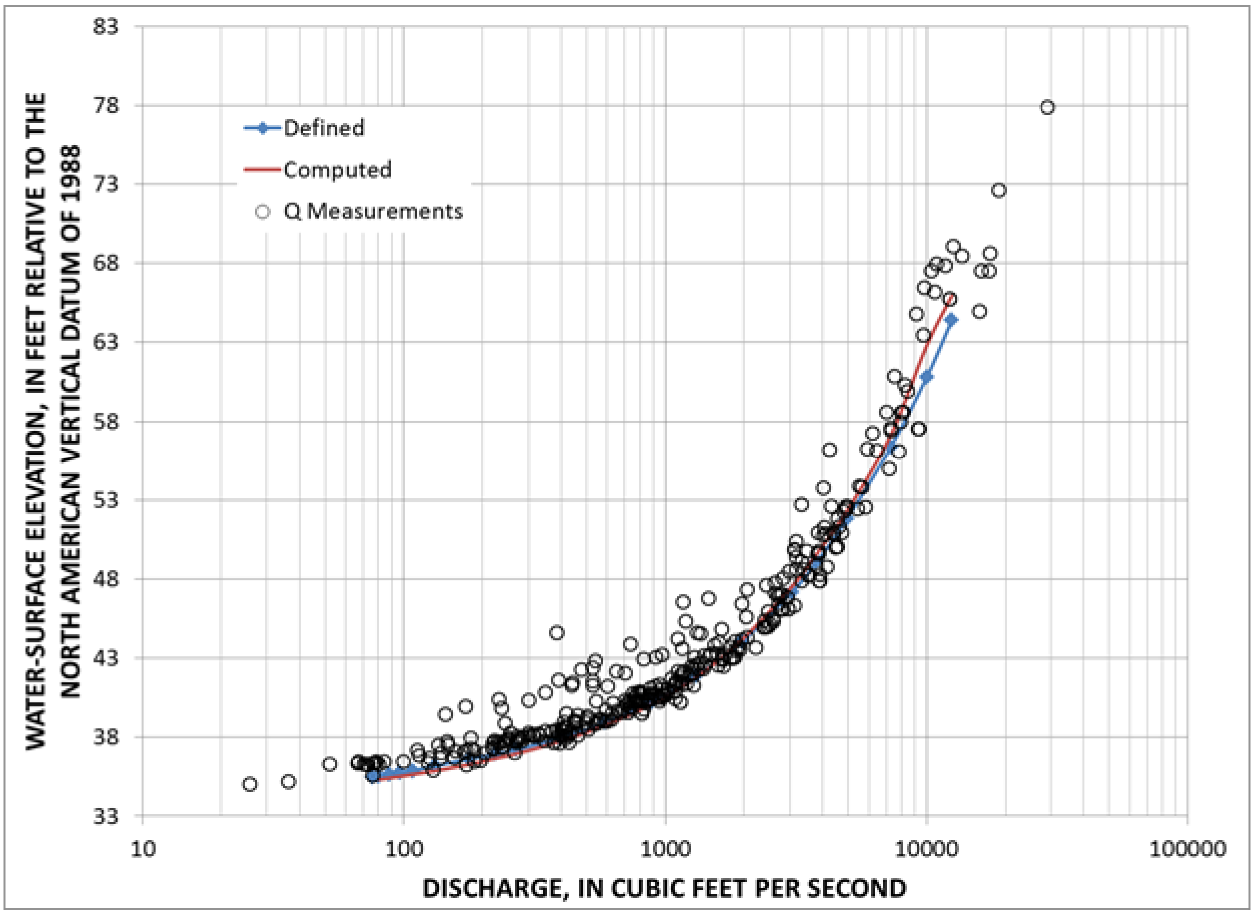


**Figure 2. Comparison of the computed and current USGS defined rating curves and the historic USGS flow measurements at Suwannee Springs (USGS 02315550).**

**Table 5. Reference timeframe (RTF) flows at boundary locations for the steady-state HEC-RAS model runs.**

| Flow Scenario ID | Percent Time Not Exceeded | SR head @ state line | SR @ Benton | SR @ White Springs | SR @ Suwannee Springs | SR @ Ellaville | AR head | WR head |
|---|---|---|---|---|---|---|---|---|
| 1 | 99.9% | 0.50 | 0.42 | 4.63 | 76.5 | 940.0 | 35.2 | 81.9 |
| 2 | 99.8% | 1.21 | 0.82 | 5.88 | 80.7 | 985.3 | 37.9 | 89.2 |
| 3 | 99.5% | 3.94 | 3.43 | 9.94 | 88.5 | 1,054 | 43.6 | 94.7 |
| 4 | 99.0% | 4.72 | 5.15 | 12.1 | 96.3 | 1,096 | 48.7 | 101 |
| 5 | 98.0% | 6.99 | 7.20 | 15.0 | 108 | 1,150 | 55.4 | 109 |
| 6 | 95.0% | 14.5 | 14.8 | 25.8 | 132 | 1,352 | 71.7 | 129 |
| 7 | 90.0% | 37.4 | 38.3 | 57.6 | 178 | 1,615 | 90.5 | 157 |
| 8 | 85.0% | 68.0 | 69.9 | 96.2 | 223 | 1,837 | 111 | 186 |
| 9 | 80.0% | 103 | 106 | 135 | 269 | 2,046 | 136 | 212 |
| 10 | 70.0% | 194 | 201 | 248 | 395 | 2,494 | 203 | 281 |
| 11 | 60.0% | 336 | 348 | 419 | 590 | 3,067 | 312 | 399 |
| 12 | 50.0% | 554 | 576 | 677 | 880 | 3,860 | 505 | 619 |
| 13 | 40.0% | 849 | 882 | 1,051 | 1,313 | 5,052 | 806 | 979 |
| 14 | 30.0% | 1,310 | 1,360 | 1,631 | 1,969 | 6,729 | 1,333 | 1,495 |
| 15 | 20.0% | 2,174 | 2,254 | 2,721 | 3,050 | 9,511 | 2,142 | 2,444 |
| 16 | 15.0% | 2,673 | 2,760 | 3,521 | 3,800 | 11,676 | 2,781 | 3,280 |
| 17 | 10.0% | 3,376 | 3,473 | 4,721 | 4,960 | 14,488 | 3,788 | 4,563 |
| 18 | 5.0% | 4,539 | 4,595 | 7,121 | 7,272 | 19,320 | 5,673 | 6,984 |
| 19 | 2.0% | 6,223 | 6,579 | 9,954 | 9,974 | 26,114 | 7,941 | 10,608 |
| 20 | 1.0% | 8,405 | 8,801 | 12,601 | 12,451 | 31,619 | 9,796 | 14,423 |

