Effects of Groundwater Pumpage on Stream-aquifer Interaction During Droughts in the Lower Apalachicola-Chattahoochee-Flint River Basin

By

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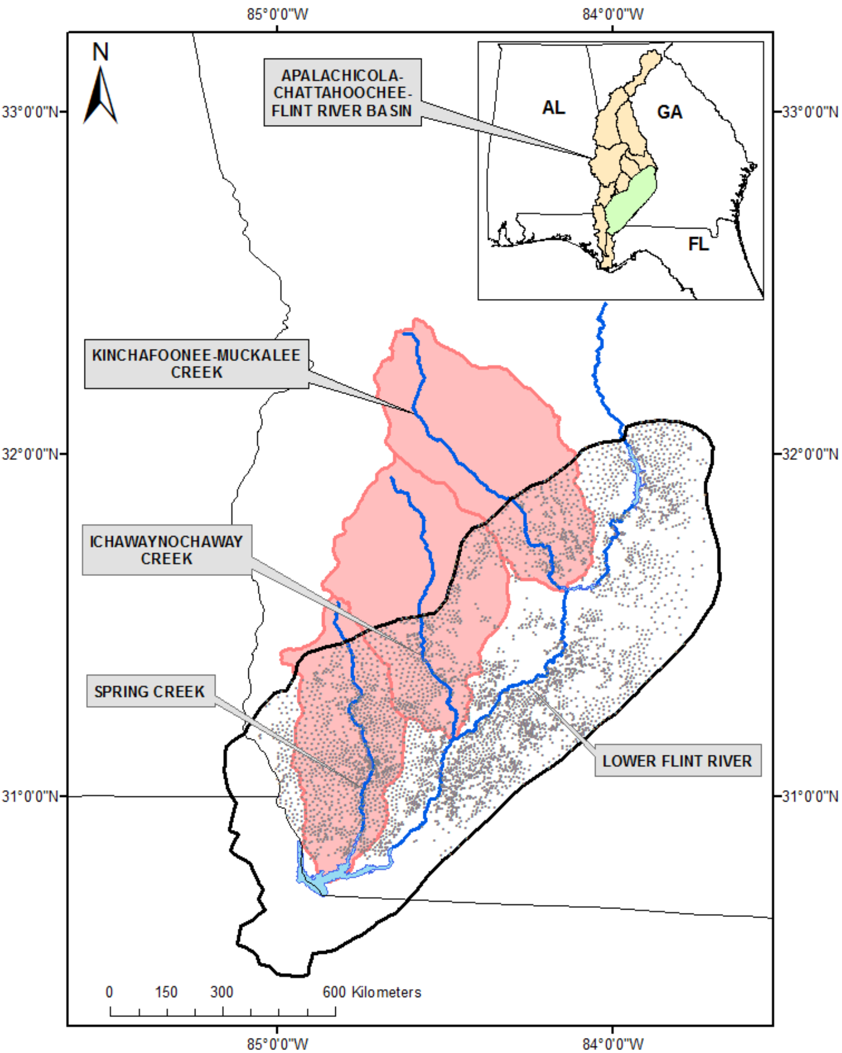
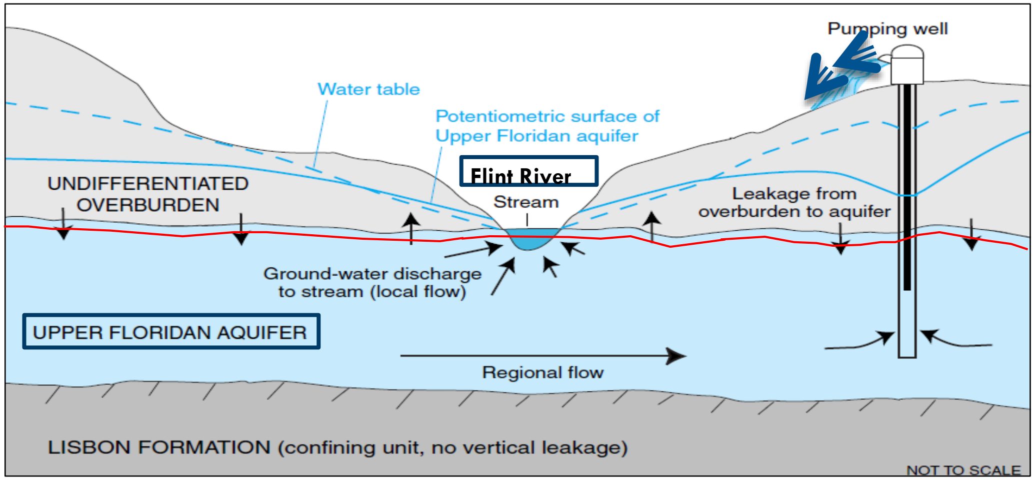
Overview

1. Introduction
2. Objective
3. Results and Discussion
4. Conclusions
5. Recommendations

Study Area





- During droughts water shortages are exacerbated by increased water demands in Atlanta area and irrigated agriculture in southwest Georgia.

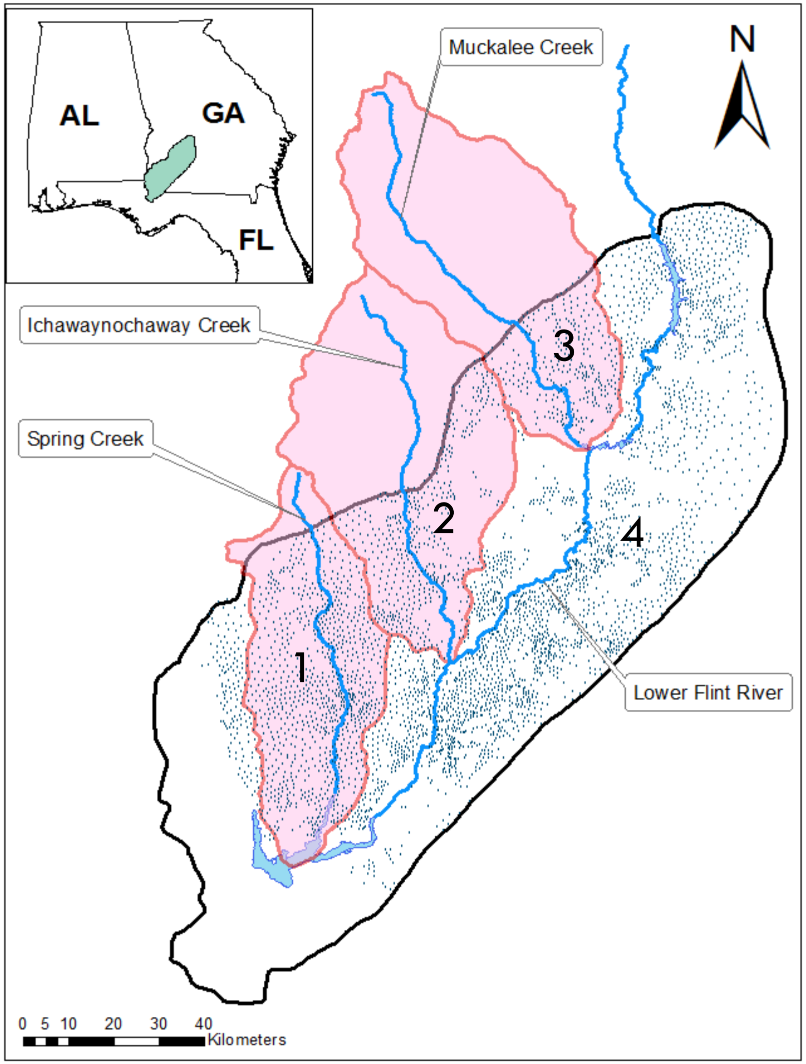
- This leads to two problems:
  - Threatens Oysters Industry at Apalachicola Bay
  - Threatens Endangered Mussel Species

