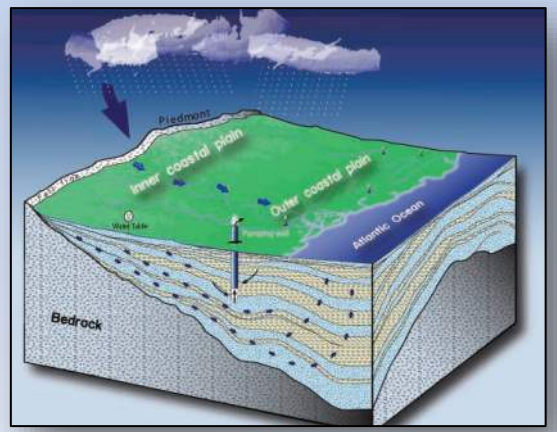
Simulation of Groundwater Flow in the Edisto River Basin, South Carolina

Greg Cherry and Matt Petkewich

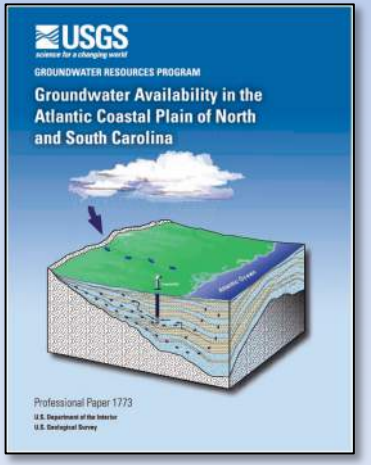
US Geological Survey – South Atlantic Water Science Center



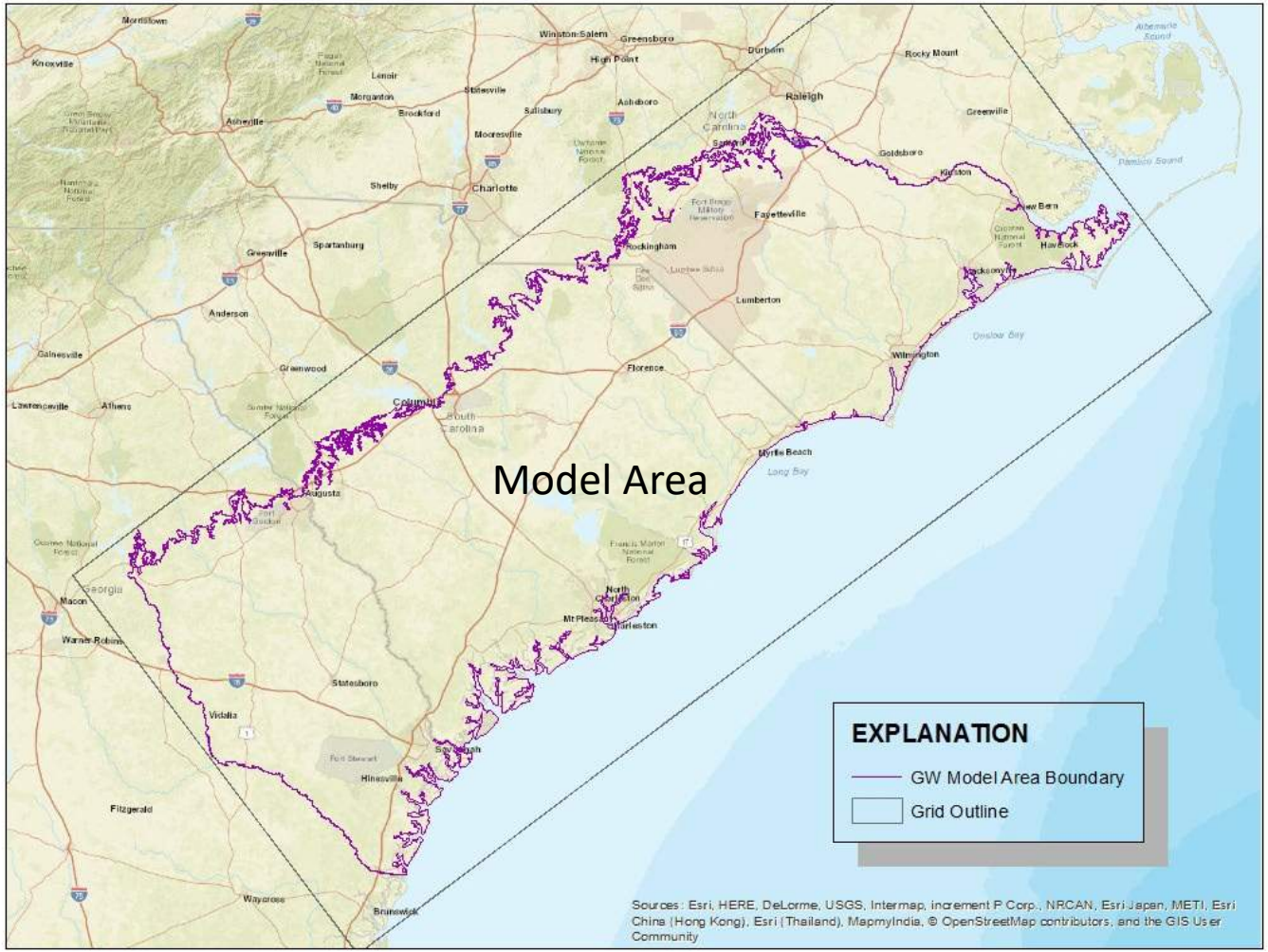
U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world

Groundwater Model Area



U.S. Department of the Interior
U.S. Geological Survey

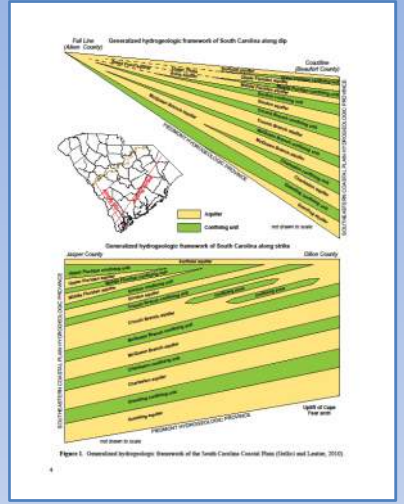


USGS
science for a changing world

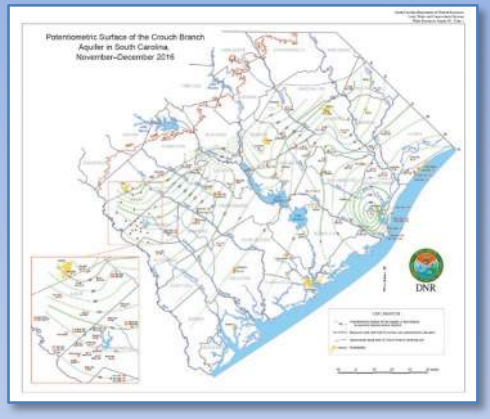
Objectives

- 2015 calibrated groundwater flow model
- Add recent groundwater use data (2016-2020)
- Include recharge from Soil-Water Balance (SWB) Model (2016-2020)
- Use existing model to simulate a series of scenarios

New GW Water-Use Data

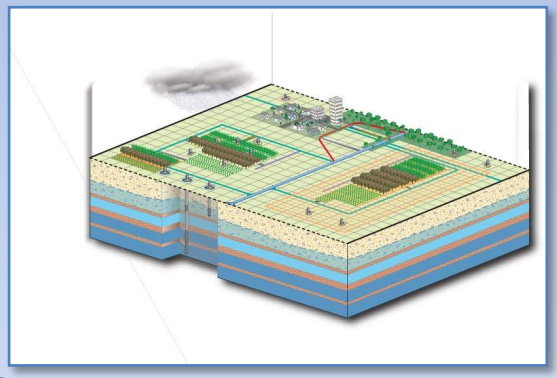


Framework

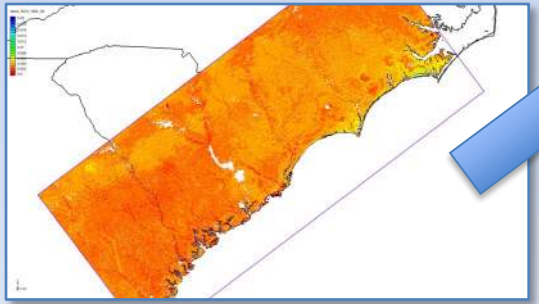


Potentiometric Maps

Groundwater Model

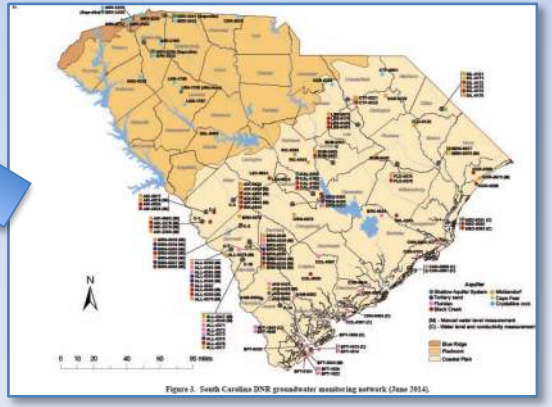


Recharge Model



U.S. Department of the Interior
U.S. Geological Survey

Groundwater Levels



Scenario model input

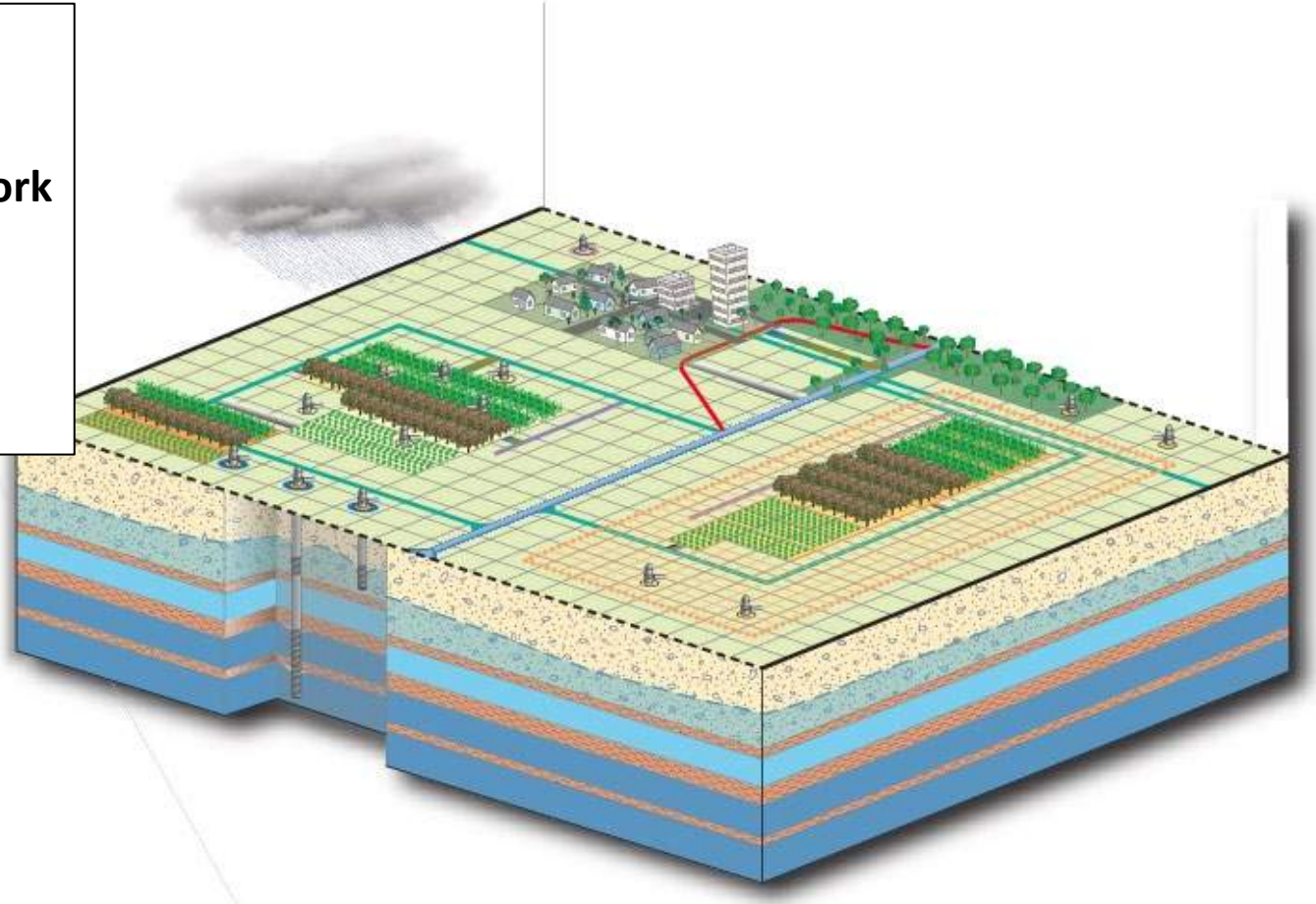
- Well and water-use data from SCDHEC database
  - 1900 – 2015 (original model)
  - 1983-2020 (updated well and water use)
- Recharge rates from Soil Water Balance model (2016 – 2020)

Primary inputs:

- Model Grid
- Hydrogeologic Framework
- Aquifer Properties
- Observation Data
- Boundaries
- Wells – Water Use Data

Primary Outputs:

- Groundwater Levels
- Budgets



Representative GW Flow Model

U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world

Groundwater Simulations

Predevelopment Conditions

Remove withdrawals and simulate levels prior to GW development

- Recharge rates from SWB model
- Focused on Edisto Basin

Historical Groundwater Conditions

- Simulated groundwater conditions from 1900-2020

Groundwater Flow Model Limitations

- Based on limited data
- Simplification of the actual groundwater flow system
- Can limit the ability of the model to predict actual hydraulic conditions over time
- Accuracy and prediction capabilities of this model are affected by the finite-difference discretization, boundary conditions, hydraulic properties, and observations used in the model calibration
- Groundwater withdrawals simulated in the model underrepresent actual historical water use because pumping rates less than 3 million gallons per month are not required to be reported to the State agencies and, therefore, are unknown.

Groundwater Scenarios

Current groundwater use

- Constant pumping rates from 2021-2070 using average pumping rates derived from groundwater use from 2016-2020

Permitted groundwater use

- Constant pumping rates from 2021-2070 using fully permitted pumping rates

Business-as-usual water demand

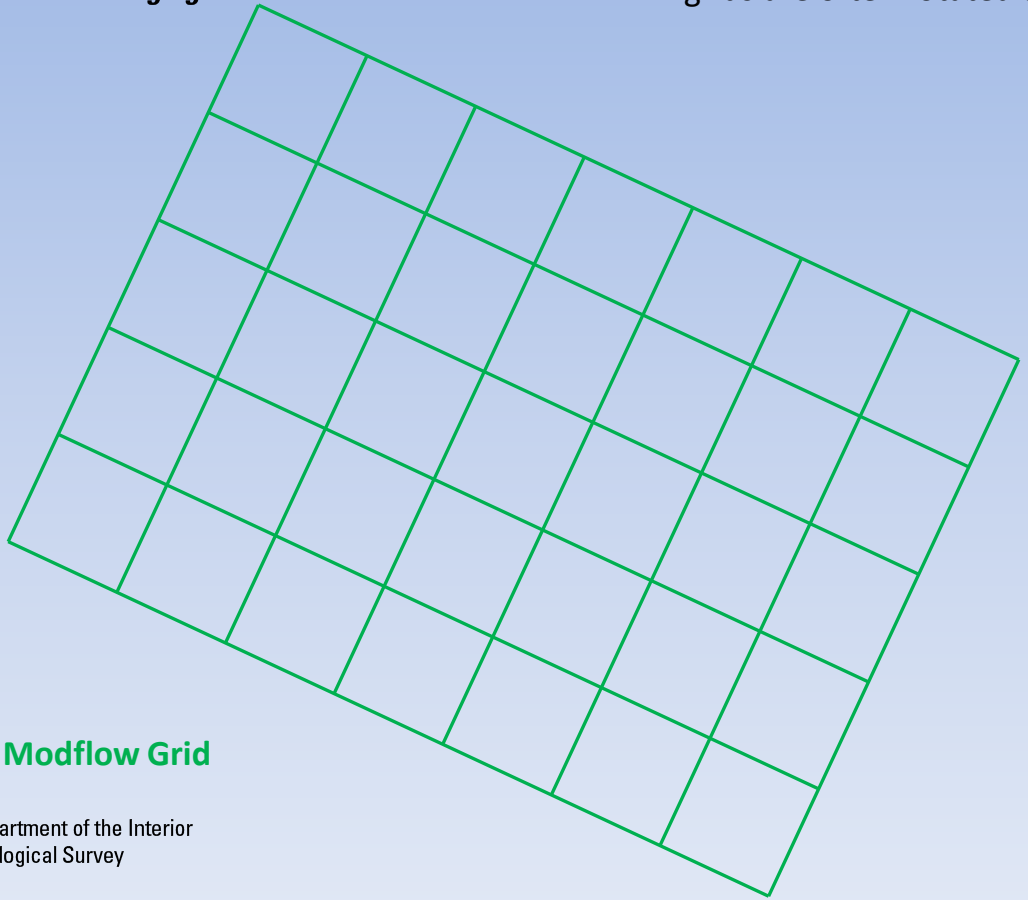
- Projections from 2021-2070 based on assumption moderate population and economic growth

High water demand trend

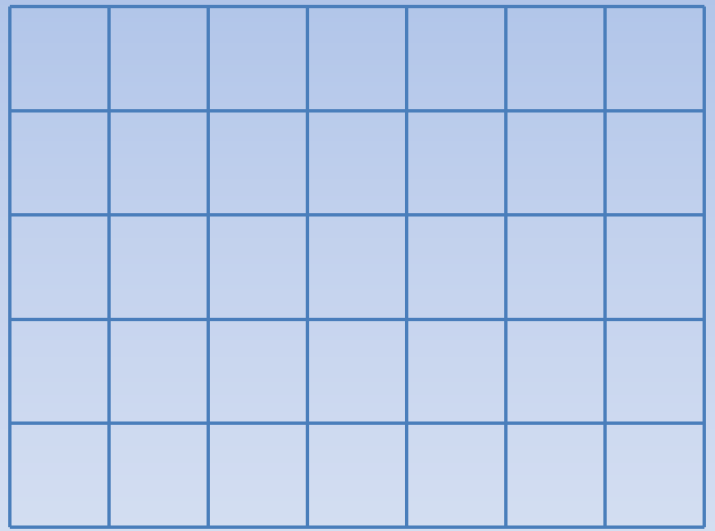
- Projections from 2021-2070 based on assumption high population and economic growth

USGS
science for a changing world

The SWB model **requires orthogonal** grids, Modflow grids are often rotated to better fit model domain

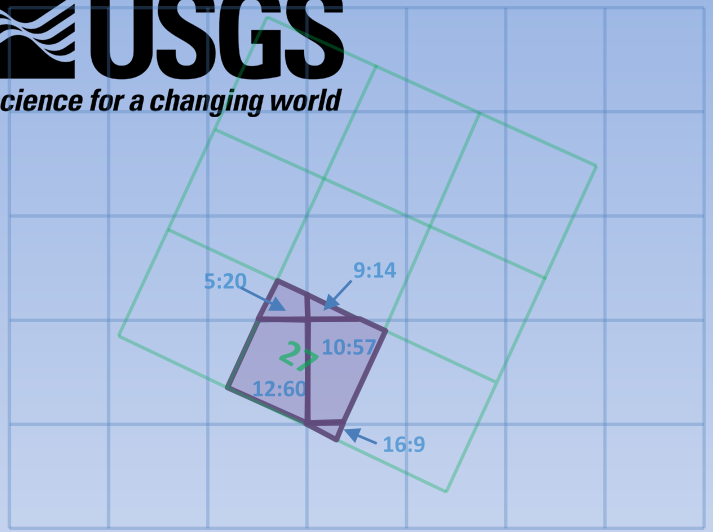


Modflow Grid



SWB Grid

USGS
science for a changing world



SWB model requires orthogonal grids

We used Area Weighted Averaging to move SWB output to Modflow gird cells

For a given Modflow cell the calculations would look like this (made up values for this example):

Item No.	Type 1 Value[b]		Type 1 Area[a]		Type 2 Value[b]		Type 2 Area[a]		Type 3 Value[b]		Type 3 Area[a]		Total Area		Weighted Average Value
	[(_____)	x	(_____)	+	(_____)	x	(_____)	+	(_____)	x	(_____)]	÷		=	

example table from WS-2R.pdf (santa-ana.org)

Notation description

Example = **12:60** in **27**

- **12 is the value of the SWB cell (estimated recharge)**
- **60 is the area of SWB grid cell that intersects with a given Modflow cell (in map units)**
- **27 is the Modflow cell ID**

Area weighted calcs for Modflow cell #27 in cartoon example

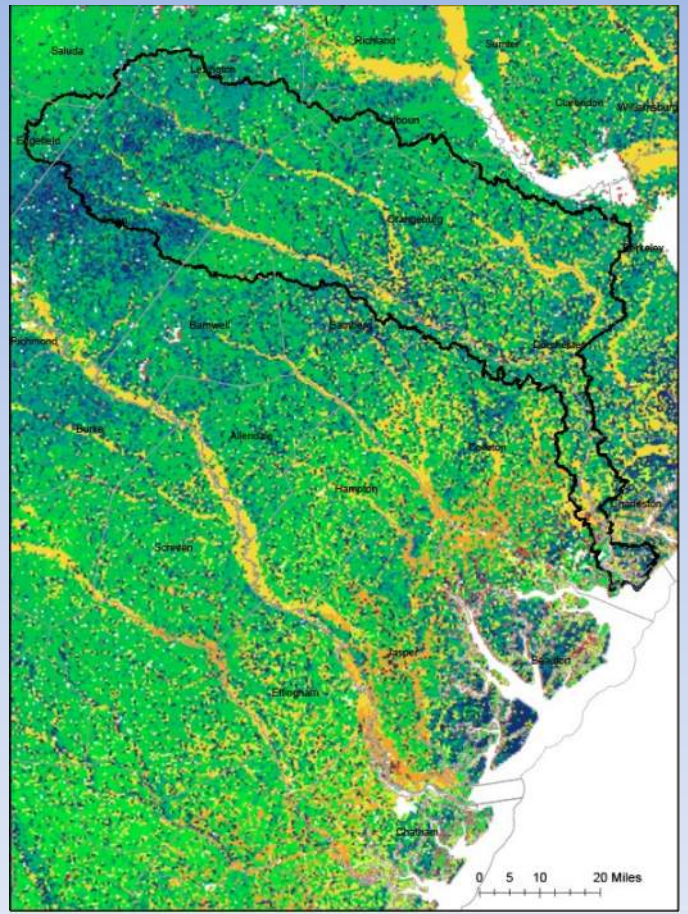
Modflow Cell	SWB part Val1 * Area		SWB part Val2 * Area		SWB part Val3 * Area		SWB part Val4 * Area		SWB part Val5 * Area		Total Area		Weighted Ave
27	[5 * 20	+	9 * 14	+	10 * 57	+	16 * 9	+	12 * 60]	/	160	=	10.375

This calculation was done on a cell-by-cell basis for each cell in the Modflow domain so that all Modflow cells had area weighted average SWB recharge values assigned.