References

EAS. (2013). *HEC-RAS Modeling of Upper Suwannee River, Phase C.* Tampa: Engineering & Applied Science (EAS).

INTERA. (2012). *HEC-RAS Model Development and Calibration of the Lower Santa Fe and Ichetucknee Rivers.* Live Oak, FL: Prepared for Suwannee River Water Management District.

Nash, J. E., & Sutcliffe, J. V. (1970). River Flow Forecasting Through Conceptual Models, Part 1-A, Discussion of Principles. *Journal of Hydrology*, 282-290.

# Appendix E

**SEFA Area Weighted Suitability Evaluation Results**

Suwannee Springs SEFA output

| Species/Life stage | B1 Flow reduction (%)[1] | Change in average AWS (%) | Constant flow reduction (cfs) |
|---|---|---|---|
| BenthicMacro_LoGrad | 20.00% | -8.70% | |
| Blackbanded Darter-adult | 20.00% | -6.80% | |
| Bluegill -adult | 20.00% | 14.20% | |
| **Bluegill -fry[2]** | **11.70%** | **15.00%** | |
| Bluegill -juvenile | 20.00% | 0.00% | |
| Bluegill -spawning | 20.00% | 2.30% | |
| Channel Catfish-adult | 20.00% | 9% | |
| Channel Catfish-fry | 20.00% | 1.60% | |
| Channel Catfish-juvenile | 20.00% | -3.50% | |
| Channel Catfish-juvenile-Fall | 20.00% | -4.50% | |
| Channel Catfish-juvenile-Spring | 20.00% | -6.90% | |
| Channel Catfish-juvenile-Summer | 20.00% | 4.10% | |
| Channel Catfish-spawning | 20.00% | 4.60% | |
| Cyprinidae -adult | 20.00% | -7.30% | |
| Ephemeroptera | 20.00% | -1.20% | |
| EPT Total | 20.00% | -1.90% | |
| Generic Darters-adult | 20.00% | -1.40% | |
| Habitat Guilds-DF | 20.00% | -3.70% | |
| Habitat Guilds-DS | 20.00% | 11% | |
| Habitat Guilds-SF | 20.00% | -0.90% | |
| Habitat Guilds-SS | 20.00% | 0.90% | |
| Hydropsychidae -Total | 20.00% | -1.90% | |
| **Largemouth Bass-adult** | **10.20%** | **15.00%** | **143** |
| **Largemouth Bass-fry** | **7.80%** | **15.00%** | **126** |
| Largemouth Bass-juvenile | 20.00% | 9.30% | |
| Largemouth Bass-spawning | 20.00% | 2.80% | |
| Metallic Shiner | 20.00% | -5.90% | |
| Plecoptera | 20.00% | 1.00% | |
| Redbreast Sunfish-adult | 20.00% | 3.10% | |
| **Redbreast Sunfish-fry** | **14.00%** | **15.00%** | |
| Redbreast Sunfish-juvenile | 20.00% | 4.70% | |
| Redbreast Sunfish-spawning | 20.00% | 7.30% | |
| Spotted Sucker - adult | 20.00% | 0.80% | |
| Spotted Sucker - juvenile | 20.00% | 1.20% | |
| Spotted Sunfish-adult | 20.00% | -0.90% | |
| Spotted Sunfish-fry | 20.00% | 2.40% | |
| Spotted Sunfish-juvenile | 20.00% | -3.50% | |
| Spotted Sunfish-spawning | 20.00% | 2.80% | |
| Suwannee Bass-adult | 20.00% | -4.00% | |
| Suwannee Bass-juvenile | 20.00% | -22.30% | |
| **Suwannee Bass-Spawning** | **6.90%** | **15.00%** | **129** |
| Tricoptera | 20.00% | 2.70% | |
| Tvetenia vitracies-larvae | 20.00% | -5.00% | |

