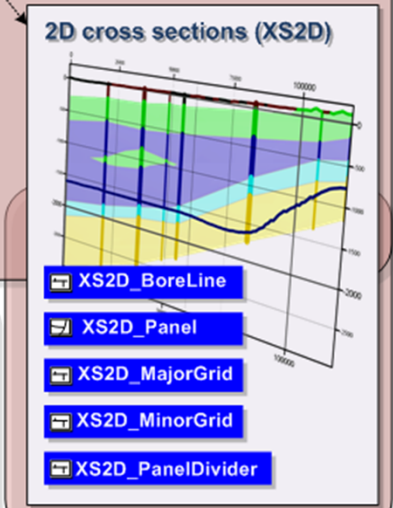
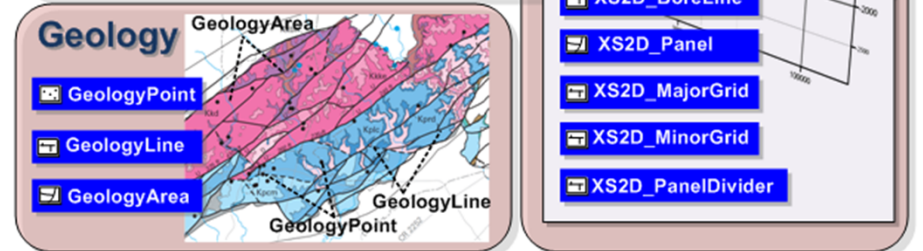
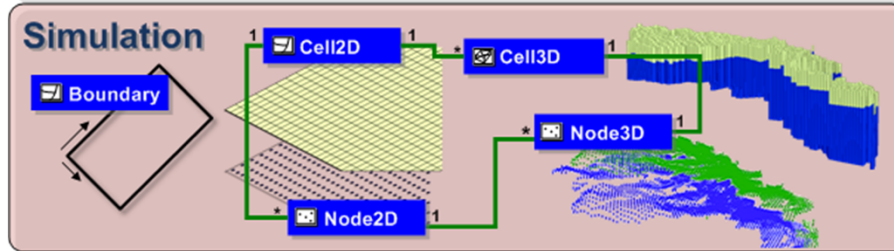
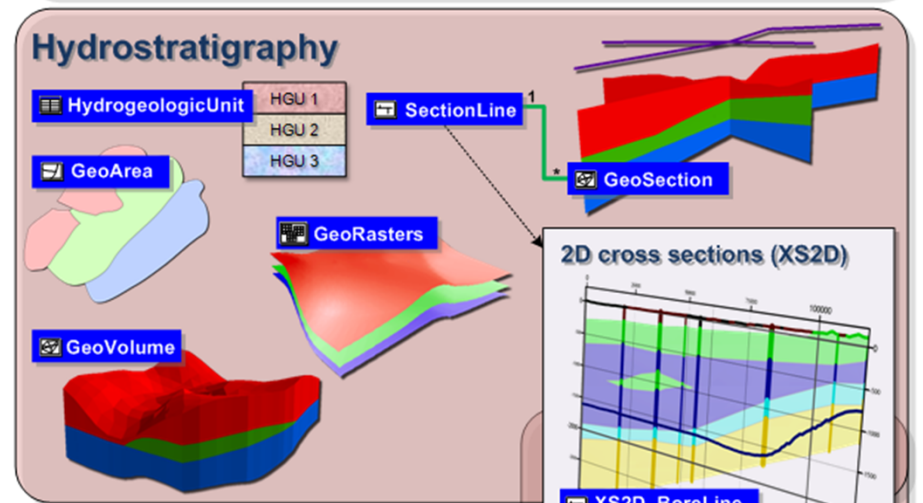
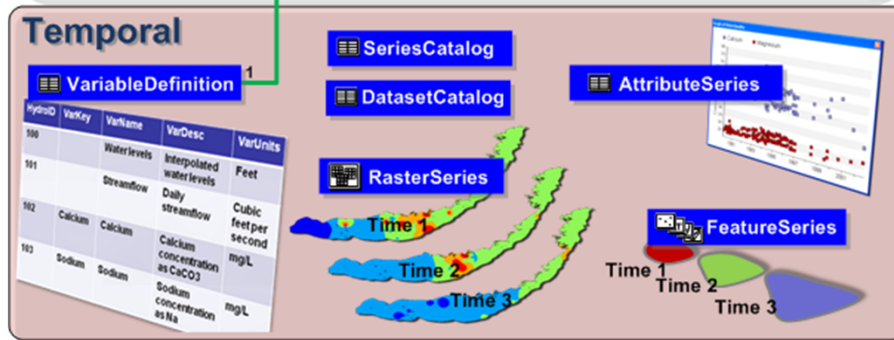
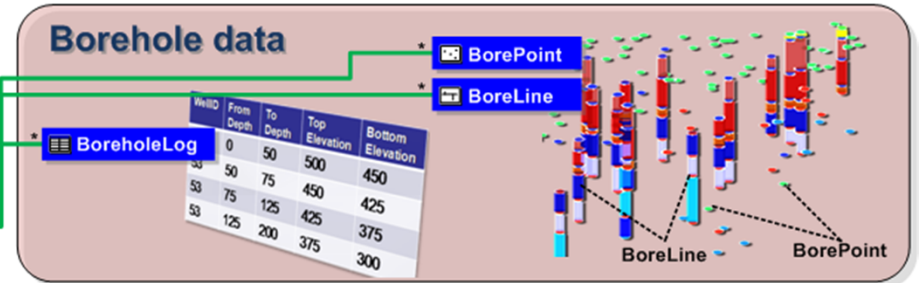
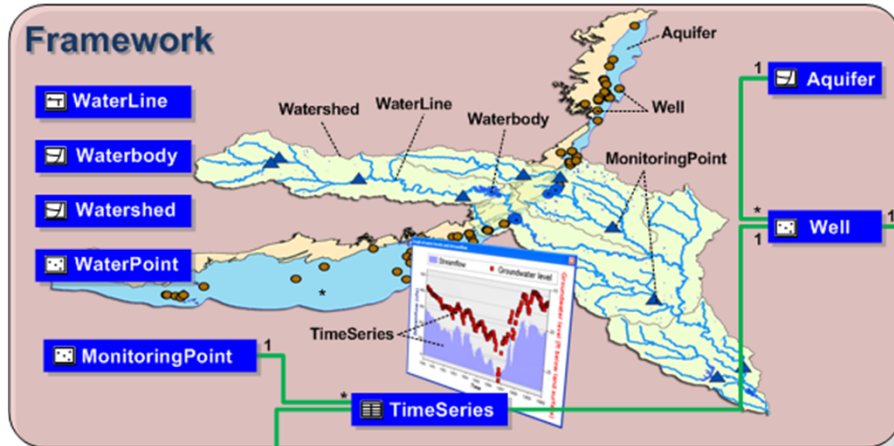


