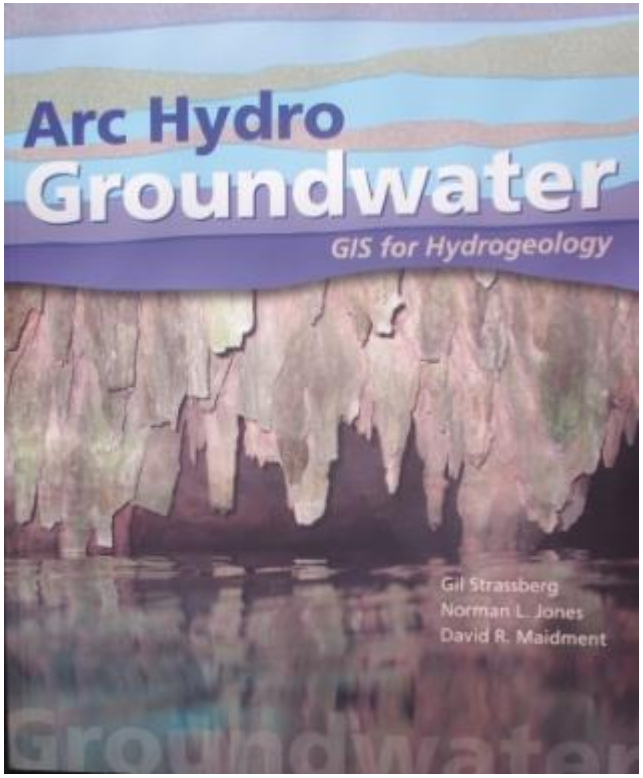
Arc Hydro Groundwater Data Model

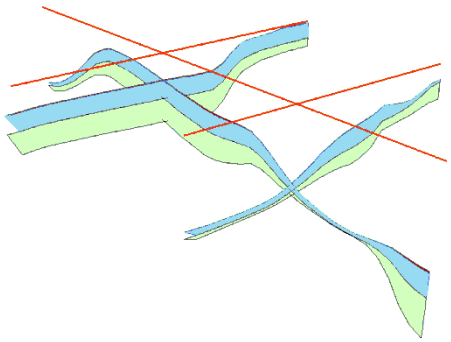
This is a modified and abridged version of a presentation given by Professor David Maidment at UTexas, Austin. It was part of GIS in Water Resources - Fall 2017. The original version can be found on Professor Maidment's website http://www.caee.utexas.edu/prof/maidment

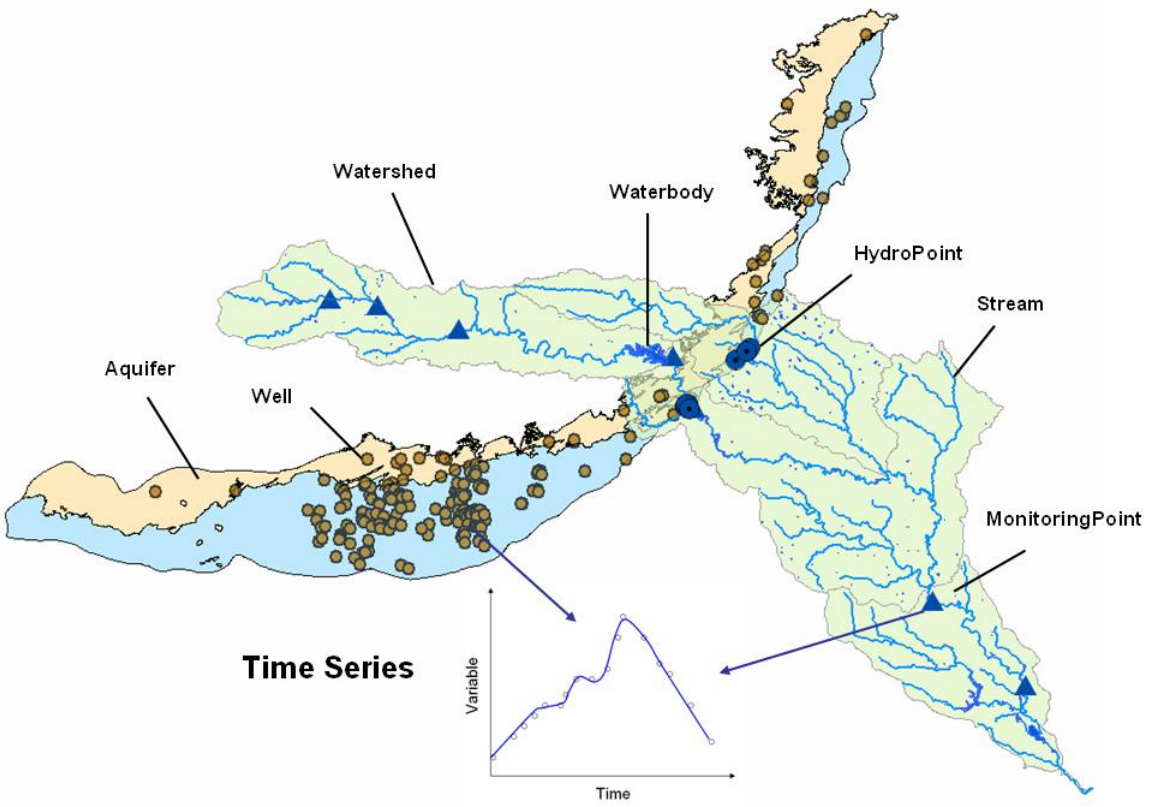


Additional material provided by Aqualinc Research Ltd and the Ecan website.

David Painter, 21 March 2018

Arc Hydro Groundwater Data Model





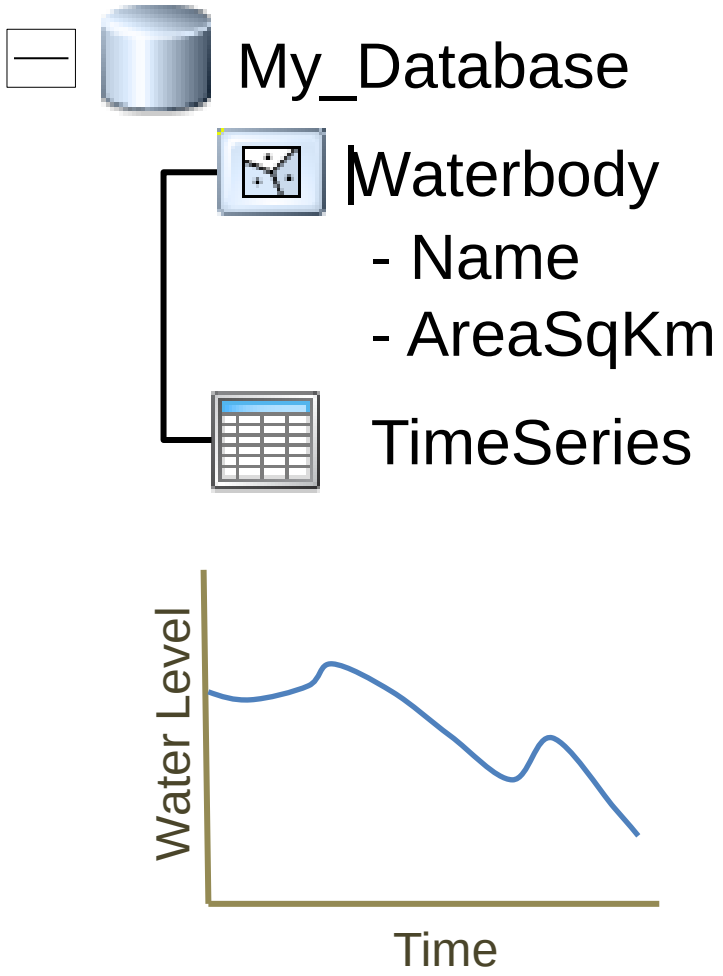
GIS in Water Resources - Fall 2017

Thanks to Dr Tim Whiteaker for help with the slides

What To Look For in this Presentation

- Ideas on how we think about groundwater features in a GIS context
- What kinds of geologic features does the model cover? What does it not cover?
- How are relationships used to tie pieces of the data model together

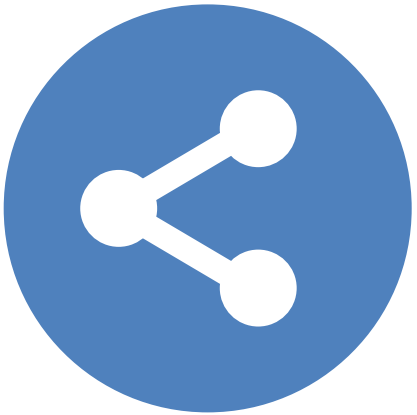
A data model helps you design your database