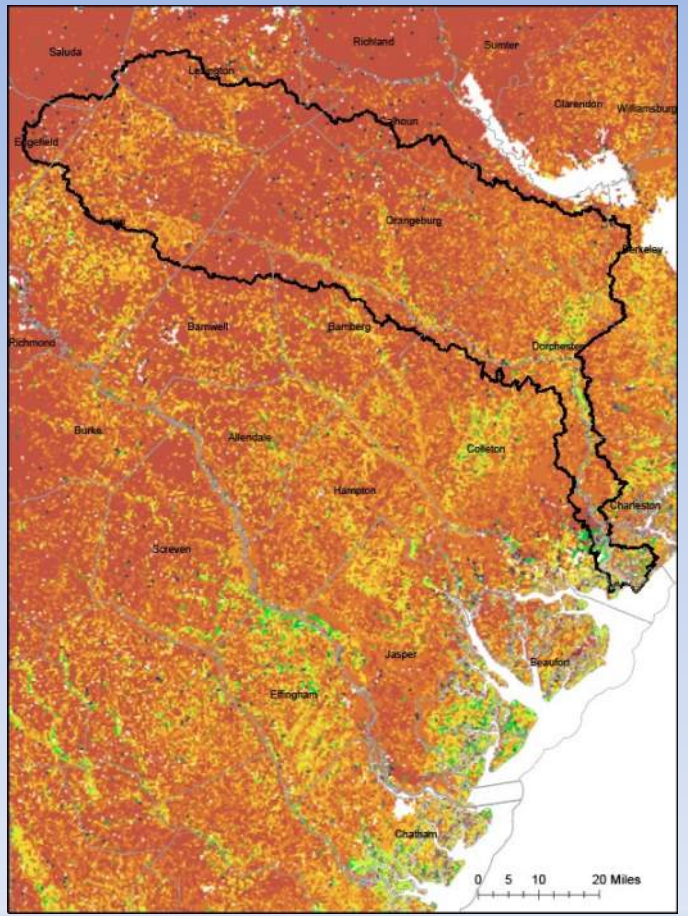
USGS
science for a changing world

SWB Model Input

1998



2012



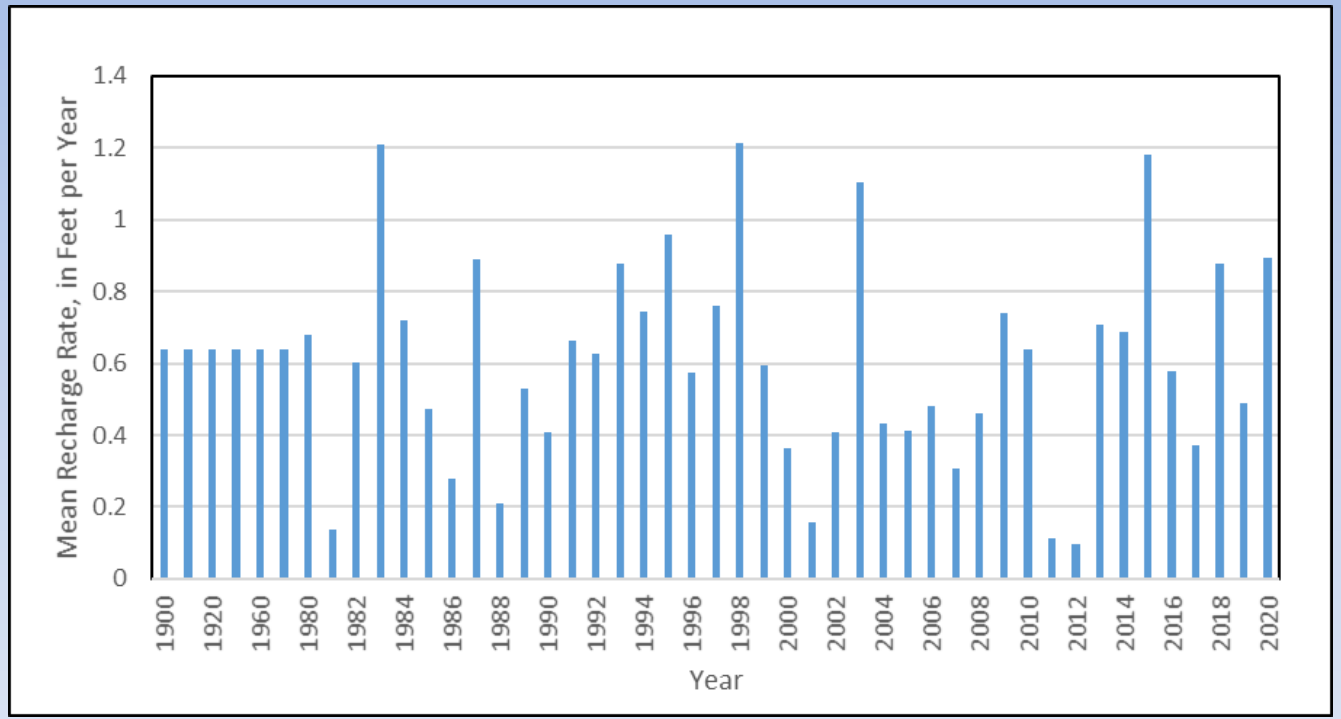
Recharge, in inches

0 - 2
2.01 - 4
4.01 - 6
6.01 - 8
8.01 - 10
10.01 - 12
12.01 - 14
14.01 - 16
16.01 - 18
18.01 - 20

U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

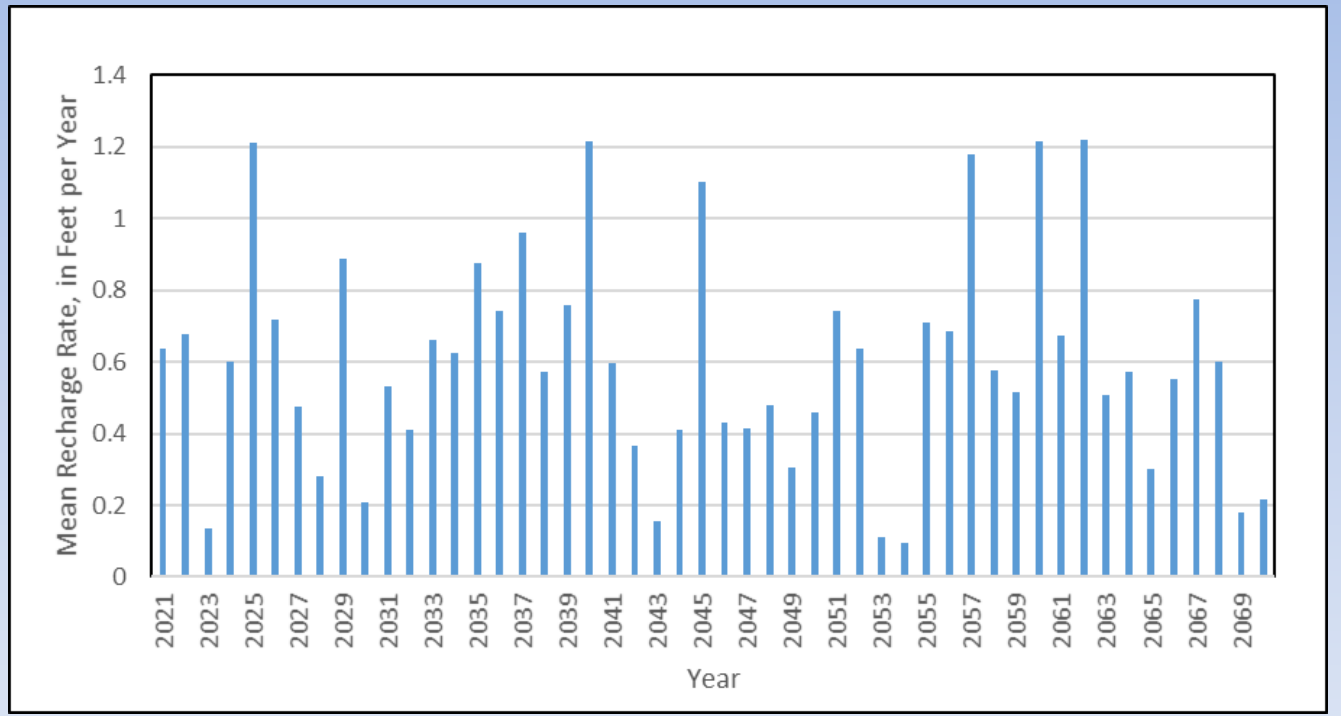
Recharge: pre-development - 2020



U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

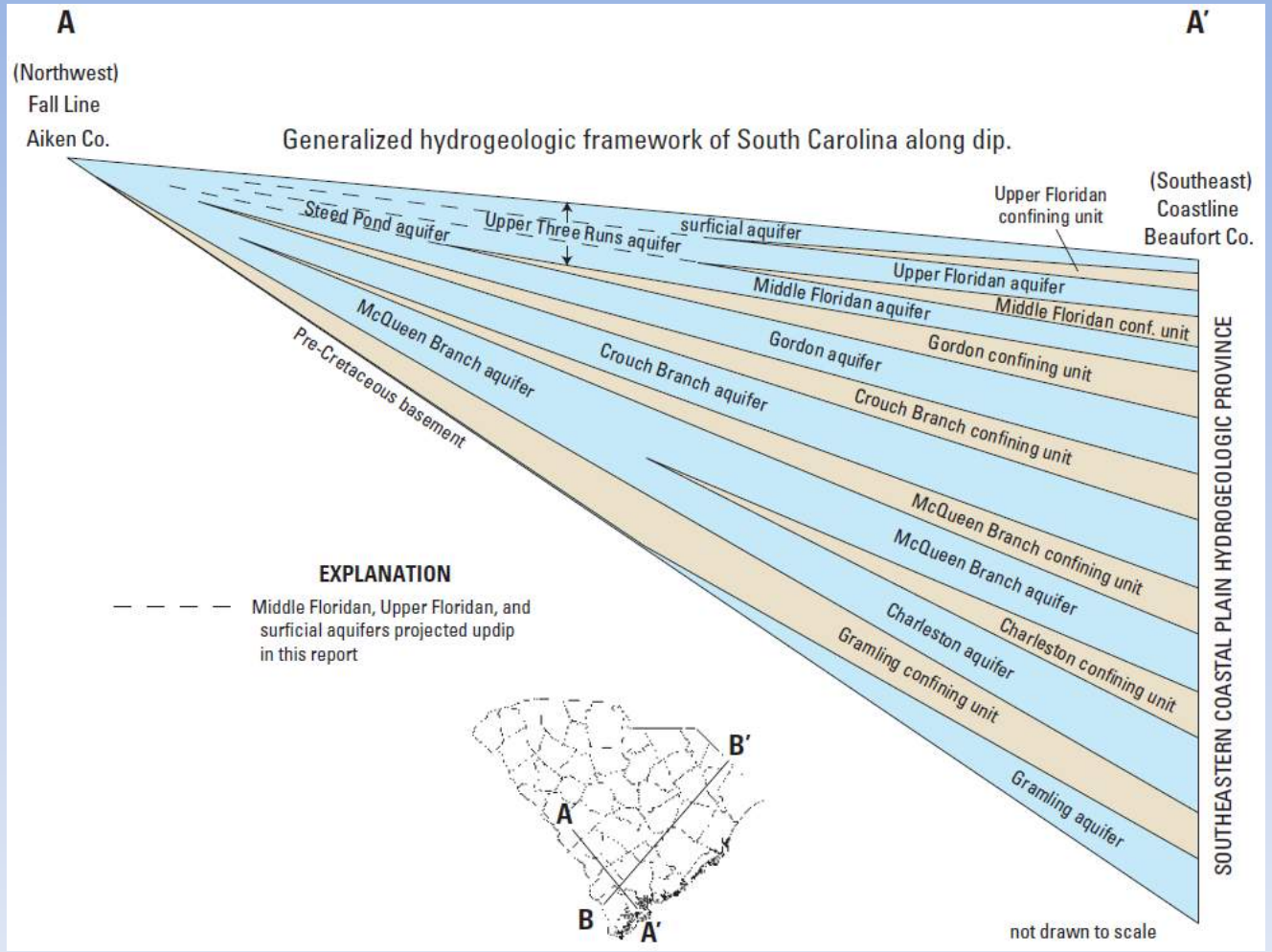
Recharge: 2021 - 2070



U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

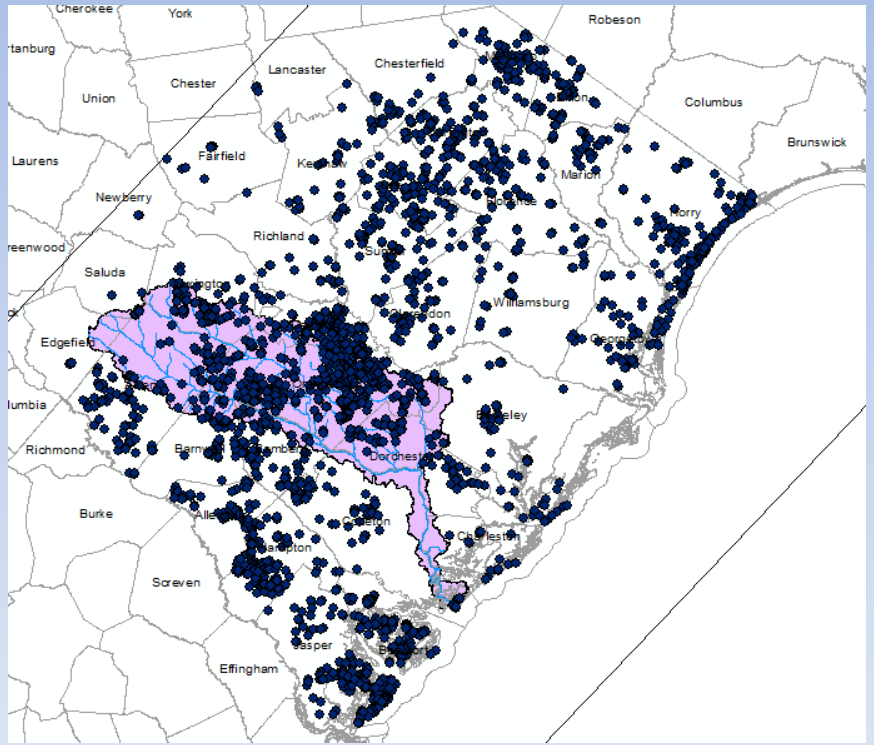
Hydrogeologic Framework



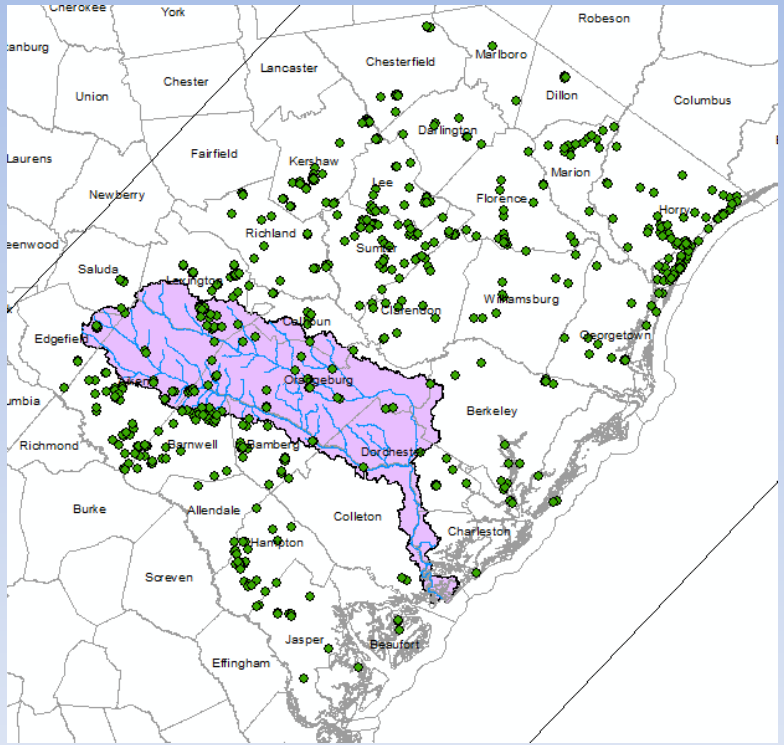
U.S. Department of the Interior
U.S. Geological Survey

Groundwater use in model

WEL package - 3,079 wells

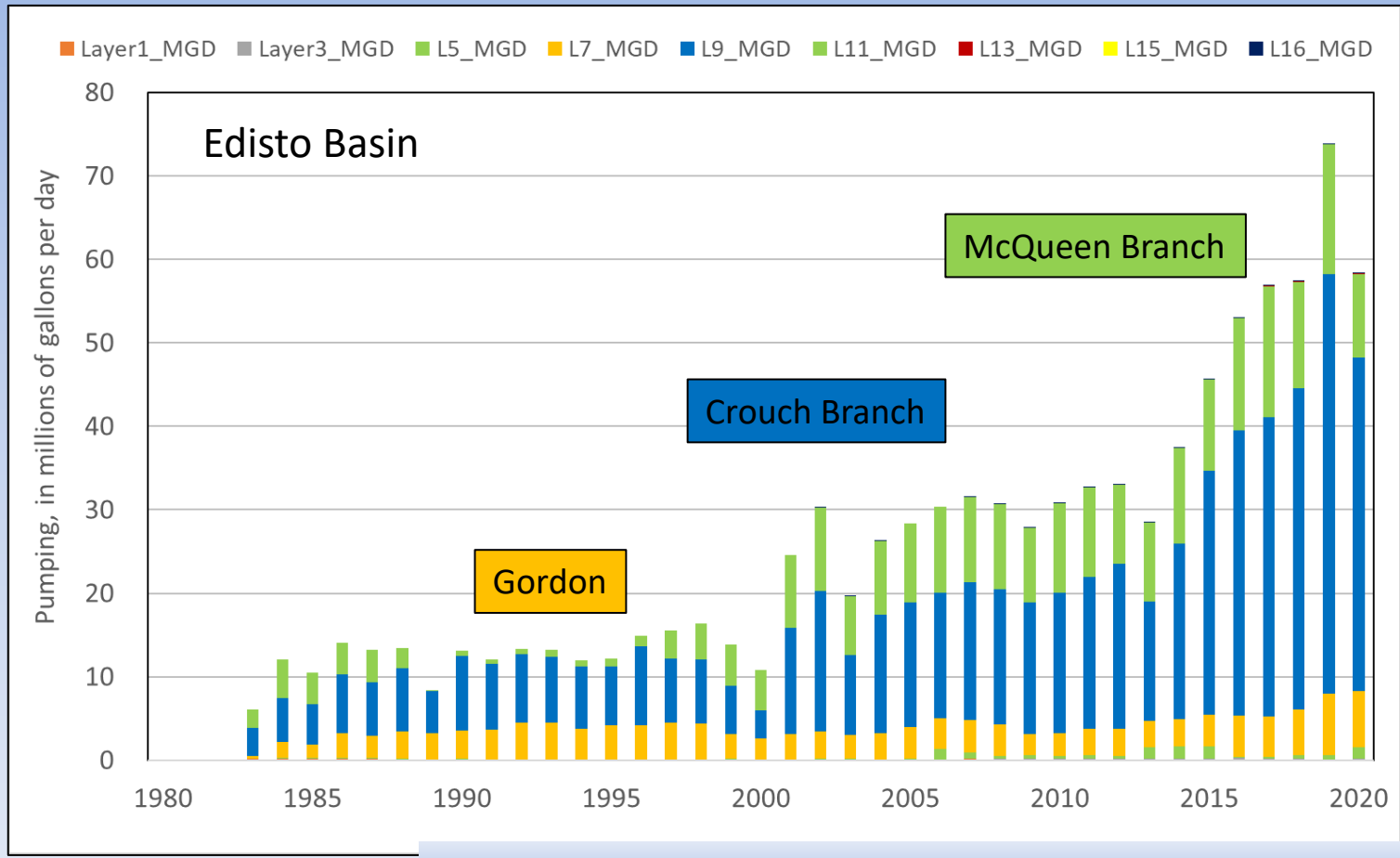


Multi-node well package (MNW2) – 700 wells



Provisional – All data is considered provisional and subject to revision.