Norm Jones
Brigham Young University

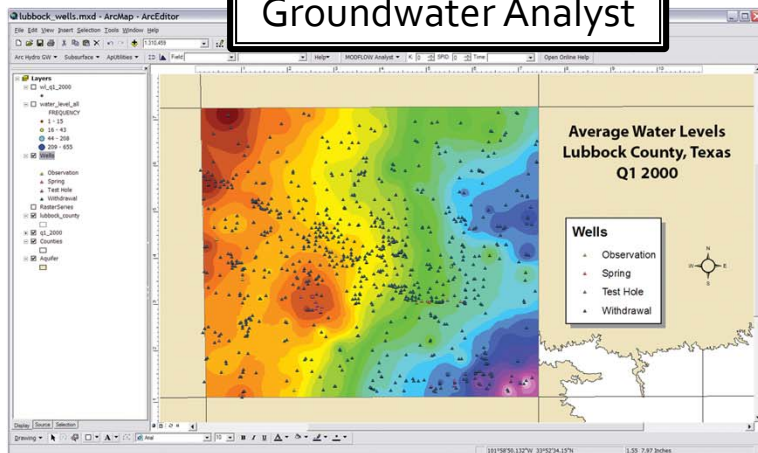
MODFLOW Simulations on the Cloud

Arc Hydro GW Data Model

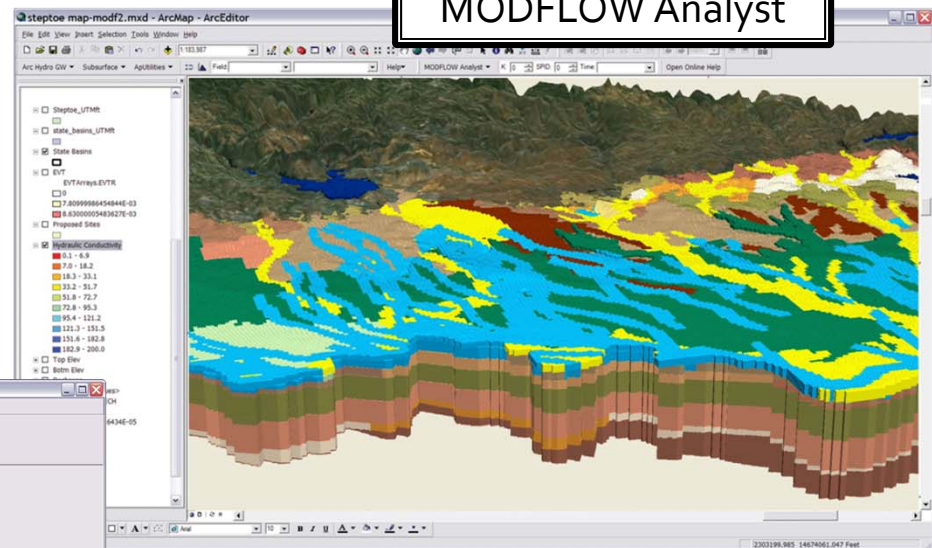


Arc Hydro GW Tools

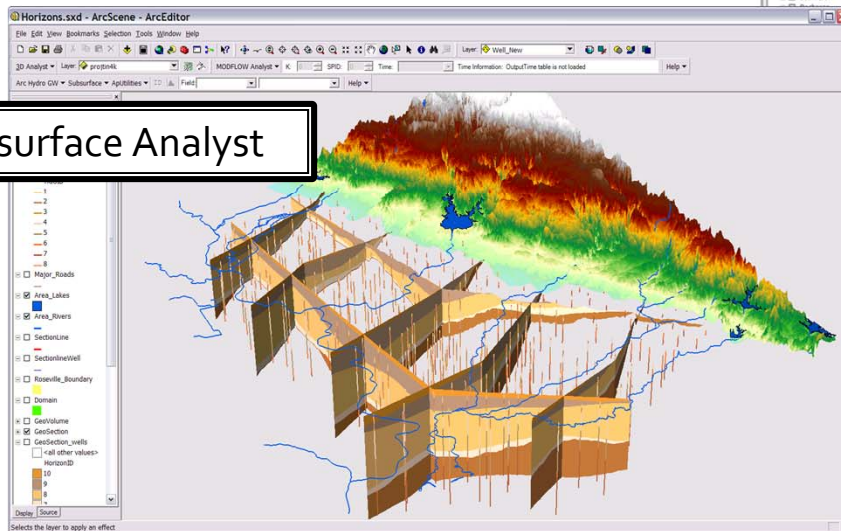
Groundwater Analyst



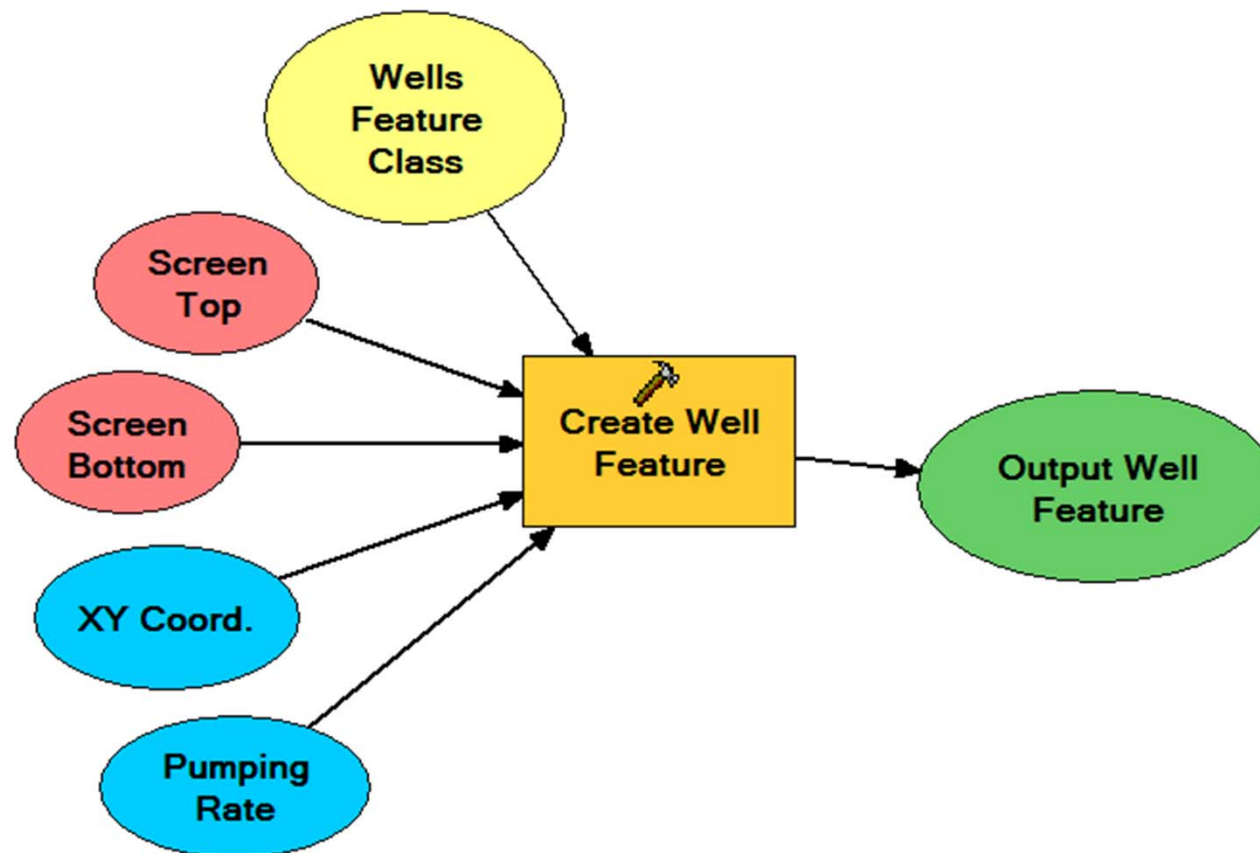
MODFLOW Analyst



Subsurface Analyst

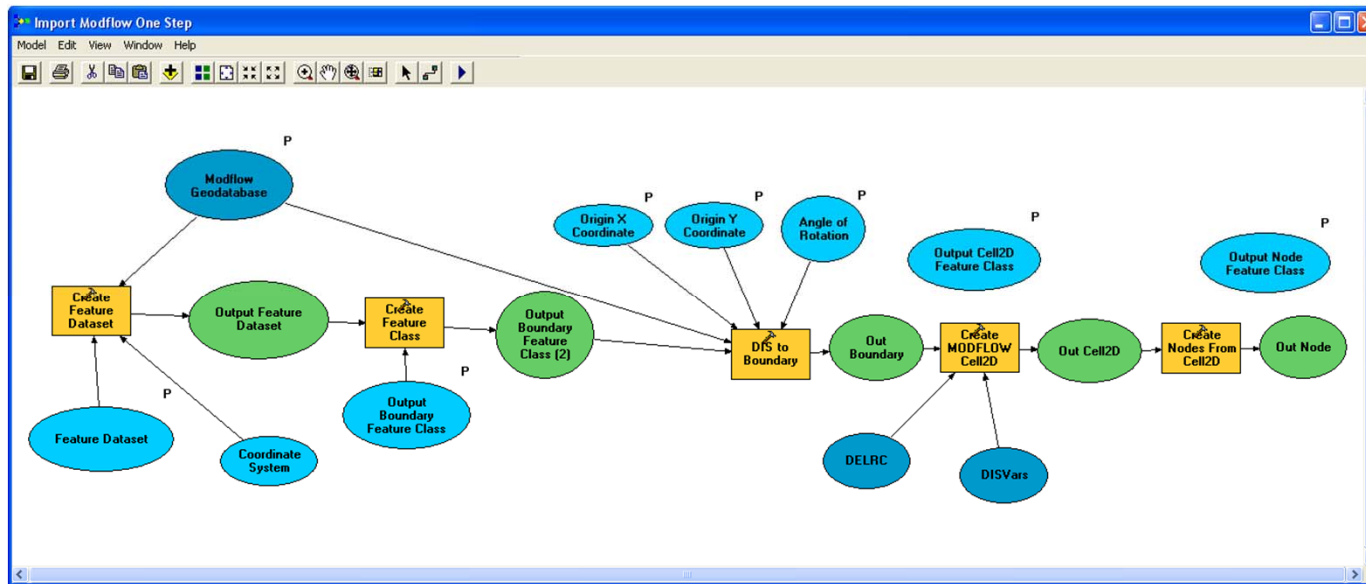


Geoprocessing Tools



Geoprocessing Tools - Workflows

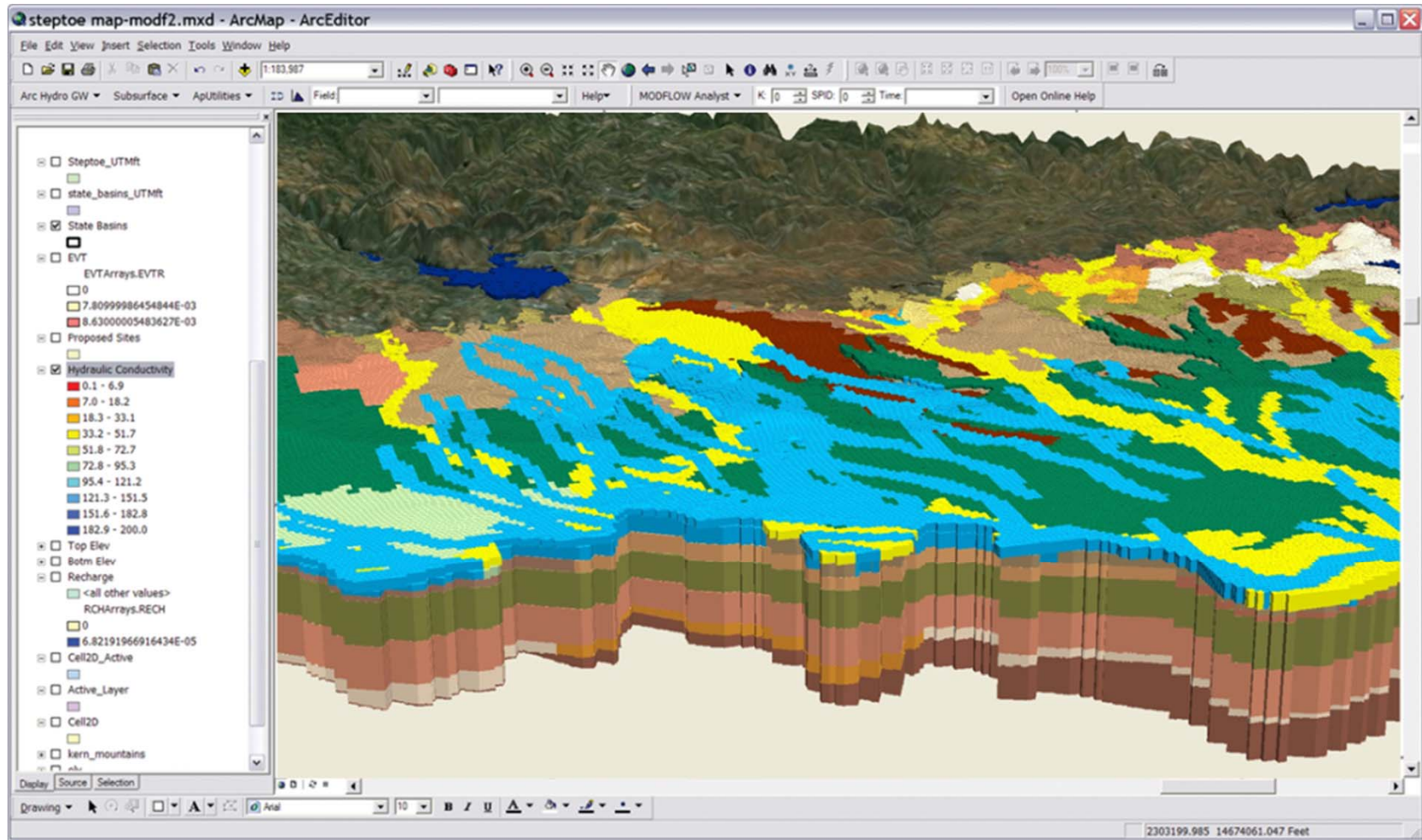
- GP tools enable the development of **workflows** as models or scripts
- **Extendable** – You can create your own workflows
- Leverage low-level tools to **create new tools**



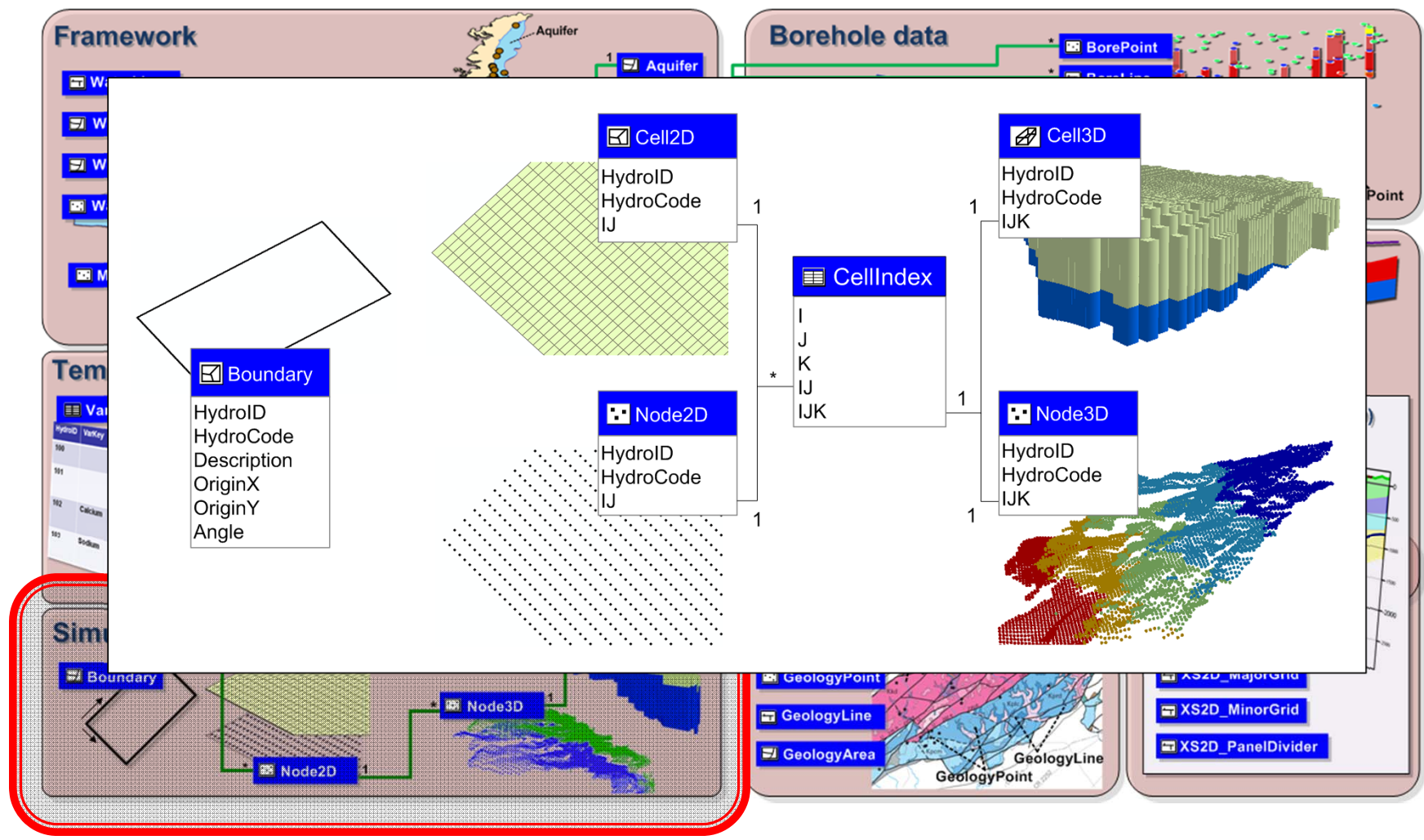
Automated Well Impact Analysis

Scripting MODFLOW simulations

MODFLOW



Simulation Feature Data Set



MODFLOW Data Model

MODFLOW DATA MODEL v3.0

Norm Jones
njones@byu.edu

Last updated: May 16, 2011

Arc Hydro Groundwater

Cell2D, Node2D, CellIndex, Cell3D, Node3D

Discretization (DIS)