Objectives

- The objective of this study is divided into two parts:

  - To identify critical reaches and tributaries of the Flint River.

  - Effectiveness of various possible simulated water restrictions scenarios suggested by the Flint River Drought Protection Act (FRDPA) (Georgia General Assembly), Environmental Protection Division (EPD) policies, and Flint River Basin Regional Water Development and Conservation Plan (the Flint Plan).



Methodology

- The USGS MODular Finite-Element model (MODFE) was used to study the effects of irrigation on stream-aquifer fluxes.

- Groundwater flow in the Upper Floridan Aquifer is governed by the following two-dimensional flow equation:

$$\frac{\partial}{\partial x}\left(T_{xx}\frac{dh}{dx}+T_{xy}\frac{dh}{dx}\right)+\frac{\partial}{\partial y}\left(T_{yx}\frac{dh}{dx}+T_{yy}\frac{dh}{dx}\right)+R(H-h)+W+P=S\frac{\partial h}{\partial t}$$

where, (x,y) = Cartesian coordinate directions; S= Storage Coefficient;

T = Transmissivity; R= Vertical Hydraulic Conductance; P = Source or Sinks;

h= aquifer hydraulic head; H= Head in the Confining unit; W = Infiltration

- The model uses initial and boundary conditions to solve for the groundwater heads using the above equation.

Components of Groundwater Budget

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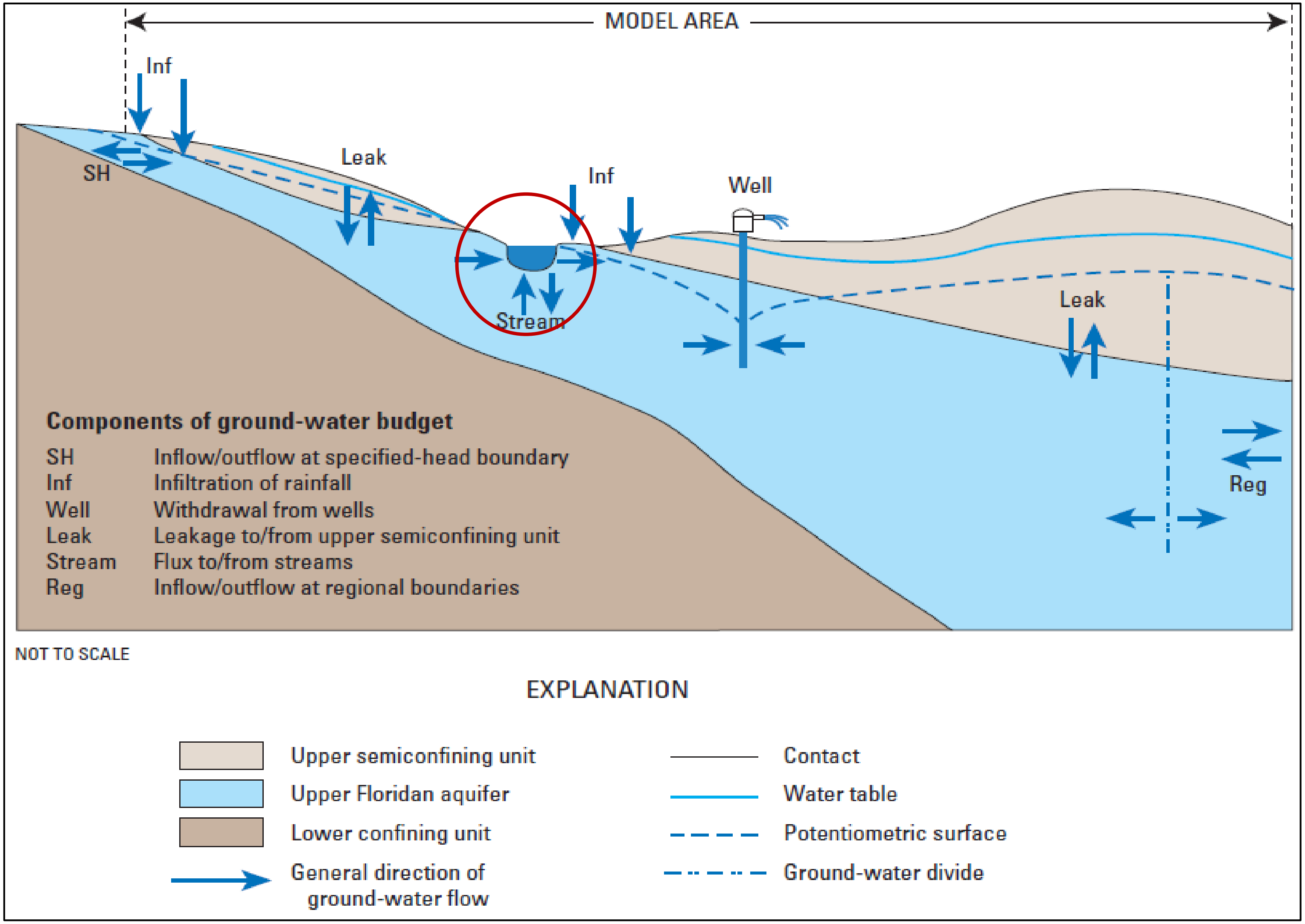