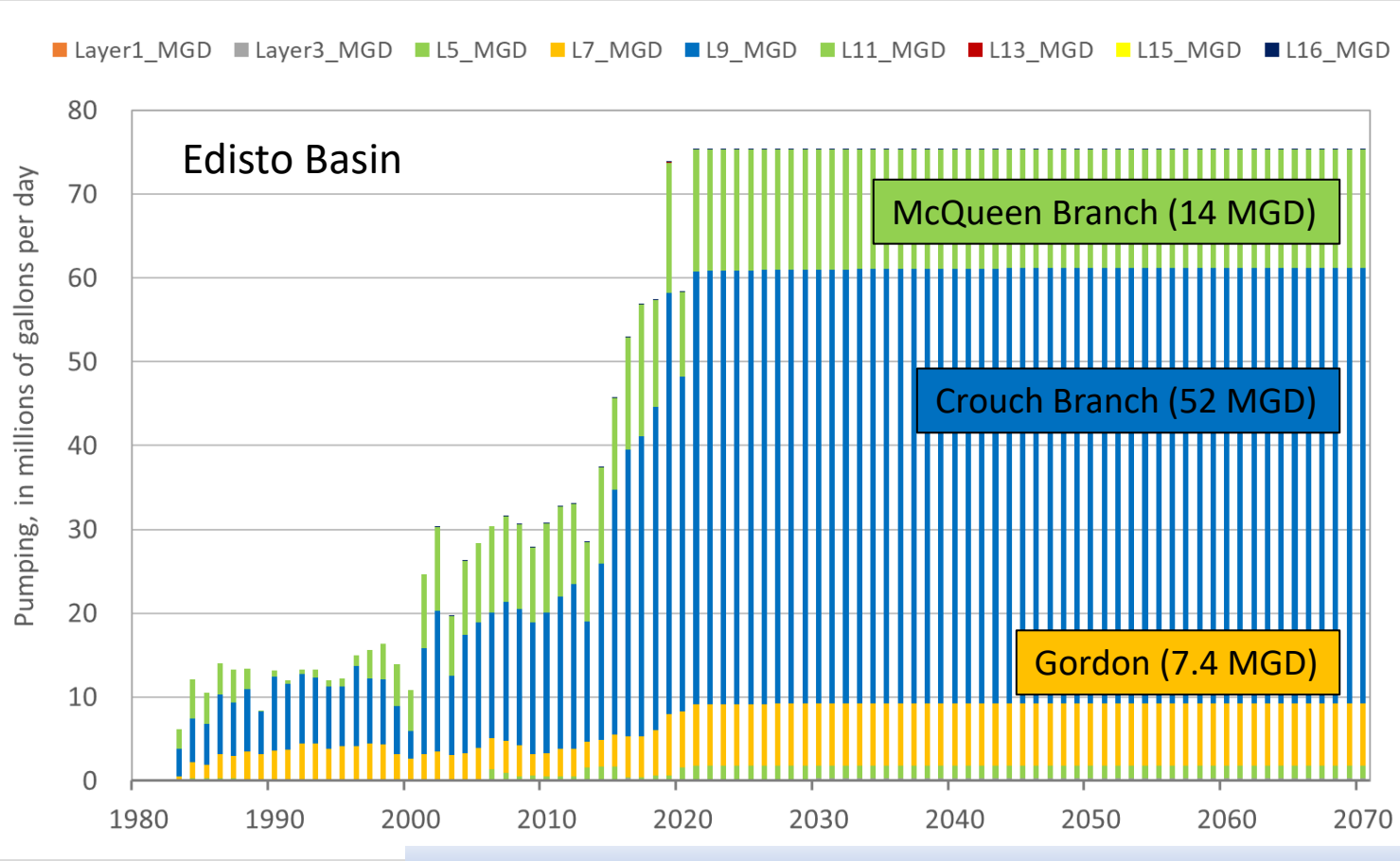
Simulated pumping – Predevelopment - 2020



U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

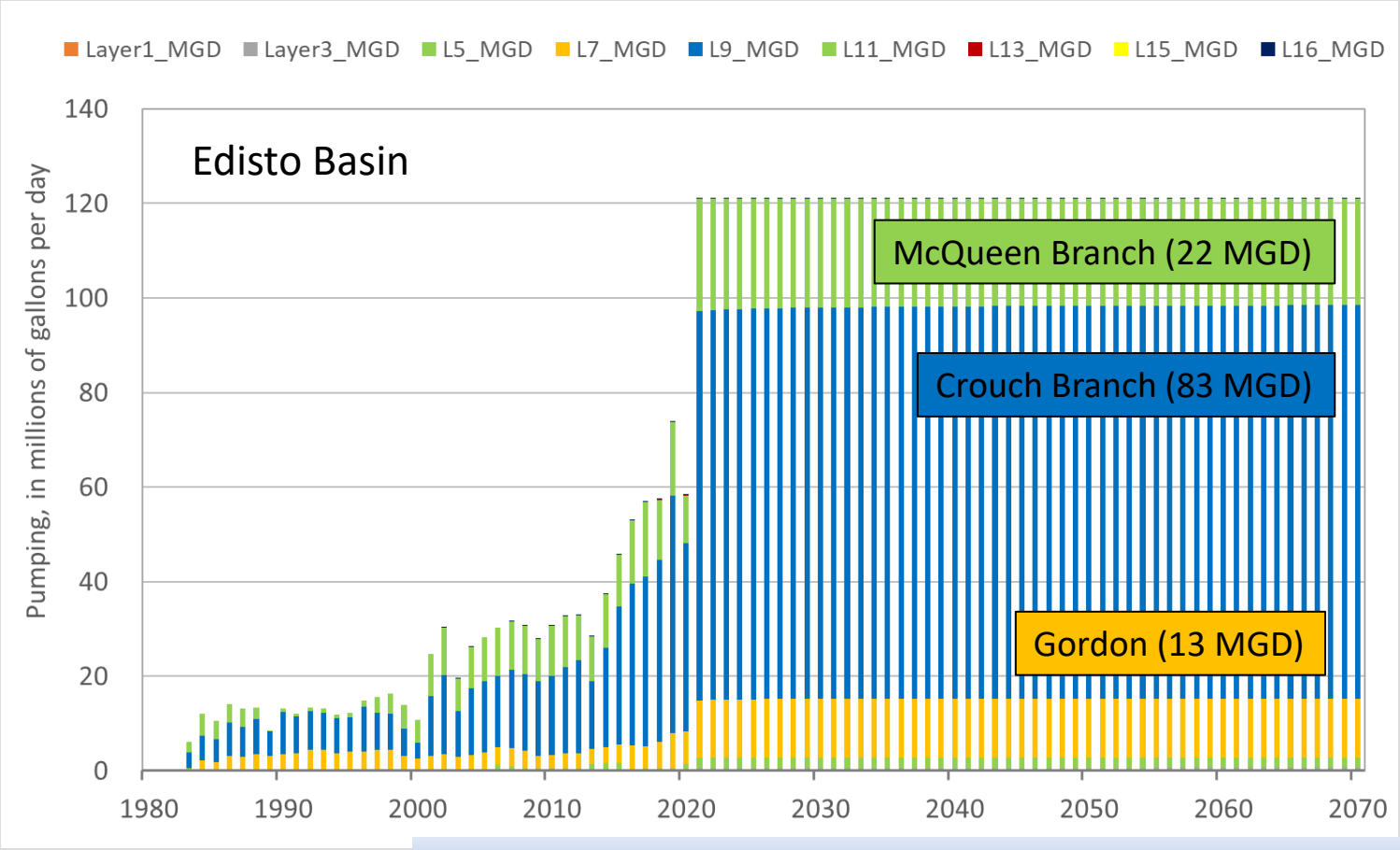
Simulated pumping – Current Scenario model



U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Simulated pumping – Permitted Scenario model

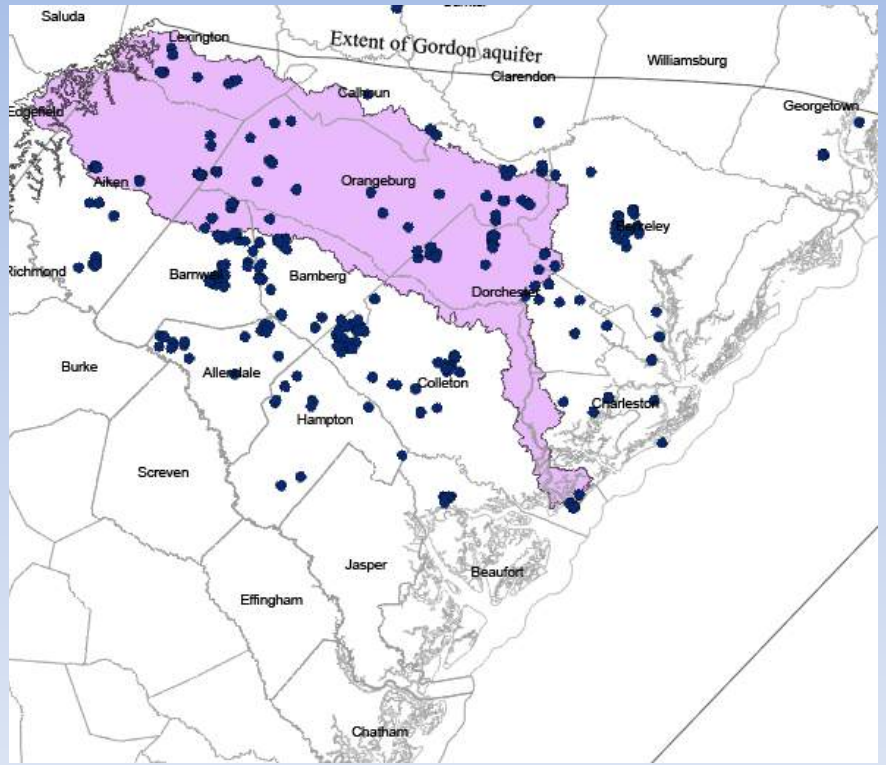


U.S. Department of the Interior
U.S. Geological Survey

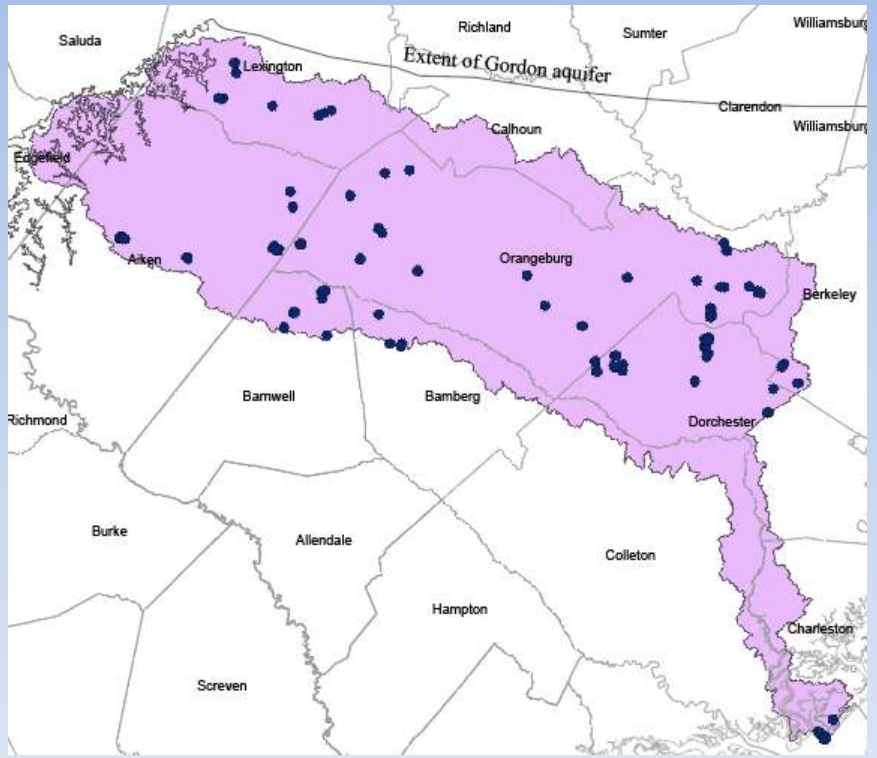
Provisional – All data is considered provisional and subject to revision.

GW use in Gordon aquifer (model layer 7)

South Carolina - 330 wells



Edisto Basin – 113 wells

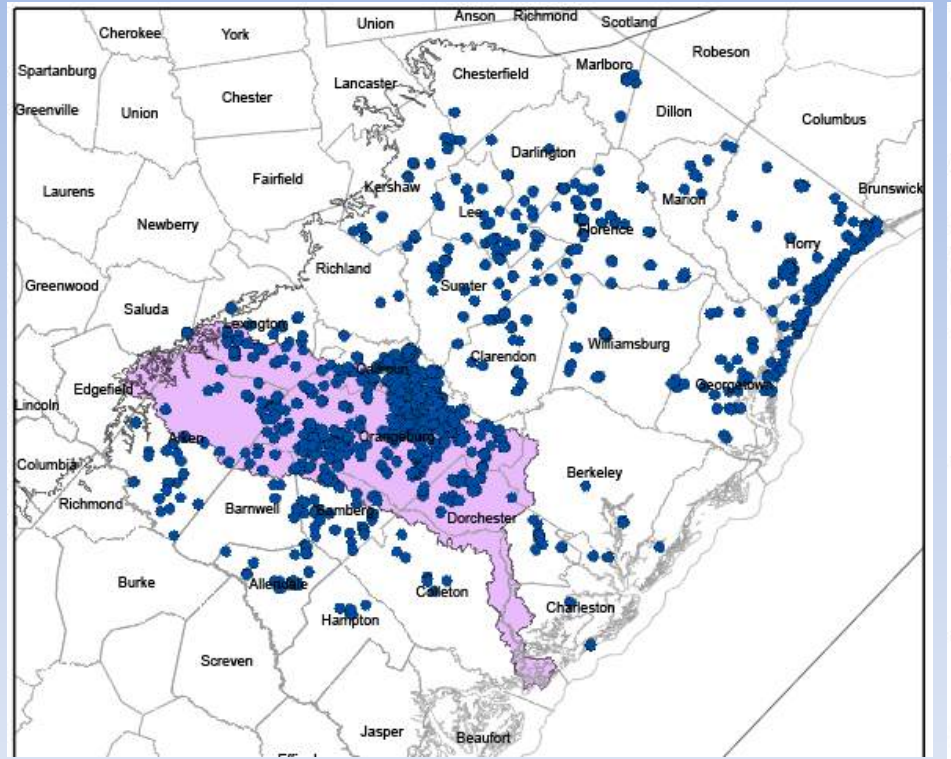


U.S. Department of the Interior
U.S. Geological Survey

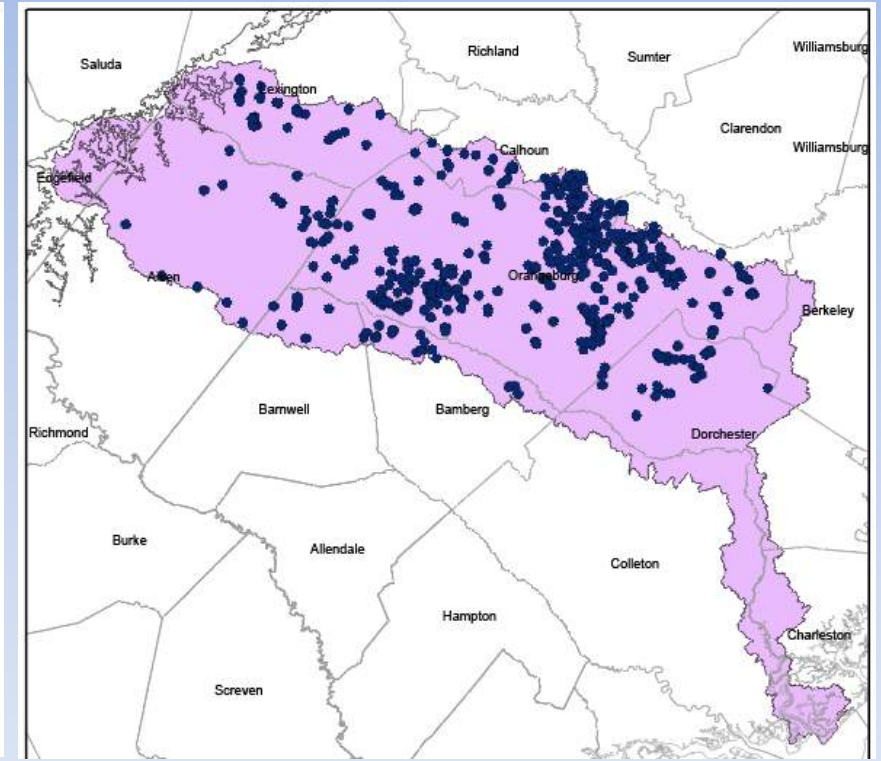
Provisional – All data is considered provisional and subject to revision.

GW use in Crouch Branch aquifer (model layer 9)

South Carolina – 1,128 wells



Edisto Basin – 493 wells

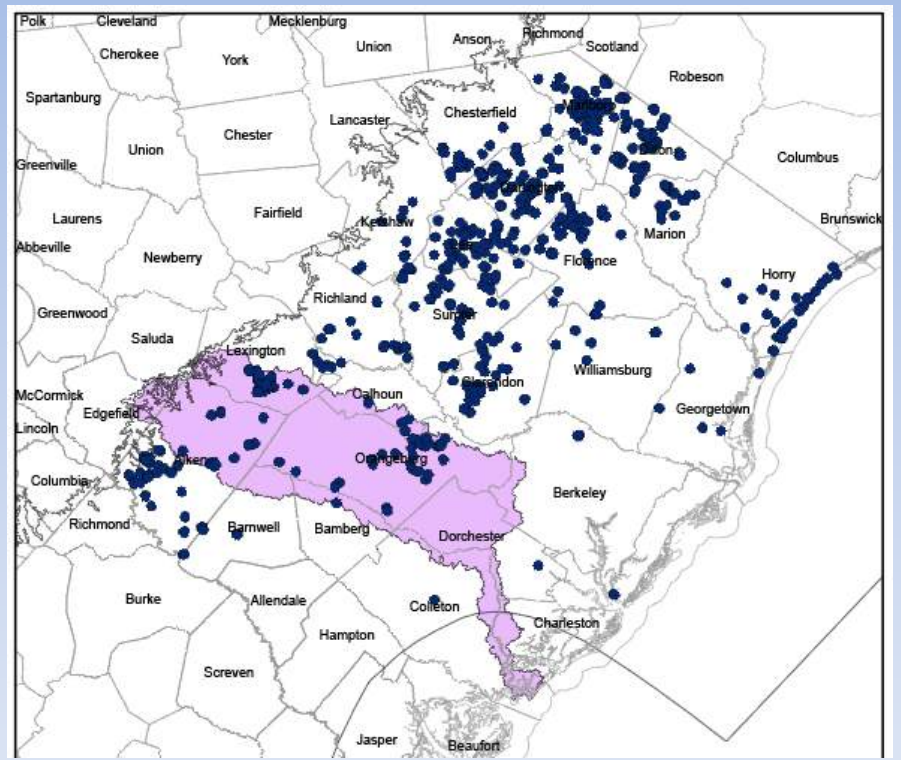


U.S. Department of the Interior
U.S. Geological Survey

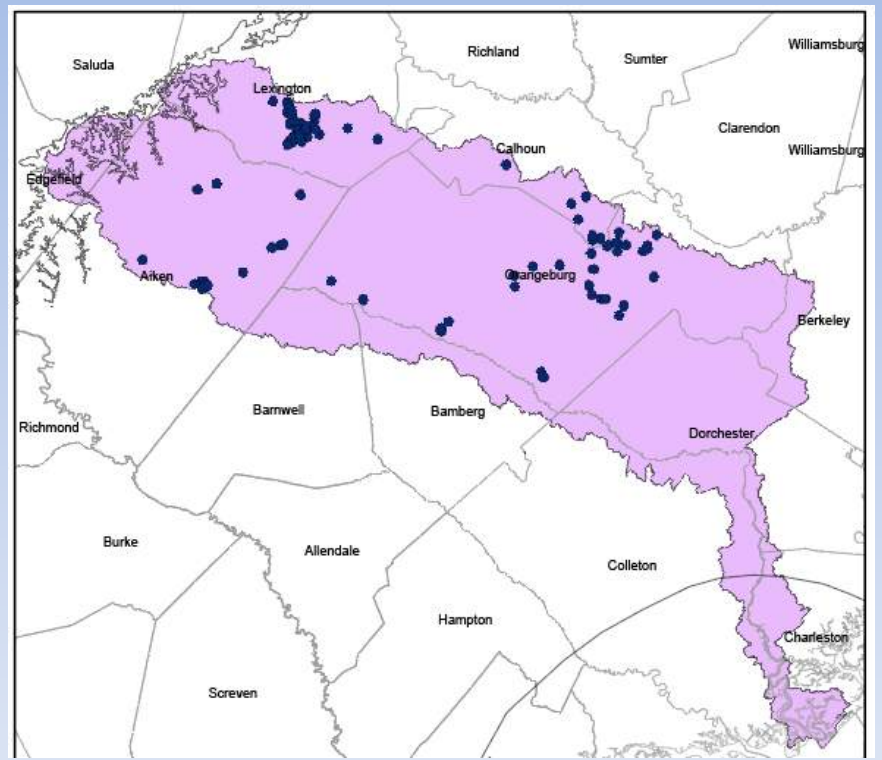
Provisional – All data is considered provisional and subject to revision.