DISVars, StressPeriods, DELRC, TopElev, BotmElev

Output Control (OC)

OCVars, ICRFlags, ICRS

Layer-Property Flow (LPF)

LPFVars, LPFLayers, LPFProperties

Unsaturated Zone Flow (UZF)

UZFVars, UZFArrayMult, UZF-Gages, UZFArrays, UZFStressAnlyst, UZFStressArrayMult

Global Settings

MODGlobal, NameFile

Basic (BAS6)

BASVars, BasicArrayMult

List-Based Stress

IRV, DRN

Array-Based Stress

Recharge (RCH), RCHVars

Layer-Property Flow (LPF)

LPFVars		LPFLayers		LPFProperties	
HDRY	Double	Layer	Long Int.	IJK	Long Int.
WETFCT	Double	LAYTYP	Short Int.	HK	Double
IWETIT	Long Int.	LAYAVG	Short Int.	HANI	Double
IHDWET	Short Int.	CHANI	Double	VKA	Double
		LAYVKA	Short Int.	Ss	Double
		LAYWET	Short Int.	Sy	Double
		AM_HK	Double	WETDRY	Double
		AM_HANI	Double	VKCB	Double
		AM_VKA	Double		
		AM_Ss	Double		
		AM_Sy	Double		
		AM_WETDRY	Double		
		AM_VKCB	Double		

Flow (HUF2)

HUFUnits, JFWetDry

Storage (SFR2)

SFRSegments, SFRXsect

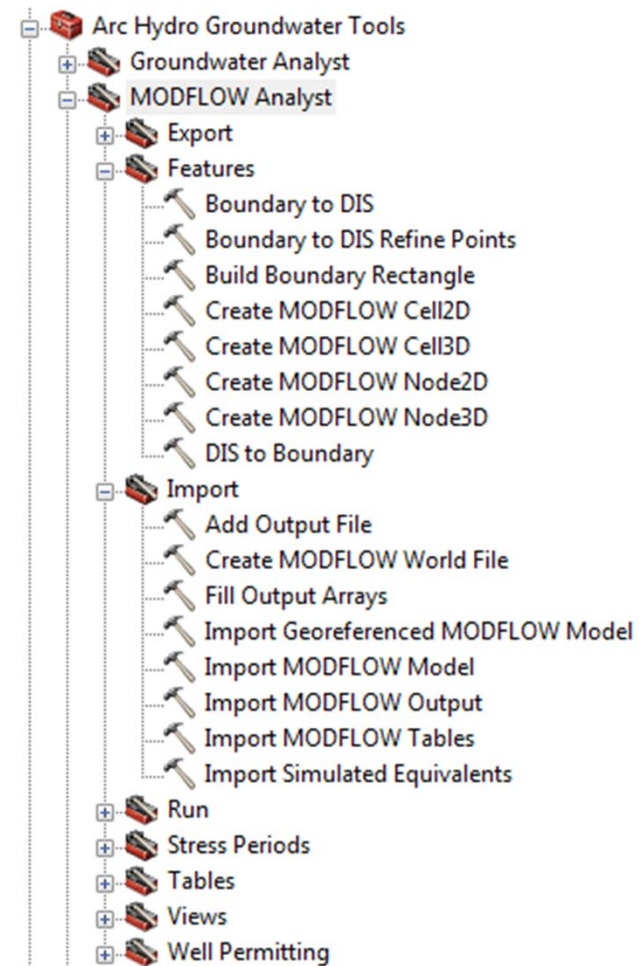
Storage (STR6)

STRReaches

MODFLOW Analyst Tools



- Developed as geoprocessing (GP) tools
- Classes of tools
 - Import
 - Export
 - Visualization/Map Layers
 - Model editing
 - Building package input
 - Working with transient input/solutions



Import MODFLOW Model Tool

modfmap.drn - WordPad

Name	Size	Type	Date Modified
modfmap.rch	1 KB	RCH File	8/2/2007 10:37 AM
modfmap.wel	1 KB	WEL File	8/2/2007 10:37 AM

Object ID	CellID	SPID	Elevation	Cond	IFACE	Condfact
1	731	1	222.808304	16264.19043	6	29.304848
2	803	1	222.399811	18392.214844	6	33.139126
3	875	1	222.06926	9653.232422	6	17.393211
4	876	1	221.872177	7066.963379	6	12.733267
5	948	1	221.609726	15200.177734	6	27.387709
6	1020	1	221.227173	17256.447266	6	31.092699
7	1092	1	220.942413	6902.006836	6	12.436049
8	1091	1	220.717331	12195.496094	6	21.973867
9	1163	1	220.17421	33883.140625	6	61.050709
10	1162	1	219.386047	32986.417969	6	59.434986
11	1161	1	218.734497	22291.667969	6	40.165169
12	1233	1	218.200867	22982.591797	6	41.410076
13	1232	1	217.841705	7488.561523	6	13.492904
14	1304	1	217.394287	30471.154297	6	54.902981
15	1376	1	216.794037	20455.853516	6	36.857395
16	1448	1	216.31456	20223.103516	6	36.438026
17	1520	1	215.817566	21943.632813	6	39.538074
18	1592	1	215.297638	22167.060547	6	39.940647
19	1664	1	214.607651	36372.414063	6	65.535881
20	1736	1	214.166122	1087.577393	6	1.959599
21	1735	1	213.817459	28494.275391	6	51.341038
22	1807	1	213.243118	20233.802734	6	36.457302
23	1879	1	212.874512	11039.427734	6	19.890862
24	1885	1	221.774063	20479.730469	6	36.900417
25	1886	1	221.299652	22523.244141	6	40.58242
26	1887	1	220.825287	20475.675781	6	36.893108
27	1888	1	220.395462	18485.587891	6	33.307365
28	1816	1	220.190109	128.663498	6	0.231826
29	1817	1	220.001999	16922.046875	6	30.490173
30	1818	1	219.631989	16618.207031	6	29.942715
31	1819	1	219.311005	12476.114258	6	22.479485
32	1747	1	219.10434	6257.23291	6	11.274294
33	1748	1	218.828674	18730.206484	6	33.74863



Attributes of DRN

Object ID	CellID	SPID	Elevation	Cond	IFACE	Condfact
1	731	1	222.808304	16264.19043	6	29.304848
2	803	1	222.399811	18392.214844	6	33.139126
3	875	1	222.06926	9653.232422	6	17.393211
4	876	1	221.872177	7066.963379	6	12.733267
5	948	1	221.609726	15200.177734	6	27.387709
6	1020	1	221.227173	17256.447266	6	31.092699
7	1092	1	220.942413	6902.006836	6	12.436049
8	1091	1	220.717331	12195.496094	6	21.973867
9	1163	1	220.17421	33883.140625	6	61.050709
10	1162	1	219.386047	32986.417969	6	59.434986
11	1161	1	218.734497	22291.667969	6	40.165169
12	1233	1	218.200867	22982.591797	6	41.410076
13	1232	1	217.841705	7488.561523	6	13.492904
14	1304	1	217.394287	30471.154297	6	54.902981
15	1376	1	216.794037	20455.853516	6	36.857395
16	1448	1	216.31456	20223.103516	6	36.438026
17	1520	1	215.817566	21943.632813	6	39.538074
18	1592	1	215.297638	22167.060547	6	39.940647
19	1664	1	214.607651	36372.414063	6	65.535881
20	1736	1	214.166122	1087.577393	6	1.959599
21	1735	1	213.817459	28494.275391	6	51.341038
22	1807	1	213.243118	20233.802734	6	36.457302
23	1879	1	212.874512	11039.427734	6	19.890862
24	1885	1	221.774063	20479.730469	6	36.900417
25	1886	1	221.299652	22523.244141	6	40.58242
26	1887	1	220.825287	20475.675781	6	36.893108
27	1888	1	220.395462	18485.587891	6	33.307365
28	1816	1	220.190109	128.663498	6	0.231826
29	1817	1	220.001999	16922.046875	6	30.490173
30	1818	1	219.631989	16618.207031	6	29.942715
31	1819	1	219.311005	12476.114258	6	22.479485
32	1747	1	219.10434	6257.23291	6	11.274294
33	1748	1	218.828674	18730.206484	6	33.74863

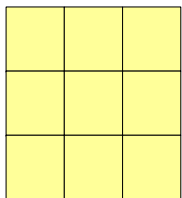
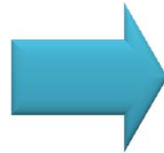
INPUT

OUTPUT

Make MODFLOW Features Tool

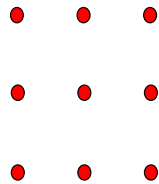
Attributes of DRN				
Object ID *	CellID	SPID	Elevation	Cond
1	731	1	222.808304	16264.19043
2	803	1	222.399811	18392.214844
3	875	1	222.06926	9653.232422
4	876	1	221.872177	7066.963379
5	948	1	221.609726	15200.177734
6	1020	1	221.227173	17256.447266
7	1092	1	220.942413	6902.006836
8	1091	1	220.717331	12195.496094
9	1163	1	220.17421	33883.140625
10	1162	1	219.386047	32986.417969
11	1161	1	218.734497	22291.667969
12	1233	1	218.200867	22982.591797
13	1232	1	217.841705	7488.561523
14	1304	1	217.394287	30471.154297
15	1376	1	216.794037	20455.853516