1. Flow change is limited to a maximum of 20%
2. Species/Life stage in bold indicates sensitive to flow reduction

White Springs SEFA output

| Species/Life stage | B1 Flow reduction (%) | Change in average AWS (%) | Constant flow reduction (cfs) |
|---|---|---|---|
| BenthicMacro_LoGrad | 20.00% | -8.50% | |
| Blackbanded Darter-adult | 20.00% | -5.80% | |
| Bluegill -adult | 20.00% | 12.30% | |
| **Bluegill -fry** | **12.50%** | **14.90%** | |
| Bluegill -juvenile | 20.00% | -0.40% | |
| Bluegill -spawning | 20.00% | 1.60% | |
| Channel Catfish-adult | 20.00% | 8% | |
| Channel Catfish-fry | 20.00% | 0.70% | |
| Channel Catfish-juvenile | 20.00% | -3.30% | |
| Channel Catfish-juvenile-Fall | 20.00% | -4.60% | |
| Channel Catfish-juvenile-Spring | 20.00% | -6.40% | |
| Channel Catfish-juvenile-Summer | 20.00% | 2.80% | |
| Channel Catfish-spawning | 20.00% | 2.90% | |
| Cyprinidae -adult | 20.00% | -6.50% | |
| Ephemeroptera | 20.00% | -1.40% | |
| EPT Total | 20.00% | -2.30% | |
| Generic Darters-adult | 20.00% | -1.90% | |
| Habitat Guilds-DF | 20.00% | -4.40% | |
| Habitat Guilds-DS | 20.00% | 10% | |
| Habitat Guilds-SF | 20.00% | -6.70% | |
| Habitat Guilds-SS | 20.00% | 1.60% | |
| Hydropsychidae -Total | 20.00% | -2.40% | |
| **Largemouth Bass-adult** | **11.00%** | **15.00%** | **130** |
| **Largemouth Bass-fry** | **8.10%** | **15.00%** | **111** |
| Largemouth Bass-juvenile | 20.00% | 8.10% | |
| Largemouth Bass-spawning | 20.00% | 2.10% | |
| Metallic Shiner | 20.00% | -4.30% | |
| Plecoptera | 20.00% | 0.20% | |
| Redbreast Sunfish-adult | 20.00% | 1.60% | |
| **Redbreast Sunfish-fry** | **15.80%** | **15.00%** | |
| Redbreast Sunfish-juvenile | 20.00% | 3.80% | |
| Redbreast Sunfish-spawning | 20.00% | 6.00% | |
| Spotted Sucker - adult | 20.00% | -0.20% | |
| Spotted Sucker - juvenile | 20.00% | 1.10% | |
| Spotted Sunfish-adult | 20.00% | -2.00% | |
| Spotted Sunfish-fry | 20.00% | 1.00% | |
| Spotted Sunfish-juvenile | 20.00% | -3.30% | |
| Spotted Sunfish-spawning | 20.00% | 1.40% | |
| Suwannee Bass-adult | 20.00% | -4.90% | |
| Suwannee Bass-juvenile | 20.00% | -14.90% | |
| **Suwannee Bass-Spawning** | **7.20%** | **15.00%** | **114** |
| Tricoptera | 20.00% | 1.60% | |
| Tvetenia vitracies-larvae | 20.00% | -5.00% | |

1. Flow change is limited to a maximum of 20%
2. Species/Life stage in bold indicates sensitive to flow reduction

# Appendix F

# Indicators of Hydrologic Alteration (IHA)

# 1. INTRODUCTION

Version 7.1 of the Indicators of Hydrologic Alteration (IHA) software (The Nature Conservancy, 2009) was used to quantify the degree of alteration from RTF (WY 1938-2015) to MFL flow regimes of the USR at the White Springs gage. The software uses daily flow time series data to generate multiple sets of hydrologic statistics.

The five principal attributes of flow data variability (magnitude, duration, amplitude, frequency, and timing) are programmed in IHA because of their influence on aquatic species at various life stages. IHA calculates two types of flow statistics; the first type includes 33 IHA statistics and the second type includes 34 flow statistics calculated for five different environmental flow components (EFCs). EFCs are a more recent suite of hydrologic flow parameters and were developed by the Nature Conservancy in version 7.1 (released in 2009) to identify and compute statistics on hydrological events such as floods and droughts. The 33 IHA statistics and 34 EFCs together describe flow attributes deemed to be ecologically relevant.

## 1.1 IHA Components

The IHA components characterize within-year variation in streamflow based on a series of hydrologic attributes (IHA statistics) organized into five groups (**Table 1**).

**Group 1**. The IHA Group 1 statistics (mean monthly streamflow) characterize seasonal patterns in the magnitude and timing of streamflow. They describe the normal condition and provide a measure of availability or sustainability of habitat or flows for various river services.

**Group 2**. The IHA Group 2 statistics focus on the magnitude and duration of annual extreme flow conditions. In addition to maximum and minimum flows over specified periods of time, it includes the base flow index, defined as 7-day minimum flow/mean flow for the year and number of almost zero flow days. Group 2 statistics provide a measure of the amount of environmental stress and disturbance during the year.

**Group 3**. The IHA Group 3 statistics characterize the timing (dates within a year) of the annual 1-day minimum and 1-day maximum flows. Timing is important to assess the degree of stress or mortality from extreme events during key periods in a species life cycle. It is also important to compare against timeframes needed for recreation or other socioeconomic services.

**Group 4**. The IHA Group 4 statistics include frequencies of high- and low-flow pulses. A pulse is defined as a daily mean flow above or below selected thresholds. The annual number of daily mean flows greater than the 80th percentile and the annual number less than the 20th percentile over the period of record were selected as thresholds for the USR analysis. The duration of time over which a specific water condition exists may determine whether a particular life cycle phase can be completed or the degree to which inundation or desiccation can occur.

**Group 5**. Group 5 IHA statistics (rise rate, fall rate and number of reversals) characterize the number and mean rate of positive (rise) and negative (fall) flow changes on two consecutive days. The rate of change in water condition affects stranding of certain organisms along the water edge or ability of plant roots to maintain contact with phreatic water supplies.

**Table 1. Summary of hydrologic attributes and regime characteristics associated with the IHA component groups** [Source: (The Nature Conservancy, 2009)]

| IHA statistics group | Regime characteristics | Hydrologic attributes |
|---|---|---|
| Group 1: Magnitude of monthly water conditions | Magnitude, Timing | Mean for each calendar month (median in this application) |
| Group 2: Magnitude and duration of annual extreme water conditions | Magnitude, Duration | Annual minimums of 1-day means<br>Annual maximums of 1-day means<br>Annual minimums of 3-day means<br>Annual maximums of 3-day means<br>Annual minimums of 7-day means<br>Annual maximums of 7-day means<br>Annual minimums of 30-day means<br>Annual maximums of 30-day means<br>Annual minimums of 90-day means<br>Annual maximums of 90-day means |
| Group 3: Timing of annual extreme water conditions | Timing | Julian data of each annual 1-day maximum<br>Julian data of each annual 1-day minimum |
| Group 4: Frequency and duration of high and low flow pulses | Magnitude, Frequency, Duration | Number of high-flow pulses each year<br>Number of low-flow pulses each year<br>Mean duration of high-flow pulses in each year<br>Mean duration of low-flow pulses in each year |
| Group 5: Rate and frequency of water condition changes | Frequency, Rate of change | Means of all positive differences between consecutive daily means<br>Means of all negative differences between consecutive daily means<br>Number of rises<br>Number of falls |