GW use in McQueen Branch aquifer (model layer 11)

South Carolina – 648 wells



Edisto Basin – 97 wells

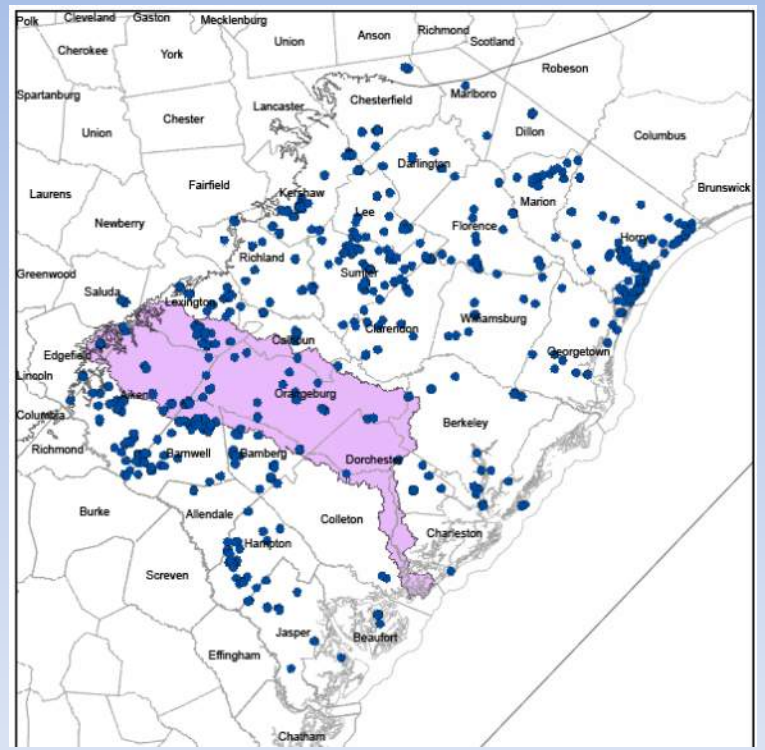


U.S. Department of the Interior
U.S. Geological Survey

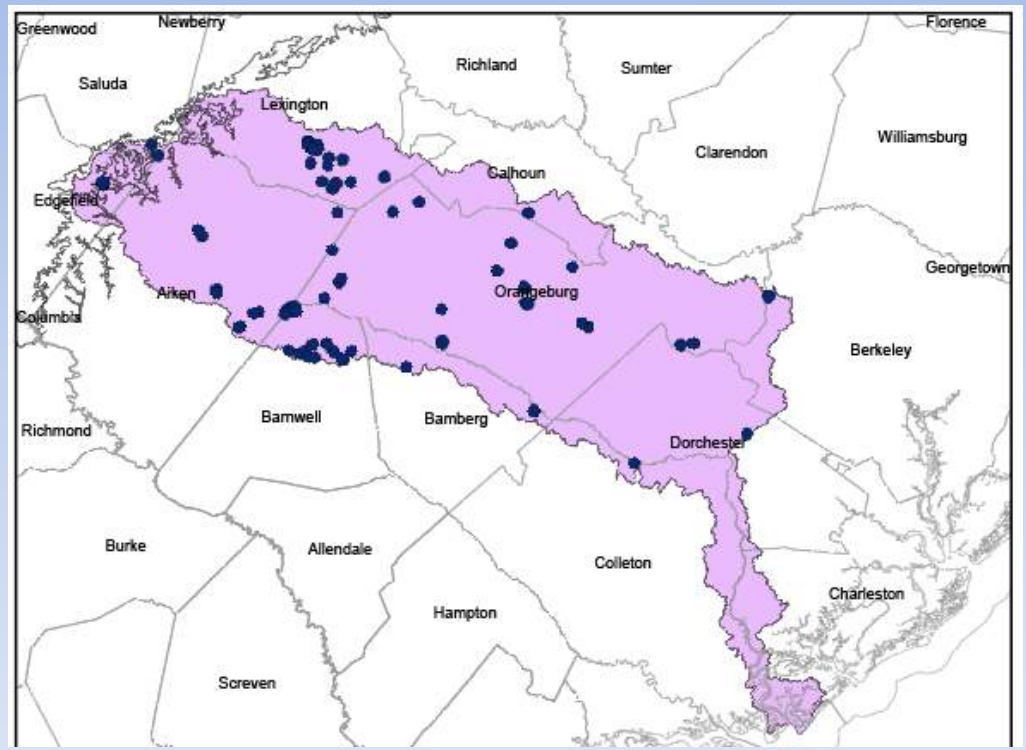
Provisional – All data is considered provisional and subject to revision.

GW use in the Multi-Node Well package (MNW2)

South Carolina – 700 wells



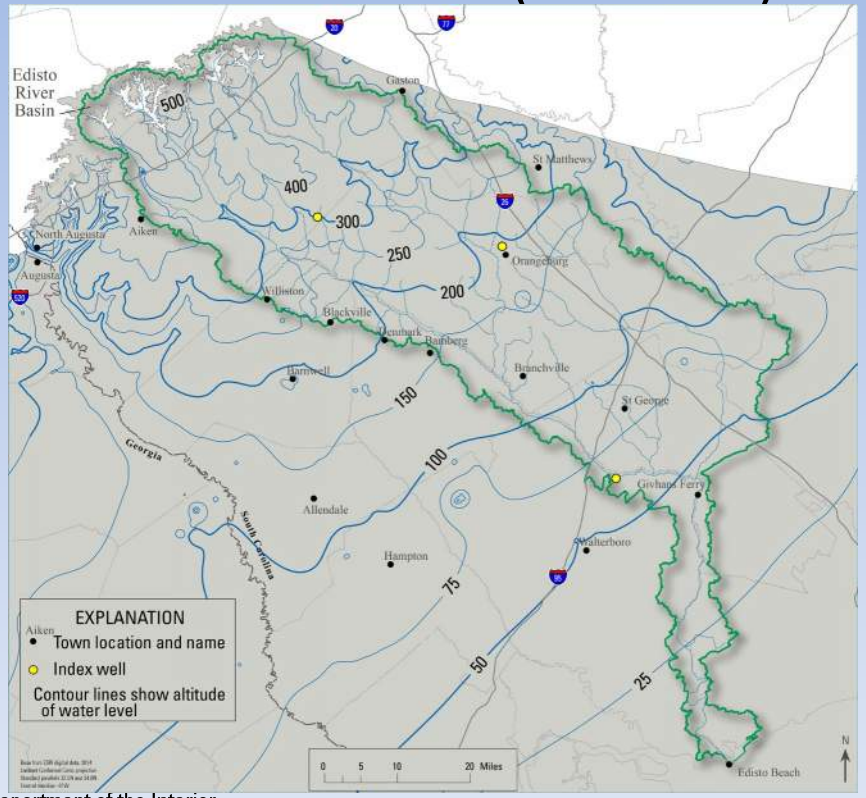
Edisto Basin – 91 wells



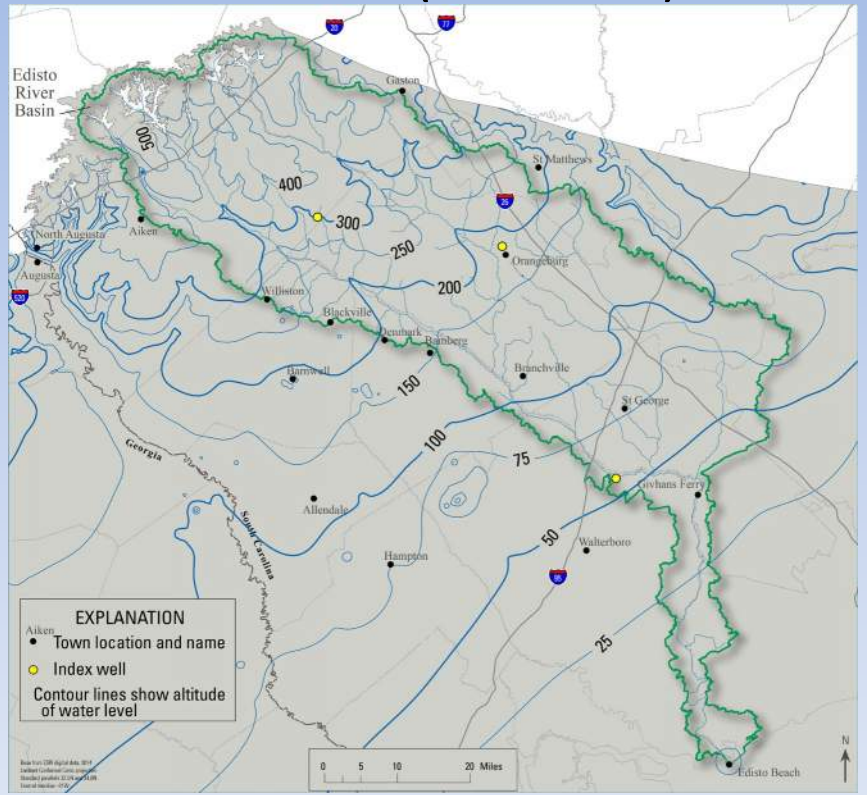
Provisional – All data is considered provisional and subject to revision.

Current Scenario - Gordon aquifer (model layer 7)

2020 (6.7 MGD)



2070 (7.4 MGD)

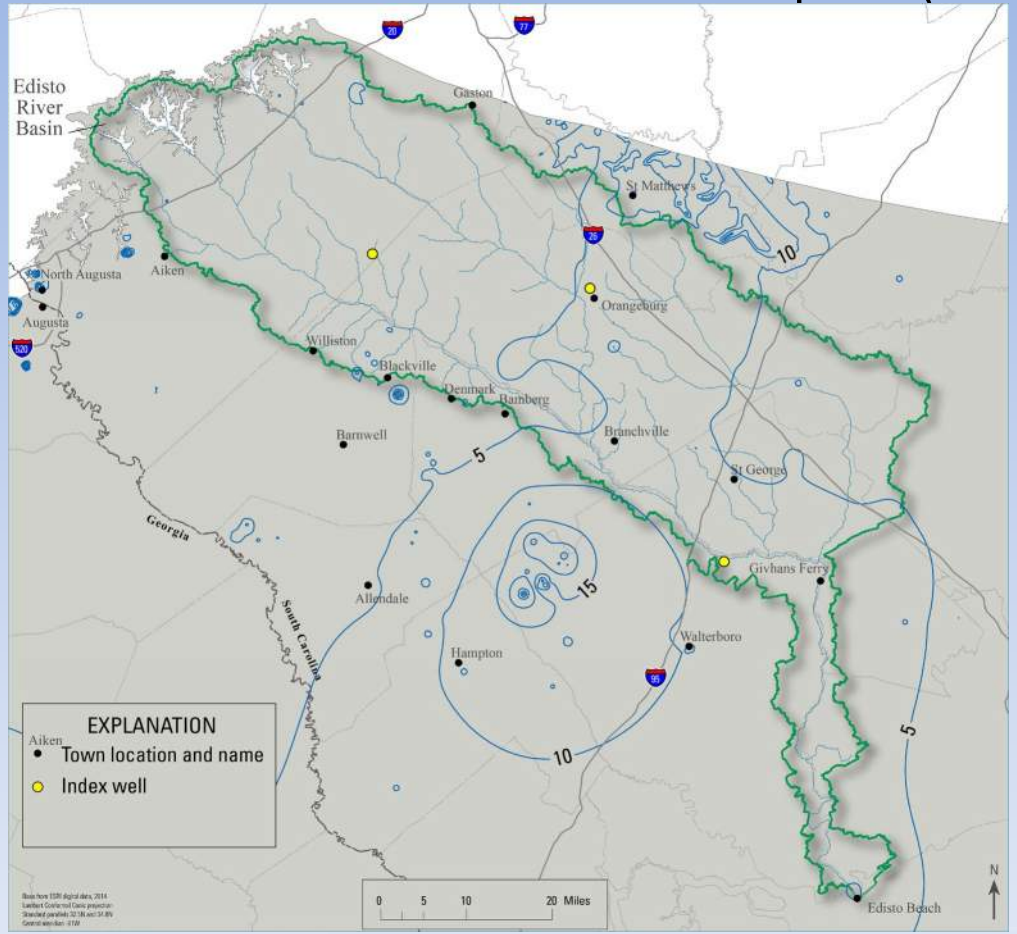


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Current Scenario - Gordon aquifer (model layer 7)

2020-2070

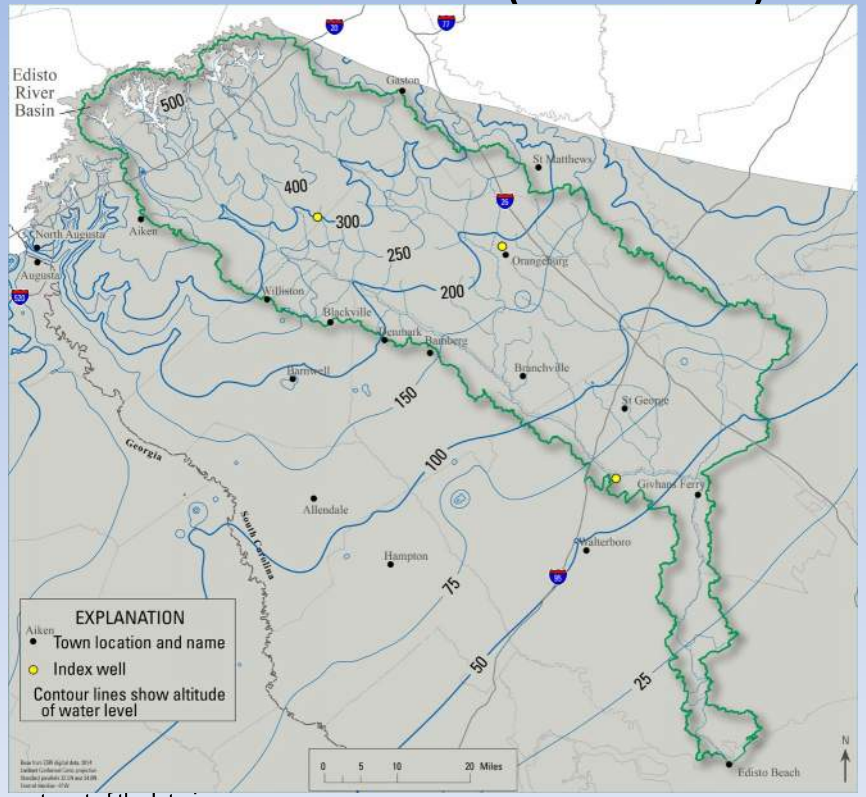


U.S. Department of the Interior
U.S. Geological Survey

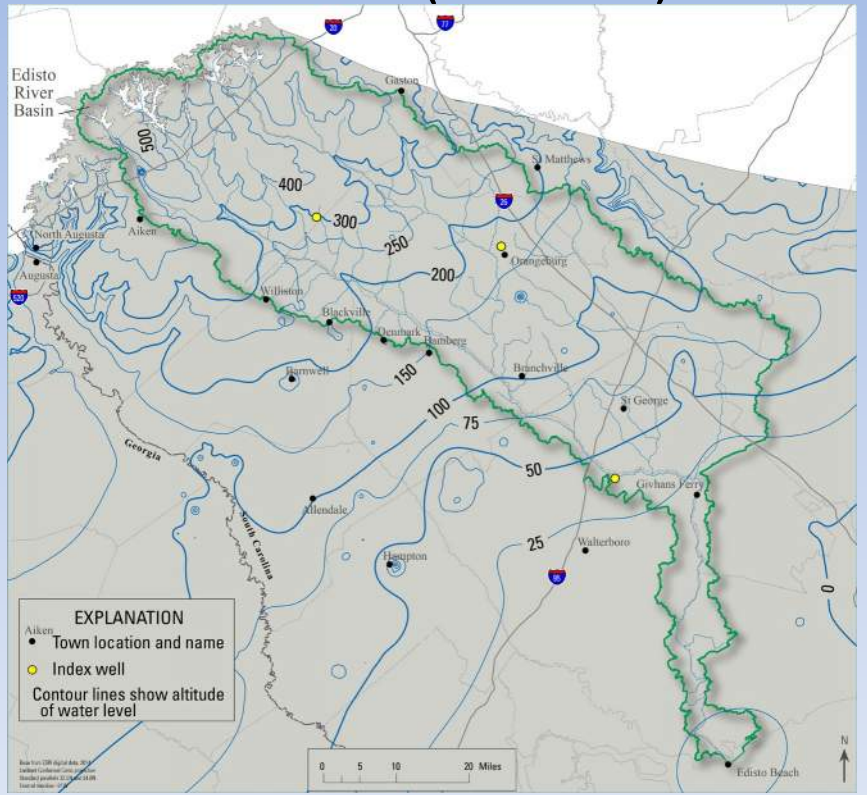
Provisional – All data is considered provisional and subject to revision.

Permitted Scenario - Gordon aquifer (model layer 7)

2020 (6.7 MGD)



2070 (13 MGD)

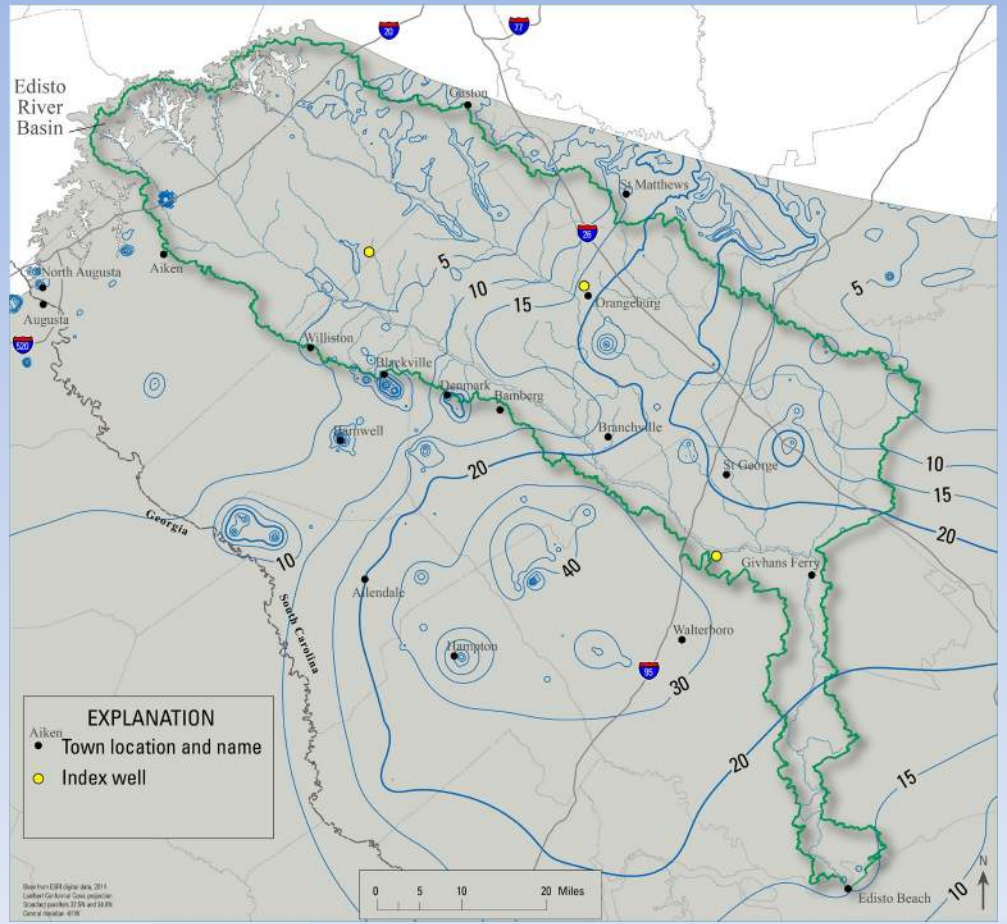


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Permitted Scenario - Gordon aquifer (model layer 7)

2020-2070

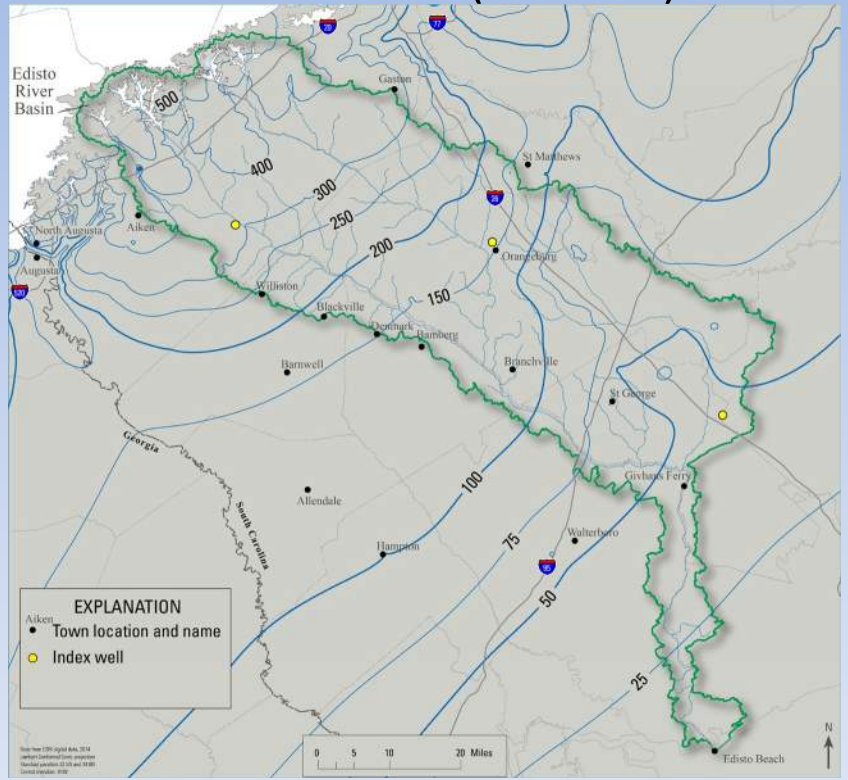


U.S. Department of the Interior
U.S. Geological Survey

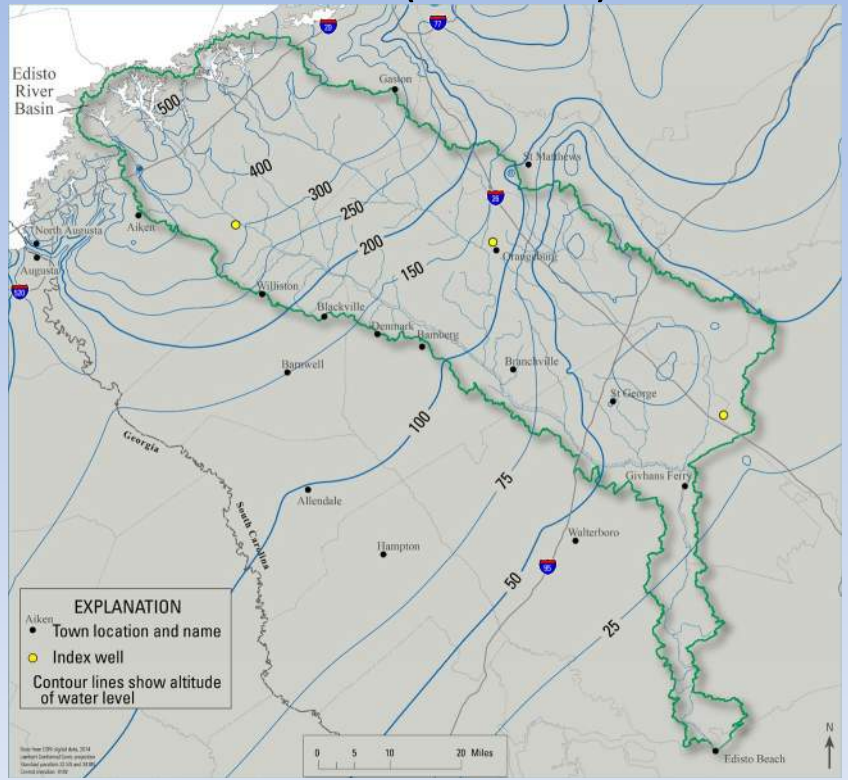
Provisional – All data is considered provisional and subject to revision.