+



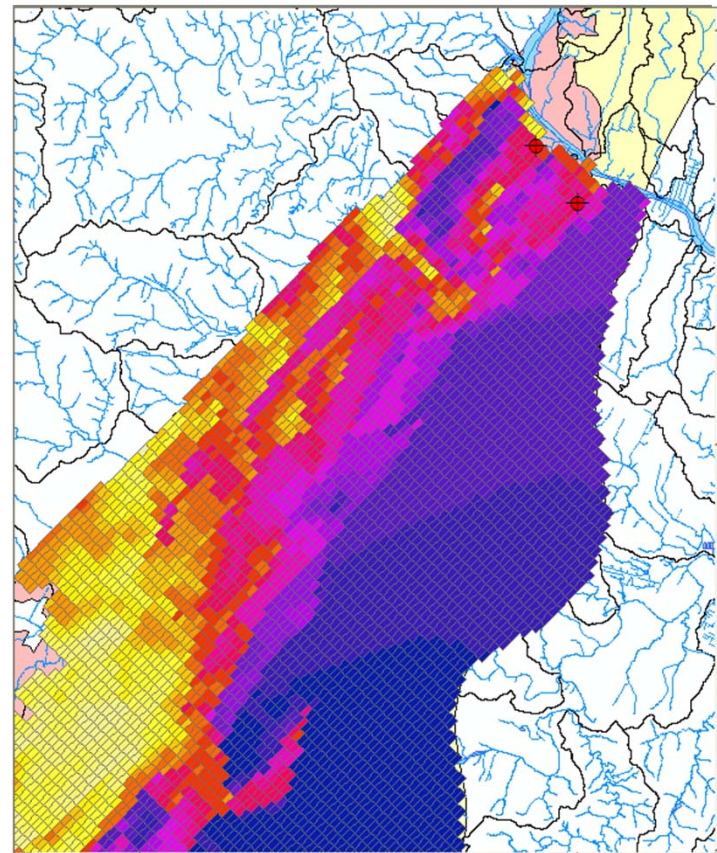
Cell2
D

Or



Node2
D

INPUT



OUTPUT

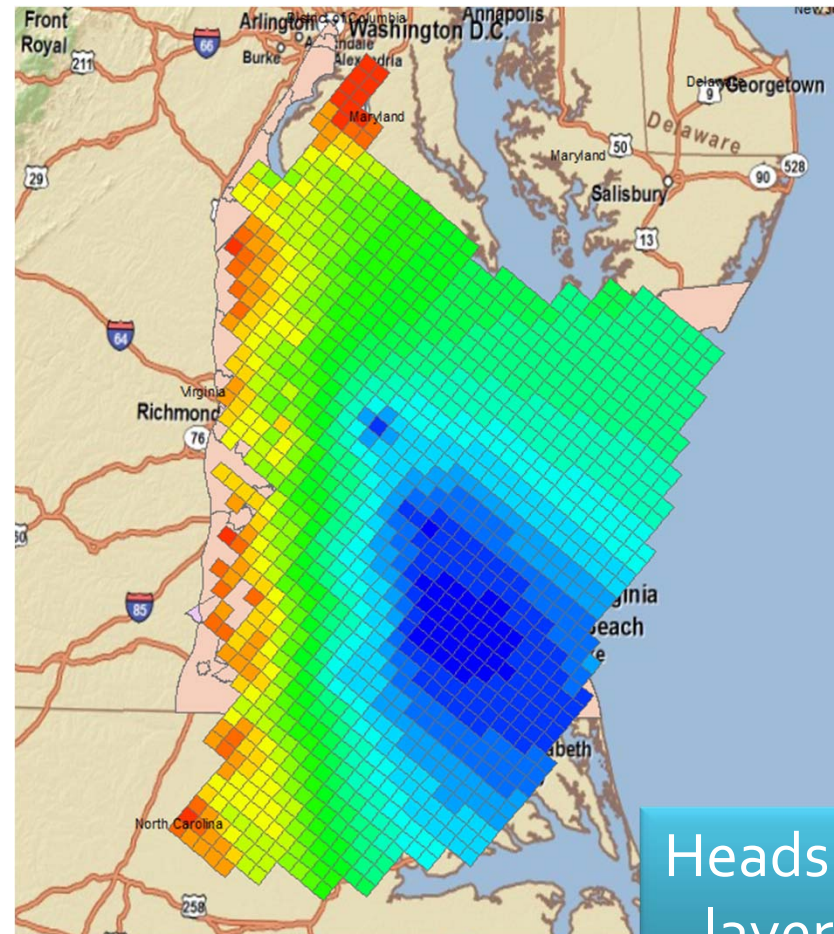
Automated Well Permitting

- Calibrated regional model is imported to ArcGIS as a “baseline” model
- Candidate wells are added to baseline model using well package.
- Impact of new well is analyzed using MODFLOW and/or SEAWAT



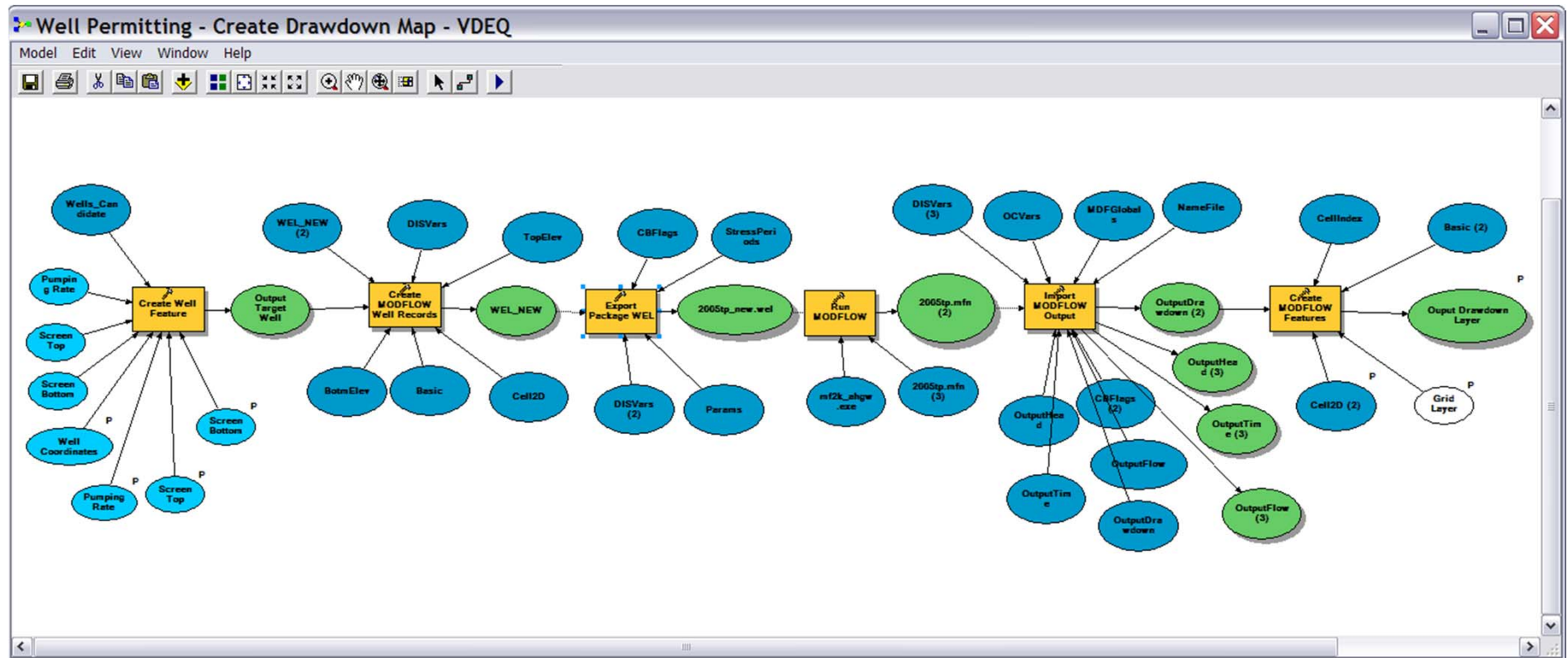
Case Study #1 – Virginia DEQ

- Virginia Coastal Plain Model (VCPM)
- 10-layer MODFLOW model used to analyze impacts of candidate wells
- Criteria based on state law
 - Potentiometric surface cannot fall below a critical surface (80% drawdown)
 - Area of Impact defined by drawdown = 1 ft



Heads for
layer 8

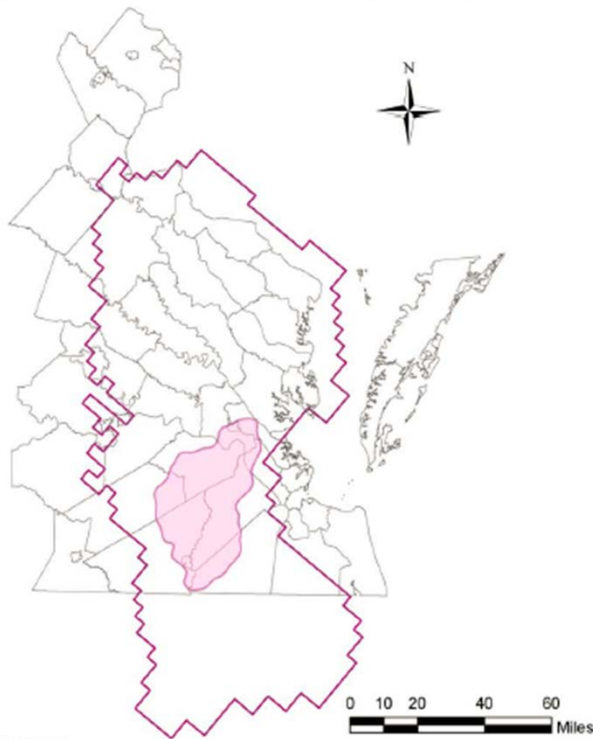
Well Permitting Workflow





Create new well → update well table → export well package file → run MODFLOW → import solution → build drawdown map layer

GIS Products

**City of Norfolk
Mitigation Area of Impact - Aquia Aquifer**



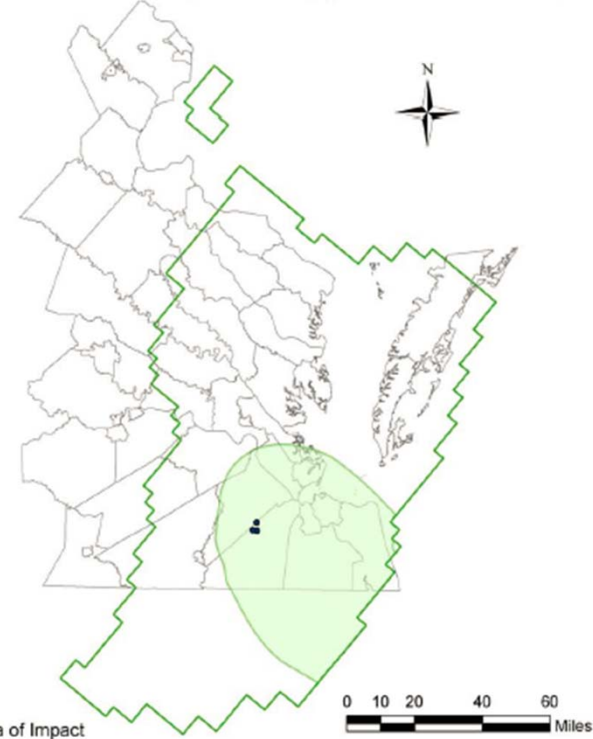
-  Area of Impact
-  Aquia Aquifer Model Boundary

Simulated drawdown at or exceeding one foot in the Aquia aquifer resulting from an 15,940,000 gpd, 172 day duration, multi-aquifer withdrawal. The Virginia Coastal Plain Model developed in Modflow by the USGS was used to simulate drawdown.

Technical Evaluation
Performed by Alan Lemon
Ground Water Modeler
April 6, 2010



**City of Norfolk
Stabilized Area of Impact - Upper Potomac Aquifer**



-  Area of Impact
-  Production Wells
-  Upper Potomac Model Boundary

Simulated drawdown at or exceeding one foot in the Upper Potomac aquifer resulting from a 790,000 gpd, steady-state, multi-aquifer withdrawal. The Virginia Coastal Plain Model developed in Modflow by the USGS was used to simulate drawdown.