## 1.2 Environmental Flow Components

The IHA software calculates 34 EFC parameters grouped into five different types of Environment Flow Components (EFCs): low flows, extreme low flows, high flow pulses, small floods, and large floods. The five EFC types are described in more detail in section 2.3 of the IHA manual (The Nature Conservancy 2009). This categorization of flow into five EFCs is based on the realization by research ecologists that river hydrographs can be divided into a repeating set of ecologically important hydrographic patterns that should be considered to sustain riverine ecological integrity. Not only is it important to maintain adequate flows during low-flow periods, but also higher flows and floods and extreme low-flow conditions that perform important ecological functions.

The IHA software incorporates default parameters for delineating the five EFCs as well as an interface for users to modify the default values (The Nature Conservancy, 2009), see **Figure 1**. The thresholds that can be modified include flow exceedances (e.g., 10th percentile), recurrence intervals (e.g., 2-year event), and rate of change (e.g., 25% flow increase from previous day).

In the IHA EFC model, all daily flows fall within one of the five categories, and an algorithm parses the hydrograph accordingly based on the delineation thresholds being employed. The program logic (**Figure 2**) separates flow into base flows and flow pulse periods using a base-flow separation method. Pulses are subsequently classified by flow rate-of-change (i.e., percent difference from previous day), and base flows classified by magnitude (expressed as recurrence interval).