Why Use a Data Model

Concepts

Tools

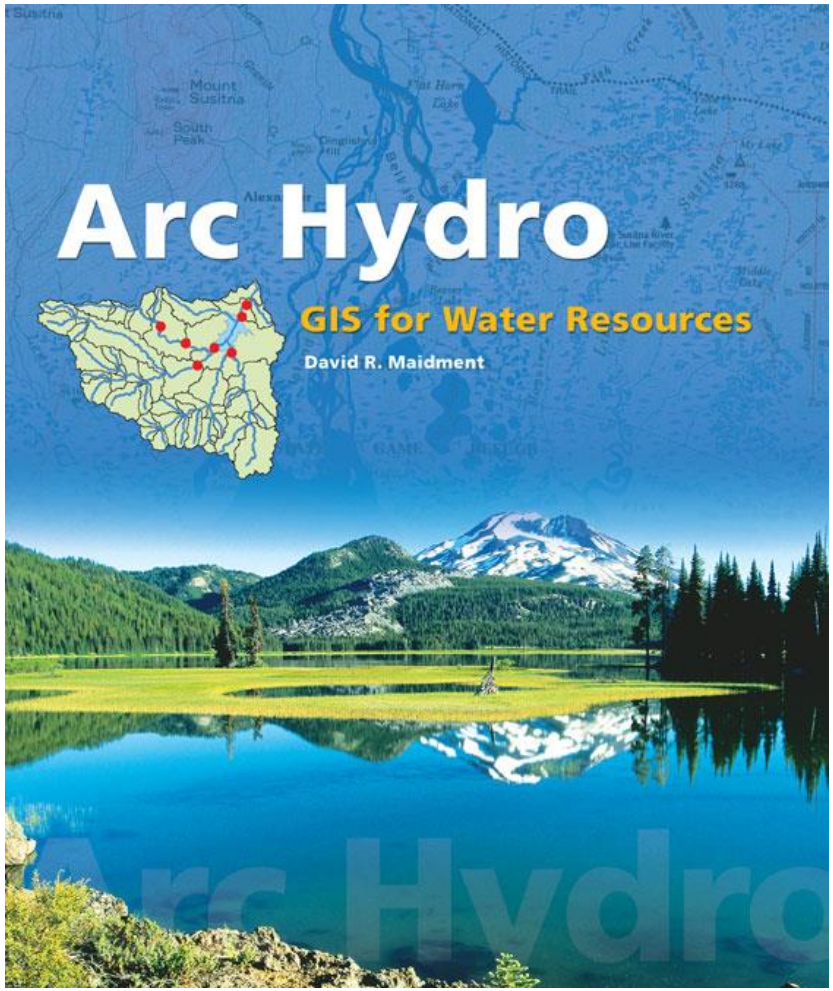


Sharing

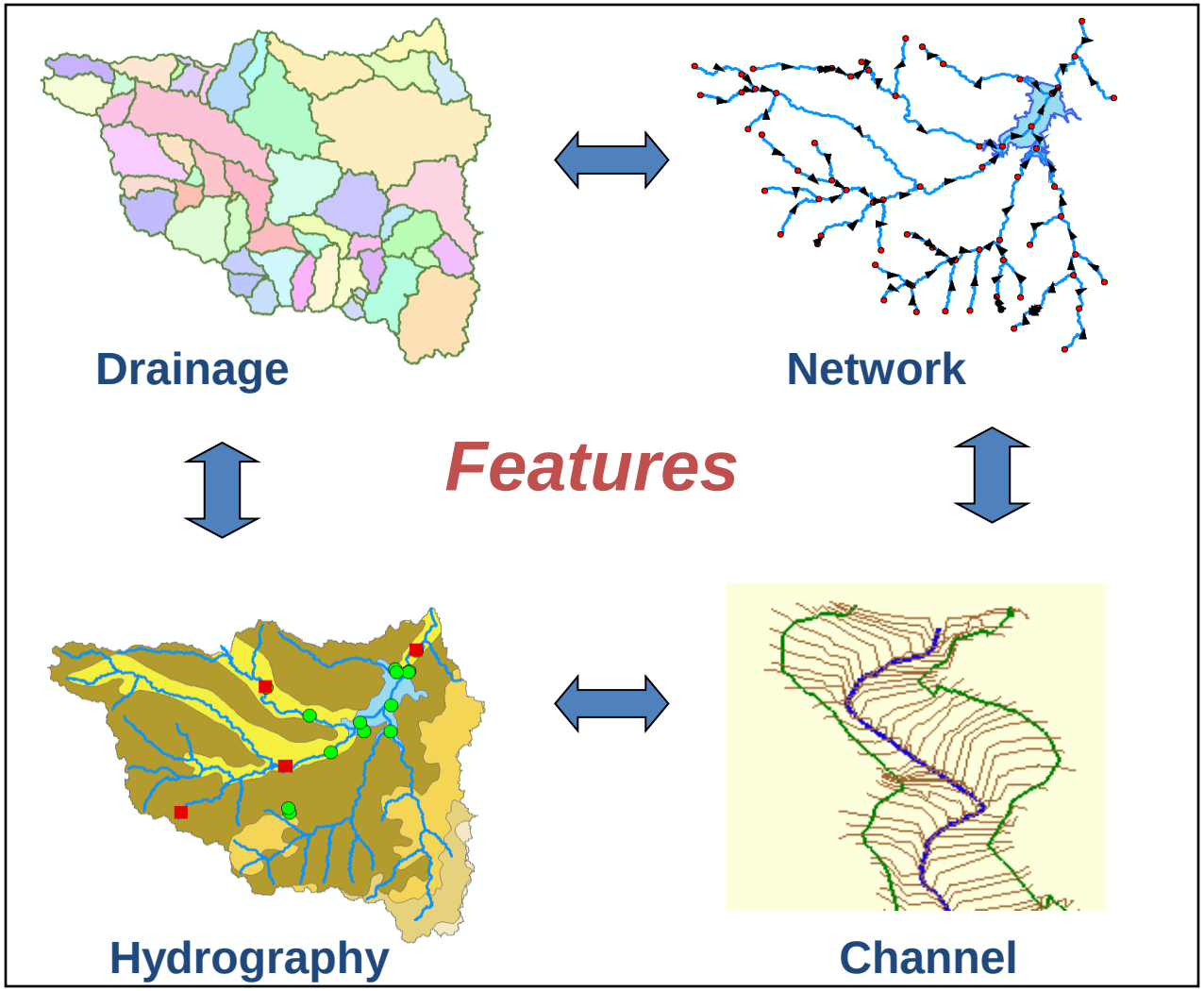
Arc Hydro: GIS for Water Resources

(2002)

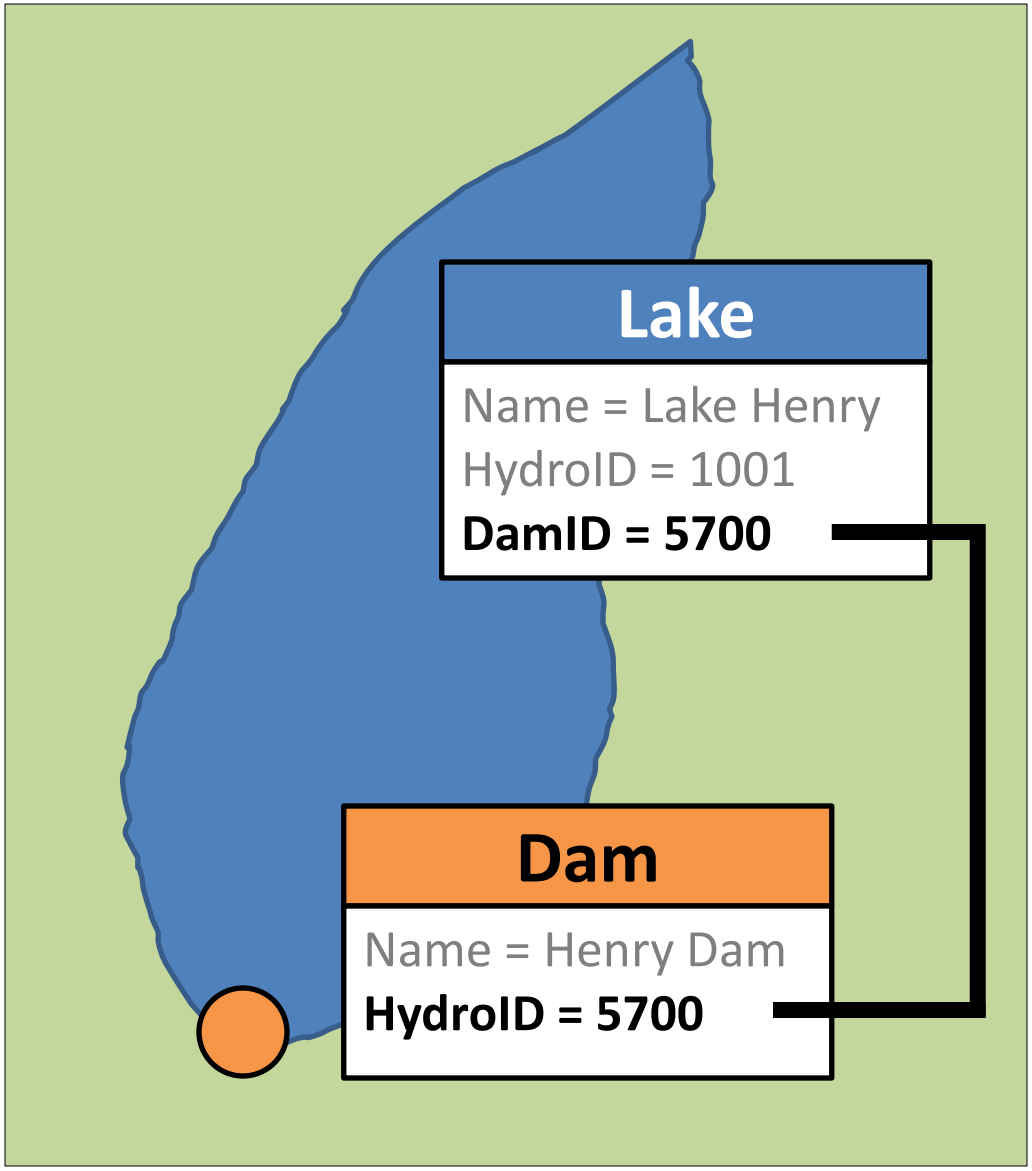
- A data model for water resources
- A toolset for implementation
- A framework for linking hydrologic simulation models
- Focus on surface water
- Free