Input Parameters

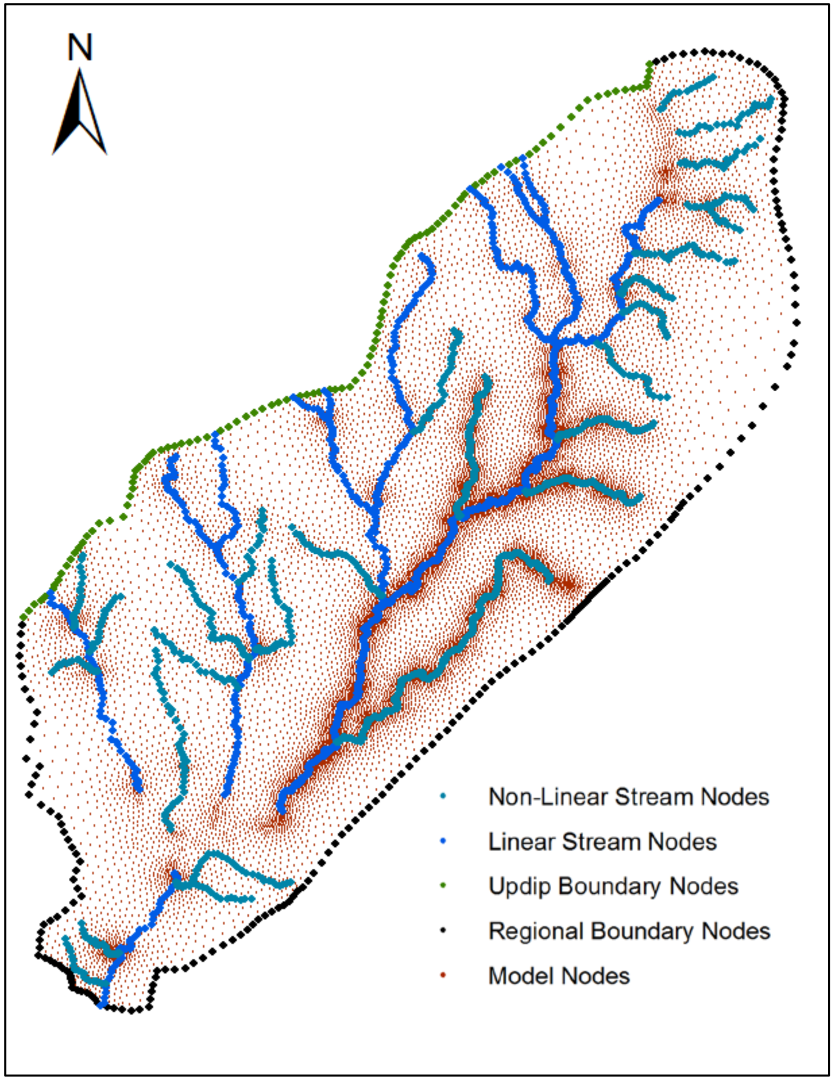
- Model uses a finite element mesh consisting of nodes and elements.

- The input parameters are:

- Infiltration
- Initial hydraulic head
- Head in the overlying confining unit
- Irrigation
- Stream and lake stages
- Regional Boundary heads.

- The model was already calibrated for the ACF by USGS.

- The calibrated model was run for water year 2011 and water year 2012.



Sensitivity Analysis

- **Principal Component Analysis (PCA):** component extraction technique to examine the spatial or temporal variability

- PCA can be described by matrix X and be presented as

$$X = SP^S + E$$

where, S is the PC score, P is the eigenvectors of the covariance matrix and E is the residual matrix (error variance that are not captured by the model).

- **K-means clustering:** assigns each data point to the cluster based on the smallest distance between the cluster centroid and the data points.

- K-means algorithm is used to distinguish the boundaries of PCs and to categorize stream zones in different sensitivity streams sections in the lower ACF River Basin.

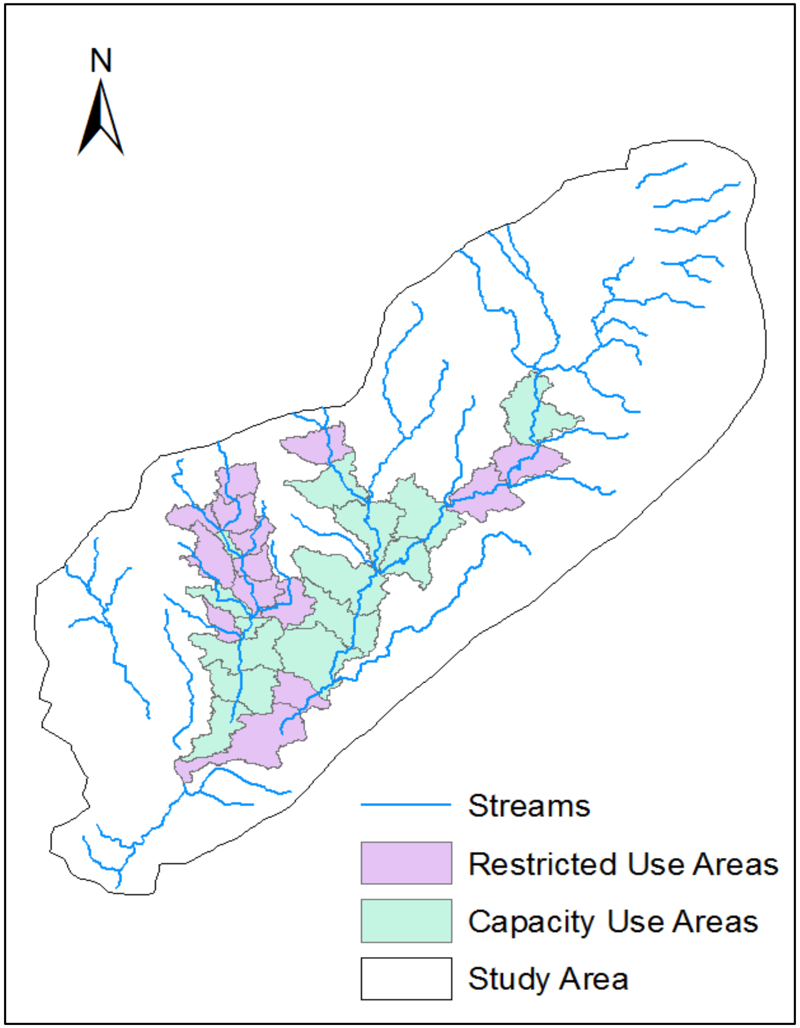
Water Restriction Scenarios

- **Scenario I (SI):** 15% reduction of current irrigation (i.e., WY 2011 and WY 2012).
- **Scenario II (SII):** 30% reduction of current irrigation (i.e., WY 2011 and WY 2012).
- **Scenario III (SIII):** Shutting irrigation in Capacity Use Area.
- **Scenario IV (SIV):** Shutting irrigation in Restricted Use Area.
- **Scenario V (SV):** Shutting irrigation in both Capacity Use Area and Restricted Use Area.
- **Scenario VI (SVI):** Shutting irrigation in a 3 mile buffer zone along the highly sensitive stream zones.
- **Scenario VII (SVII):** Shutting irrigation in a 3 mile buffer zone along the high and moderate sensitive stream zones.