Current Scenario – Crouch Branch aquifer (model layer 9)

2020 (40 MGD)



2070 (52 MGD)

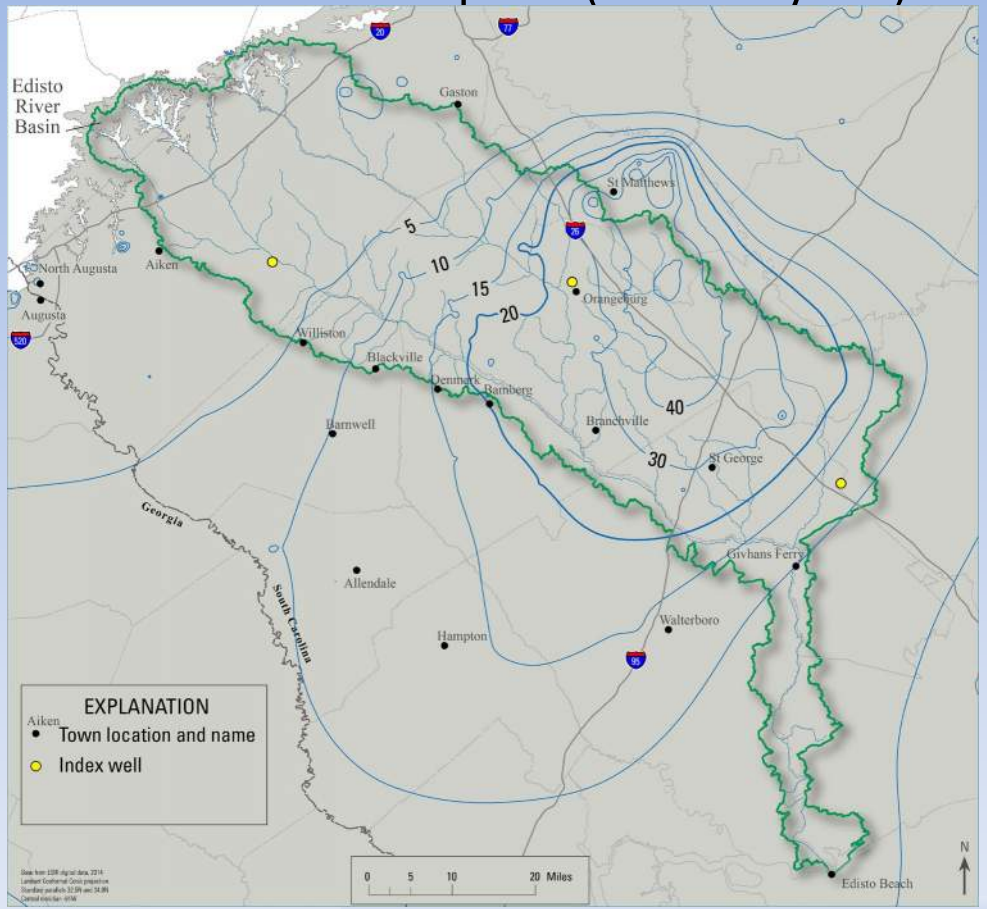


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Current Scenario – Crouch Branch aquifer (model layer 9)

2020-2070

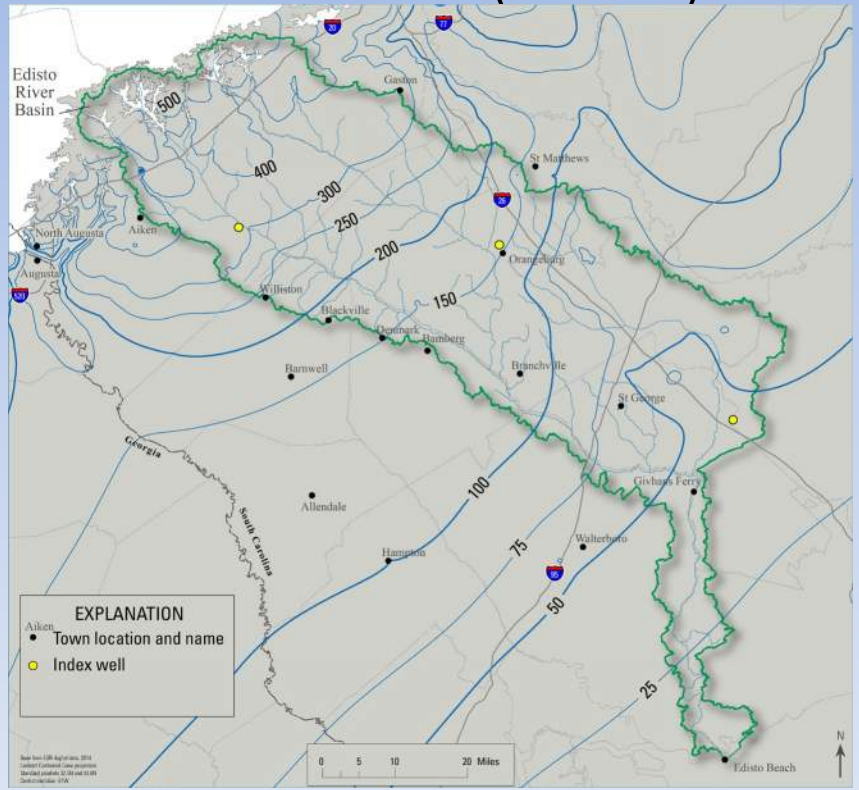


U.S. Department of the Interior
U.S. Geological Survey

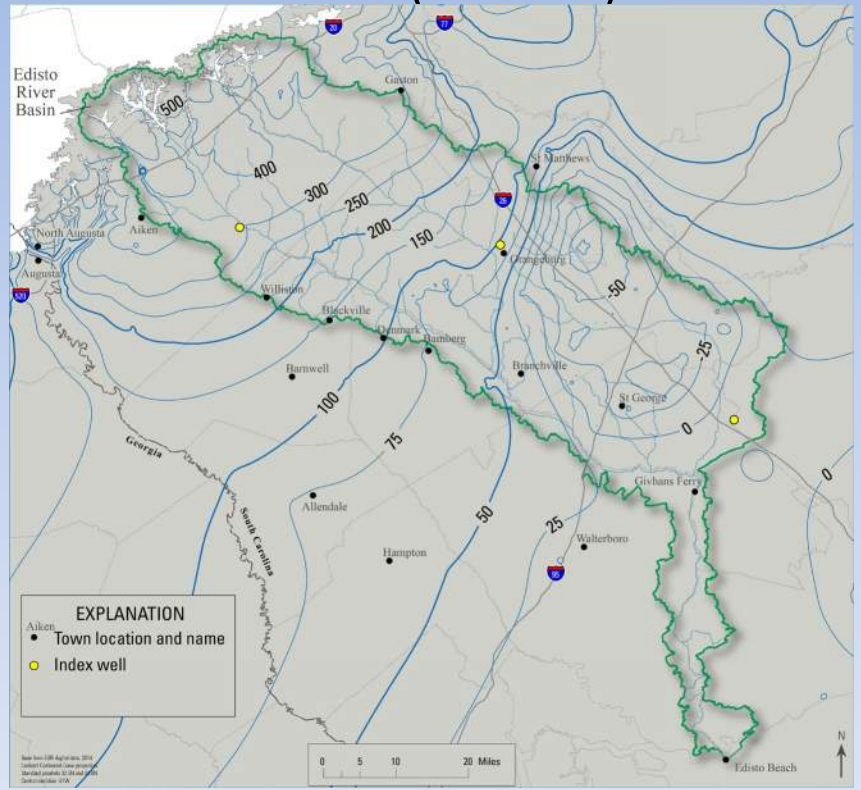
Provisional – All data is considered provisional and subject to revision.

Permitted Scenario – Crouch Branch aquifer (model layer 9)

2020 (40 MGD)



2070 (83 MGD)

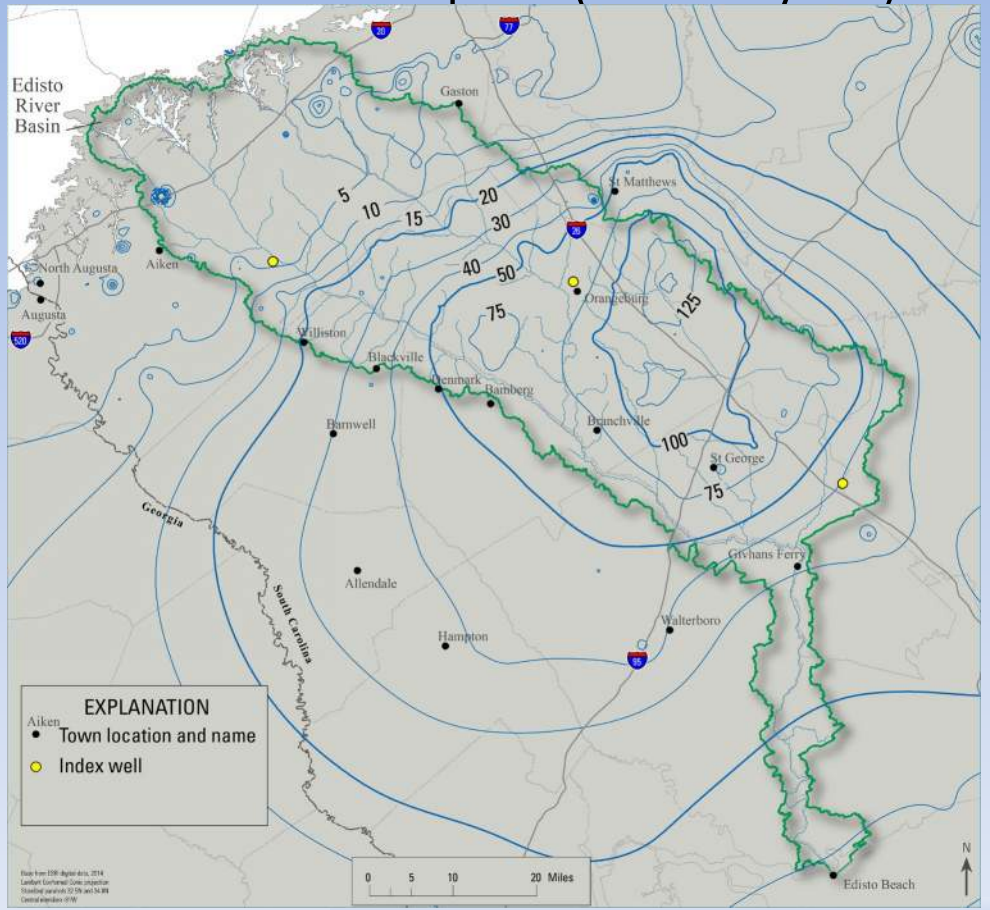


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Permitted Scenario – Crouch Branch aquifer (model layer 9)

2020-2070

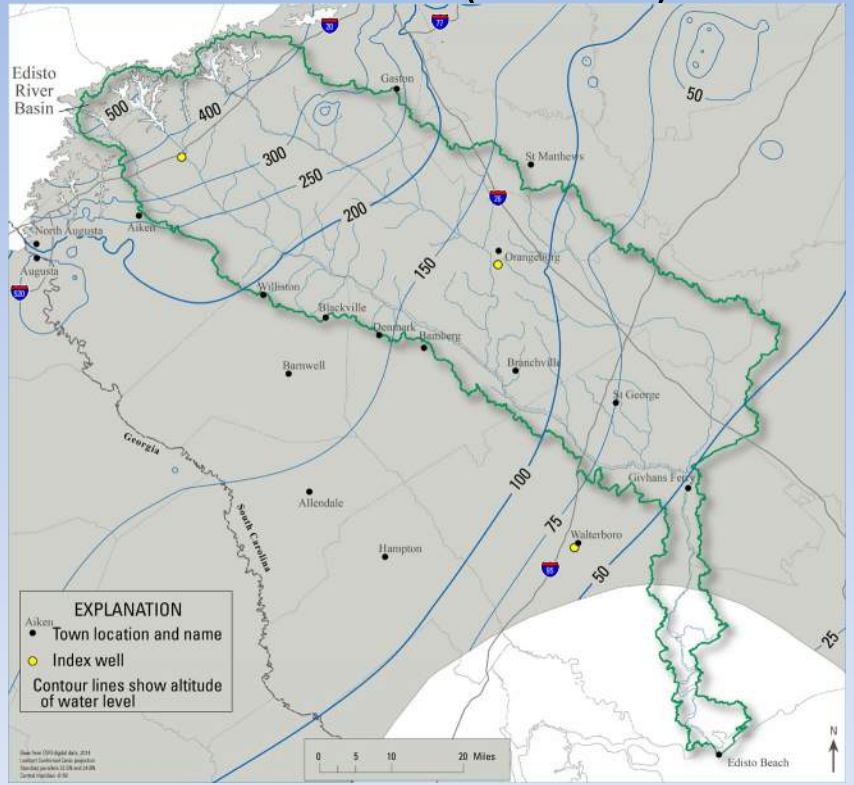


U.S. Department of the Interior
U.S. Geological Survey

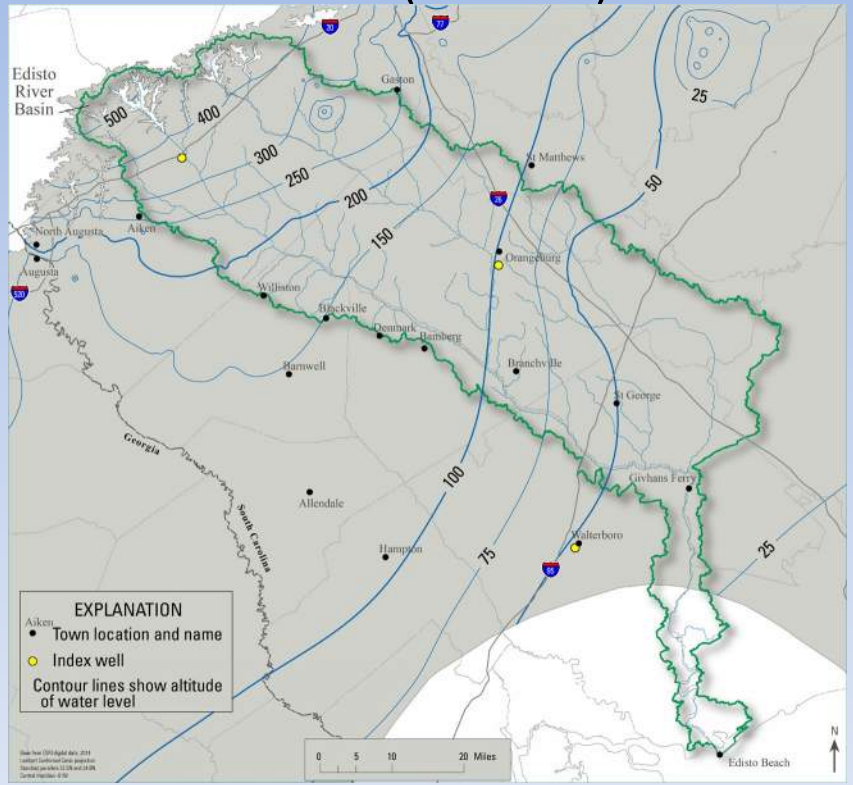
Provisional – All data is considered provisional and subject to revision.

Current Scenario – McQueen Branch aquifer (model layer 11)

2020 (10 MGD)



2070 (14 MGD)

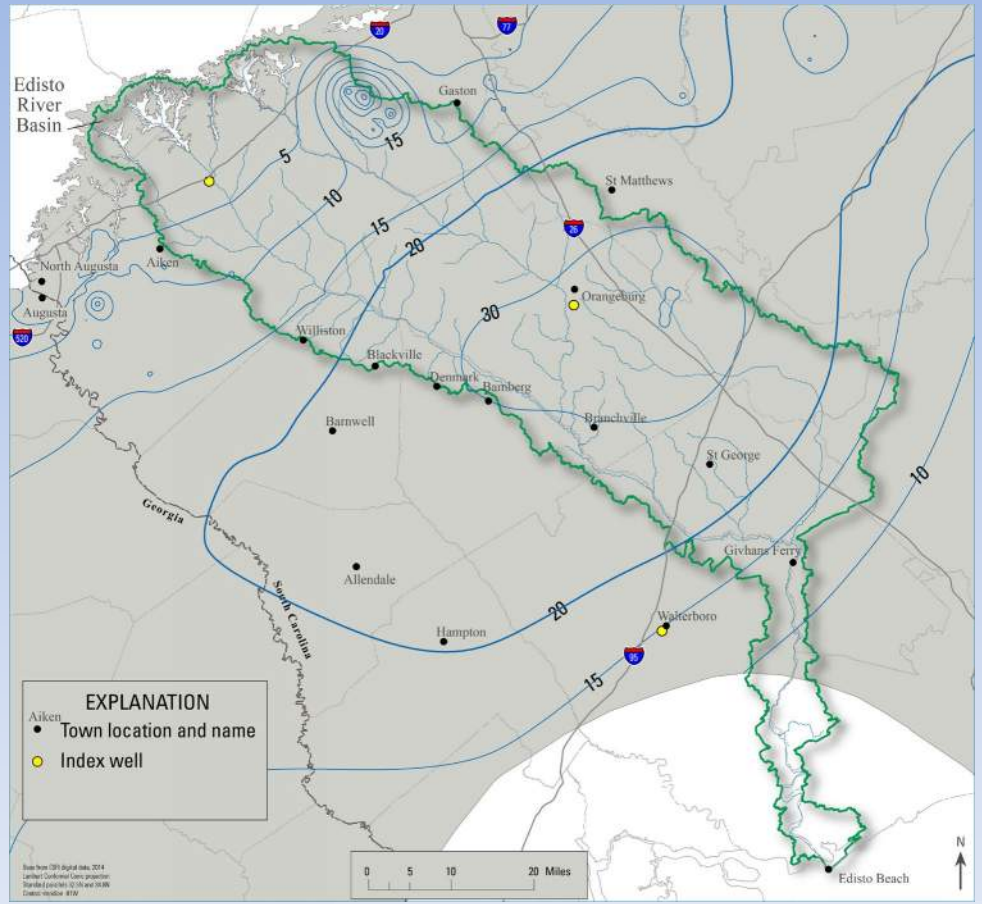


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Current Scenario – McQueen Branch aquifer (model layer 11)