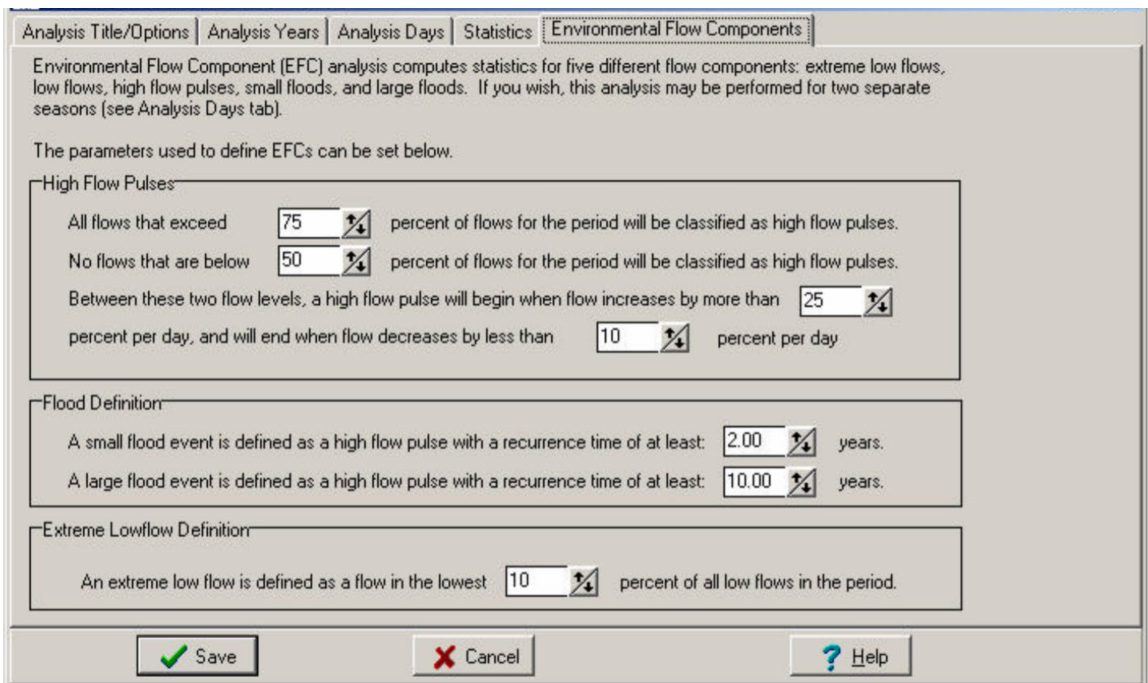


**Figure 1. IHA EFC definitions interface screen, displaying default thresholds**

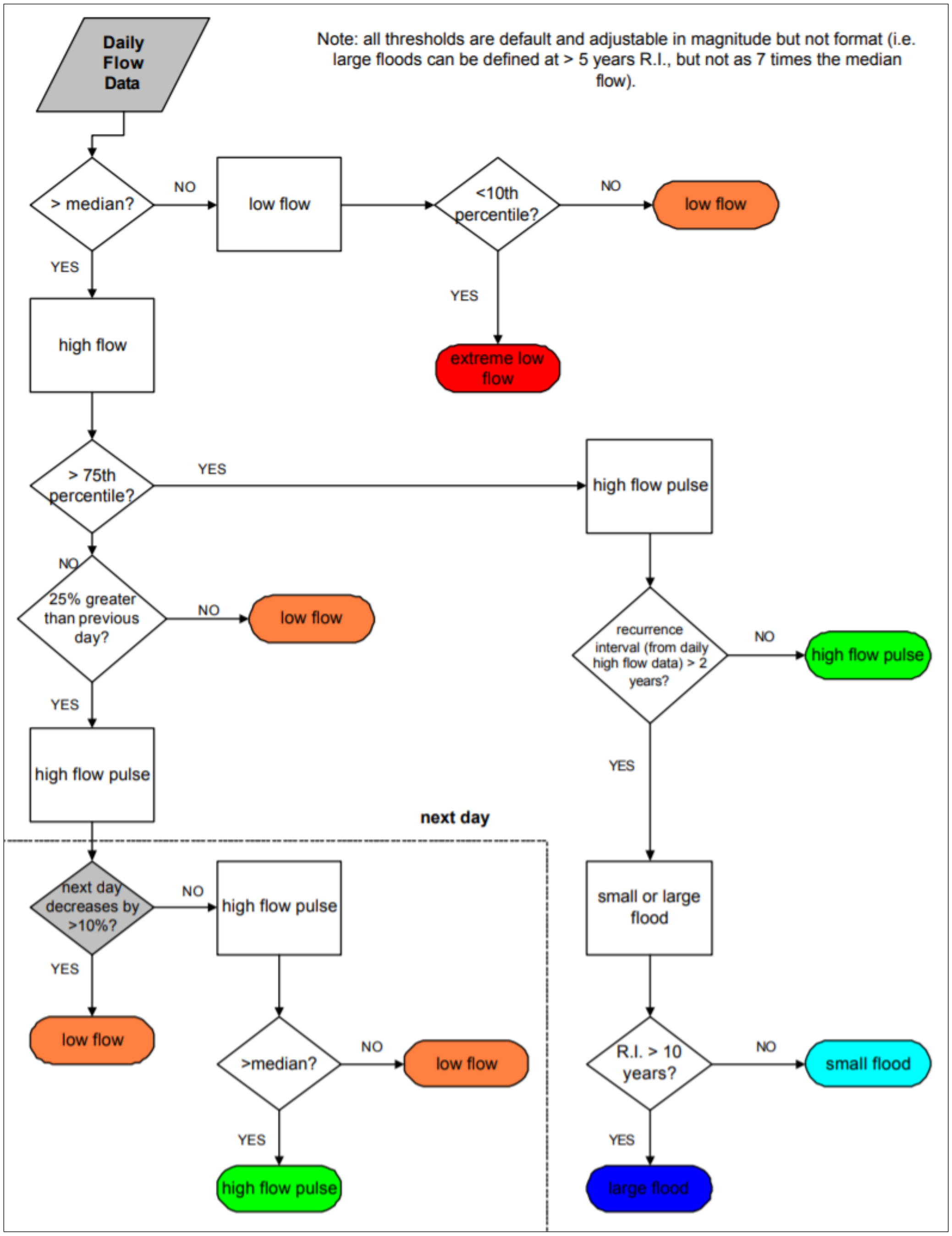


**Figure 2. IHA environmental flow component algorithm flow chart**
[Source: (Hersh & Maidment, 2006)]

## 2. IHA RESULTS FOR USR AT SUWANNEE SPRINGS

IHA was used to compare the hydrologic characteristics of two time series of flow at the White Springs gage: Reference Timeframe Flow (RTF) for WYs 1938-2015 and MFL flow for WYs 1938-2015. The program calculated deviation factors and corresponding significance counts for the 33 IHA and 34 EFC parameter medians and coefficients of dispersion (($75^{th}$ percentile-$25^{th}$ percentile)/$50^{th}$ percentile, in Table 2). The coefficient of dispersion (C.D. in Table 2) is a nonparametric interquartile spread normalized to the median. Deviation factors are calculated by comparing MFL values with RTF values for each parameter, as shown in the equation below, which is interpreted as the proportional change in the median (or coefficient of dispersion) relative to the RTF value.

$$\text{Deviation factor} = \frac{\text{RTF value} - \text{MFL value}}{\text{RTF value}}$$

For example, the median 90-day minimum flow values (highlighted in Table 2 Parameter Group #2) for RTF and MFL flows are 179.1 cfs and 104 cfs, respectively. Using the above equation, the deviation factor is 0.4194 ((179.1-104)/179.1), i.e., a 41.94-percent change from the RTF value. Similarly, a deviation factor (DF) of 0.6189 is calculated for the coefficient of dispersion using the RTF and MFL coefficient of dispersion values of 1.779 and 2.881, respectively.

The significance count for the deviation values can be interpreted similar to a p-value in parametric statistics and indicates whether the difference between RTF and MFL flows (deviation factor) is significant. A low significance count (minimum value is 0) implies that the difference between the two flow regimes is significant. The IHA software calculates the significance count values by randomly shuffling all years of input data and recalculates fictitious RTF and MFL medians and coefficient of dispersions 1,000 times (The Nature Conservancy, 2009). The significance count is the fraction of trials for which the deviation values for the medians or coefficient of dispersions were greater than for the real case. So, a high significance count (maximum value of 1) means that there is little difference between the RTF and MFL data. The significance counts may differ slightly each time the IHA analysis is completed, since a new set of randomized cases is generated each time.

The IHA analysis quantifies the extent of possible hydrologic alteration (attributable to withdrawal) between RTF and MFL flows. The proposed MFL is implemented as a constant withdrawal, thus the influence of the MFL would be most apparent in the low- to moderately low flow statistics. Group parameters with significance counts at 0.05 or less are highlighted in bold in Table 3 and Table 4. All are associated with low flows.