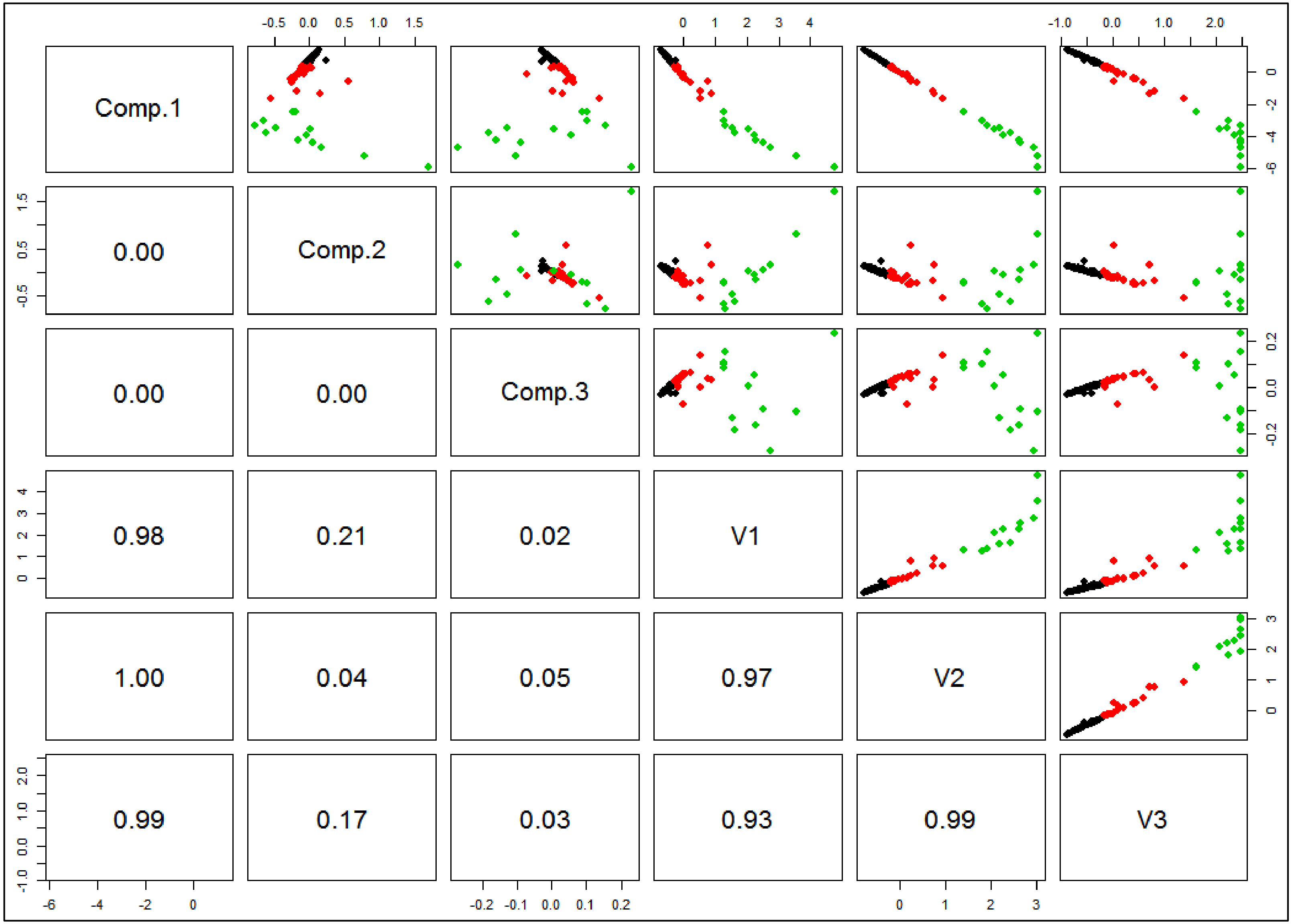
Capacity and Restricted Use Areas

- **Capacity Use Areas (CUA):** Those watersheds in which hydrologic models indicate that baseflow has decreased in any month of a drought year by more than 5 cfs, 10 cfs, and 30 cfs in the Spring Creek, Ichawaynochaway Creek, and Lower Flint River sub-basins respectively.

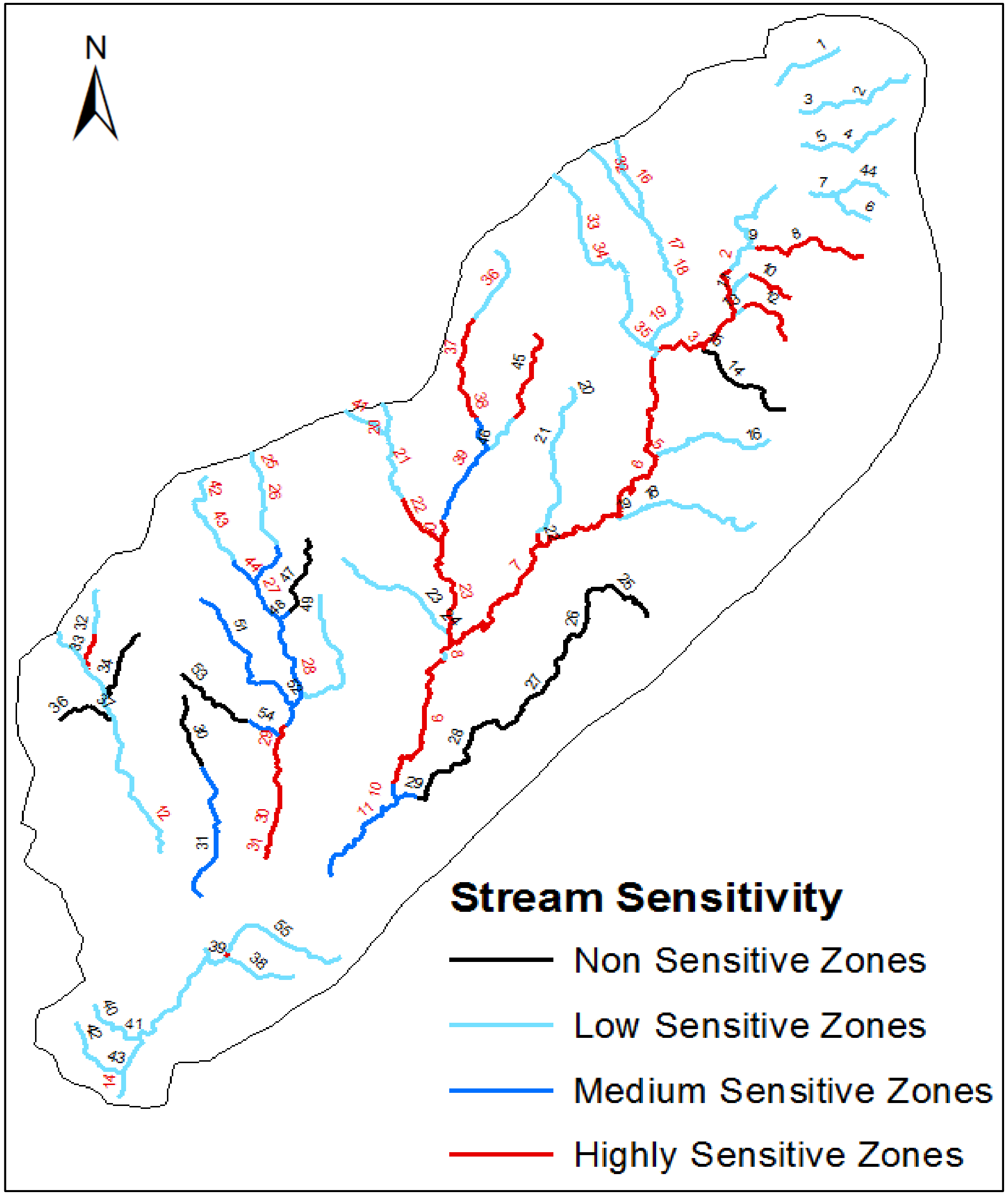
- **Restricted Use Areas (RUA):** Those watersheds in which hydrologic models indicate that baseflow has decreased in any month of a drought year by 1-5 cfs, 1-10 cfs, and 3-30 cfs in Spring Creek, Ichawaynochaway Creek, and Lower Flint River sub-basins respectively.