Arc Hydro Describes Surface Water

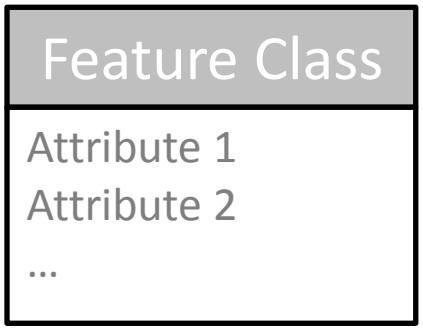


A key concept from Arc Hydro is **HydroID**



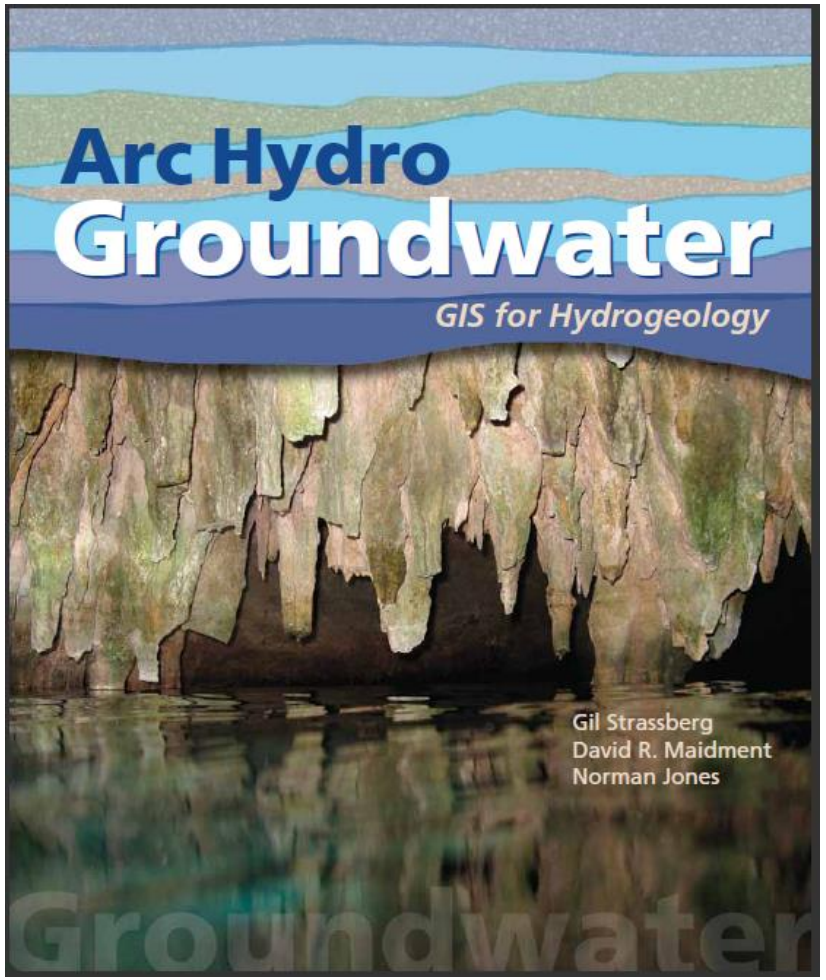
- Like Social Security Number for features
- Unique in a geodatabase
- Used in relationships

Legend

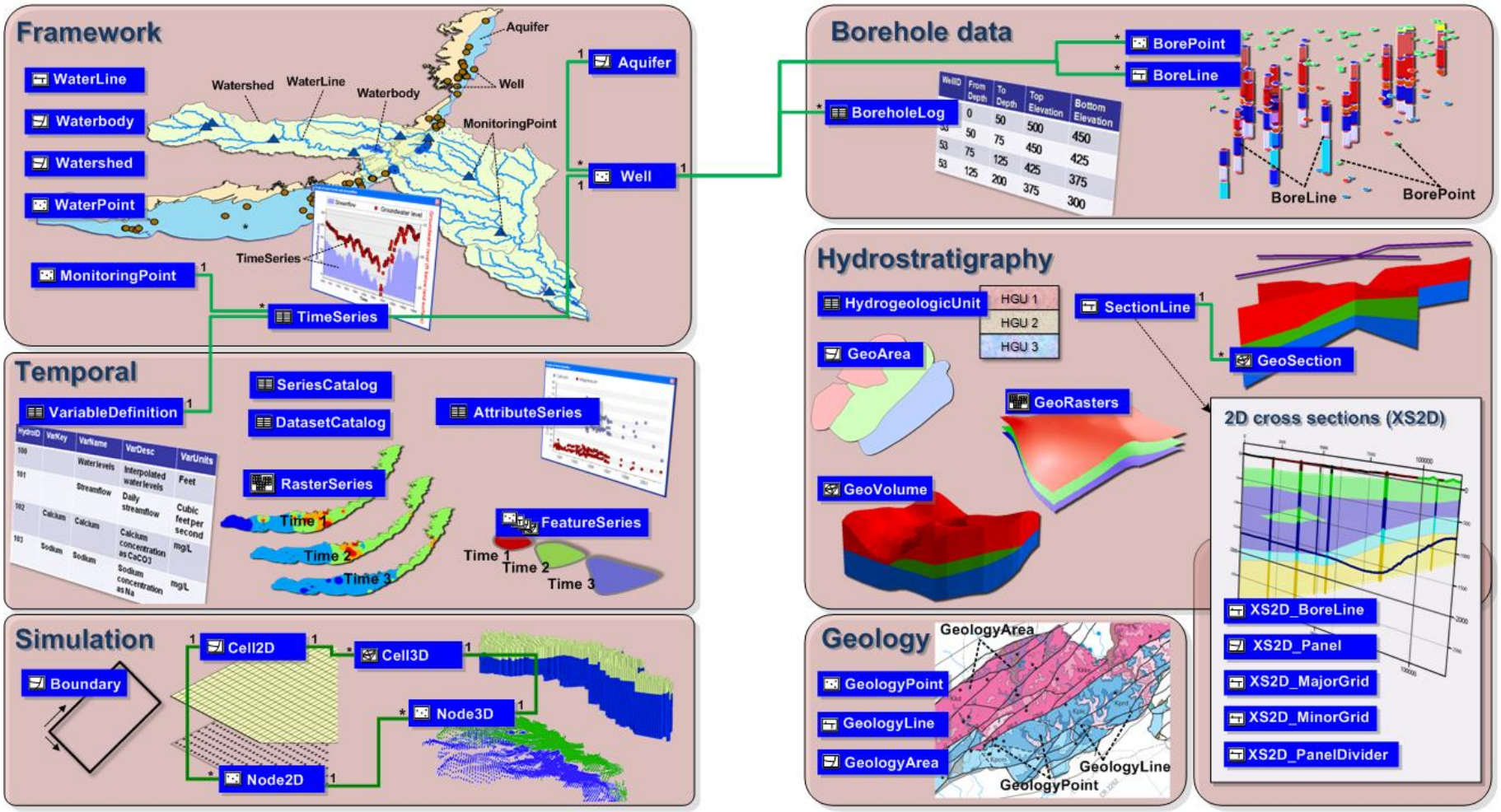


Arc Hydro Groundwater: GIS For Hydrogeology
(2011)

- Builds on Arc Hydro
- Includes data model and tools
- Expands Arc Hydro temporal components
- Some tools free, some not