2020-2070

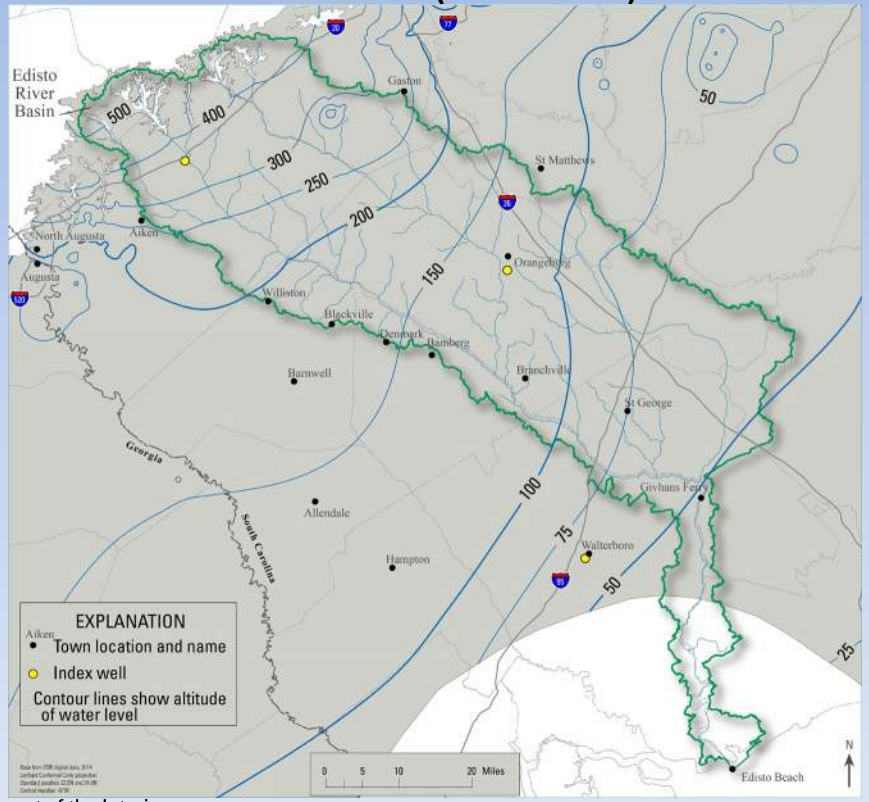


U.S. Department of the Interior
U.S. Geological Survey

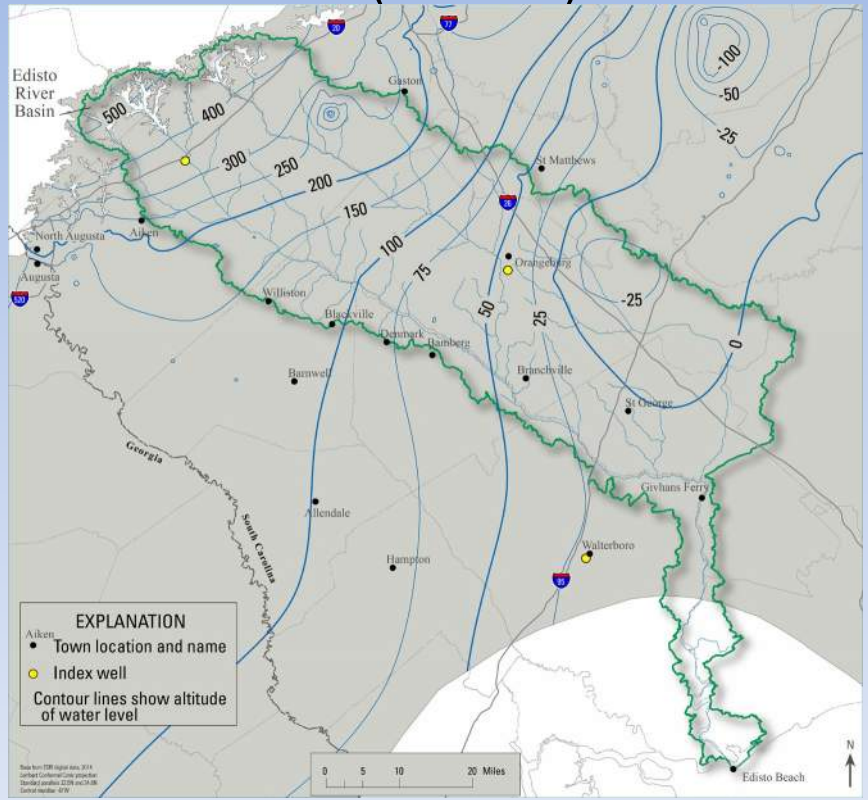
Provisional – All data is considered provisional and subject to revision.

Permitted Scenario – McQueen Branch aquifer (model layer 11)

2020 (10 MGD)



2070 (22 MGD)

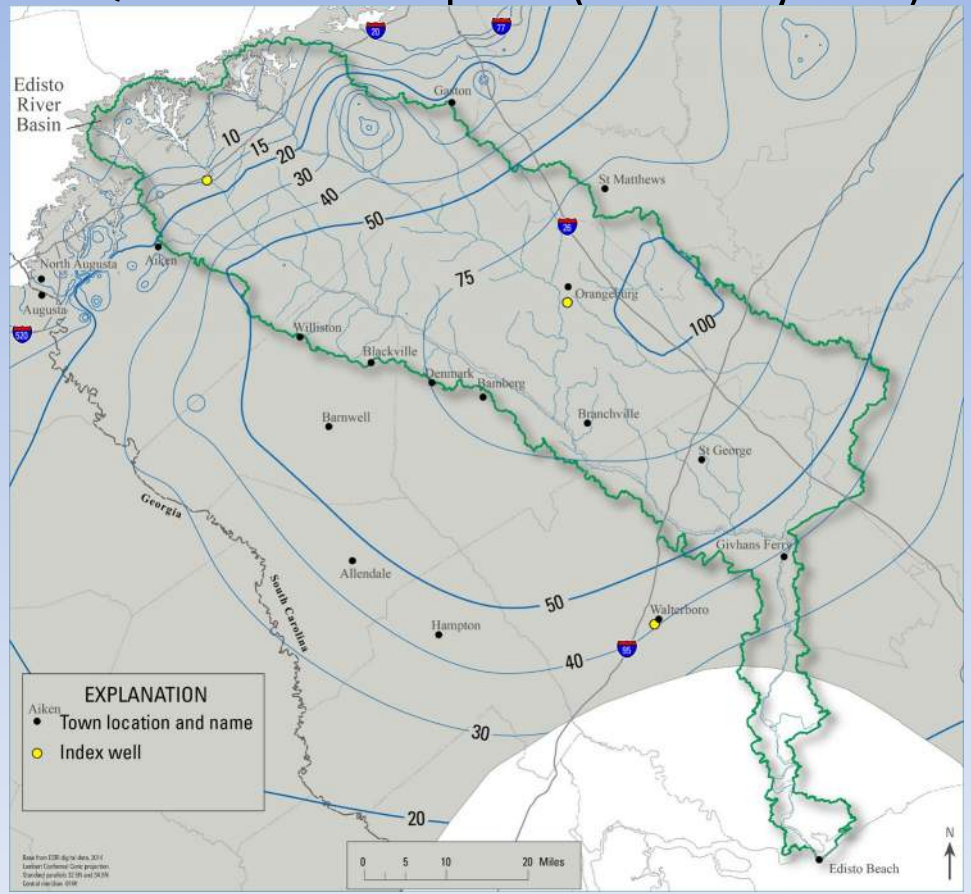


U.S. Department of the Interior
U.S. Geological Survey

Provisional – All data is considered provisional and subject to revision.

Drawdown Permitted Scenario – McQueen Branch aquifer (model layer 11)

2020-2070



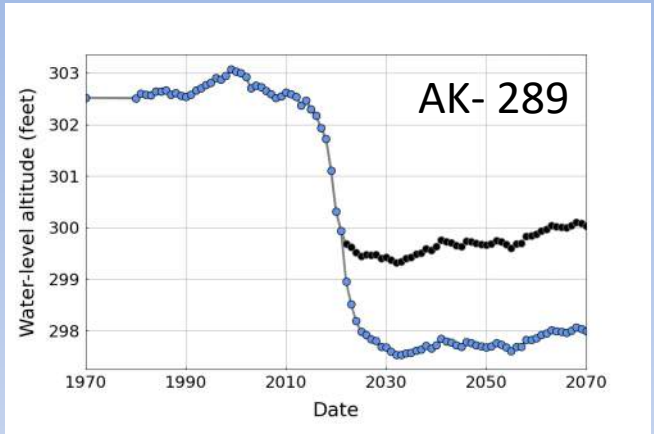
U.S. Department of the Interior
U.S. Geological Survey

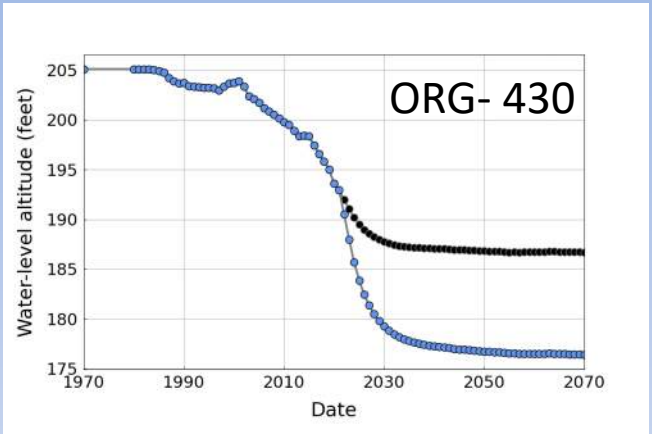
Provisional – All data is considered provisional and subject to revision.

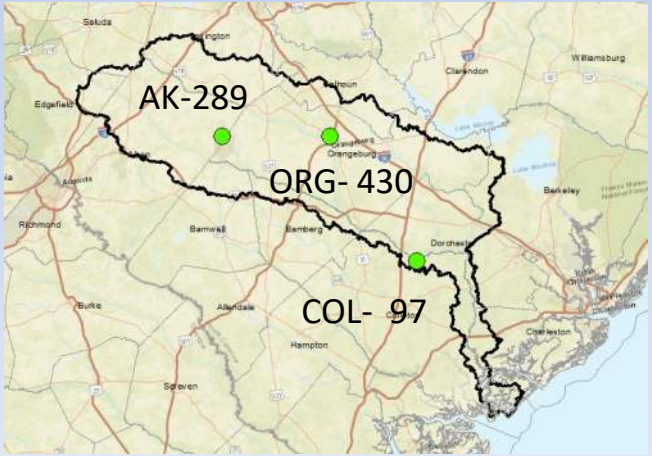
Simulated water levels in the Gordon aquifer

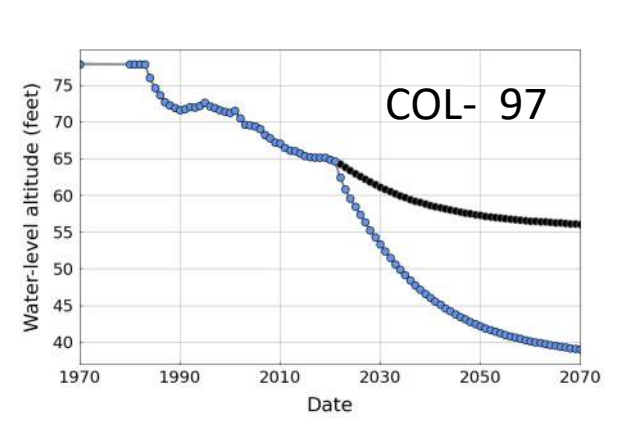
USGS
science for a changing world

EXPLANATION
- Current
- Permitted







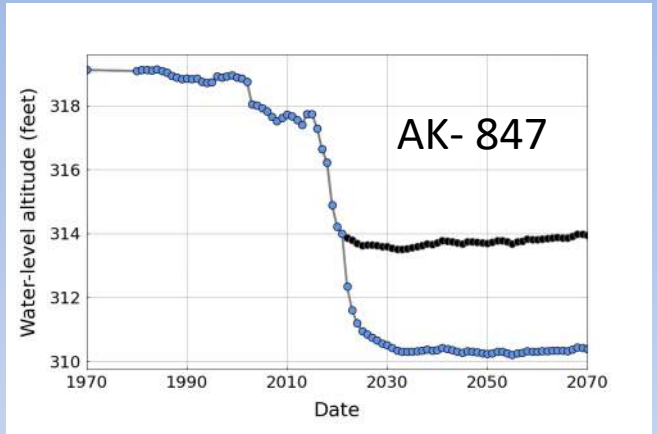


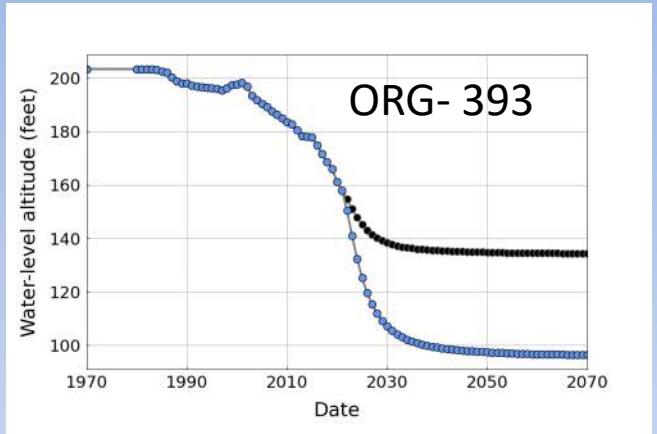
U.S. Department of the Interior
U.S. Geological Survey

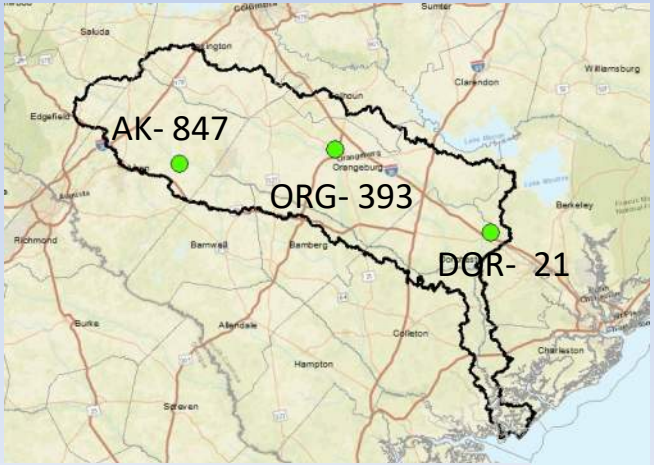
Provisional – All data is considered provisional and subject to revision.

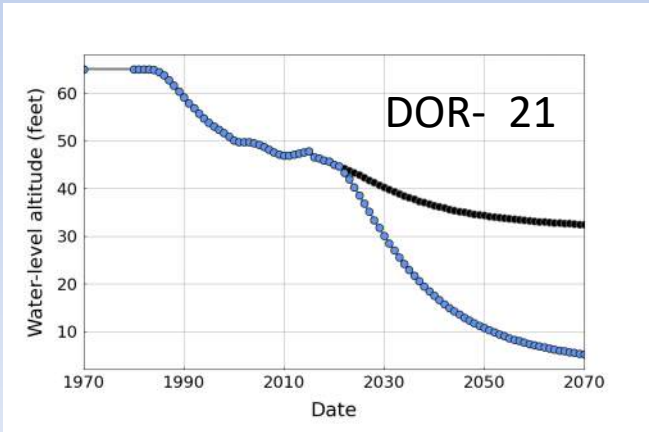
Simulated water levels in the Crouch Branch aquifer

EXPLANATION
- Current
- Permitted





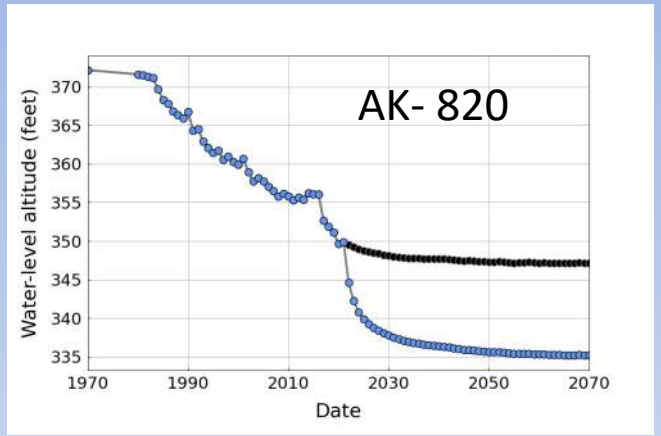


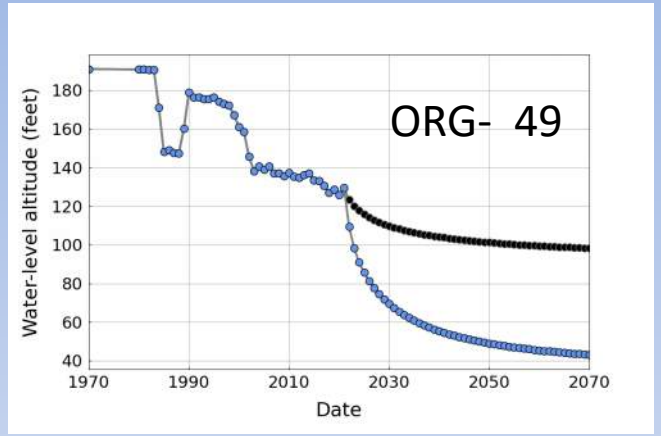


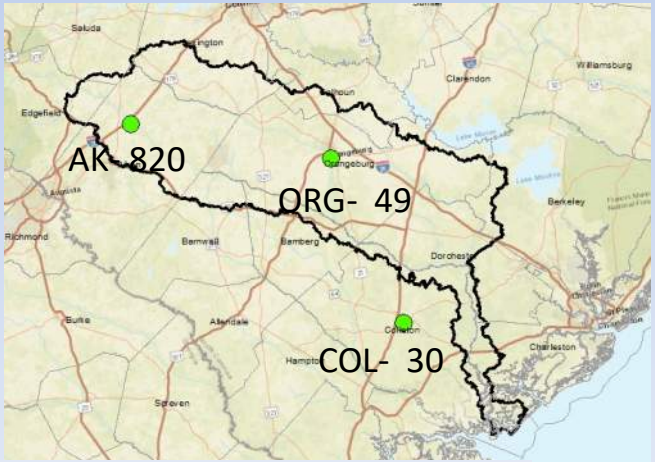
U.S. Department of the Interior
U.S. Geological Survey

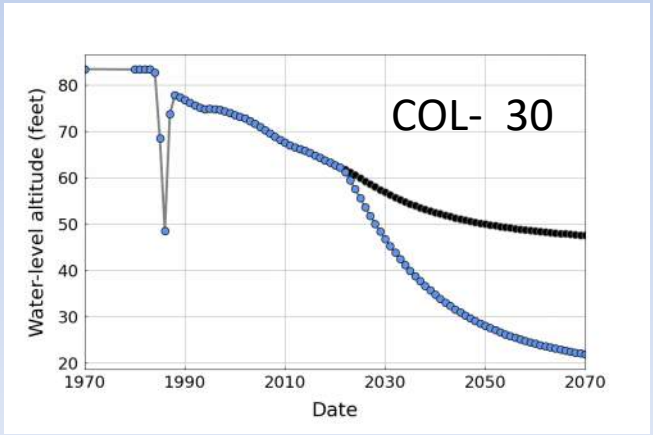
Provisional – All data is considered provisional and subject to revision.