Sensitivity Analysis Results



Sensitivity Analysis Results



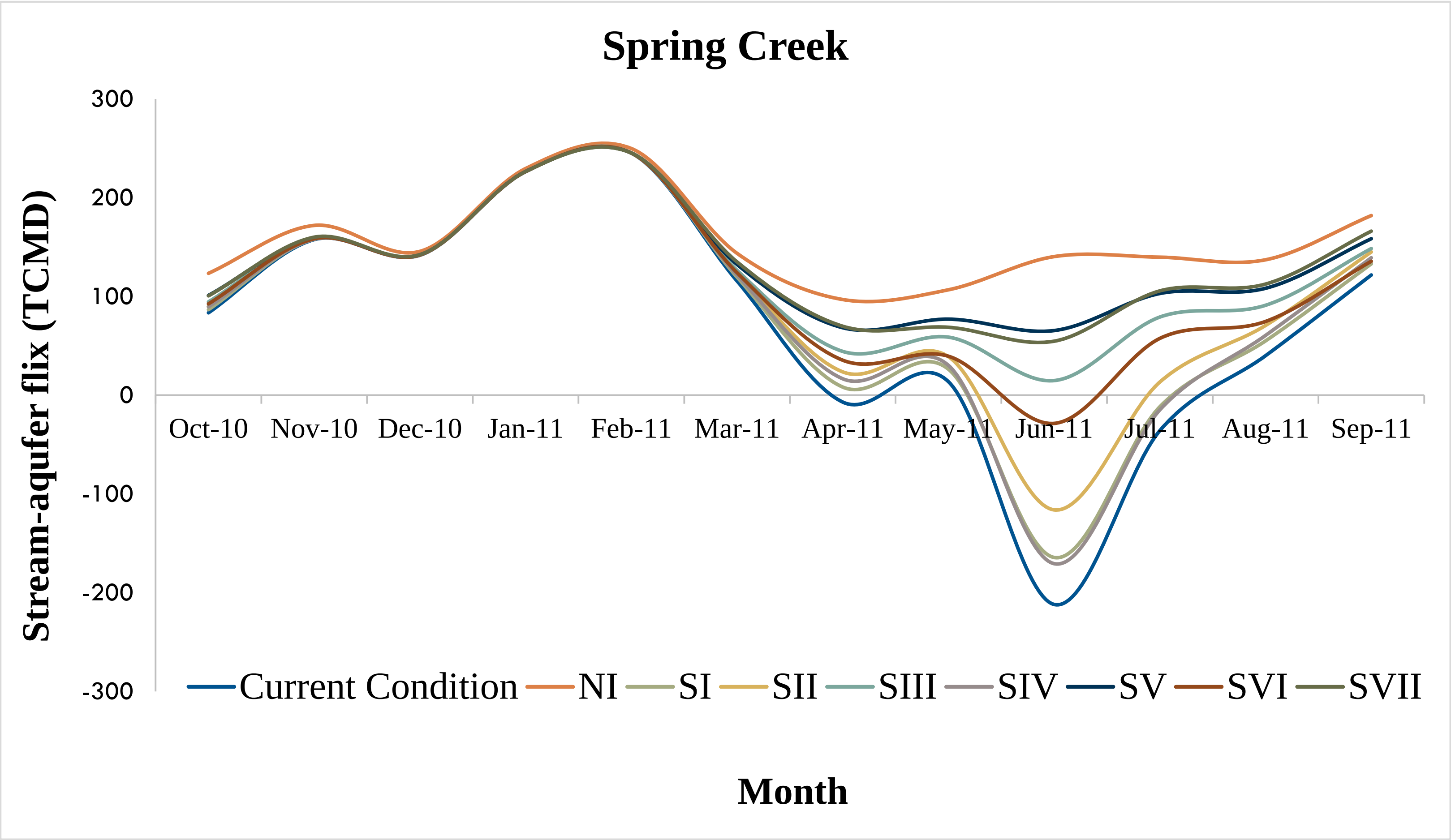
Spring Creek

Stream-aquifer flux for current and different scenarios in TCMD

(TCMD=1000 cubic meters per day)

Month	Pumpage	Current Condition	NI	SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	-101	83	123	87	90	95	90	101	92	101
Nov-10	0	158	172	158	159	159	158	159	158	160
Dec-10	0	142	146	142	142	142	142	142	142	142
Jan-11	0	226	230	226	227	227	226	227	226	227
Feb-11	0	245	250	245	245	245	245	245	245	245
Mar-11	-111	116	144	120	124	126	122	132	124	135
Apr-11	-358	-7	97	8	24	44	17	68	35	70
May-11	-332	14	107	26	39	59	30	77	39	69
Jun-11	-1468	-212	140	-164	-116	15	-171	65	-29	55
Jul-11	-396	-36	140	-12	13	79	-15	103	58	106
Aug-11	-311	40	137	55	71	91	61	108	75	113
Sep-11	-150	122	182	133	145	149	139	158	136	166
Total	**-3227**	**891**	**1867**	**1024**	**1162**	**1430**	**1044**	**1587**	**1303**	**1587**