Technical Evaluation
Performed by Alan Lemon
Ground Water Modeler
April 6, 2010

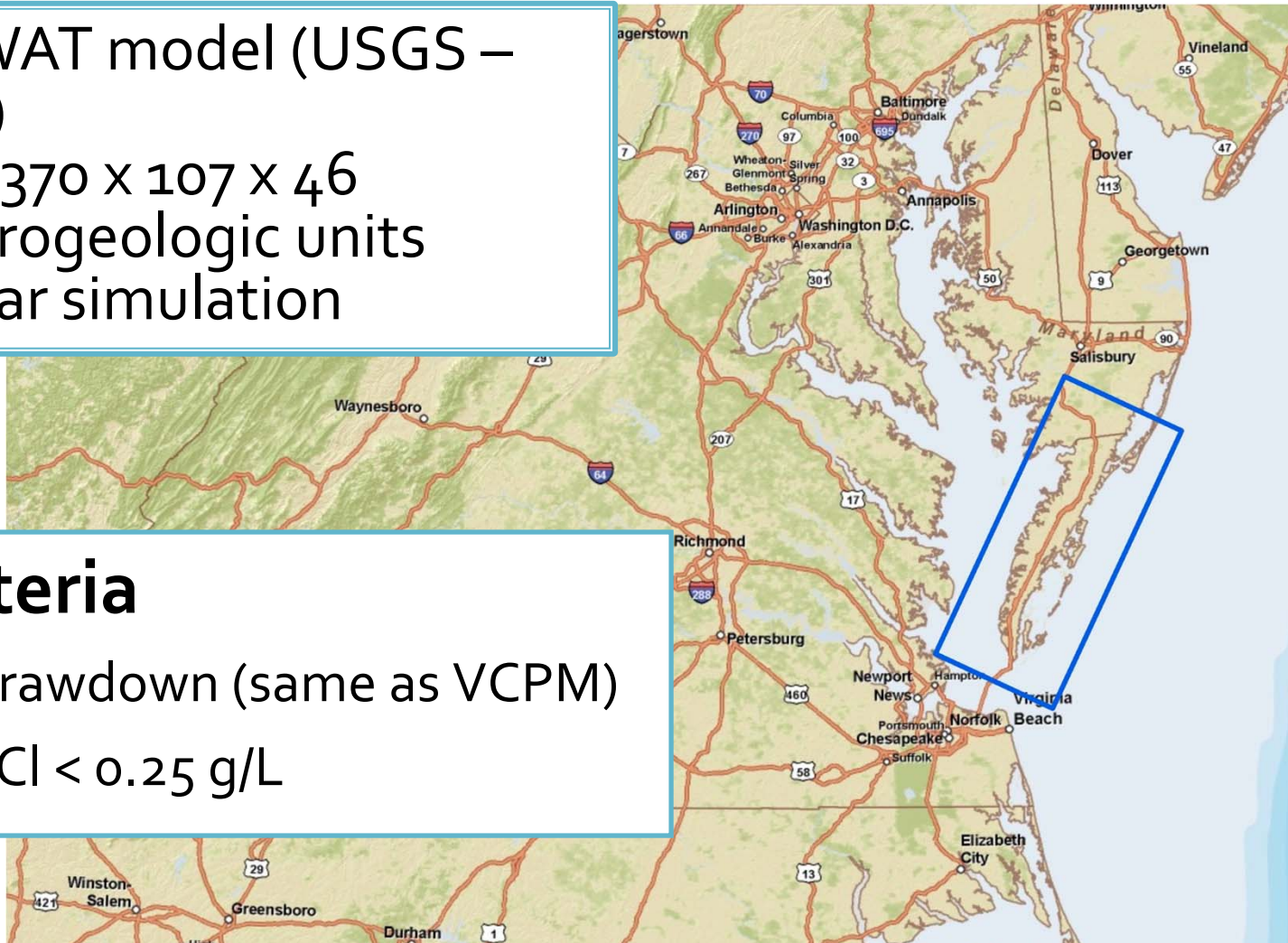


Eastern Shore Model

- SEAWAT model (USGS – 2009)
- Grid: 370 x 107 x 46
- 7 hydrogeologic units
- 50 year simulation