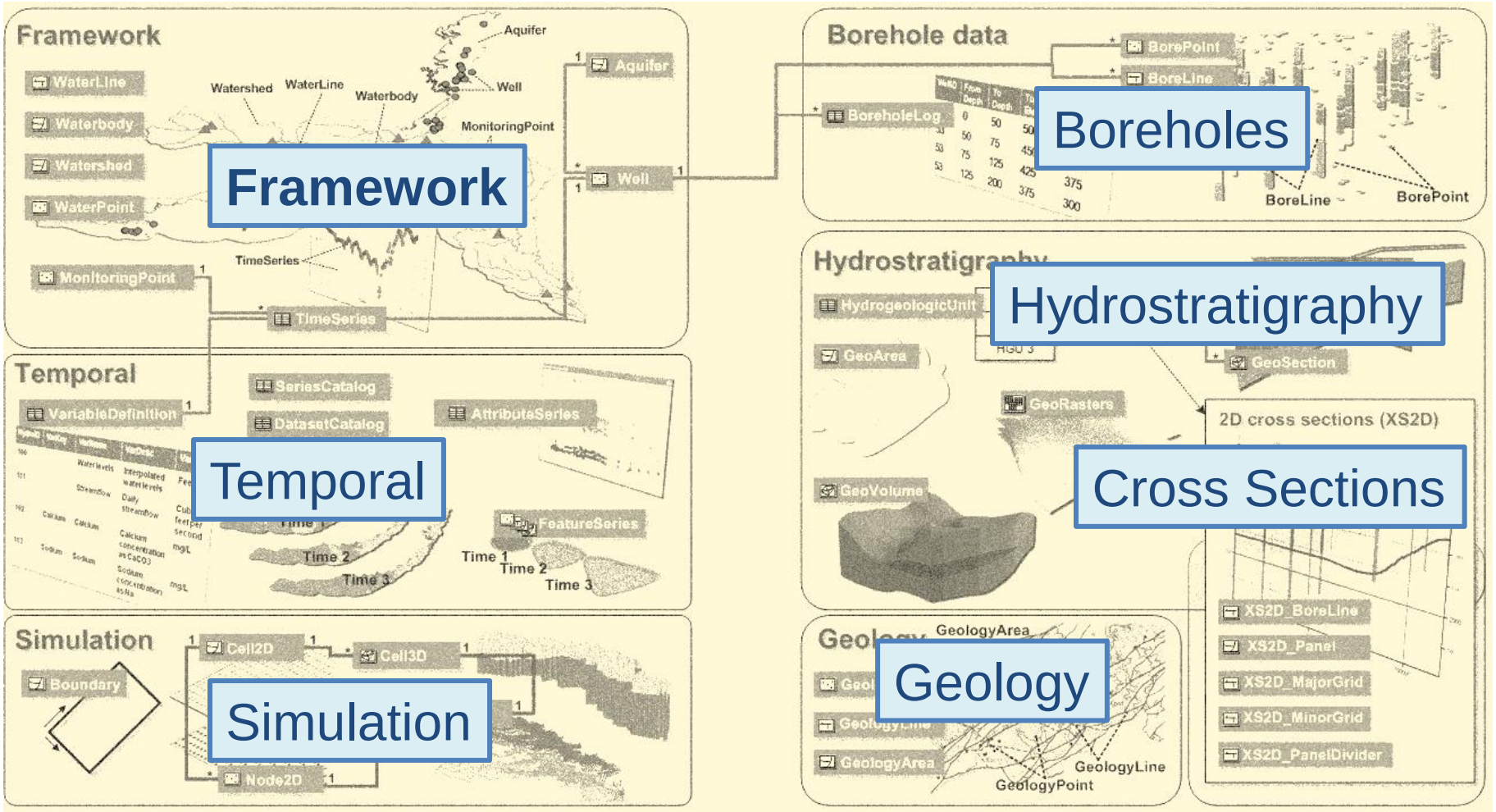


Arc Hydro Groundwater Data Model



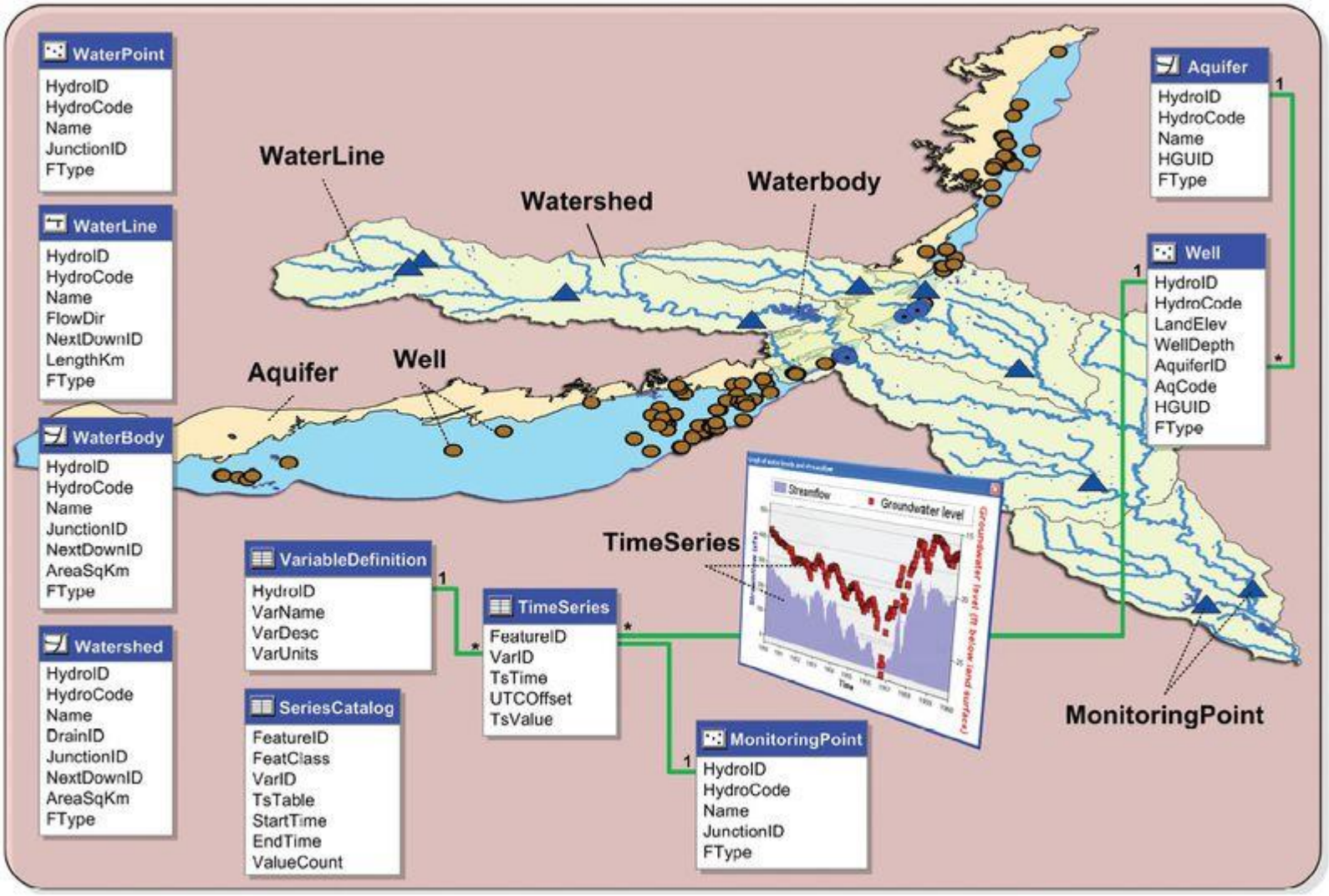
http://www.archydrogw.com/File:Archydrogw_overview.JPG

Arc Hydro Groundwater Data Model



Arc Hydro Framework

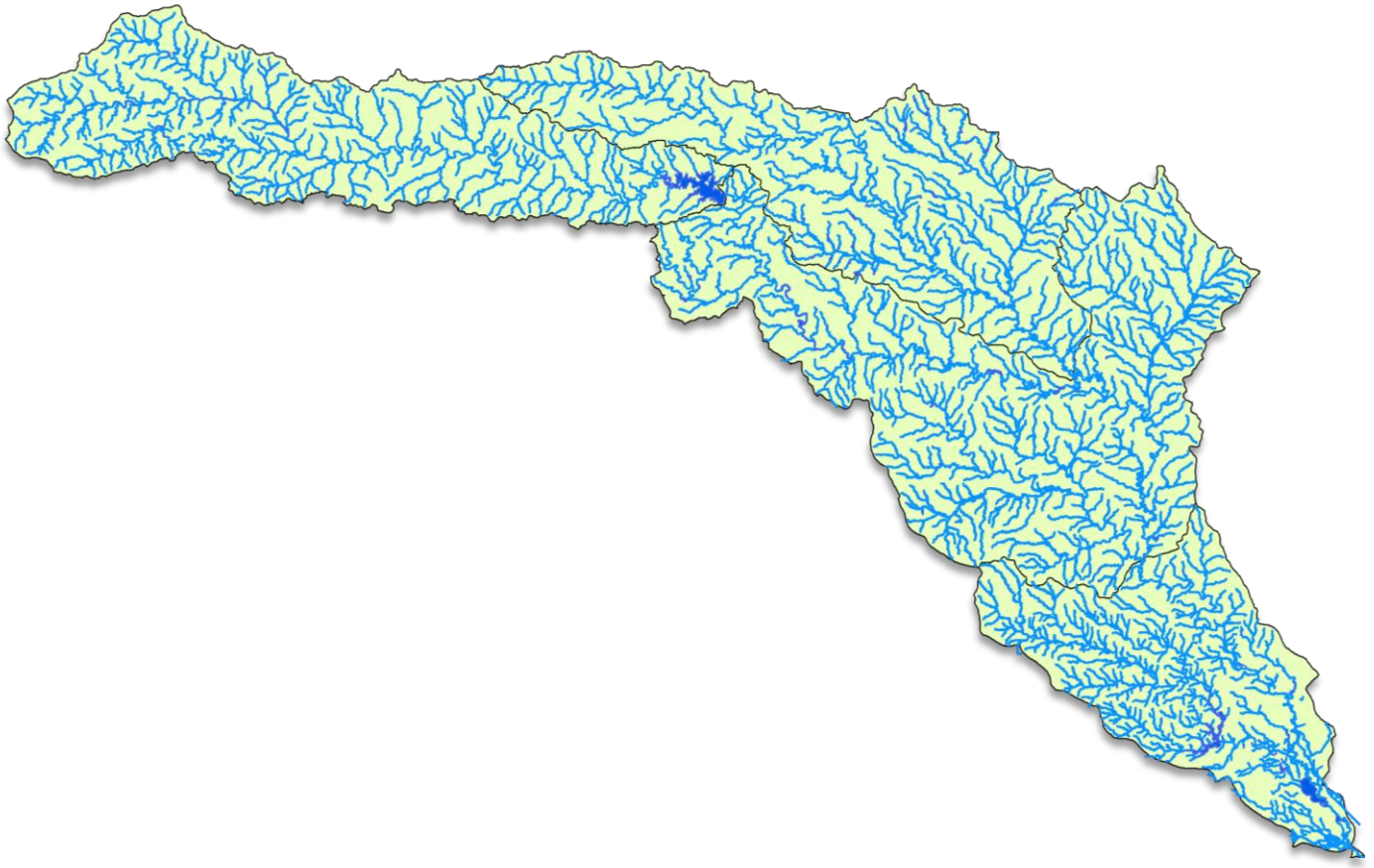
Extensible representation of surface water and groundwater



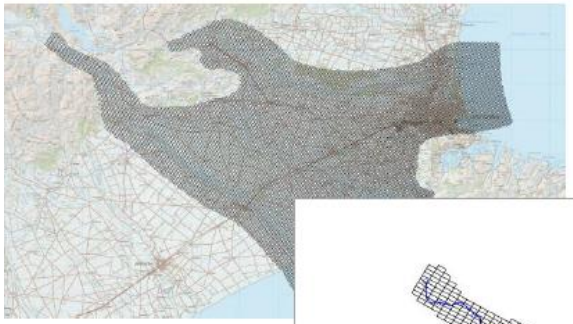
http://www.archydrogw.com/File:Archydrogw_framework.JPG