Spring Creek



Ichawaynochaway Creek

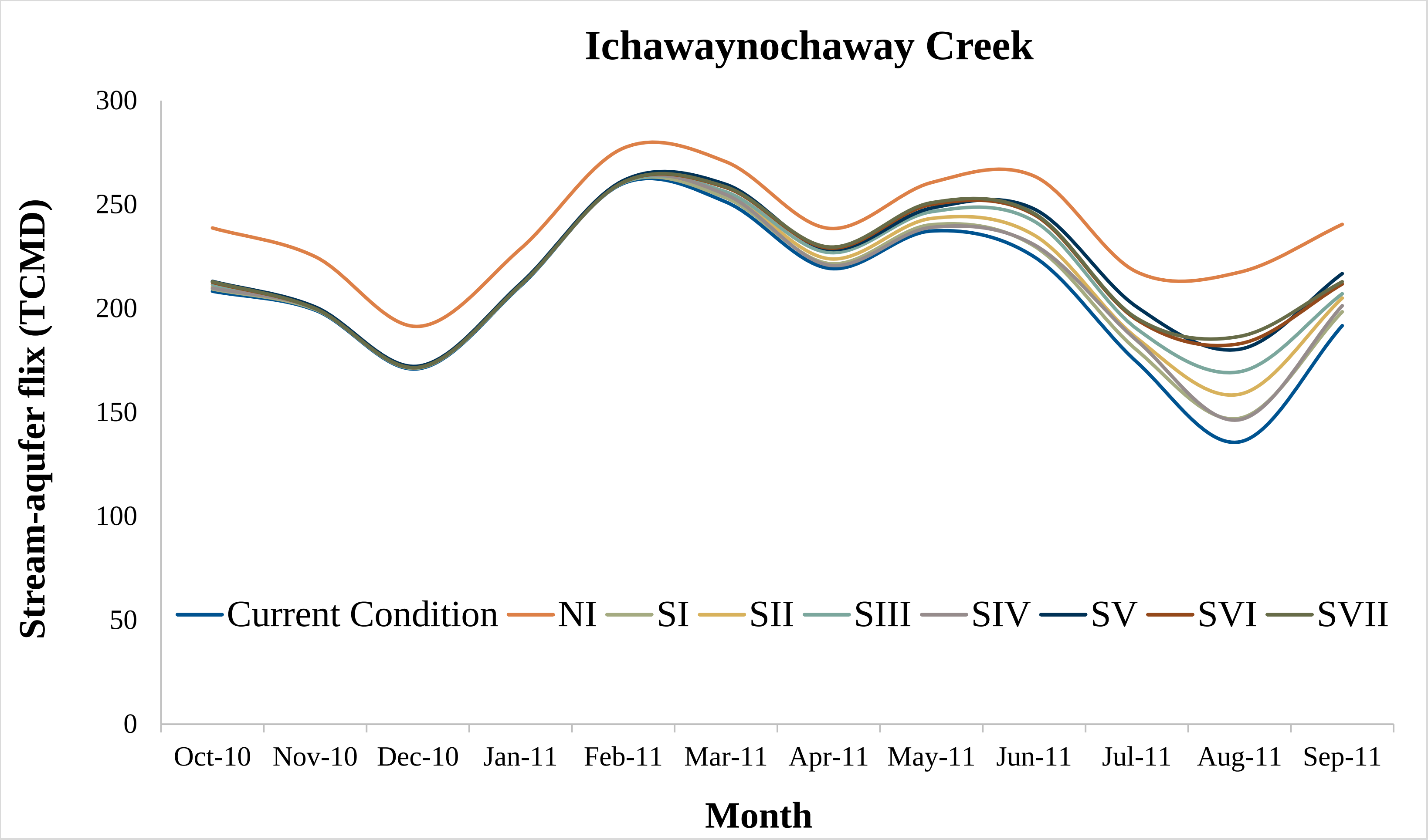
Results

Stream-aquifer flux for current and different scenarios in TCMD

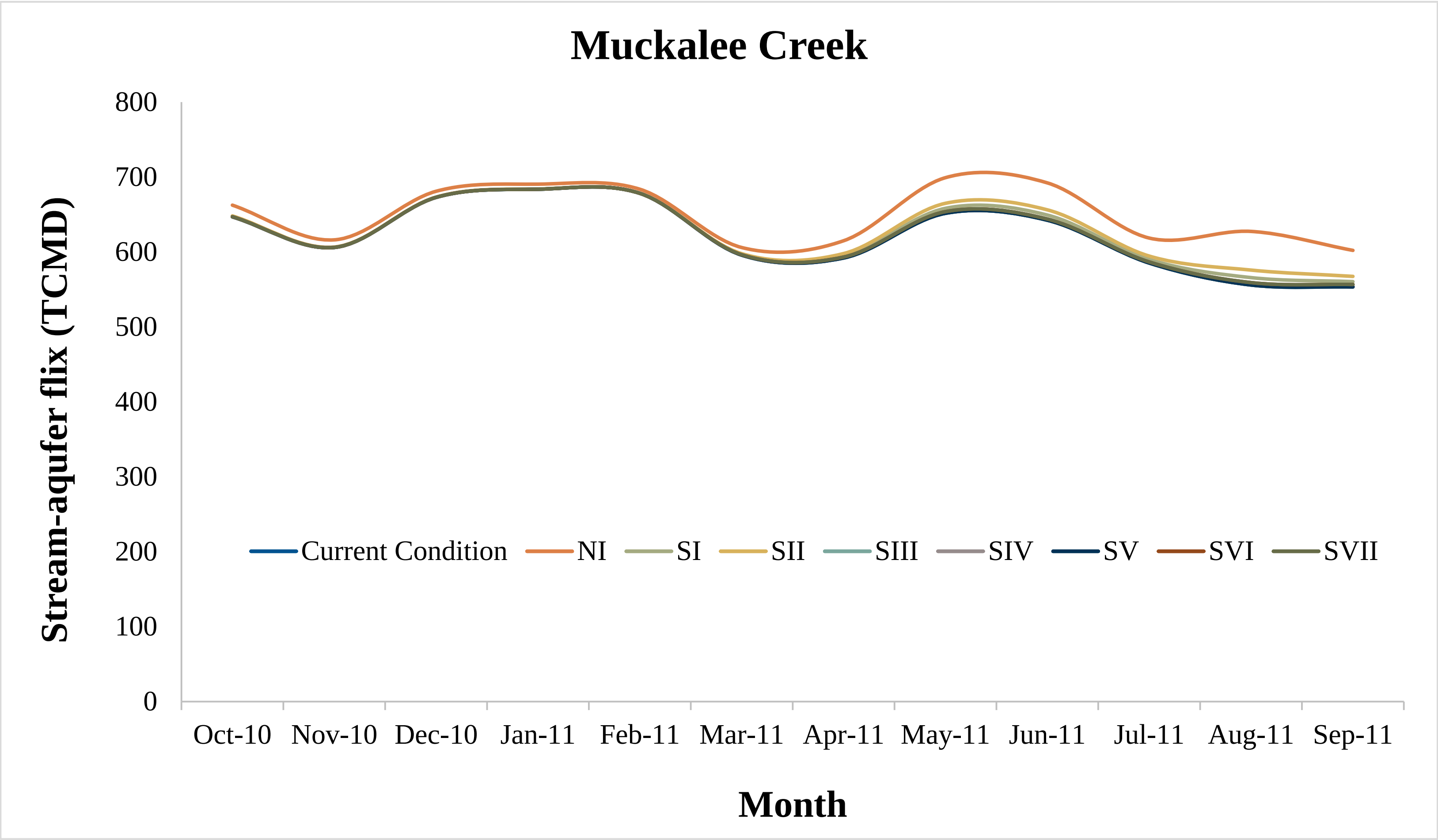
Month	Pumpage	Current Condition	NI	SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	-67	208	239	209	210	212	210	213	213	213
Nov-10	0	199	225	200	200	200	200	201	200	200
Dec-10	0	171	191	171	172	171	172	172	172	172
Jan-11	0	211	229	211	211	211	212	212	211	211
Feb-11	0	260	277	261	261	260	261	262	261	261
Mar-11	-76	251	271	253	255	256	255	260	258	258
Apr-11	-99	219	239	222	224	227	221	228	229	230
May-11	-131	237	261	240	243	247	239	248	250	251
Jun-11	-378	225	264	230	235	242	231	248	245	246
Jul-11	-207	174	218	180	186	190	185	201	195	195
Aug-11	-517	136	217	147	159	170	146	180	183	187
Sep-11	-94	192	240	198	205	207	201	217	212	213
Total	**-1569**	**2484**	**2870**	**2522**	**2561**	**2593**	**2532**	**2642**	**2628**	**2636**