**Table 2. IHA output for USR at the White Springs gage pre-impact period (RTF) and post-impact period (MFL) flows**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Non-Parametric IHA Scorecard** | | | | | | | | |
| | | | | | | | | |
| WS-RTF-MFL-12202021 | | | | | | | | |
| | | | | | | | | |
| **IHA Parameters** | | | | | | | | |
| **Pre-impact (RTF) period: 1938-2015 (78 years)** | | | | **Post-impact (MFL) period: 1938-2015 (78 years)** | | | | |
| Normalization Factor | 1 | | | 1 | | | | |
| Mean annual flow | 1731 | | | 1654 | | | | |
| Non-Normalized Mean Flow | 1731 | | | 1654 | | | | |
| Annual C. V. | 1.58 | | | 1.65 | | | | |
| Flow predictability | 0.17 | | | 0.18 | | | | |
| Constancy/predictability | 0.72 | | | 0.74 | | | | |
| % of floods in 60d period | 0.31 | | | 0.31 | | | | |
| Flood-free season | 0 | | | 0 | | | | |
| | | | | | | | | |
| | **MEDIANS** | | **COEFF. of DISP.** | | **DEVIATION FACTOR** | | **SIGNIFICANCE COUNT** | |
| | **Pre** | **Post** | **Pre** | **Post** | **Medians** | **C.D.** | **Medians** | **C.D.** |
| | | | | | | | | |
| **Parameter Group #1** | | | | | | | | |
| October | 463.2 | 380.9 | 3.187 | 3.876 | 0.1777 | 0.2161 | 0.5135 | 0.6607 |
| November | 266 | 183.7 | 2.38 | 3.446 | 0.3095 | 0.4481 | 0.4625 | 0.2152 |
| December | 340.7 | 258.4 | 2.61 | 3.442 | 0.2416 | 0.3185 | 0.3293 | 0.2503 |
| January | 820.3 | 738 | 2.785 | 3.095 | 0.1003 | 0.1115 | 0.7728 | 0.7758 |
| February | 1685 | 1603 | 2.164 | 2.275 | 0.04883 | 0.05134 | 0.9259 | 0.8569 |
| March | 1856 | 1773 | 2.289 | 2.396 | 0.04435 | 0.04641 | 0.9419 | 0.9189 |
| April | 1458 | 1376 | 2.34 | 2.48 | 0.05644 | 0.05982 | 0.8028 | 0.8478 |
| May | 466.5 | 384.2 | 2.49 | 3.024 | 0.1764 | 0.2142 | 0.5596 | 0.4394 |
| June | 278.7 | 196.4 | 2.667 | 3.785 | 0.2954 | 0.4191 | 0.7908 | 0.3634 |
| July | 750.5 | 668.2 | 1.861 | 2.09 | 0.1097 | 0.1232 | 0.5876 | 0.6386 |
| August | 815.2 | 732.9 | 2.516 | 2.799 | 0.101 | 0.1123 | 0.6346 | 0.7327 |
| September | 879 | 796.7 | 1.982 | 2.187 | 0.09363 | 0.1033 | 0.7207 | 0.7377 |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter Group #2** | | | | | | | | |
| 1-day minimum | 56.85 | 0 | 1.646 | 0 | 1 | 1 | 0.1542 | 0.08809 |
| 3-day minimum | 59.18 | 0 | 1.718 | 0 | 1 | 1 | 0.1291 | 0.06707 |
| 7-day minimum | 62.69 | 0 | 1.718 | 0 | 1 | 1 | 0.1371 | 0.06907 |
| 30-day minimum | 87.92 | 11.85 | 1.383 | 6.374 | 0.8652 | 3.609 | 0.07307 | 0.00 |
| 90-day minimum | 179.1 | 104 | 1.779 | 2.881 | 0.4194 | 0.6189 | 0.2002 | 0.06607 |
| 1-day maximum | 7386 | 7304 | 0.8452 | 0.8547 | 0.01114 | 0.01127 | 0.9179 | 0.955 |
| 3-day maximum | 7281 | 7199 | 0.8521 | 0.8618 | 0.0113 | 0.01143 | 0.9489 | 0.955 |
| 7-day maximum | 7050 | 6967 | 0.8815 | 0.8919 | 0.01167 | 0.01181 | 0.996 | 0.959 |
| 30-day maximum | 5273 | 5190 | 1.11 | 1.127 | 0.01561 | 0.01586 | 0.9029 | 0.9379 |
| 90-day maximum | 3405 | 3322 | 1.002 | 1.027 | 0.02417 | 0.02477 | 0.8919 | 0.9259 |
| Number of zero days | 0 | 16 | 0 | 4.719 | | | | |
| Base flow index | 0.05065 | 0 | 1.17 | 0 | 1 | 1 | 0.03203 | 0.01802 |
| | | | | | | | | |
| **Parameter Group #3** | | | | | | | | |
| Date of minimum | 210.5 | 275 | 0.3757 | 0.3811 | 0.3525 | 0.01455 | 0.1341 | 0.9199 |
| Date of maximum | 91 | 91 | 0.4809 | 0.4809 | 0 | 0 | 0.993 | 0.992 |
| | | | | | | | | |
| **Parameter Group #4** | | | | | | | | |
| Low pulse count | 2 | 2 | 1.5 | 1.5 | 0 | 0 | 0.0951 | 0.2653 |
| Low pulse duration | 23.25 | 25.75 | 1.575 | 1.816 | 0.1075 | 0.1525 | 0.8539 | 0.6386 |
| High pulse count | 3 | 3 | 1 | 1 | 0 | 0 | 0.7057 | 0.6567 |
| High pulse duration | 25 | 24 | 1.36 | 1.089 | 0.04 | 0.1996 | 0.7778 | 0.5115 |
| Low Pulse Threshold | 185.7 | | | | | | | |