Simulated water levels in the McQueen Branch aquifer





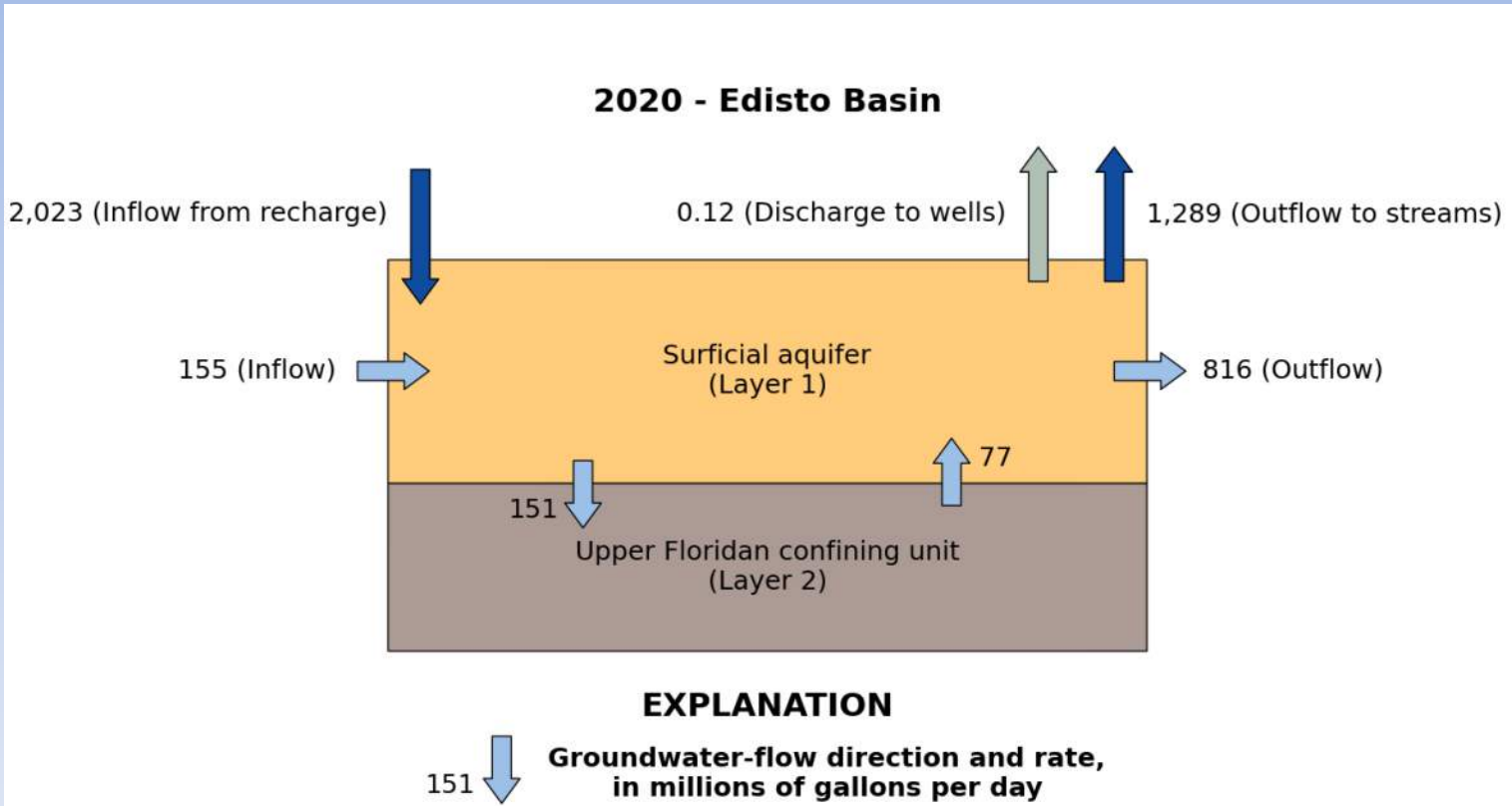




U.S. Department of the Interior
U.S. Geological Survey

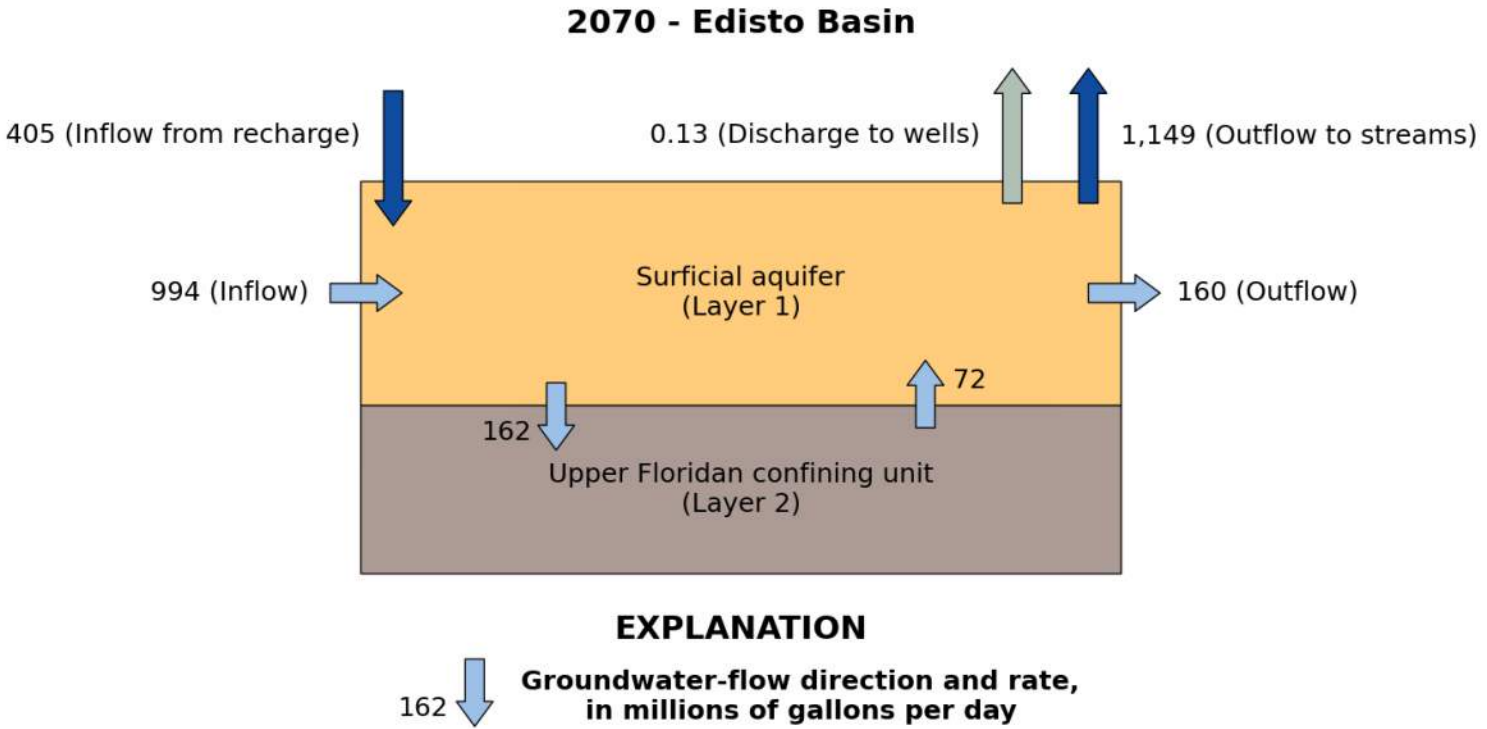
Provisional – All data is considered provisional and subject to revision.

Simulated 2020 water budget in the Surficial aquifer



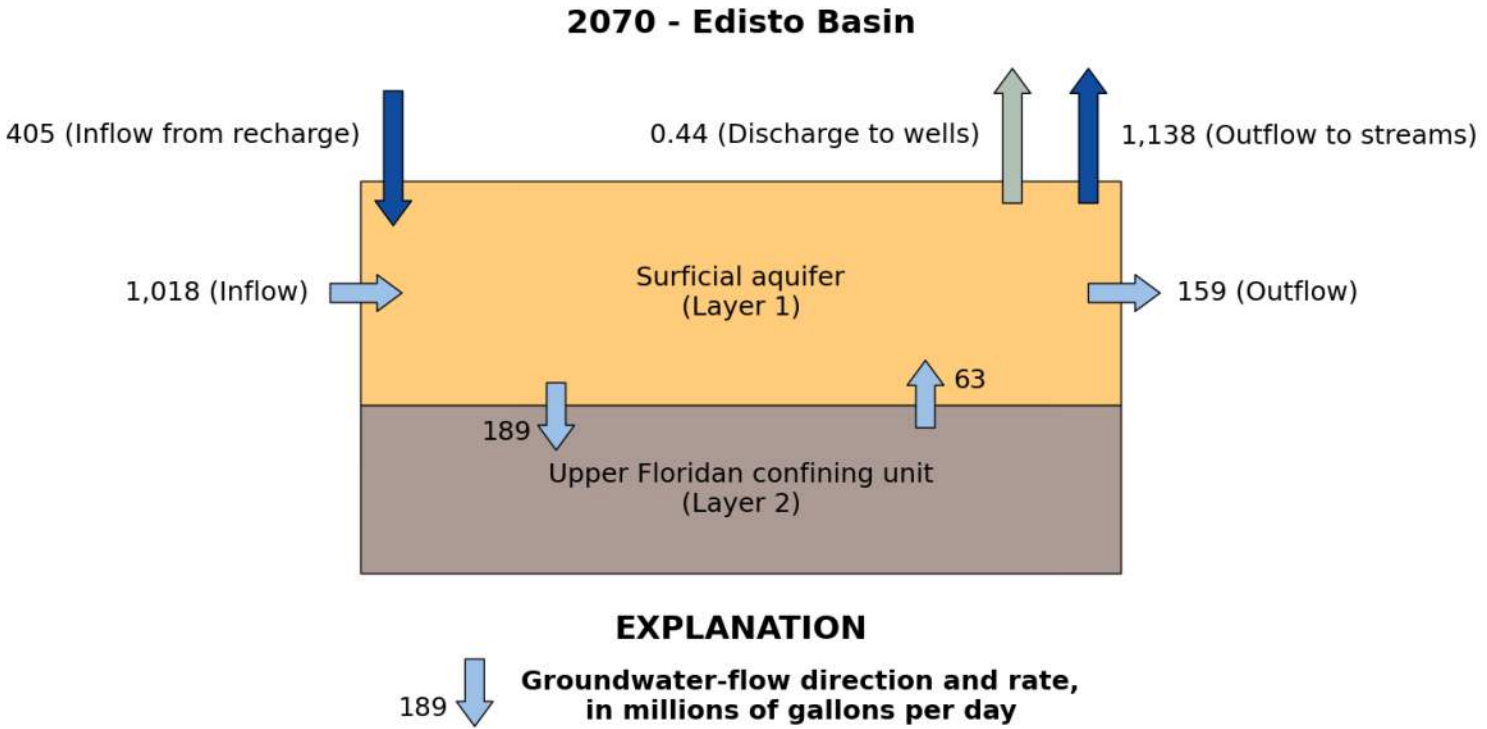
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2070 water budget in the Surficial aquifer (Current Scenario)



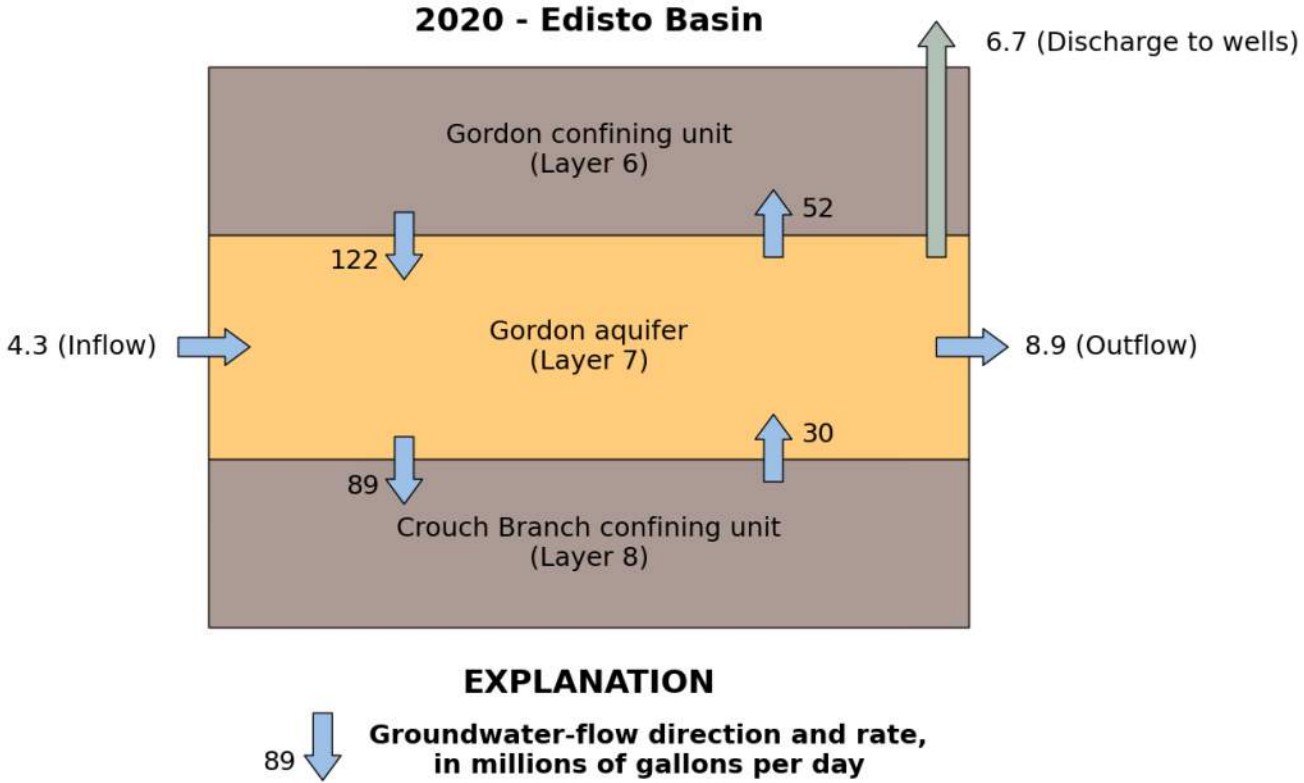
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2070 water budget in the Surficial aquifer (Permitted Scenario)



U.S. Department of the Interior
U.S. Geological Survey

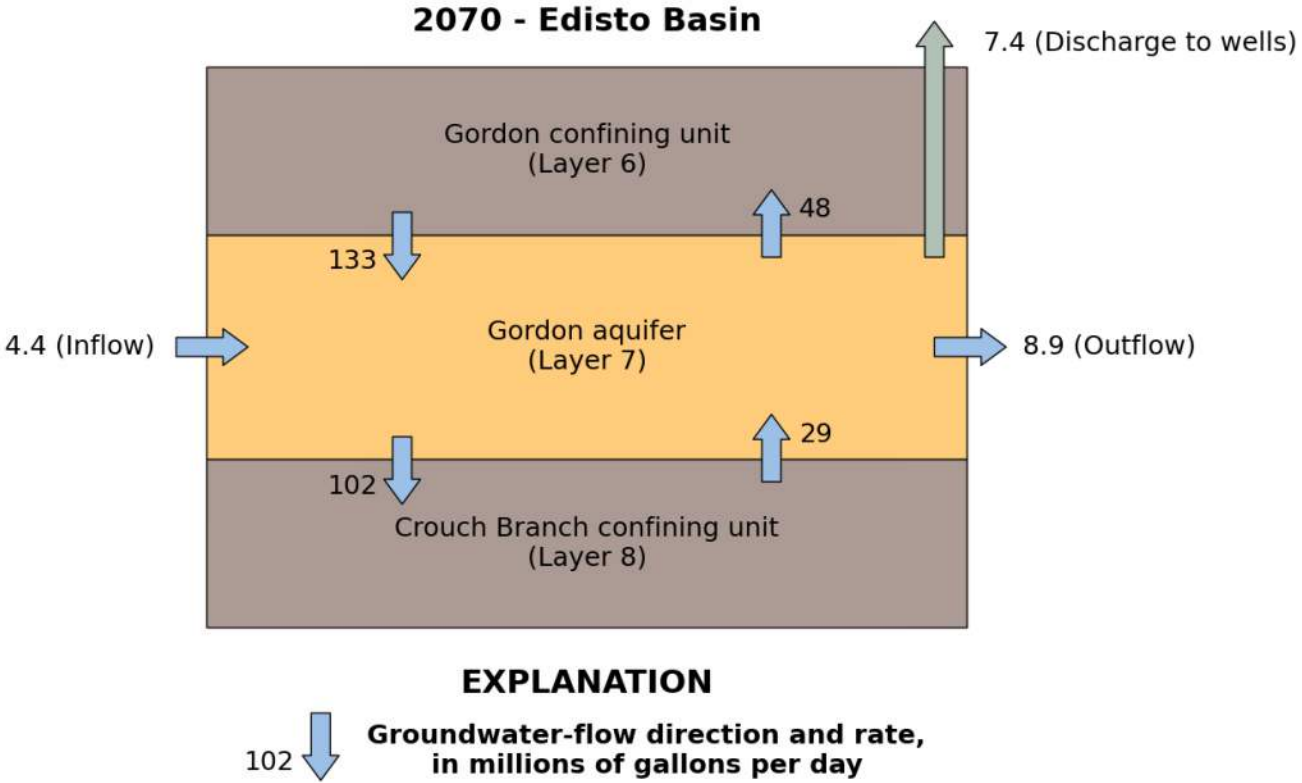
Simulated 2020 water budget in the Gordon aquifer



U.S. Department of the Interior
U.S. Geological Survey

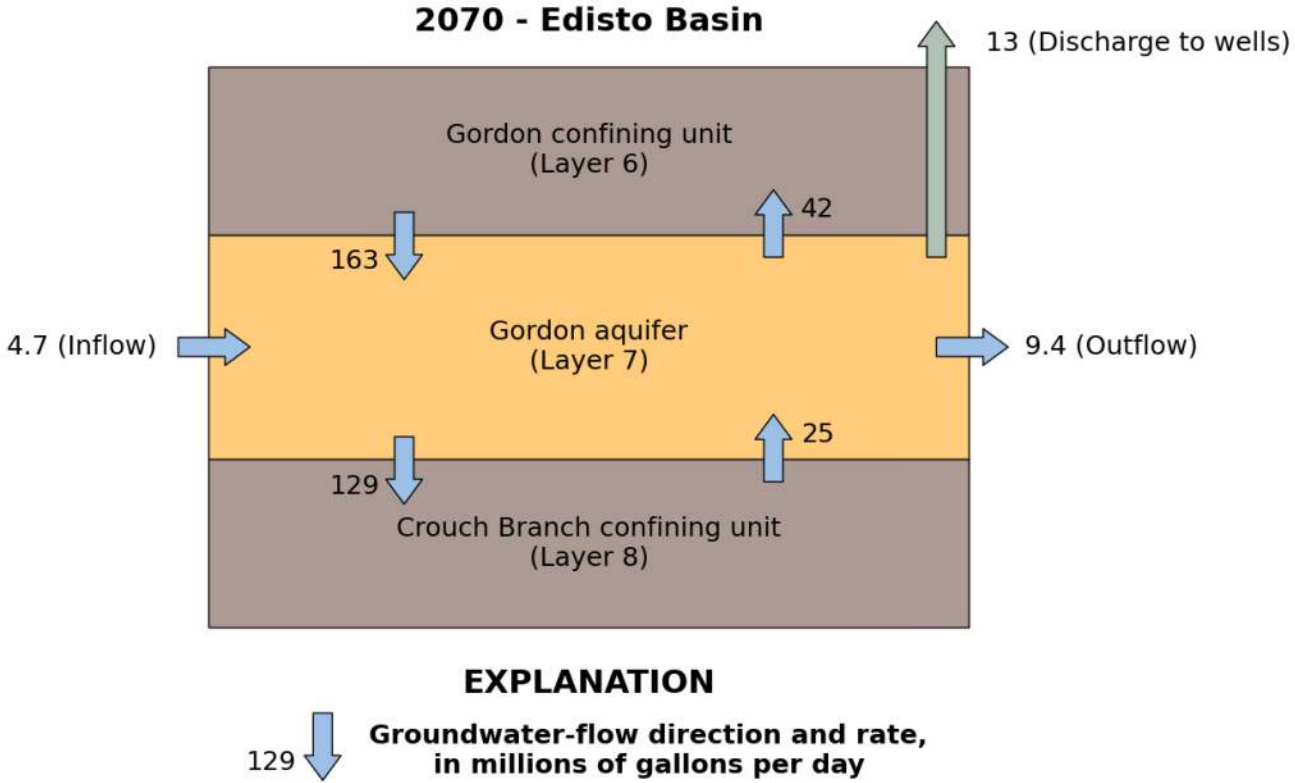
Provisional – All data is considered provisional and subject to revision.