Ichawaynochaway Creek

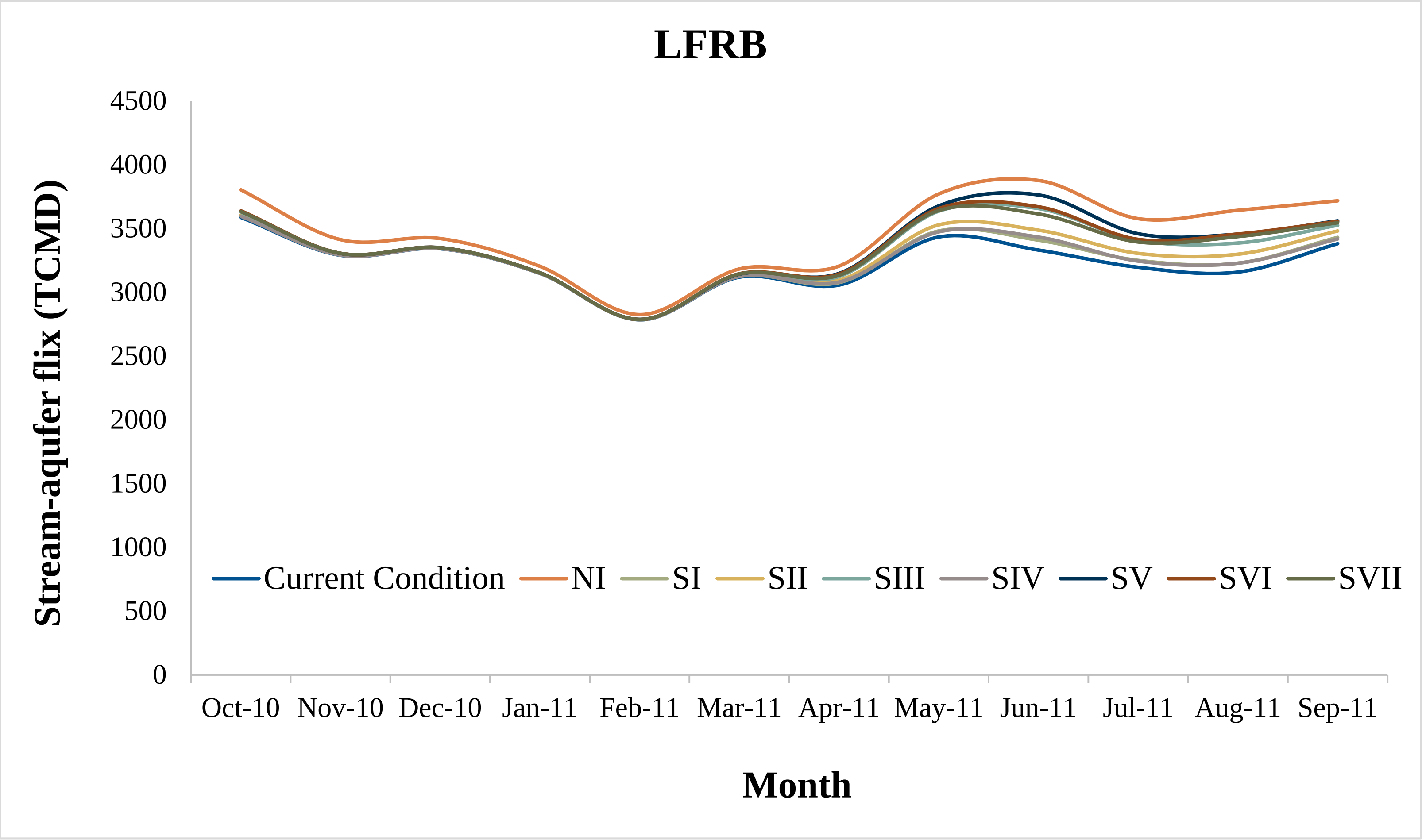
Results



Muckalee Creek



Lower Flint River Basin (LFRB)



Acreage Buyout Analysis

Scenarios	Area (Acres)	Percentage Acreage (%)	Cost (Millions of Dollars)		
			at $150/ac	at $200/ac	at $300/ac
Total Area	536810	100	81	107	161
SIII	**116443**	**22**	**17**	**23**	**35**
SIV	69678	13	10	14	21
SV	**186121**	**35**	**28**	**37**	**56**
SVI	138487	26	21	28	42
S2*	95154	18	14	19	29
SVII	**233641**	**44**	**35**	**47**	**70**

S2 indicate water restriction for the moderate sensitive zones*

Conclusions

- The results of the study indicated that groundwater withdrawal from the UFA in the lower ACF resulted in lowering of stream-aquifer flux during droughts.

- In the Spring Creek, increased pumpage during the months of April, June and July resulted in significant decrease in stream-aquifer flux that changed the stream characteristics from gaining to losing stream in this region.

- The results from sensitivity analysis identified the critical reaches where stream-aquifer hydraulic connectivity is strong and stream-aquifer flux is sensitive to pumpage.

- The results from the simulated water restriction scenarios suggested that reducing the pumpage in highly sensitive and capacity use areas were more effective in streamflow recovery than reducing the irrigation intensity (15% or 30%) throughout the study area.

- Analysis of acreage buyout suggested that water restrictions on irritation withdrawal can have significant impacts on stream-aquifer flux in the study area especially the critical watersheds such as Spring Creek and Ichawaynochaway Creek.