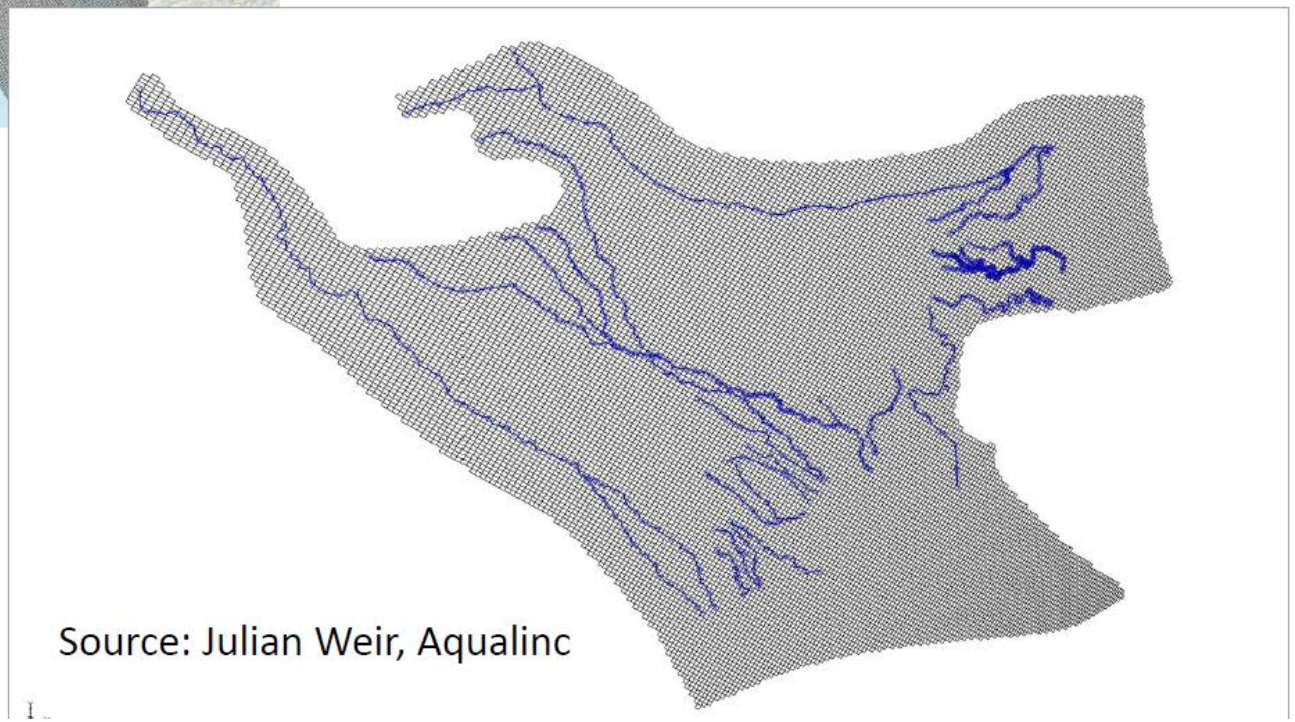
Surface Water Features

- WaterLine, WaterBody represent hydrography
- Watershed represents drainage areas



Rivers in Selwyn Groundwater Model

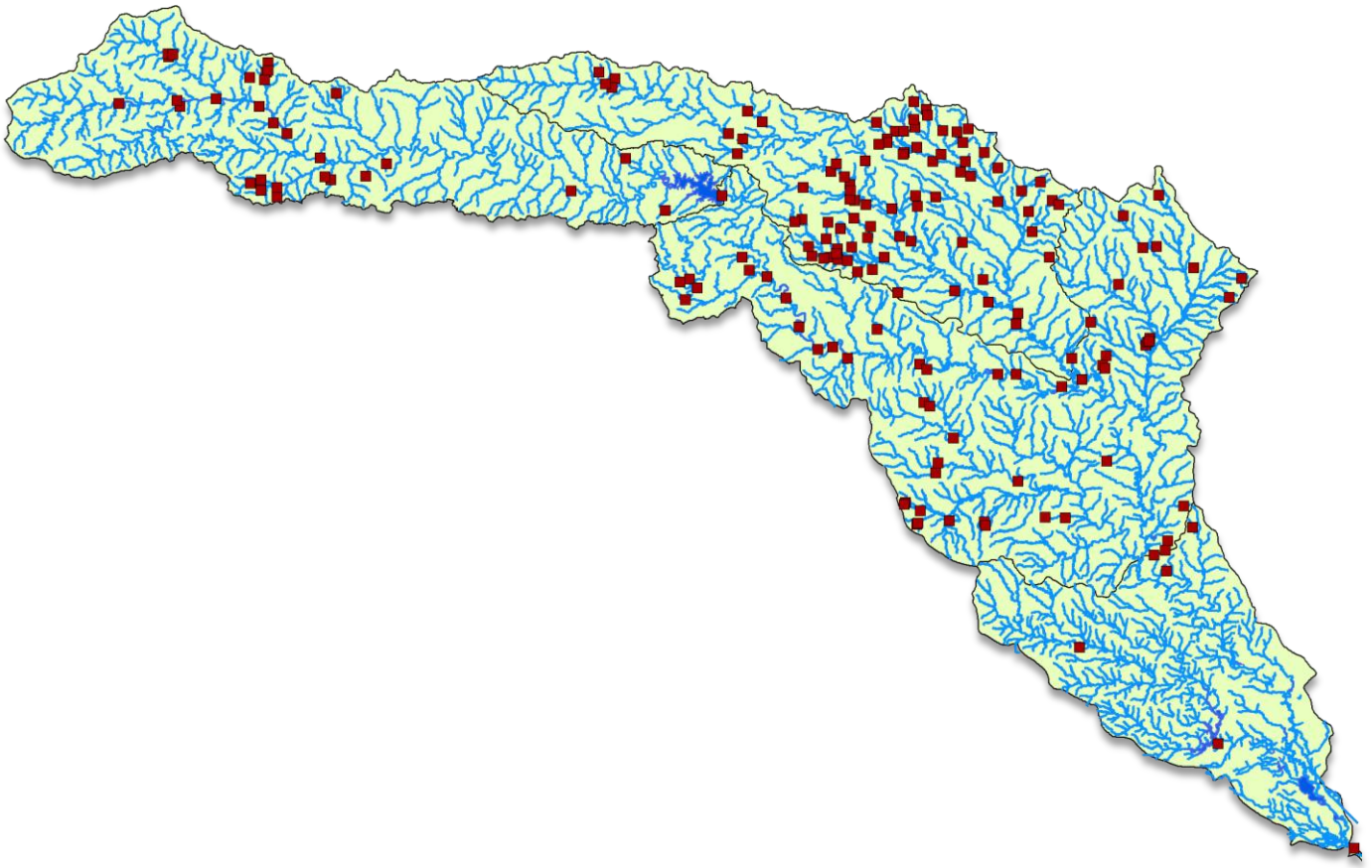




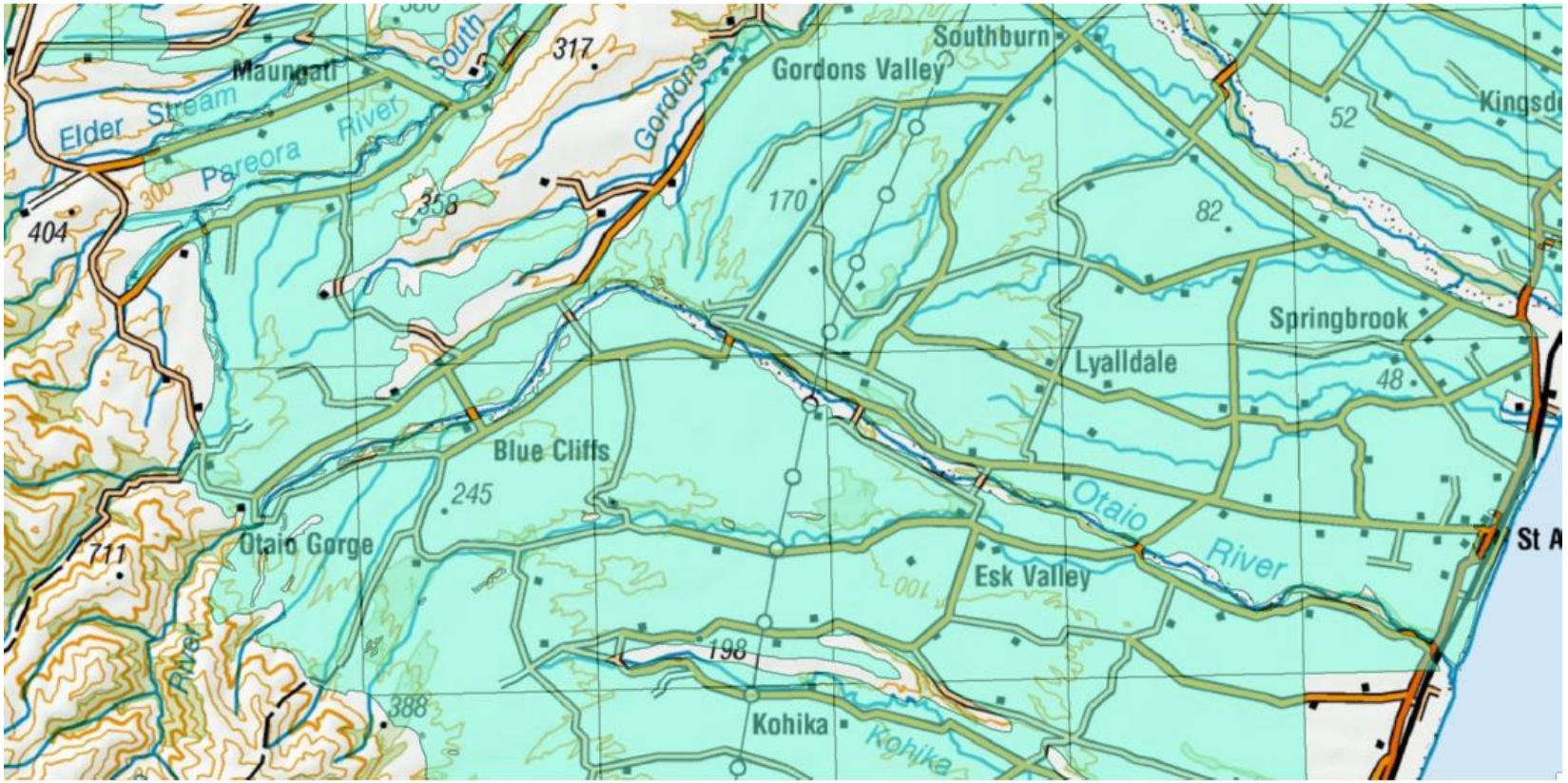
Source: Julian Weir, Aqualinc

WaterPoint

- Structures, dams, springs, diversions, etc.