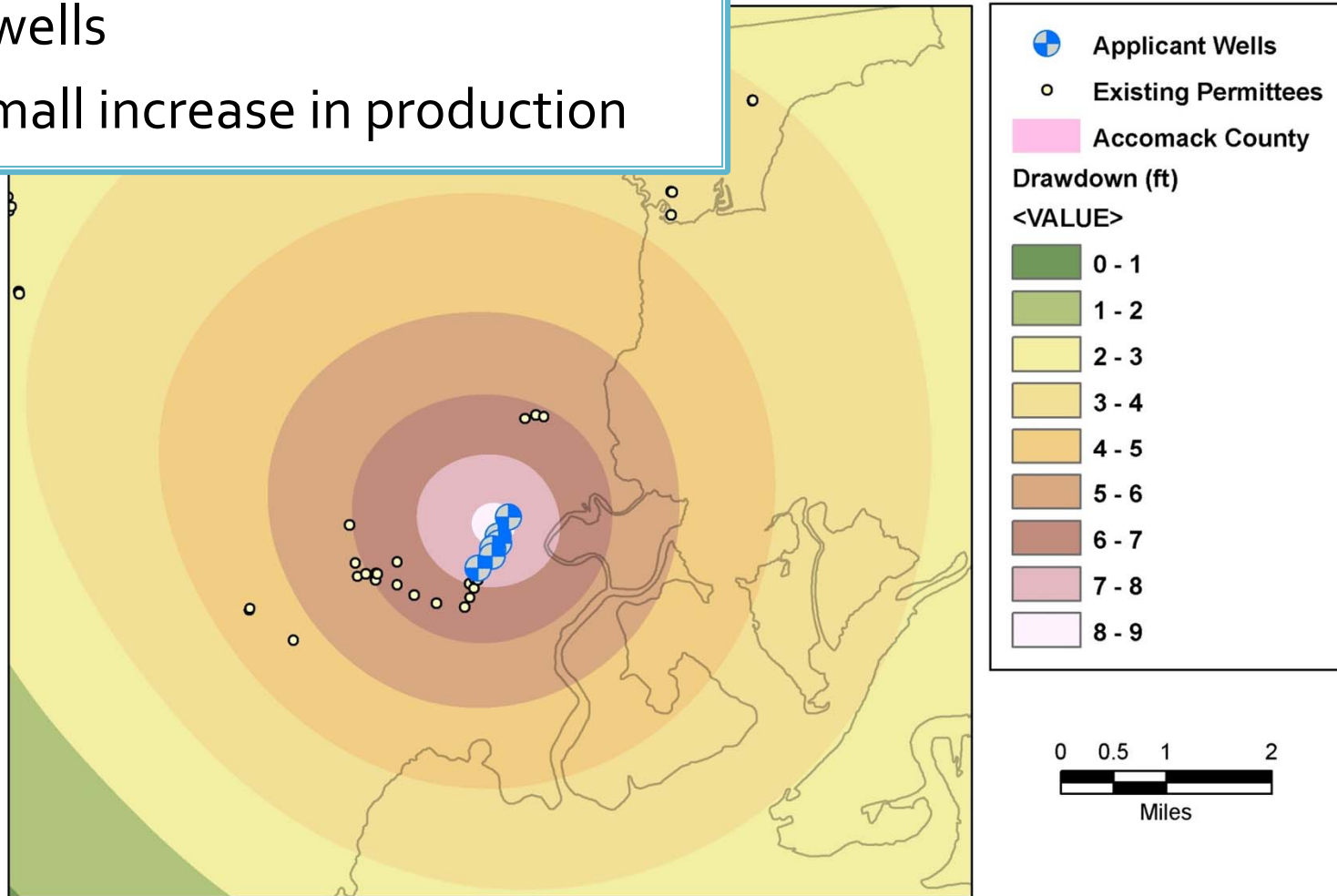
Criteria

- Drawdown (same as VCPM)
- $\Delta Cl < 0.25 \text{ g/L}$

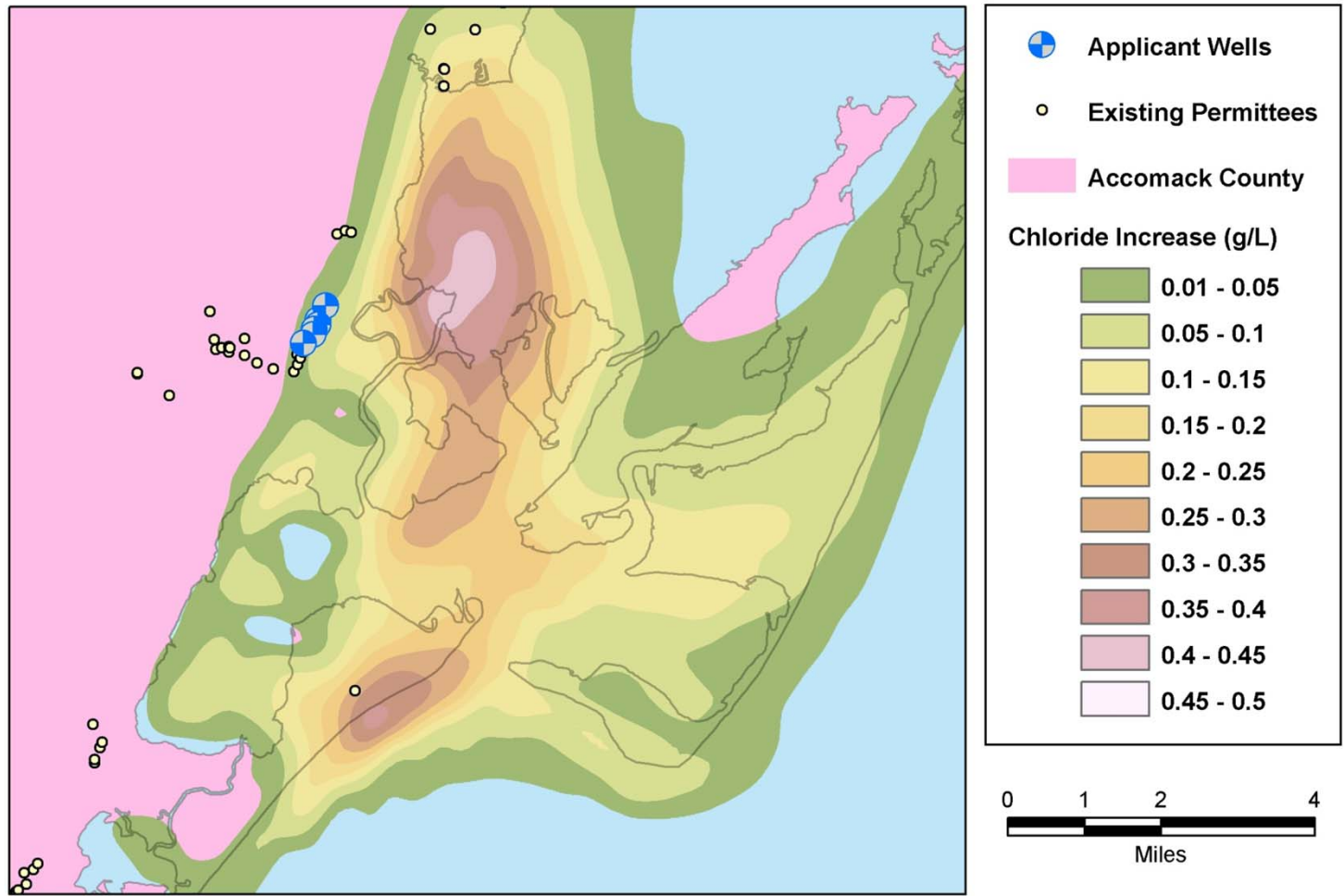


Sample Application

- 7 wells
- Small increase in production



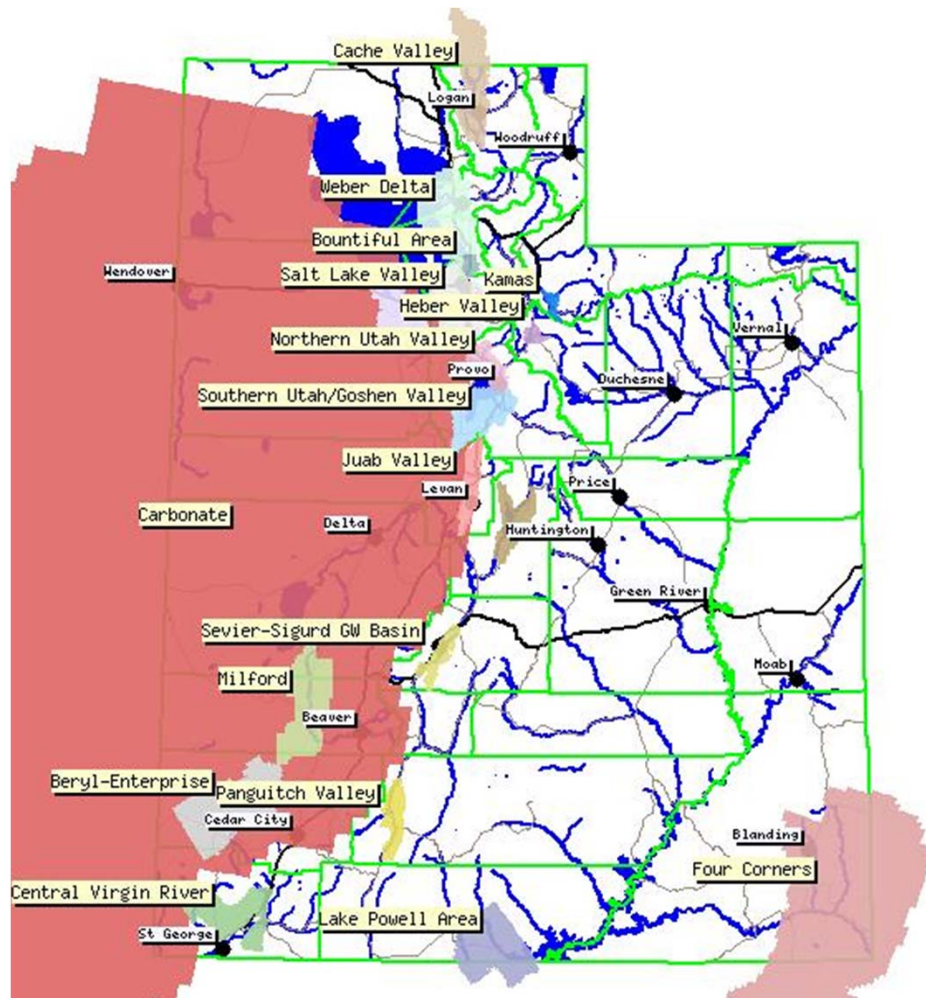
Changes in Chloride Concentration



MODFLOW in the Cloud

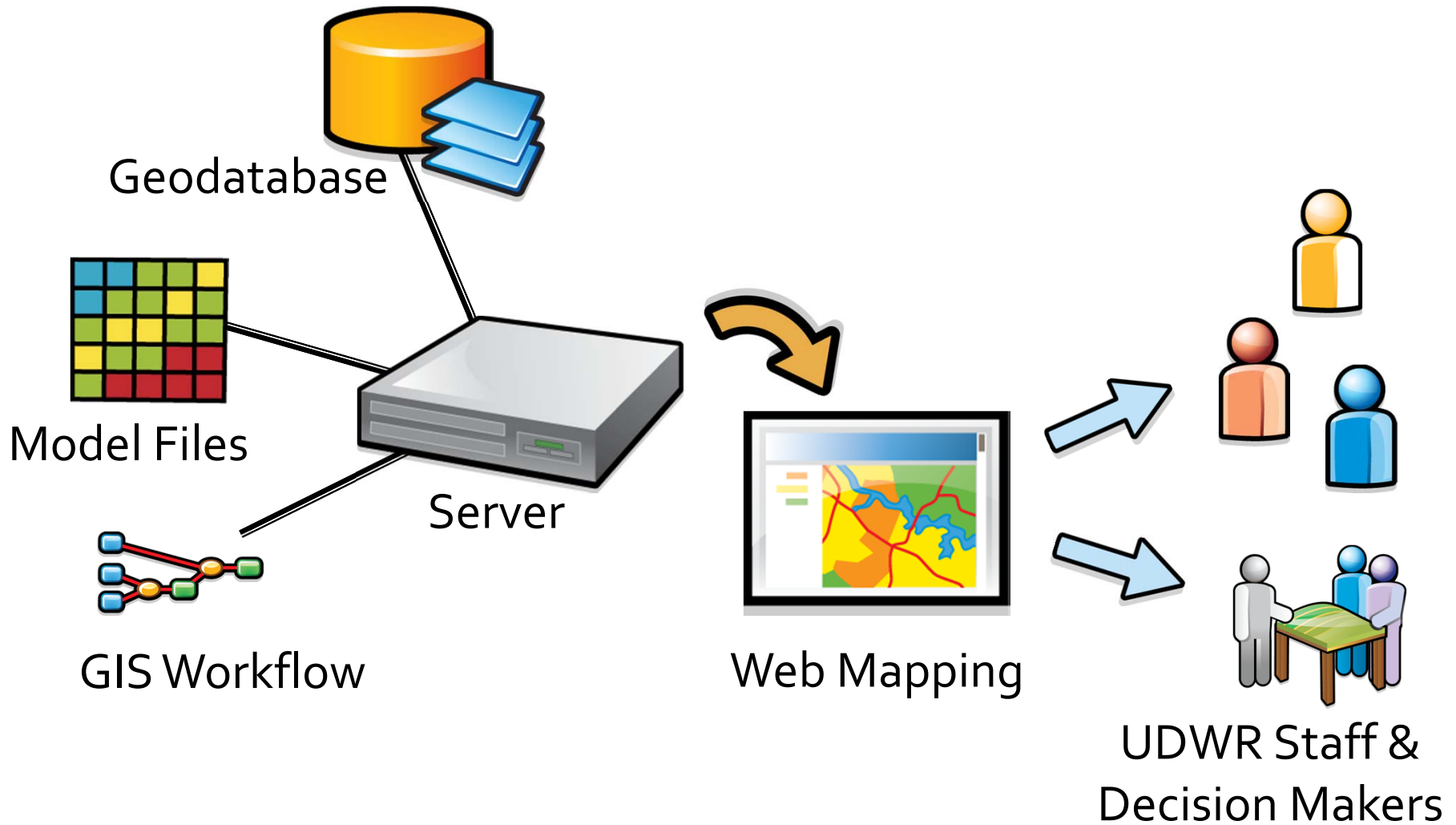
Utah Division of Water Rights Well Impact Simulator

Utah Division of Water Rights



- 31 MODFLOW models used for impact analysis
- Challenges
 - Modeling expertise
 - Software installation and maintenance
 - User error
 - Cost

Cloud-Based Solution



Web Interface

The screenshot displays the 'Automated Well Permitting Tool' web interface. The browser address bar shows the URL <http://utahdwr.groups.et.byu.net/app3/>. The interface includes a navigation menu with 'Tool Input and Map View', 'Table of Well Applications', and 'Documentation'. The main content area is divided into a left sidebar and a central map.

Tool Input and Map View

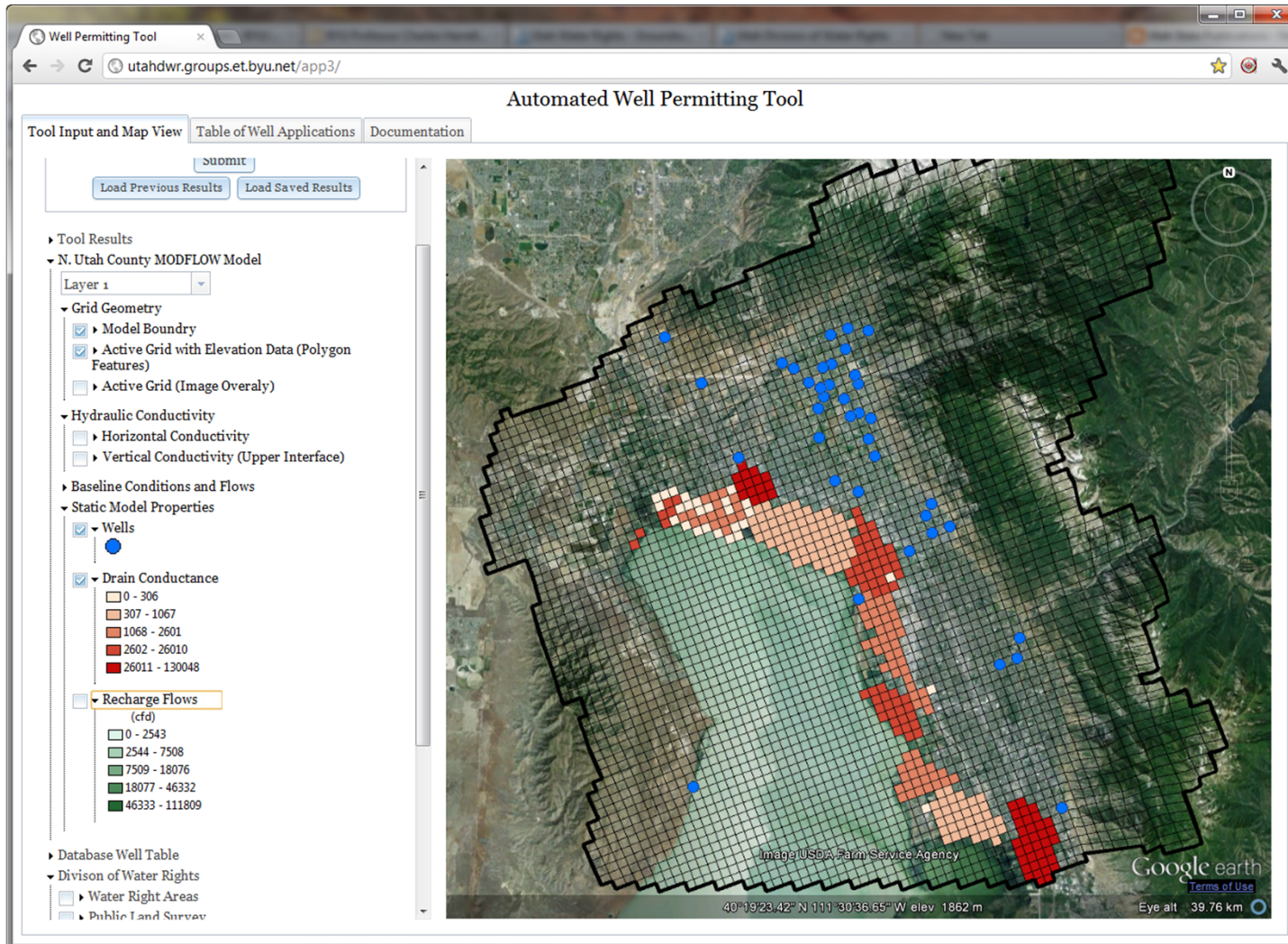
- Application ID:
- Output Options:

Tool Results

- N. Utah County MODFLOW Model
 - Layer 1:
 - Grid Geometry
 - Model Boundary
 - Active Grid with Elevation Data (Polygon Features)
 - Active Grid (Image Overlay)
 - Hydraulic Conductivity
 - Horizontal Conductivity
 - Conductivity (ft/day) legend:
 - 0
 - 1 - 2
 - 3 - 5
 - 6 - 10
 - 11 - 20
 - 21 - 50
 - 51 - 100
 - 101 - 200
 - 201 - 500
 - 501 - 1000
 - 1001 - 3000
 - Vertical Conductivity (Upper Interface)
 - Baseline Conditions and Flows
 - Static Model Properties
 - Wells
 - Drain Conductance
 - Recharge Flows

<http://utahdwr.groups.et.byu.net/app3/>

Static Model Data



Map Layers from UDWR Server

The screenshot displays the 'Automated Well Permitting Tool' web application. The browser address bar shows the URL `utahdwr.groups.et.byu.net/app3/`. The interface includes a sidebar with various map layers and a main map area.

Map Layers:

- Hydraulic Conductivity
 - Horizontal Conductivity
 - Vertical Conductivity (Upper Interface)
- Baseline Conditions and Flows
- Static Model Properties
 - Wells
- Drain Conductance
 - 0 - 306
 - 307 - 1067
 - 1068 - 2601
 - 2602 - 26010
 - 26011 - 130048
- Recharge Flows (cfd)
 - 0 - 2543
 - 2544 - 7508
 - 7509 - 18076
 - 18077 - 46332
 - 46333 - 111809
- Database Well Table
- Division of Water Rights
 - Water Right Areas
 - Public Land Survey
 - Points of Diversion
- Roads and Cities
 - Borders and Labels
 - Roads
- Map Options and Components
 - 3D Elevation
 - Navigation
 - Status Bar
 - Historical Imagery
 - Scale

Well 55-6443 Details:

- Owner: LEE HANSEN
- Type: Underground
- Location: S250 W1200 E4 36 5S 1E SL
- [Click Here for more information](#)

The map shows a satellite view of a rural area with numerous well locations marked by red and blue icons. A popup window is open over well 55-6443, providing its specific details. The map also includes a Google Earth interface with navigation controls and a status bar at the bottom showing coordinates and elevation.