Recommendations

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- The results of study can also be helpful in better understanding the combined impact of the climate induced droughts and anthropogenic stresses on stream-aquifer dynamics of Flint River that might help the state of Georgia to formulate an alternative drought-water policy that can address the current water scarcity condition.

- Additionally, the results from this study can be helpful to better manage groundwater resources, protect surface water flows and help avoid irrigation induced streamflow depletion in some of the most vulnerable tributaries of the Flint River.

"A change in consciousness must occur in order for us to share water and use it wisely."
....Barbara Helen Harmony

QUESTIONS…?

APPENDICES

Ichawaynochaway Creek

Stream-aquifer flux for current and different scenarios in TCMD

Month	Current Model	Percentage Recovery of Stream-Aquifer Flux						
		SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	208	0.51	1.03	1.56	0.73	2.29	2.05	2.20
Nov-10	199	0.19	0.38	0.28	0.50	0.79	0.38	0.41
Dec-10	171	0.20	0.40	0.27	0.47	0.74	0.36	0.38
Jan-11	211	0.15	0.30	0.18	0.39	0.57	0.24	0.26
Feb-11	260	0.15	0.28	0.13	0.41	0.54	0.22	0.24
Mar-11	251	0.79	1.59	1.95	1.42	3.37	2.76	2.90
Apr-11	219	1.05	2.11	3.47	0.70	4.17	4.44	4.68
May-11	237	1.27	2.55	3.90	0.74	4.64	5.36	5.74
Jun-11	225	2.31	4.64	7.61	2.59	10.23	9.01	9.29
Jul-11	174	3.30	6.62	9.16	5.95	15.23	11.69	12.10
Aug-11	136	8.36	16.87	24.84	7.85	32.83	34.77	37.36
Sep-11	192	3.48	6.93	8.00	5.01	13.06	10.44	11.02

Muckalee Creek

Month	Pumpage	Current Condition	NI	SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	-27	647	663	648	648	647	647	647	647	647
Nov-10	0	606	616	606	607	606	606	606	606	606
Dec-10	0	673	681	673	673	673	673	673	673	673
Jan-11	0	684	691	684	684	684	684	684	684	684
Feb-11	0	678	684	678	678	678	678	678	678	678
Mar-11	-32	596	606	597	598	596	596	596	596	596
Apr-11	-85	592	615	595	598	592	592	592	593	593
May-11	-225	652	699	658	665	652	652	652	654	654
Jun-11	-175	642	692	649	656	642	642	642	644	644
Jul-11	-46	585	619	590	595	585	585	585	587	587
Aug-11	-347	556	627	566	576	556	556	556	559	559
Sep-11	-77	553	602	560	567	553	553	553	557	557
Total	**-1013**	**7465**	**7795**	**7505**	**7545**	**7465**	**7465**	**7465**	**7478**	**7478**

Muckalee Creek

Month	Current Condition	Percentage Recovery of Stream-Aquifer Flux						
		SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	647	0.10	0.19	0.00	0.00	0.00	0.03	0.03
Nov-10	606	0.05	0.09	0.00	0.00	0.00	0.02	0.02
Dec-10	673	0.03	0.06	0.00	0.00	0.00	0.01	0.01
Jan-11	684	0.02	0.04	0.00	0.00	0.00	0.01	0.01
Feb-11	678	0.02	0.03	0.00	0.00	0.00	0.01	0.01
Mar-11	596	0.16	0.32	0.00	0.00	0.00	0.09	0.09
Apr-11	592	0.49	0.99	0.00	0.00	0.00	0.20	0.20
May-11	652	1.02	2.04	0.00	0.00	0.00	0.33	0.33
Jun-11	642	1.07	2.15	0.00	0.00	0.00	0.24	0.24
Jul-11	585	0.80	1.59	0.00	0.00	0.00	0.24	0.24
Aug-11	556	1.77	3.58	0.00	0.00	0.00	0.57	0.57
Sep-11	553	1.27	2.54	0.00	0.00	0.01	0.57	0.58

Lower Flint River Basin (LFRB)

Results

Month	Pumpage	Current Condition	NI	SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	-268	3589	3806	3599	3609	3629	3598	3638	3641	3635
Nov-10	0	3291	3414	3295	3299	3305	3293	3306	3307	3306
Dec-10	0	3343	3423	3345	3347	3350	3344	3351	3351	3350
Jan-11	0	3149	3205	3151	3152	3154	3150	3154	3154	3154
Feb-11	0	2785	2826	2786	2787	2788	2786	2788	2788	2788
Mar-11	-203	3120	3184	3126	3131	3137	3125	3143	3146	3144
Apr-11	-475	3058	3207	3077	3096	3125	3081	3149	3144	3134
May-11	-1044	3435	3772	3482	3530	3637	3475	3679	3659	3642
Jun-11	-1504	3332	3878	3410	3488	3658	3434	3765	3672	3616
Jul-11	-625	3197	3579	3251	3306	3409	3246	3460	3416	3396
Aug-11	-1564	3160	3644	3229	3300	3387	3229	3457	3458	3438
Sep-11	-355	3382	3718	3432	3482	3527	3419	3561	3557	3547
Total	**-6038**	**38841**	**41656**	**39183**	**39527**	**40106**	**39179**	**40451**	**40293**	**40149**

LFRB

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Results

Month	Current Model	Percentage Recovery of Stream-Aquifer Flux						
		SI	SII	SIII	SIV	SV	SVI	SVII
Oct-10	3589	0.28	0.57	1.13	0.25	1.38	1.45	1.28
Nov-10	3291	0.12	0.24	0.41	0.05	0.46	0.48	0.46
Dec-10	3343	0.07	0.13	0.22	0.03	0.25	0.24	0.23
Jan-11	3149	0.04	0.09	0.14	0.02	0.16	0.14	0.14
Feb-11	2785	0.03	0.06	0.09	0.01	0.11	0.10	0.09
Mar-11	3120	0.18	0.37	0.56	0.17	0.74	0.85	0.78
Apr-11	3058	0.62	1.25	2.19	0.77	2.98	2.83	2.50
May-11	3435	1.38	2.77	5.90	1.17	7.11	6.52	6.04
Jun-11	3332	2.33	4.68	9.78	3.05	12.98	10.19	8.51
Jul-11	3197	1.69	3.41	6.62	1.52	8.23	6.85	6.21
Aug-11	3160	2.20	4.43	7.21	2.20	9.40	9.46	8.81
Sep-11	3382	1.47	2.95	4.27	1.10	5.30	5.18	4.87

Overall Conclusions

- Groundwater withdrawal from the UFA in the lower ACF resulted in lowering of stream-aquifer flux during droughts.

- In the Spring Creek, increased pumpage during the months of April, June and July resulted in significant decrease in stream-aquifer flux that changed the stream characteristics from gaining to losing stream in this region.

- The results from the simulated water restriction scenarios suggested that reducing the pumpage in highly sensitive and capacity use areas were more effective in streamflow recovery than other scenarios.