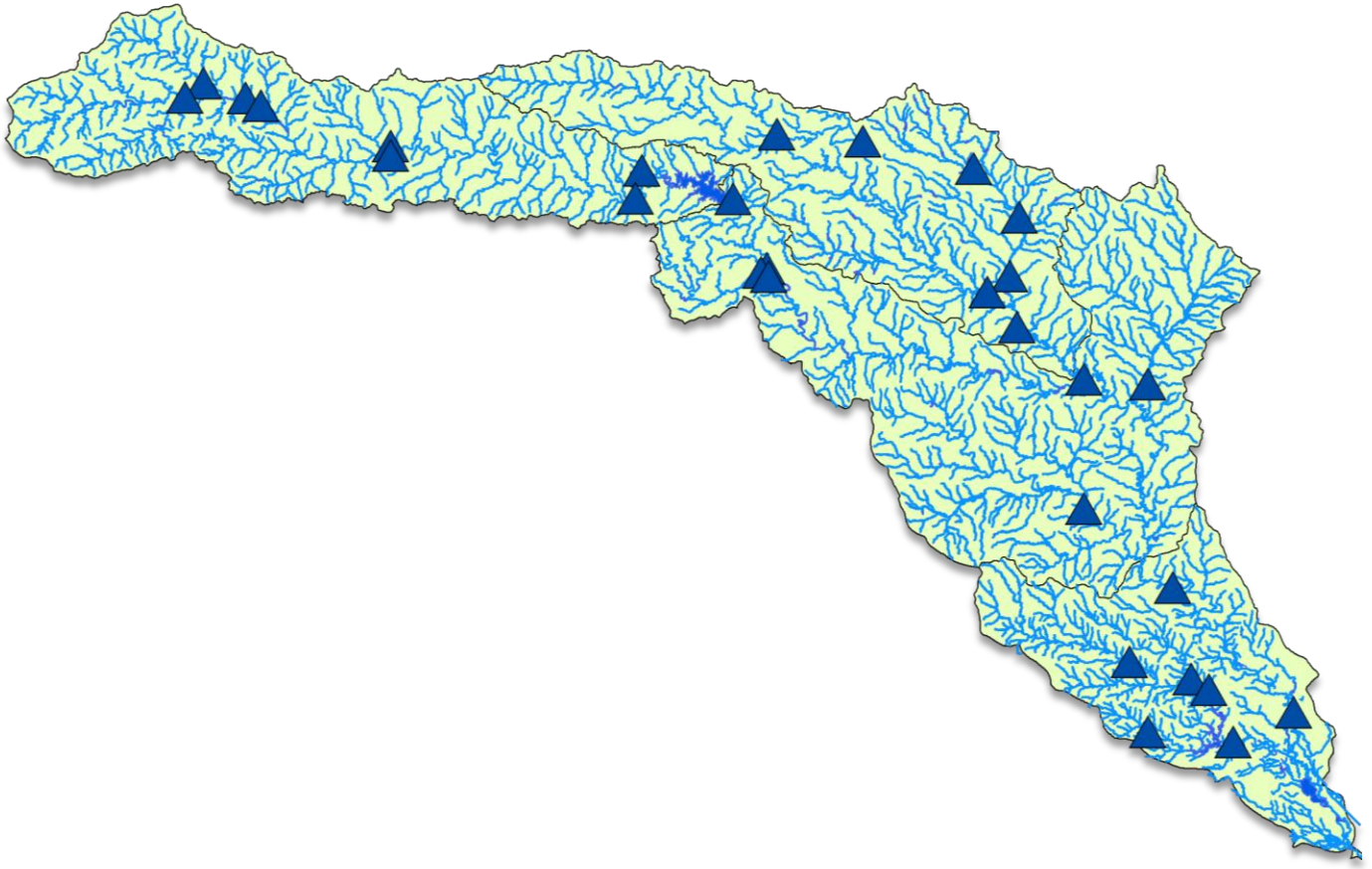
Groundwater at Blue Cliffs



Source of Data: Andrew Dark, Aqualinc

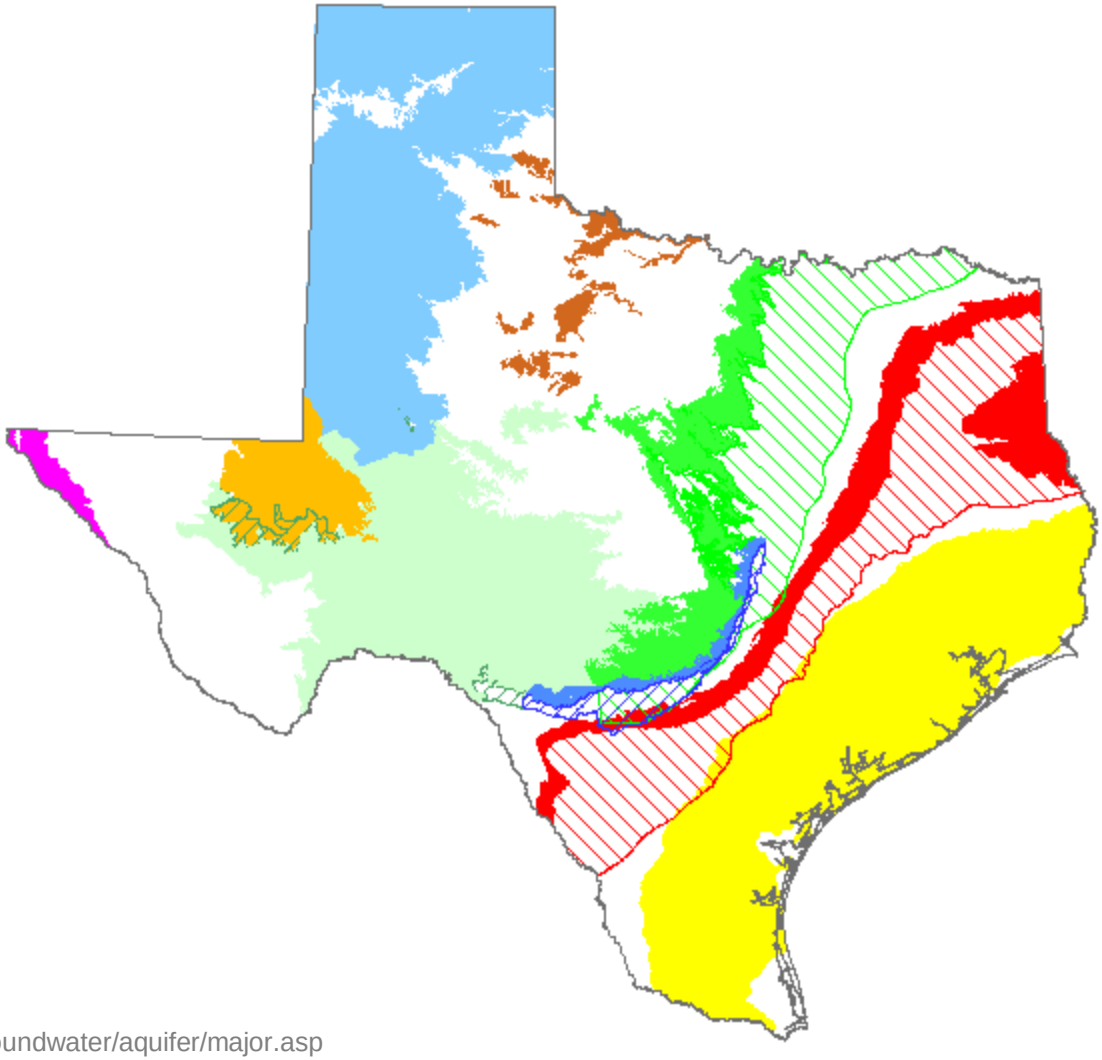
MonitoringPoint

- Locations where water is measured



Aquifer

- Polygon features of aquifer boundaries



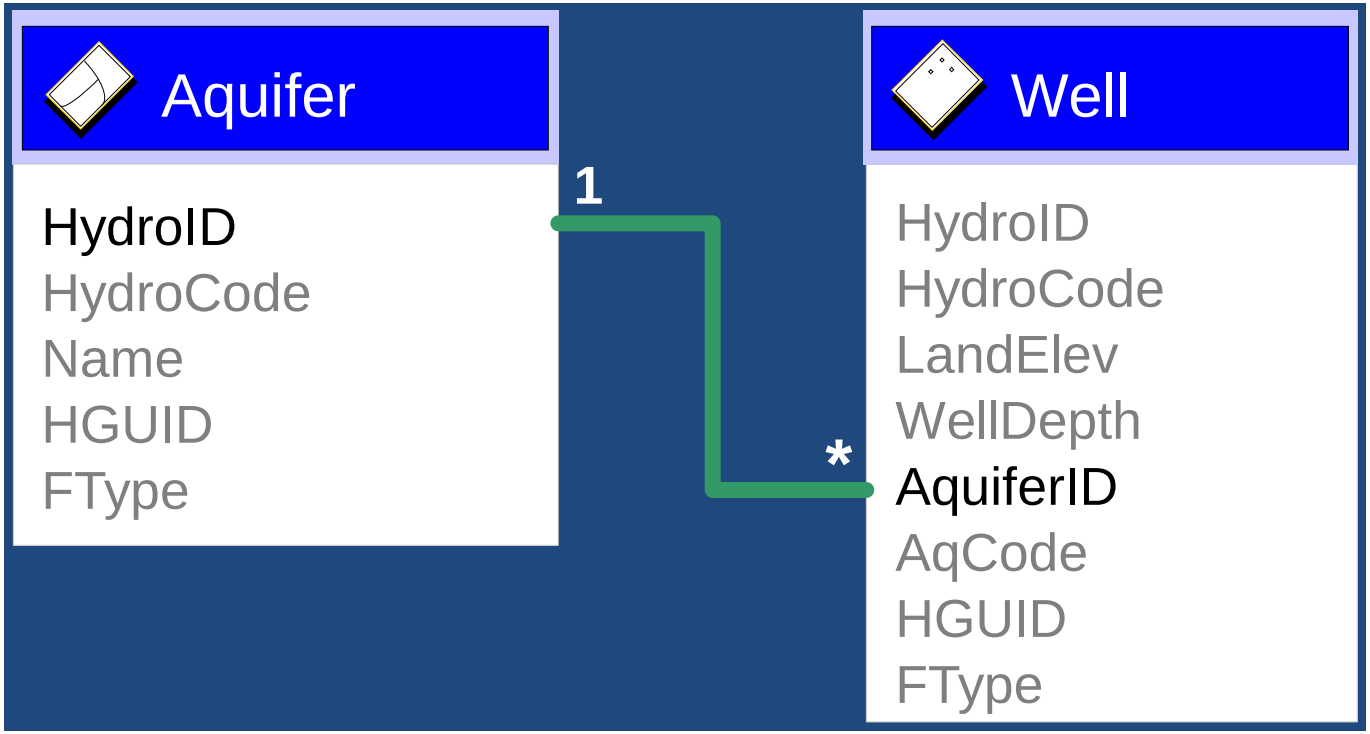
http://www.twdb.texas.gov/groundwater/aquifer/major.asp