| High Pulse Threshold | 2141 | | | | | | | |
| | | | | | | | | |
| **Parameter Group #5** | | | | | | | | |
| Rise rate | 50 | 60 | 1.395 | 1.252 | 0.2 | 0.1024 | 0.1221 | 0.5756 |
| Fall rate | -35 | -40 | -1.143 | -1.113 | 0.1429 | 0.02656 | 0.4294 | 0.8939 |
| Number of reversals | 57 | 50.5 | 0.2982 | 0.3218 | 0.114 | 0.07892 | 0.008008 | 0.7417 |
| | | | | | | | | |
| **EFC Low flows** | | | | | | | | |
| October Low Flow | 475 | 528.8 | 1.755 | 1.483 | 0.1133 | 0.1553 | 0.7267 | 0.6246 |
| November Low Flow | 327.6 | 362.3 | 1.895 | 1.728 | 0.1059 | 0.08806 | 0.7067 | 0.7728 |
| December Low Flow | 403.3 | 374.7 | 1.815 | 2.135 | 0.07091 | 0.1765 | 0.6737 | 0.4785 |
| January Low Flow | 502.9 | 431.5 | 1.978 | 2.419 | 0.1421 | 0.2226 | 0.7097 | 0.5455 |
| February Low Flow | 738.2 | 798.2 | 1.613 | 1.492 | 0.08128 | 0.07501 | 0.8398 | 0.8238 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| March Low Flow | 1085 | 1078 | 1.01 | 1.143 | 0.006726 | 0.131 | 0.954 | 0.6236 |
| April Low Flow | 900.8 | 928.7 | 1.147 | 1.146 | 0.03097 | 0.0007298 | 0.8969 | 1 |
| May Low Flow | 461.9 | 438.6 | 1.969 | 1.902 | 0.05044 | 0.0339 | 0.9029 | 0.8689 |
| June Low Flow | 354.3 | 318.9 | 1.846 | 2.384 | 0.09992 | 0.2915 | 0.8088 | 0.3243 |
| July Low Flow | 655.8 | 641.2 | 1.652 | 1.592 | 0.02226 | 0.0359 | 0.9389 | 0.8699 |
| August Low Flow | 705.2 | 694.4 | 1.533 | 1.55 | 0.01531 | 0.0109 | 0.985 | 0.974 |
| September Low Flow | 721.2 | 715.8 | 1.353 | 1.251 | 0.007488 | 0.07587 | 0.963 | 0.7908 |
| | | | | | | | | |
| **EFC Parameters** | | | | | | | | |
| Extreme low peak | 33.85 | 8.775 | 0.743 | 2.624 | 0.7408 | 2.532 | 0.01602 | 0.00 |
| Extreme low duration | 14 | 18 | 2 | 1.535 | 0.2857 | 0.2326 | 0.3093 | 0.4414 |
| Extreme low timing | 207.5 | 172 | 0.3689 | 0.3497 | 0.194 | 0.05185 | 0.2703 | 0.8729 |
| Extreme low freq. | 0.5 | 2 | 4 | 1.5 | 3 | 0.625 | 0.00 | 0.2492 |
| High flow peak | 3476 | 3409 | 0.4691 | 0.4482 | 0.0192 | 0.04444 | 0.7768 | 0.8068 |
| High flow duration | 16.5 | 15.5 | 1.144 | 1.097 | 0.06061 | 0.04123 | 0.8068 | 0.8288 |
| High flow timing | 189.8 | 192 | 0.429 | 0.4488 | 0.0123 | 0.04618 | 0.98 | 0.7828 |
| High flow frequency | 2 | 2 | 1 | 1 | 0 | 0 | 0.2272 | 0.2452 |
| High flow rise rate | 228.3 | 222.7 | 1.351 | 1.439 | 0.02435 | 0.06531 | 0.9399 | 0.8068 |
| High flow fall rate | -135.8 | -130 | -0.6094 | -0.6458 | 0.04294 | 0.05981 | 0.5075 | 0.7888 |
| Small Flood peak | 9661 | 9669 | 0.2725 | 0.2632 | 0.0007763 | 0.03392 | 0.971 | 0.8939 |
| Small Flood duration | 67 | 58.5 | 0.7201 | 0.8974 | 0.1269 | 0.2462 | 0.5075 | 0.4244 |
| Small Flood timing | 116 | 117 | 0.418 | 0.4098 | 0.005464 | 0.01961 | 0.951 | 0.9369 |
| Small Flood freq. | 0 | 0 | 0 | 0 | | | | |
| Small Flood rise rate | 353.8 | 370 | 1.268 | 1.458 | 0.04591 | 0.1505 | 0.4444 | 0.8308 |
| Small Flood fallrate | -262.3 | -270.4 | -0.5816 | -0.7307 | 0.03094 | 0.2563 | 0.8989 | 0.4875 |
| Large flood peak | 26200 | 26120 | 0.3282 | 0.3293 | 0.003141 | 0.003151 | 0.951 | 0.989 |
| Large flood duration | 122 | 121 | 0.7705 | 0.7769 | 0.008197 | 0.008265 | 0.9389 | 0.981 |
| Large flood timing | 101 | 101 | 0.2678 | 0.2678 | 0 | 0 | 0.8118 | 0.97 |
| Large flood freq. | 0 | 0 | 0 | 0 | | | | |
| Large flood rise rate | 359.7 | 359.7 | 0.9777 | 0.9777 | 0 | 0 | 0.8919 | 0.991 |
| Large flood fall rate | -782.6 | -801 | -0.6505 | -0.6308 | 0.02354 | 0.03025 | 0.8879 | 0.958 |
| EFC low flow threshold: | | | | | | | | |
| EFC high flow threshold: | | 2141 | | | | | | |
| EFC extreme low flow threshold: | | 57.6 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| EFC small flood minimum peak flow: | | 6826 | | | | | | |
| EFC large flood minimum peak flow: | | 17670 | | | | | | |