Table of Well Applications

Well Permitting Tool

utahdwr.groups.et.byu.net/app3/

Automated Well Permitting Tool

Tool Input and Map View | **Table of Well Applications** | Documentation

Well_ID	Latitude	Longitude	Flow_cfd	ScreenTopElev_ft	ScreenBotmElev_ft	ApplicationID	TIMESTAMP		
1	40.337982	-111.737053	-40000	4100	4000	1001	0000-00-00 00:00:00	Edit	Delete
2	40.369701	-111.813683	-24000	4100	4000	1001	0000-00-00 00:00:00	Edit	Delete
3	40.329506	-111.816437	-22000	4200	4000	1002	0000-00-00 00:00:00	Edit	Delete
4	40.34351	-111.728073	-200000	4100	4000	1003	2011-11-02 17:54:33	Edit	Delete
5	40.343044	-111.725983	-100000	4100	4000	1003	2011-11-02 17:54:36	Edit	Delete
6	40.337982	-111.737053	-40000	4100	4000	1110	2011-11-03 17:01:10	Edit	Delete
7	40.369701	-111.813683	-24000	4100	4000	1110	2011-11-03 17:01:10	Edit	Delete
8	40.376972	-111.768066	-3320	4100	4000	1110	2011-11-03 17:02:50	Edit	Delete
15	40.3	-111.79	421.45	4130	4000	1231	2011-11-16 16:50:53	Edit	Delete
17	40.35	-111.73	0	4100	4000	1	2012-02-11 20:40:21	Edit	Delete
18	40.35	-111.8	0	4100	4000	1004	2012-02-17 20:00:38	Edit	Delete

[Add Row](#)

Submitting a Model Run

Automated

Tool Input and Map View | Table of Well Applications | Documentation

▼ Tool: Analyze Permit Application with MODFLOW

Application ID:


▼ Output Options

- New Wells
- Drawdown Contours
- Change in Spring Flows
- Total Change in Spring Flows
- PDF Report

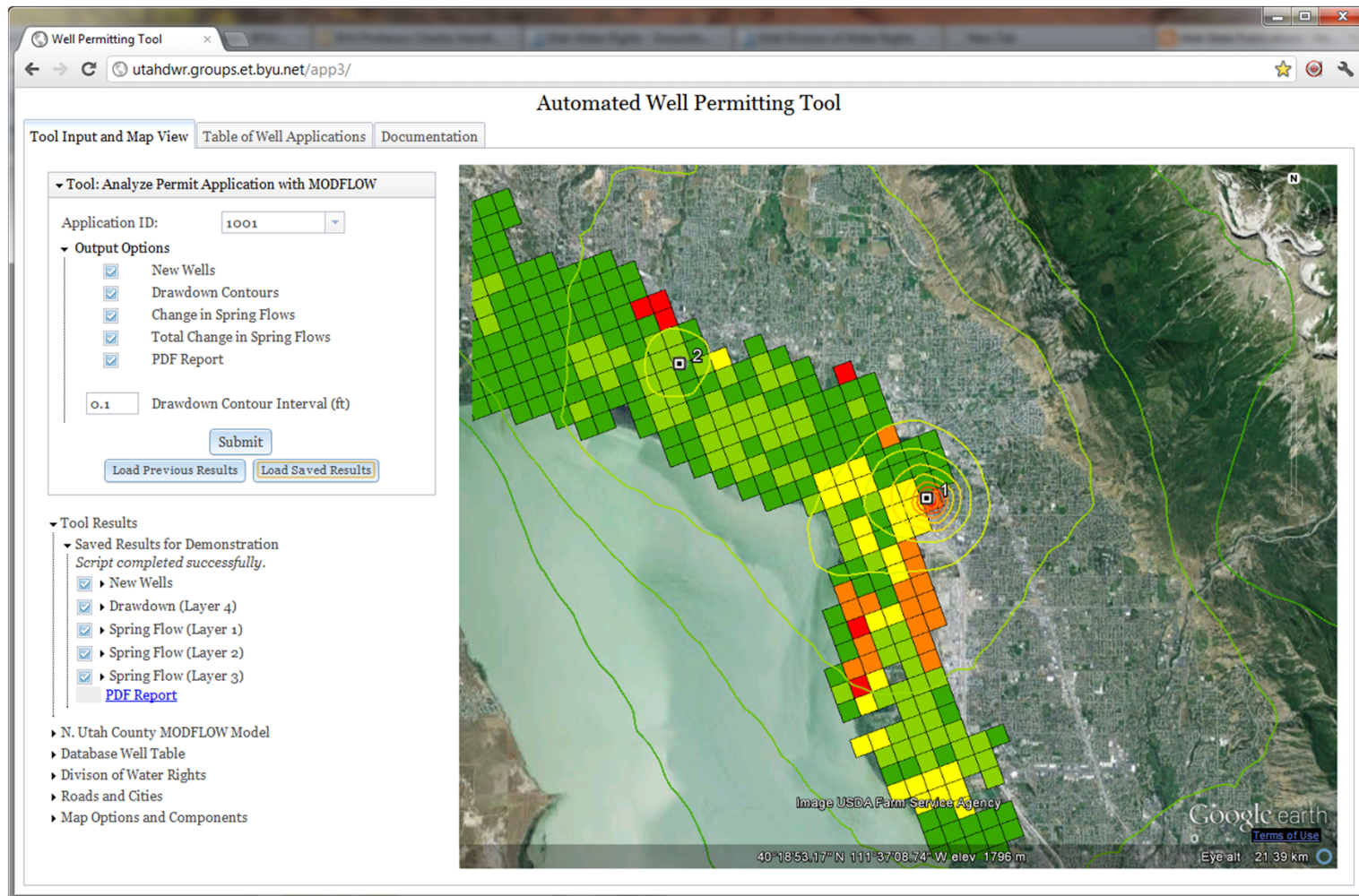
Drawdown Contour Interval (ft)

▼ Tool Results

- ▶ N. Utah County MODFLOW Model
- ▶ Database Well Table
- ▶ Division of Water Rights



Model Results



Impact on Springs

Total Change in Spring Flows
 PDF Report

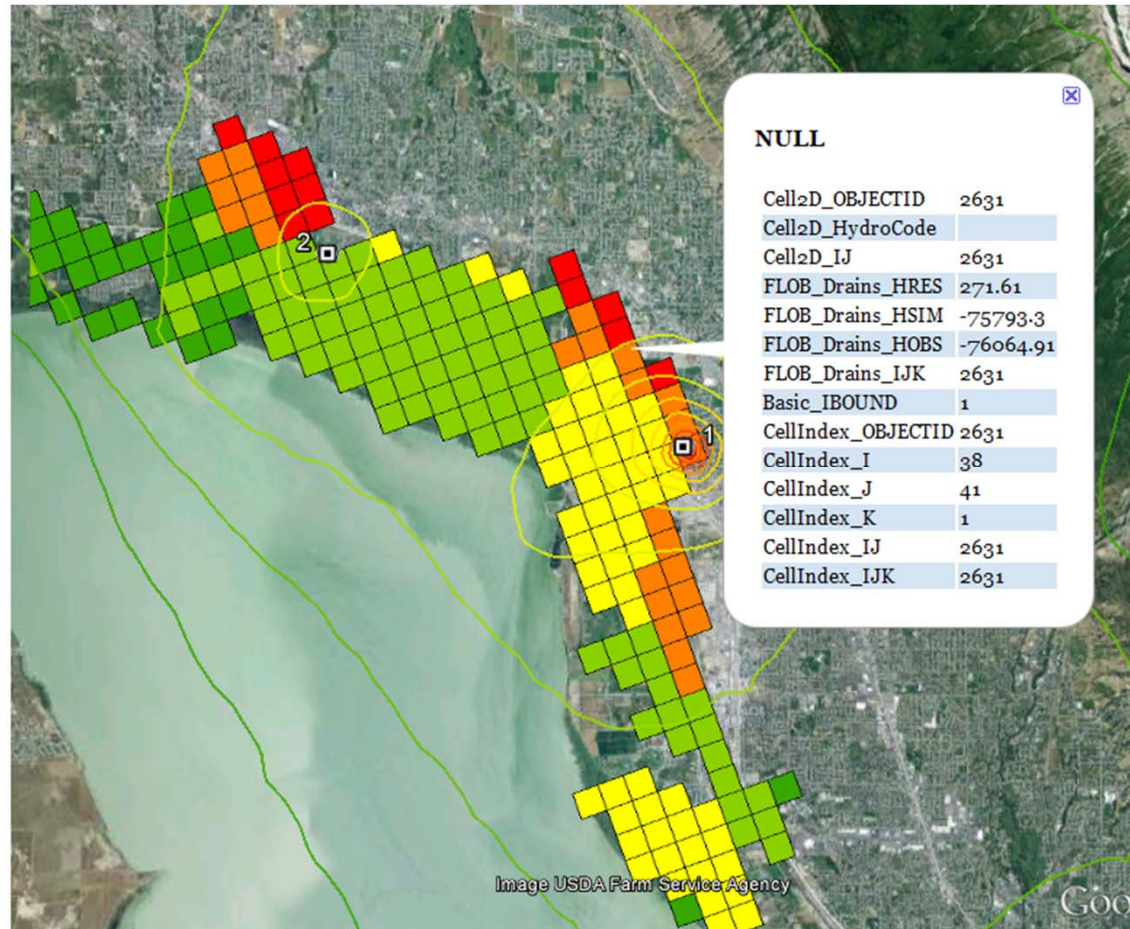
Drawdown Contour Interval (ft)

Tool Results
 Saved Results for Demonstration
Script completed successfully.

- New Wells
 - Drawdown (Layer 4)
 - Spring Flow (Layer 1)
Change in Flow (cfd)
- | |
|---|
| 0 - 32 |
| 32 - 101 |
| 101 - 195 |
| 195 - 317 |
| 317 - 573 |

- Spring Flow (Layer 2)
- Spring Flow (Layer 3)
- [PDF Report](#)

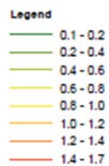
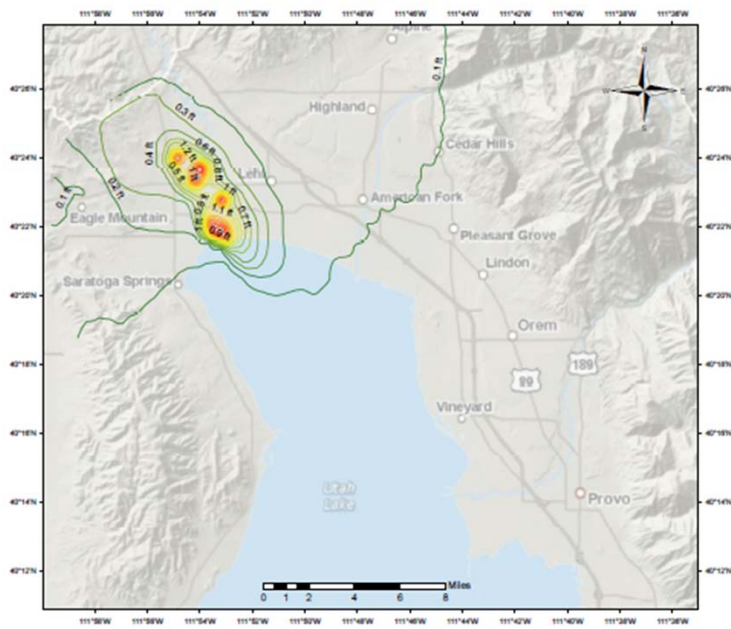
- ▶ N. Utah County MODFLOW Model
- ▶ Database Well Table
- ▶ Division of Water Rights



PDF Output

Simulated Aquifer Drawdown: Layer 3

North Utah County MODFLOW Model Simulation Results



This map was generated by a server-based automated well permitting analysis system using ArcGIS and AHGW geoprocessing tools and the Northern Utah County MODFLOW model created by the USGS.