Well

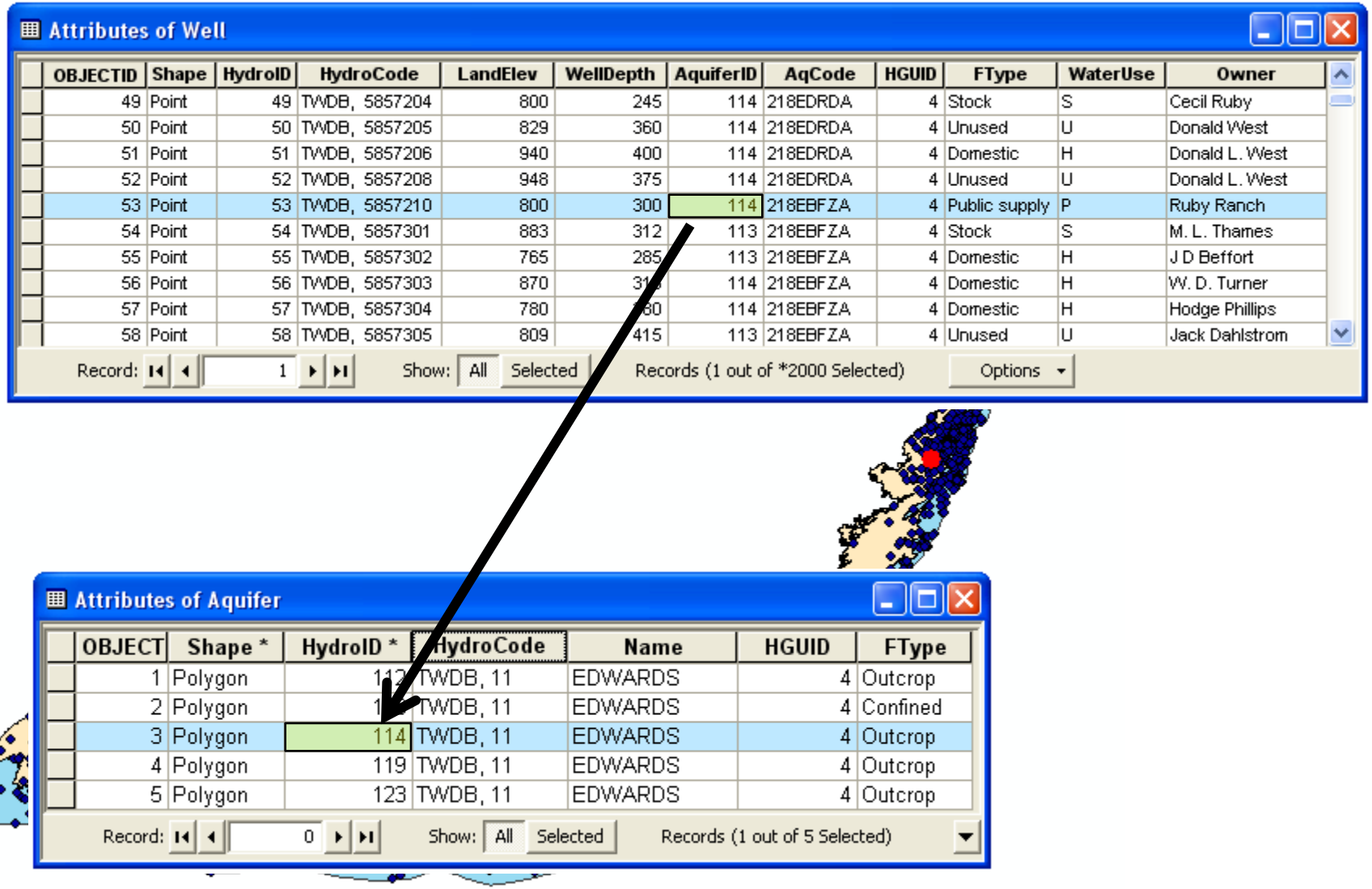
- Location where the subsurface has been drilled
- Attributes describe depth, use, etc.

Aquifers are related to Wells

- An aquifer can be related to one or more wells (1:M)



Aquifer and well



SUMMARY | WATER LEVEL GRAPHS | BORE LOG | AQUIFER TESTS | LOCATION MAP

Details

Printable Well Summary

Well Number	M36/1945	**File Number**	CO6C/00873
Owner	Mr & Mrs B L & D J Haylock	**Well Status**	Active (exist, present)
Street/Road	DAVIDSONS RD	**NZTM Grid Reference**	BX23:58452-61936
Locality	GREENPARK	**NZTM X and Y**	1558452 - 5161936
Location Description	Englishes Road. Bore located in paddock behind house.	**Location Accuracy**	2 - 15m
CWMS Zone	Selwyn - Waihora	**Use**	Irrigation,
Groundwater Allocation Zone	Selwyn-Waimakariri	**Water Level Monitoring**	
Depth	15.00m	**Water Level Count**	0
Diameter	152mm	**Initial Water Level**	
Measuring Point Description		**Highest Water Level**	
Measuring Point Elevation	4.72m above MSL (Lyttelton 1937)	**Lowest Water Level**	
Elevation Accuracy	< 2.5 m	**First reading**	
Ground Level	0.00m above MP	**Last reading**	
Strata Layers	0	**Calc Min 95%**	1.80m below MP
Aquifer Name		**Aquifer Tests**	0
Aquifer Type	Unknown	**Yield Drawdown Tests**	1
Drill Date		**Max Tested Yield**	
Driller	not known	**Drawdown at Max Tested Yield**	
Drilling Method	Unknown	**Specific Capacity**	
Casing Material	STEEL	**Last Updated**	10 Feb 2012
Pump Type	Unknown	**Last Field Check**	08 Feb 2012
Water Use Data	No		

M36/7649 details

Back to Well Search

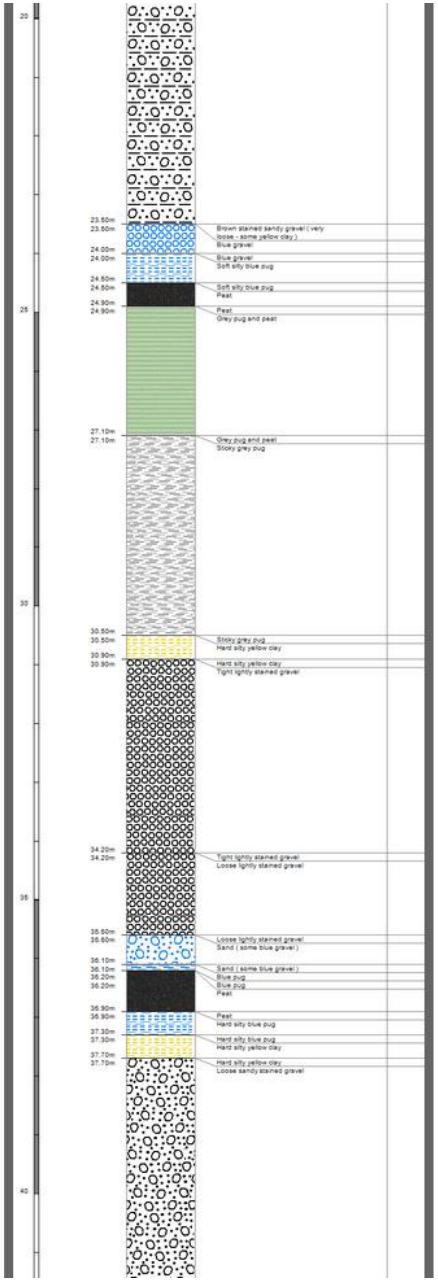
SUMMARY | WATER LEVEL GRAPHS | BORE LOG | AQUIFER TESTS | LOCATION MAP

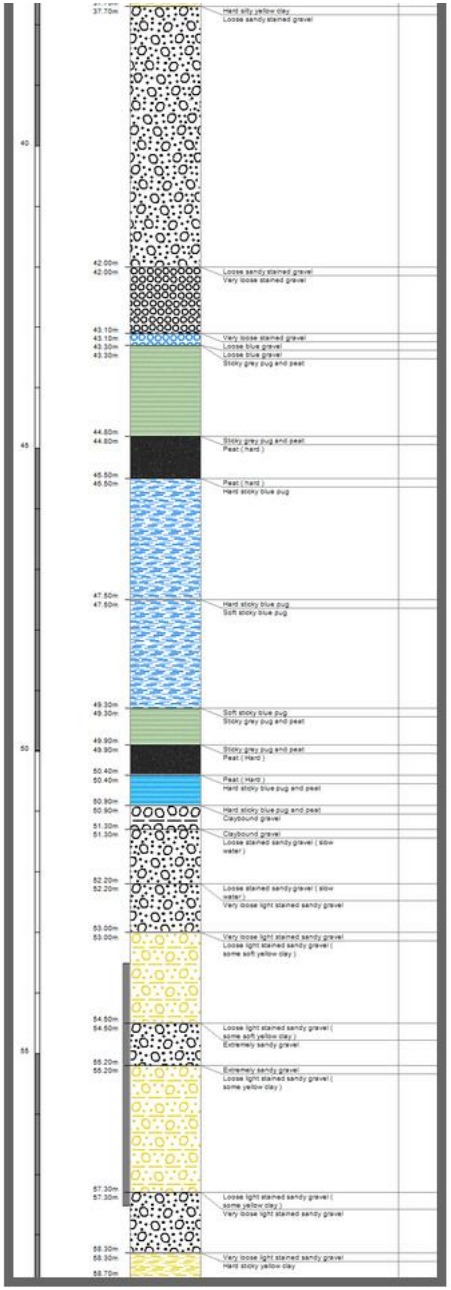
Borelog for well M36/7649

Grid Reference (NZTM): 1558475 mE, 5161944 mN
Location Accuracy: 50 - 300m
Ground Level Altitude: 4.0 m +MSD Accuracy: < 0.5 m
Driller: Clemence Drilling Contractors
Drill Method: Rotary/Percussion
Borelog Depth: 58.7 m Drill Date: 01-Sep-2004