**Table 3. Summary of 33 IHA parameters for USR**

[**Bold** indicates a statistically significant change at 5 percent level of significance]

| Group | EFC Parameter | Median | | Coefficient of dispersion | |
|---|---|---|---|---|---|
| | | Deviation Factor | Significance Count* | Deviation Factor | Significance Count* |
| Group#1 | January | 0.1003 | 0.7728 | 0.1115 | 0.7758 |
| | February | 0.04883 | 0.9259 | 0.05134 | 0.8569 |
| | March | 0.04435 | 0.9419 | 0.04641 | 0.9189 |
| | April | 0.05644 | 0.8028 | 0.05982 | 0.8478 |
| | May | 0.1764 | 0.5596 | 0.2142 | 0.4394 |
| | June | 0.2954 | 0.7908 | 0.4191 | 0.3634 |
| | July | 0.1097 | 0.5876 | 0.1232 | 0.6386 |
| | August | 0.101 | 0.6346 | 0.1123 | 0.7327 |
| | September | 0.09363 | 0.7207 | 0.1033 | 0.7377 |
| | October | 0.1777 | 0.5135 | 0.2161 | 0.6607 |
| | November | 0.3095 | 0.4625 | 0.4481 | 0.2152 |
| | December | 0.2416 | 0.3293 | 0.3185 | 0.2503 |
| Group#2 | 1-day minimum | 1 | 0.1542 | 1 | 0.08809 |
| | 3-day minimum | 1 | 0.1291 | 1 | 0.06707 |
| | 7-day minimum | 1 | 0.1371 | 1 | 0.06907 |
| | 30-day minimum | 0.8652 | 0.07307 | **3.609** | **0.00** |
| | 90-day minimum | 0.4194 | 0.2002 | 0.6189 | 0.06607 |
| | 1-day maximum | 0.01114 | 0.9179 | 0.01127 | 0.955 |
| | 3-day maximum | 0.0113 | 0.9489 | 0.01143 | 0.955 |
| | 7-day maximum | 0.01167 | 0.996 | 0.01181 | 0.959 |
| | 30-day maximum | 0.01561 | 0.9029 | 0.01586 | 0.9379 |
| | 90-day maximum | 0.02417 | 0.8919 | 0.02477 | 0.9259 |
| | Number of zero days | | | | |
| | Base flow index | **1** | **0.03203** | **1** | **0.01802** |
| Group#3 | Date of minimum | 0.3525 | 0.1341 | 0.01455 | 0.9199 |
| | Date of maximum | 0 | 0.993 | 0 | 0.992 |
| Group#4 | Low pulse count | 0 | 0.0951 | 0 | 0.2653 |
| | Low pulse duration | 0.1075 | 0.8539 | 0.1525 | 0.6386 |
| | High pulse count | 0 | 0.7057 | 0 | 0.6567 |
| | High pulse duration | 0.04 | 0.7778 | 0.1996 | 0.5115 |
| Group#5 | Rise rate | 0.2 | 0.1221 | 0.1024 | 0.5756 |
| | Fall rate | 0.1429 | 0.4294 | 0.02656 | 0.8939 |
| | Number of reversals | **0.114** | **0.008008** | 0.07892 | 0.7417 |

*Deviation factor is significant if significance count<0.05

Bolded values have significance count<0.05

**Table 4. Summary of 34 IHA environmental flow component parameters for USR**
[**Bold** indicates a statistically significant change at 5 percent level of significance]

| Group | EFC Parameter | Median | | Coefficient of dispersion | |
|---|---|---|---|---|---|
| | | Deviation Factor | Significance Count* | Deviation Factor | Significance Count* |
| Low flow | January low flow | 0.1421 | 0.7097 | 0.2226 | 0.5455 |
| | February low flow | 0.08128 | 0.8398 | 0.07501 | 0.8238 |
| | March low flow | 0.006726 | 0.954 | 0.131 | 0.6236 |
| | April low flow | 0.03097 | 0.8969 | 0.0007298 | 1 |
| | May low flow | 0.05044 | 0.9029 | 0.0339 | 0.8689 |
| | June low flow | 0.09992 | 0.8088 | 0.2915 | 0.3243 |
| | July low flow | 0.02226 | 0.9389 | 0.0359 | 0.8699 |
| | August low flow | 0.01531 | 0.985 | 0.0109 | 0.974 |
| | September low flow | 0.007488 | 0.963 | 0.07587 | 0.7908 |
| | October low flow | 0.1133 | 0.7267 | 0.1553 | 0.6246 |
| | November low flow | 0.1059 | 0.7067 | 0.08806 | 0.7728 |
| | December low flow | 0.07091 | 0.6737 | 0.1765 | 0.4785 |
| Extreme low flow | Extreme low peak | **0.7408** | **0.01602** | **2.532** | **0.00** |
| | Extreme low duration | 0.2857 | 0.3093 | 0.2326 | 0.4414 |
| | Extreme low timing | 0.194 | 0.2703 | 0.05185 | 0.8729 |
| | Extreme low frequency | **3** | **0.00** | 0.625 | 0.2492 |
| High flow pulse | High flow peak | 0.0192 | 0.7768 | 0.04444 | 0.8068 |
| | High flow duration | 0.06061 | 0.8068 | 0.04123 | 0.8288 |
| | High flow timing | 0.0123 | 0.98 | 0.04618 | 0.7828 |
| | High flow frequency | 0 | 0.2272 | 0 | 0.2452 |
| | High flow rise rate | 0.02435 | 0.9399 | 0.06531 | 0.8068 |
| | High flow fall rate | 0.04294 | 0.5075 | 0.05981 | 0.7888 |
| Small flood | Small flood peak | 0.0007763 | 0.971 | 0.03392 | 0.8939 |
| | Small flood duration | 0.1269 | 0.5075 | 0.2462 | 0.4244 |
| | Small flood timing | 0.005464 | 0.951 | 0.01961 | 0.9369 |
| | Small flood frequency | | | | |
| | Small flood rise rate | 0.04591 | 0.4444 | 0.1505 | 0.8308 |
| | Small flood fall rate | 0.03094 | 0.8989 | 0.2563 | 0.4875 |
| Large flood | Large flood peak | 0.003141 | 0.951 | 0.003151 | 0.989 |
| | Large flood duration | 0.008197 | 0.9389 | 0.008265 | 0.981 |
| | Large flood timing | 0 | 0.8118 | 0 | 0.97 |
| | Large flood frequency | | | | |
| | Large flood rise rate | 0 | 0.8919 | 0 | 0.991 |
| | Large flood fall rate | 0.02354 | 0.8879 | 0.03025 | 0.958 |

*Deviation factor is significant if significance count<0.05

Bolded values have significance count<0.05

## 3. References

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