Simulated 2070 water budget in the Gordon aquifer (Current Scenario)



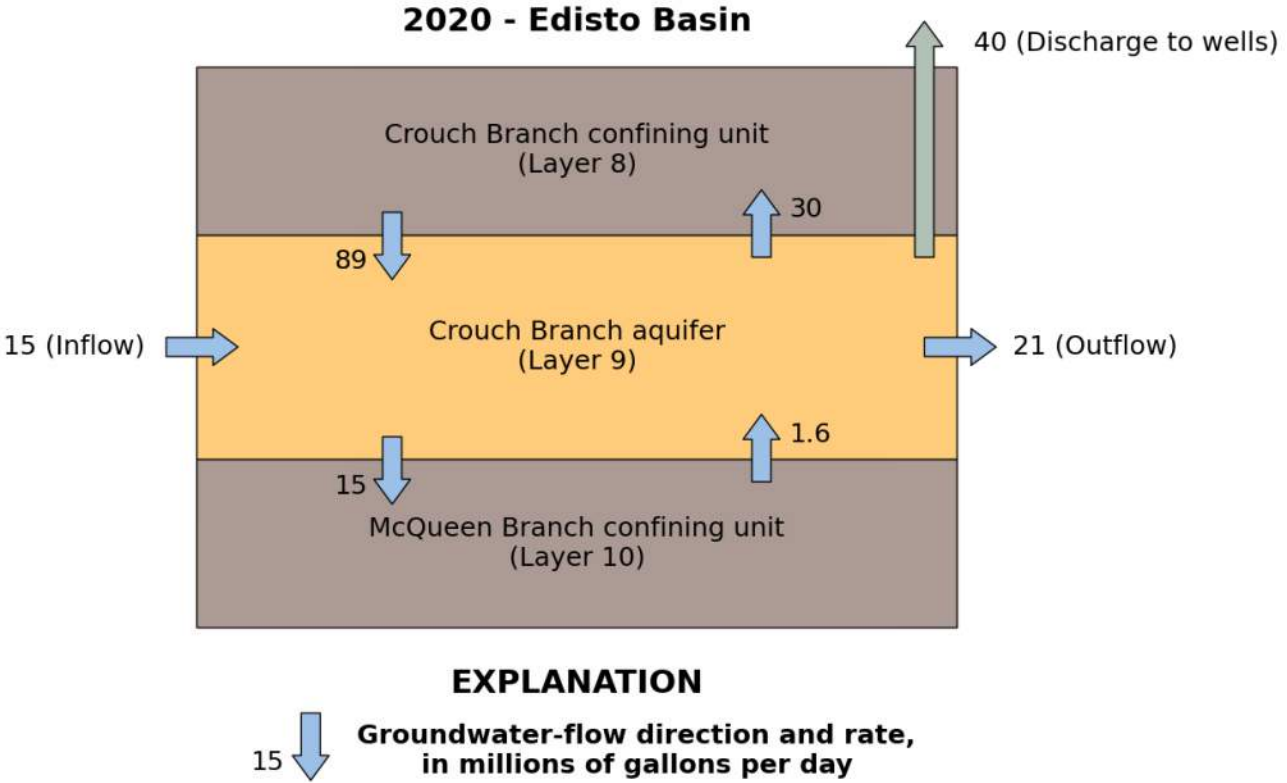
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2070 water budget in the Gordon aquifer (Permitted Scenario)



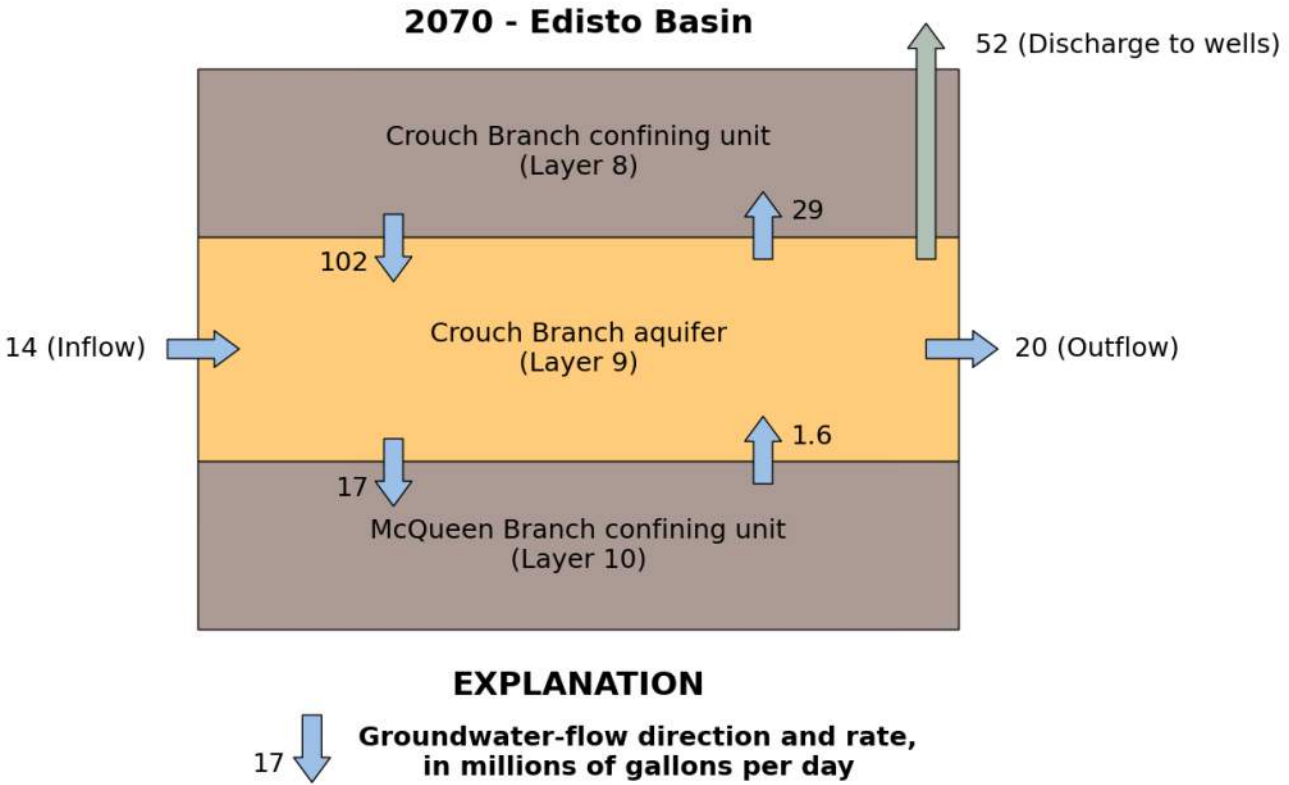
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2020 water budget in the Crouch Branch aquifer



U.S. Department of the Interior
U.S. Geological Survey

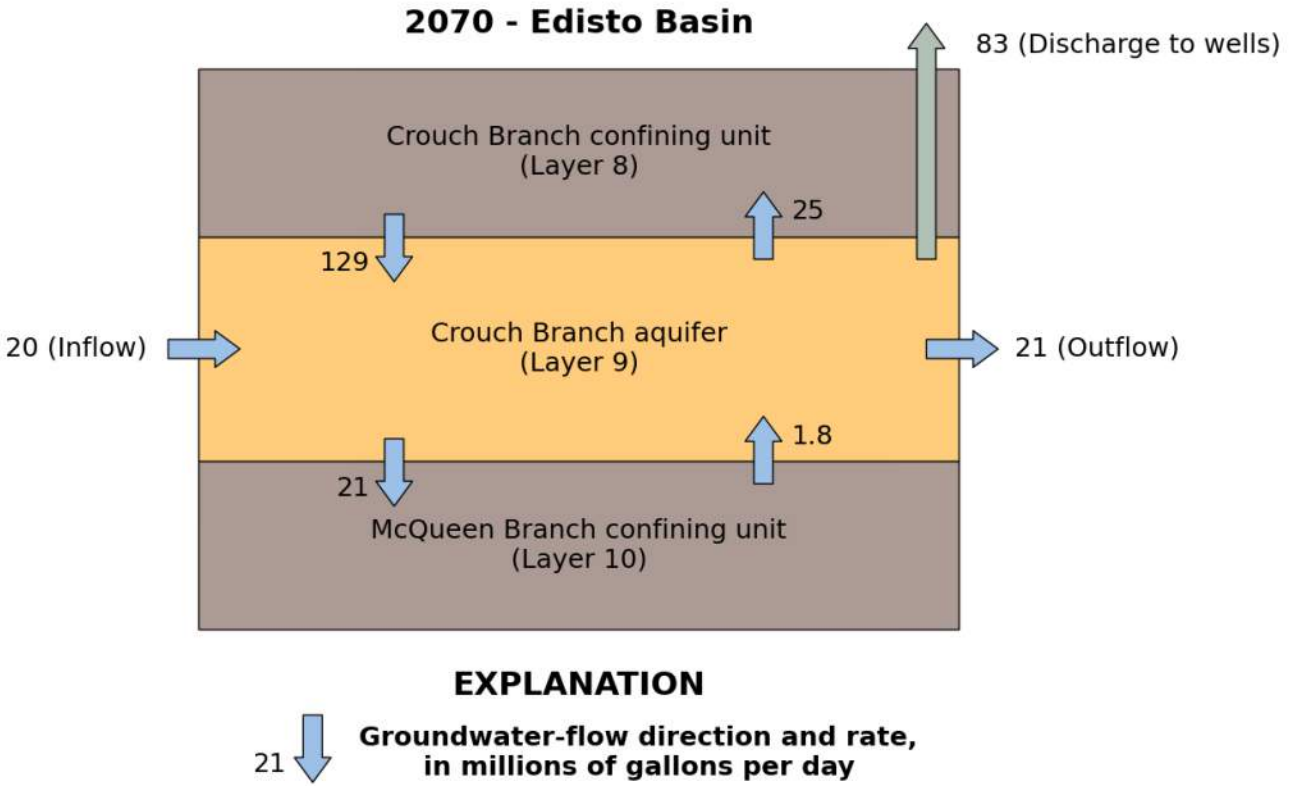
Simulated 2070 water budget in the Crouch Branch aquifer (Current Scenario)



U.S. Department of the Interior
U.S. Geological Survey

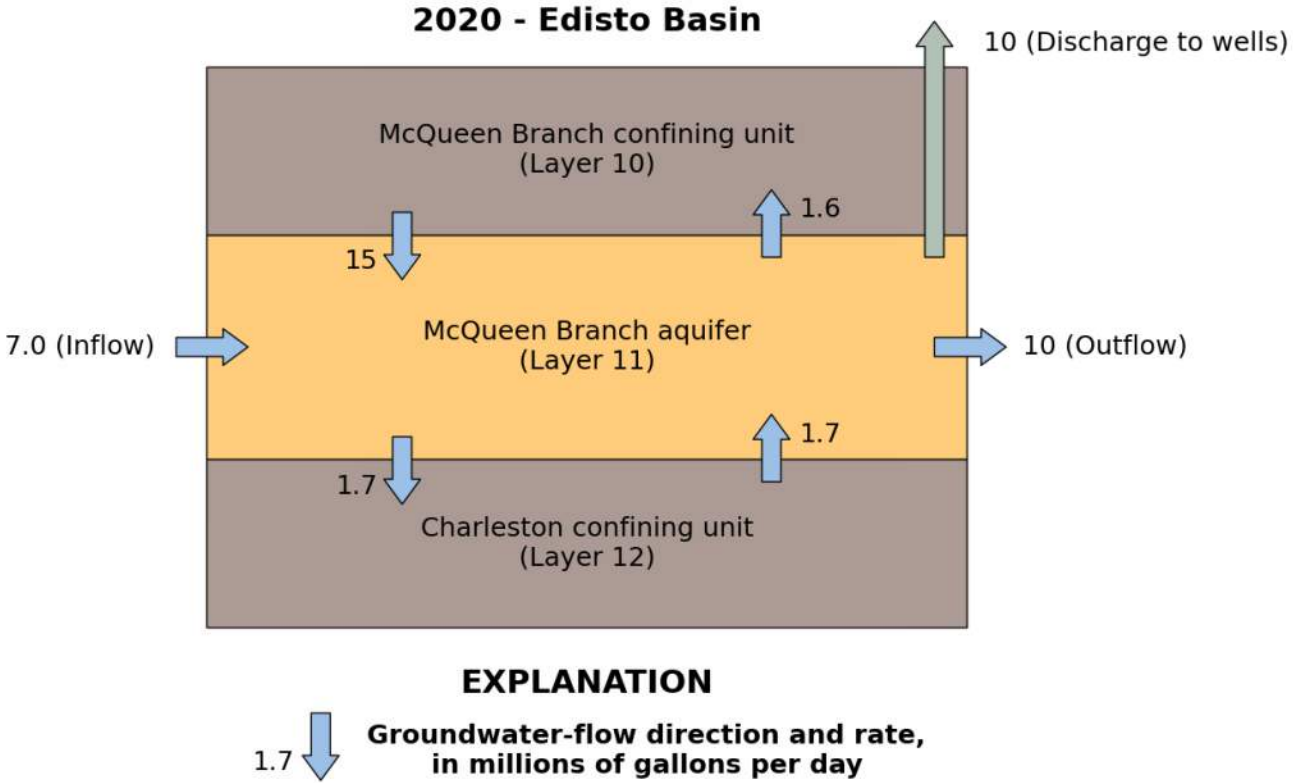
Provisional – All data is considered provisional and subject to revision.

Simulated 2070 water budget in the Crouch Branch aquifer (Permitted Scenario)



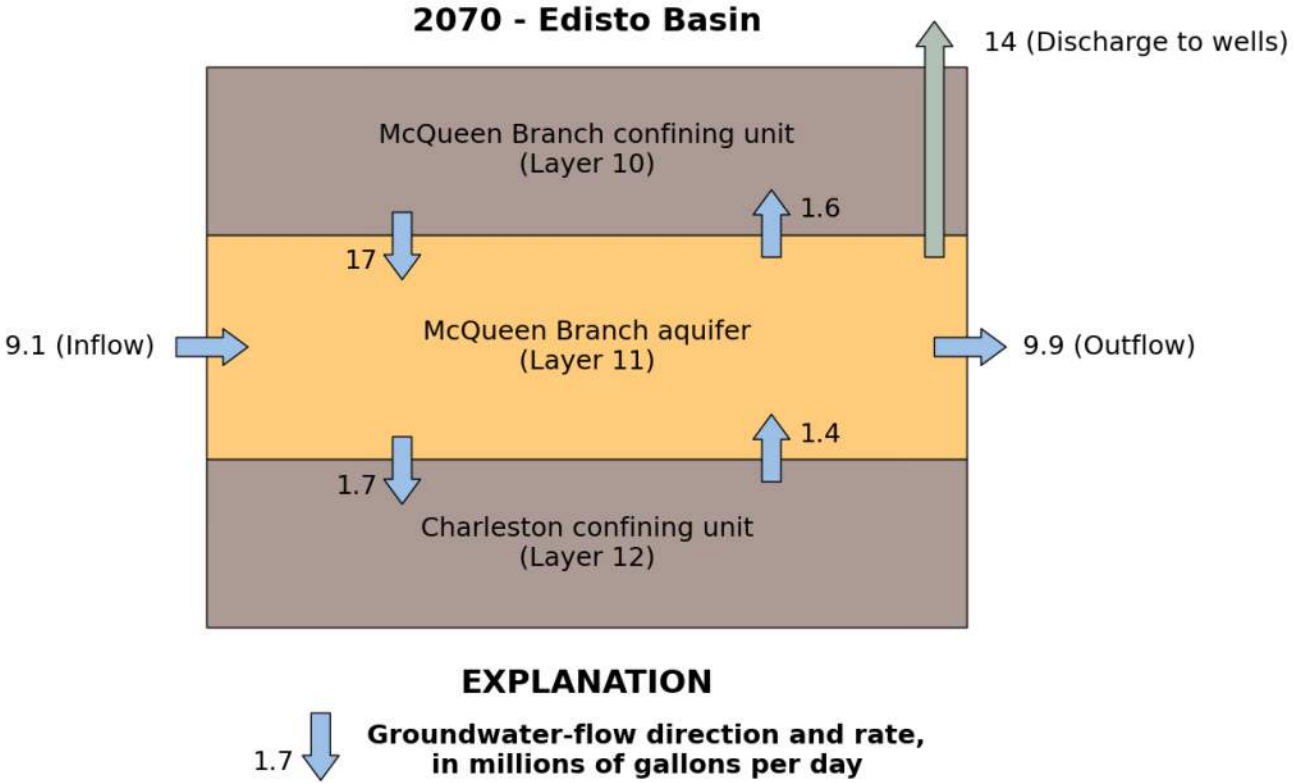
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2020 water budget in the McQueen Branch aquifer



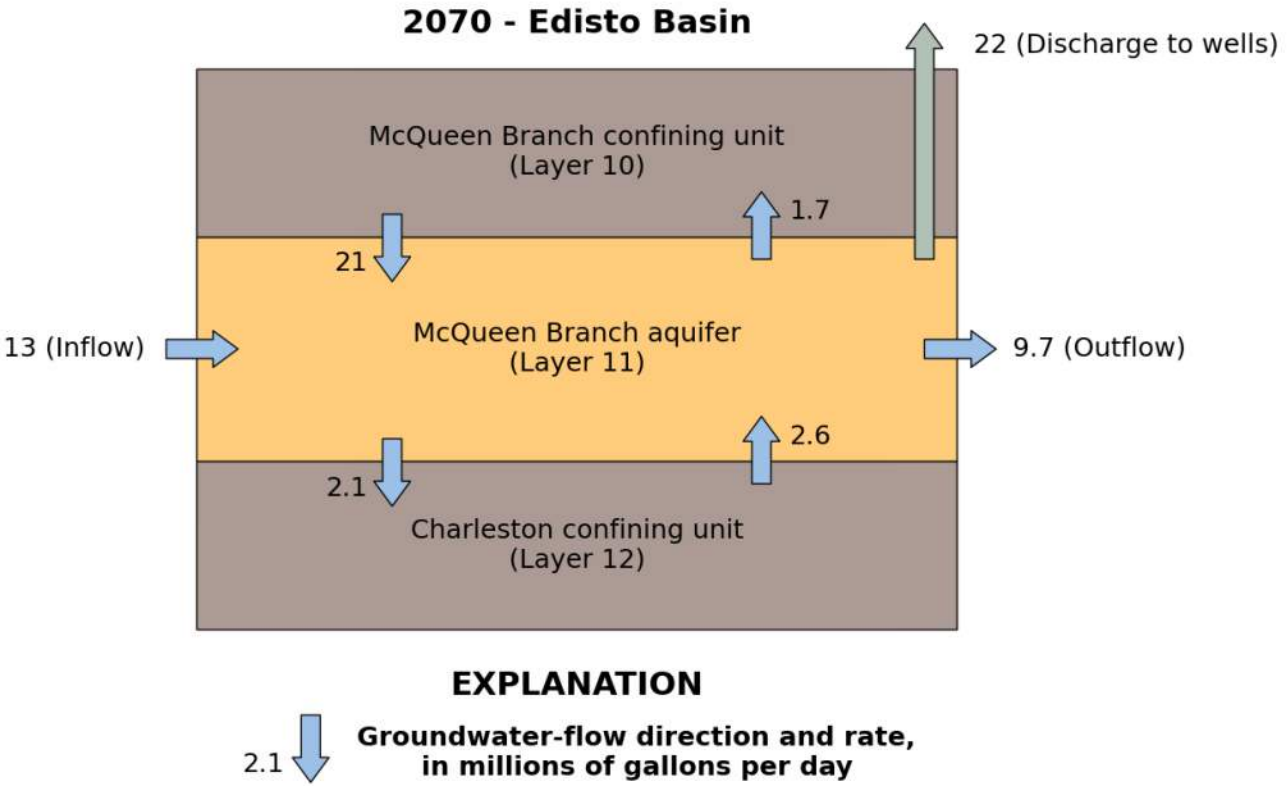
U.S. Department of the Interior
U.S. Geological Survey

Simulated 2070 water budget in the McQueen Branch aquifer (Current Scenario)



U.S. Department of the Interior
U.S. Geological Survey

Simulated 2070 water budget in the McQueen Branch aquifer (Permitted Scenario)



U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world

Flow budget in the Edisto Basin
Surficial aquifer (in MGD)

	2020	2070	2070	2070
		Current	Permitted	Difference
Recharge	2,023	405	405	0.0
Outflow to streams	-1,289	-1,149	-1,138	11
Discharge to wells	-0.1	-0.1	-0.4	-0.3
Lateral inflow	156	994	1,018	24
Lateral outflow	-815	-160	-159	1.0
Vertical inflow	77	72	63	-9.0
Vertical outflow	-151	-162	-189	-27

Provisional – All data is considered provisional and subject to revision.

USGS
science for a changing world

Flow budget in the Edisto Basin Gordon aquifer (in MGD)

	2020	2070	2070	2070
		Current	Permitted	Difference
Discharge to wells	-6.7	-7.4	-13	-5.6
Lateral inflow	4.3	4.4	4.7	0.3
Lateral outflow	-8.9	-8.9	-9.4	-0.5
Vertical inflow	152	162	188	26
Vertical outflow	-141	-150	-171	-21

Provisional – All data is considered provisional and subject to revision.

USGS
science for a changing world

Flow budget in the Edisto Basin Crouch Branch aquifer (in MGD)

	2020	2070	2070	2070
		Current	Permitted	Difference
Discharge to wells	-40	-52	-83	-31
Lateral inflow	15	14	20	6.2
Lateral outflow	-21	-20	-21	-1.0
Vertical inflow	91	104	131	27
Vertical outflow	-45	-46	-46	0

Provisional – All data is considered provisional and subject to revision.

USGS
science for a changing world

Flow budget in the Edisto Basin McQueen Branch aquifer (in MGD)

	2020	2070	2070	2070
		Current	Permitted	Difference
Discharge to wells	-10	-14	-22	-8.0
Lateral inflow	7.0	9.1	13	3.9
Lateral outflow	-10	-9.9	-9.7	0.2
Vertical inflow	17	18	24	5.2
Vertical outflow	-3.3	-3.3	-3.8	-0.5

Provisional – All data is considered provisional and subject to revision.

Groundwater Scenarios

Current groundwater use

- Constant pumping rates from 2021-2070 using average pumping rates derived from groundwater use from 2015-2019

Permitted groundwater use

- Constant pumping rates from 2021-2070 using fully permitted pumping rates

Business-as-usual water demand

- Projections from 2021-2070 based on assumption moderate population and economic growth

High water demand trend

- Projections from 2021-2070 based on assumption high population and economic growth

USGS
science for a changing world

Summary

- Simulated recharge rates were estimated with the SWB model output. Rates varied from 0.09 to 1.22 feet per year.
- Simulated pumping for 2021 to 2070 was 75.3 and 121.2 MGD for the Current and Permitted Scenarios, respectively.
- The number of simulated wells in the SC aquifers: Gordon (330), Crouch Branch (1,128), and McQueen Branch (648), and 700 wells in the multi-node package.
- The number of simulated wells in the SC aquifers for the Edisto Basin: Gordon (113), Crouch Branch (493), and McQueen Branch (97), and 91 wells in the multi-node package.

Summary - continued

- Maximum drawdowns over 10, 50, and 75 feet are seen in the Gordon, Crouch Branch, and McQueen Branch aquifers for the Current Scenario in the Edisto Basin.
- Maximum drawdowns over 75, 150, and 100 feet are seen in the Gordon, Crouch Branch, and McQueen Branch aquifers for the Permitted Scenario in the Edisto Basin.
- Simulated results indicate possible declines below the top of the aquifer for the Current and Permitted Scenarios in the McQueen Branch aquifer (Lexington County) and in the Permitted Scenario for the Crouch Branch aquifer (Calhoun and Orangeburg Counties).

Summary - continued

- The largest flow budget components are recharge and outflow to streams within the surficial aquifer.
- Vertical and lateral inflow into the aquifers likely provides the water needed due to the increased pumping simulated in the Permitted Scenario.

USGS
science for a changing world

Questions?

Greg Cherry
gccherry@usgs.gov
470-557-0868

Matt Petkewich
mdpetkew@usgs.gov
803-727-9041