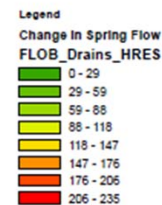
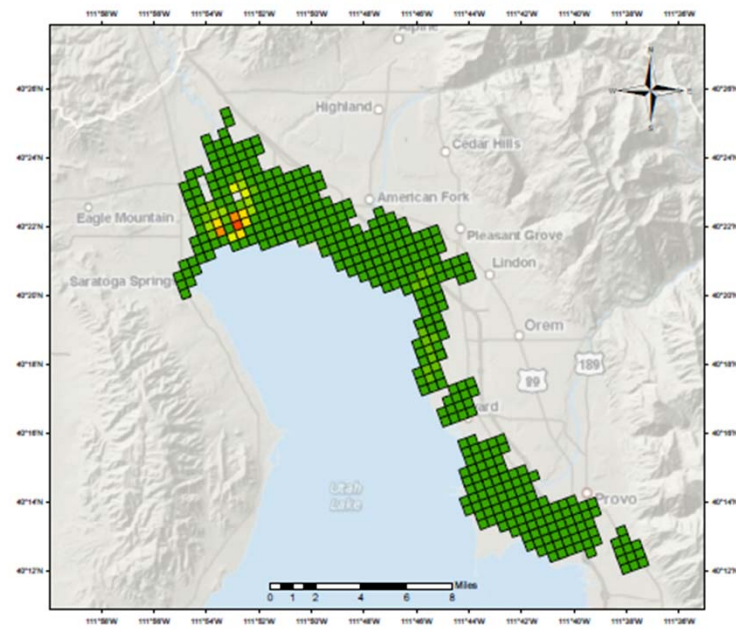
Simulation Executed 5/23/2012 at 5:44:30 PM

AQUAVEO
Water Modeling Solutions



Simulated Change in Spring Flow: Layer 3

North Utah County MODFLOW Model Simulation Results



This map was generated by a server-based automated well permitting analysis system using ArcGIS and AHGW geoprocessing tools and the Northern Utah County MODFLOW model created by the USGS.

Simulation Executed 5/23/2012 at 5:50:32 PM

AQUAVEO
Water Modeling Solutions



Texas Groundwater Availability Models

The screenshot shows a Firefox browser window with the URL www.twdb.state.tx.us/groundwater/models/gam/trnt_h/trnt_h.asp. The page features the Texas Water Development Board logo and the tagline "Sustainable and affordable water for Texas." The navigation menu includes "Home", "Financial Assistance", "Water Planning", "Flood", "Groundwater", "Surface Water", "Conservation", "Innovative Water", and "Public Water". The "Groundwater" section is active, with sub-links for "Aquifers", "Management Areas", "Conservation Districts", "Data", "Models", and "Regional Water Planning Areas". A maintenance notice states: "All TWDB websites will be offline from 6:00 p.m. on Friday, October 19, 2012 through 6:00 p.m. on Sunday, October 21, 2012 for maintenance. This advance warning to minimize service disruption." The main content area is titled "Trinity (Hill Country) Aquifer Groundwater Availability Model (GAM)". It includes a map of the Trinity Aquifer area in Texas, with a red outline indicating the model's extent. The text describes the model's history: "The Texas Water Development Board completed this model in 2000 in cooperation with the Trinity Aquifer Advisory Committee which includes members of local groundwater districts, river authorities, county governments, regional water planning groups, and concerned citizens. In 2009, the Texas Water Development Board (TWDB) completed an update to the model to include the Lower Trinity as a fourth model layer." A sidebar on the right contains a "Groundwater Resources" menu with links to "Aquifers", "Groundwater Management Areas", "Groundwater Conservation Districts", "Groundwater Data", "Groundwater Models", "Regional Water Planning Areas", and "Special Projects". The "Groundwater Models" link is highlighted, and it includes sub-links for "Groundwater Availability Models" and "Alternative Models".

Community MODFLOW models for water resource planning and management

Trinity (Hill Country) Aquifer GAM

The screenshot displays a web browser window with the URL http://kmz.aquaveo.com/WellPermitting/Trinity/gmap/index_v3.htm#. The browser tabs include "Data Recovery Softw...", "iCloud - iWork", "Main Campus - East ...", "1701 Lavaca Street, A...", "Trinity MODFLOW Se...", "report.pdf (applicatio...", and "Trinity (Hill Country) ...". The browser address bar shows "kmz.aquaveo.com/WellPermitting/Trinity/gmap/index_v3.htm#".

The interface features a sidebar on the left with the following content:

- Welcome!
- New Simulation
- Archived Simulations
 - Description: *Well near Cairn Lane*
 - 2012-07-18 18:10:38
 - Simulation #136** (Delete)
 - By: Mark
 - Description: *Two wells: one near Tarpley, another near Pipe Creek*
 - 2012-07-18 18:04:04
 - Script completed successfully.
 - Map Layers:
 - New Wells
 - Drawdown (Layer 1)
 - Drawdown (Layer 2)
 - Drawdown (Layer 3)
 - Drawdown (Layer 4)
 - Total Spring Flow
 - More Info:
 - [Browse Result Files](#)
 - [PDF Report](#)
 - Simulation #140** (Delete)
 - By: Mark
 - Description: *Well at 2219 Fawn Mist Lane, San Antonio, TX 78248*
 - 2012-07-18 18:08:52
 - Simulation #143** (Delete)
 - By: Gil
 - Description: *Test simulation 0 discharge*

The main map area shows a topographic map of Hill Country, Texas, with a black boundary representing the aquifer. A red line indicates a stream flow path. Two green circles with blue centers represent wells, with yellow arrows pointing to them. The map includes various geographical features, roads, and place names such as Fredericksburg, Comstock, Boerne, and San Marcos.

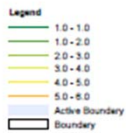
A yellow-bordered box on the right side of the map contains the text: "Simulation Options: (a) Reduced recharge (b) Well impact on water levels and stream flow".

At the bottom of the browser window, a black-bordered box contains the URL: http://kmz.aquaveo.com/WellPermitting/Trinity/gmap/index_v3.htm.

PDF Simulation Report

SIMULATED AQUIFER DRAWDOWN: LAYER 3

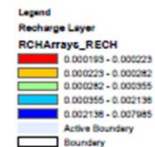
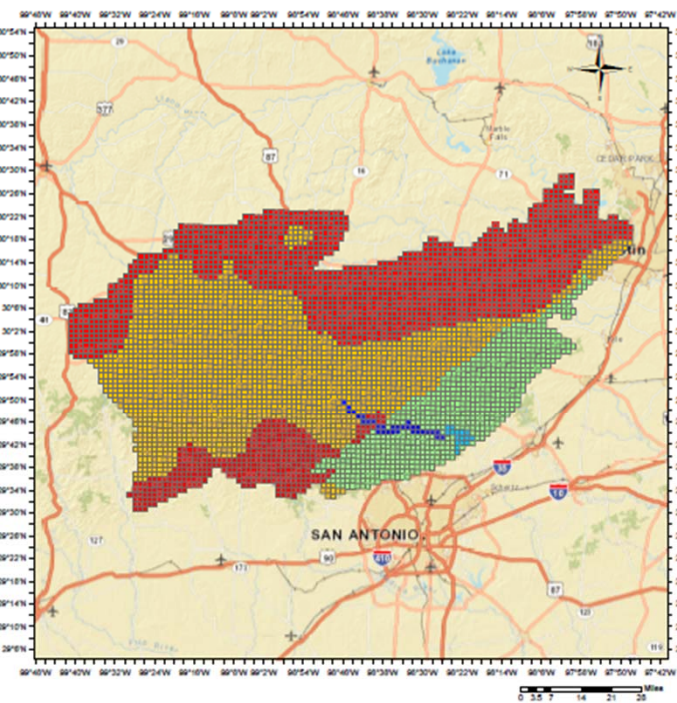
Trinity Hill Country GAM Model



Simulation Date: 7/18/2012
Simulation Time: 2:02:11 PM

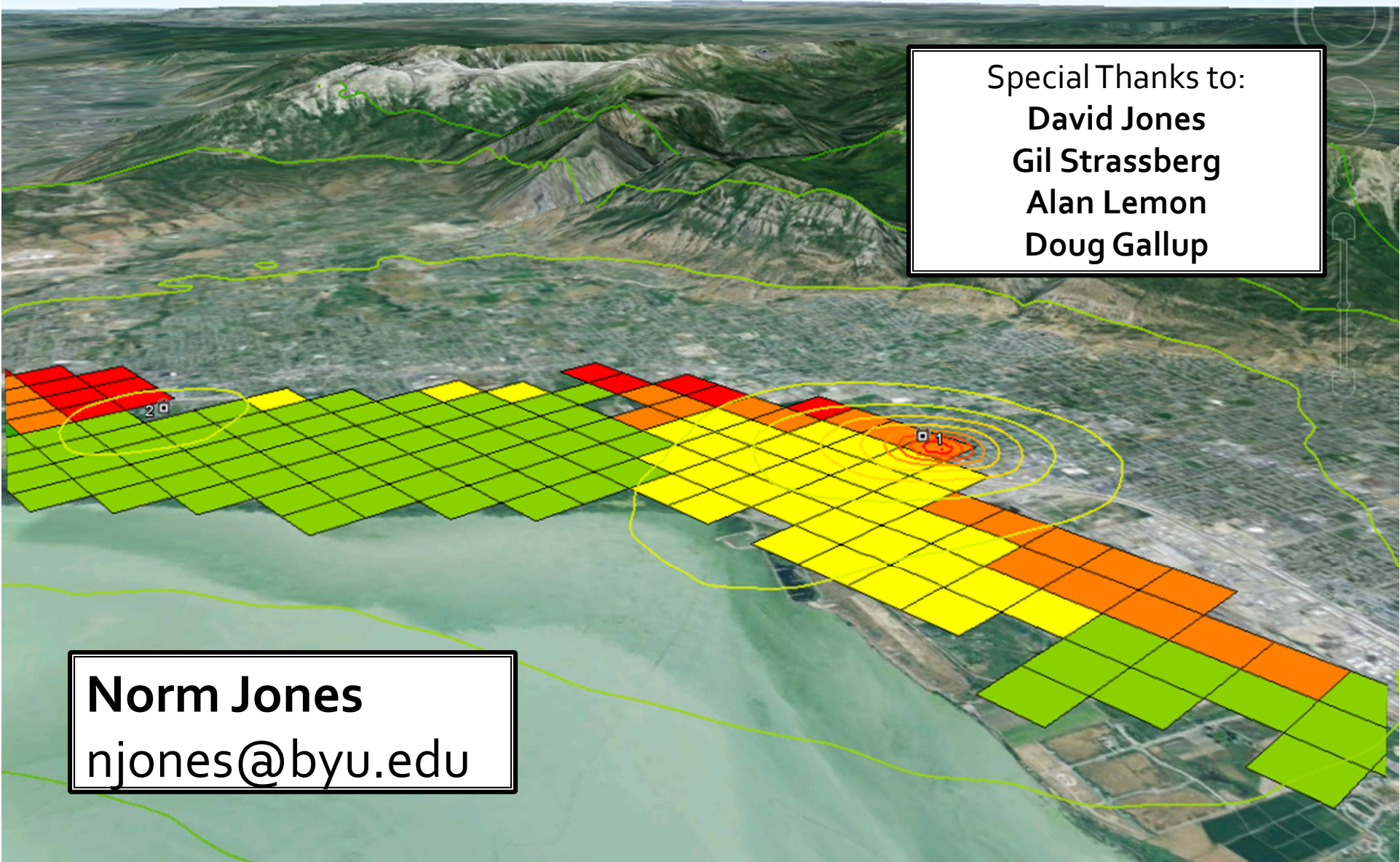
RECHARGE LAYER WITH APPLIED FACTOR = 1

Trinity Hill Country GAM Model



Simulation Date: 7/18/2012
Simulation Time: 2:04:03 PM

Thank You



Special Thanks to:
David Jones
Gil Strassberg
Alan Lemon
Doug Gallup

Norm Jones
njones@byu.edu