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Scale(m)	Water Level	Depth(m)	Full Drillers Description	Formation Code
		0.30m	Top soil	
		0.30m	Top soil Puggy yellow clay	
		0.90m	Puggy yellow clay Soft blue silty pug	
		3.50m	Soft blue silty pug Hard grey pug (some timber)	
		4.50m	Hard grey pug (some timber) Grey sand	
		6.60m	Grey sand Lightly stained grey gravel (loose)	
		11.20m	Lightly stained grey gravel (loose) Brown stained sandy gravel (very loose - tuitly water)	
		14.30m	Brown stained sandy gravel (very loose - tuitly water) Brown stained sandy gravel (very loose - some yellow clay)	





Time Series Variables

- VariableDefinition table is a catalog of time varying parameters (e.g., streamflow, water levels, concentrations)
- Each variable is indexed with a HydroID

VariableDefinition

HydroID
VarKey
VarName
VarDesc
VarUnits
Medium
DataType
IsRegular
TimeStep
TimeUnits
NoDataVal
Vocabulary
VarCode

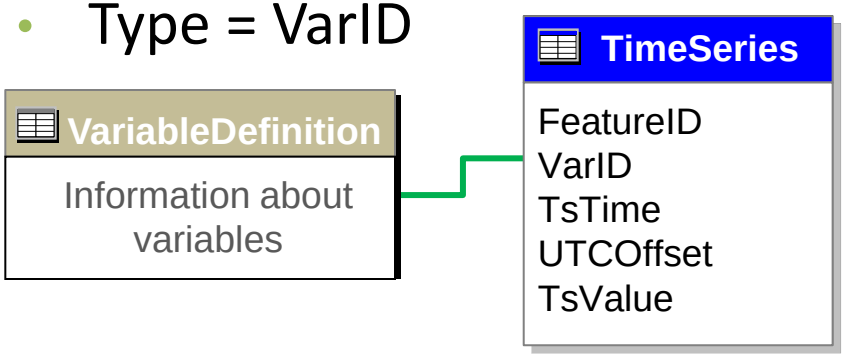
Attributes of VariableDefinition

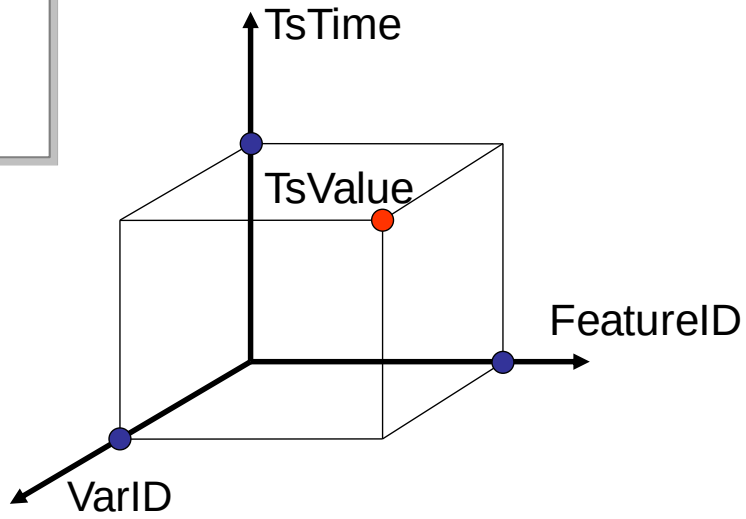
OBJECTID	HydroID	VarKey	VarName	VarDesc	VarUnits
1	6874	<Null>	Streamflow	NWIS Daily Streamflow	cubic feet per second
2	6875	<Null>	Water level	Water levels	feet above mean sea level
3	6876	silica	Silica	Silica concentration as SiO2	mg\L
4	6877	calcium	Calcium	Calcium concentration as CaCO3	mg\L
5	6878	magnes	Magnesium	Magnesium concentration as Mg	mg\L
6	6879	sodium	Sodium	Sodium concentration as Na	mg\L
7	6880	potass	Potassium	Potassium concentration as K	mg\L
8	6881	AvgWL	Groundwater level	Averaged groundwater levels	feet above mean sea level
9	6882	<Null>	Particle track	Patricle track through subsurface	<Null>
10	6883	Z_Value	Depth	Depth below ground surface	feet

Record: 0 Show: All Selected Records (0 out of 10 Selected)

TimeSeries table

- Each measurement is indexed by space, time, and type
- Space = FeatureID
- Time = TsTime
- Type = VarID



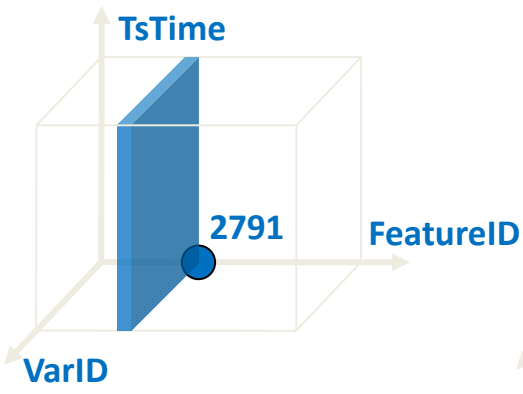


Time Series Views

We can slice the data cube to get specific views of the data

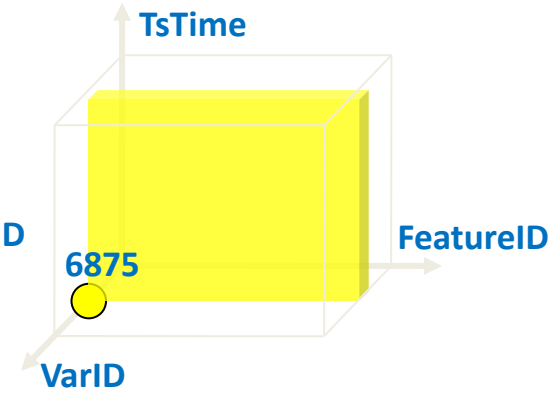
Where?

(FeatureID = 2791)



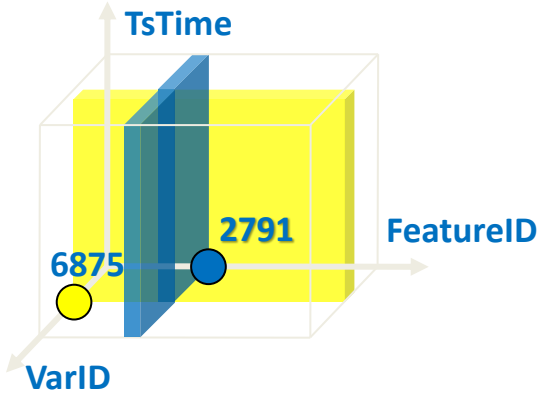
What?

(VarID = 6875)

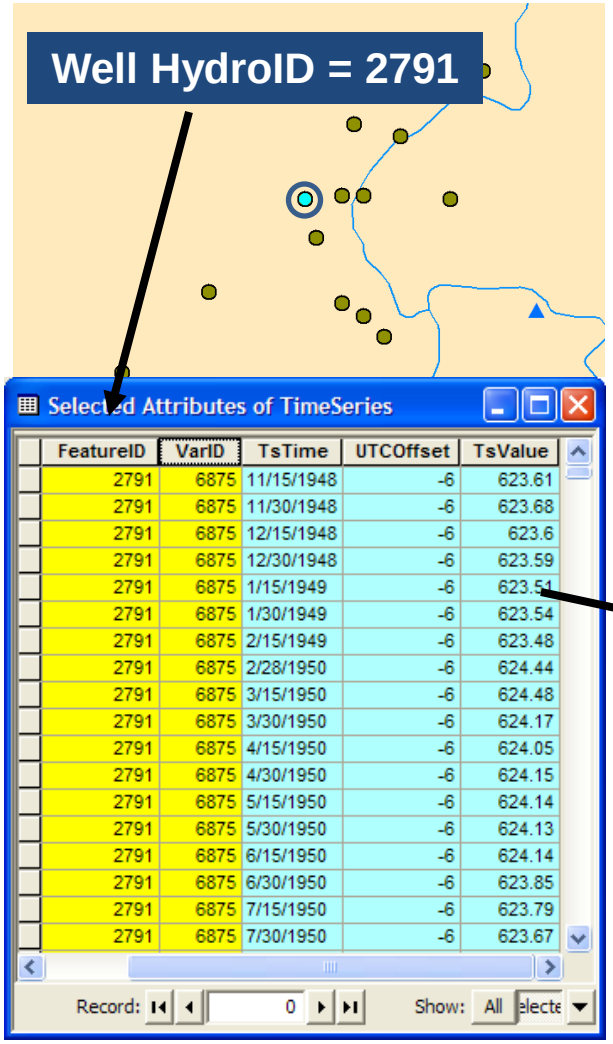


Where and What?

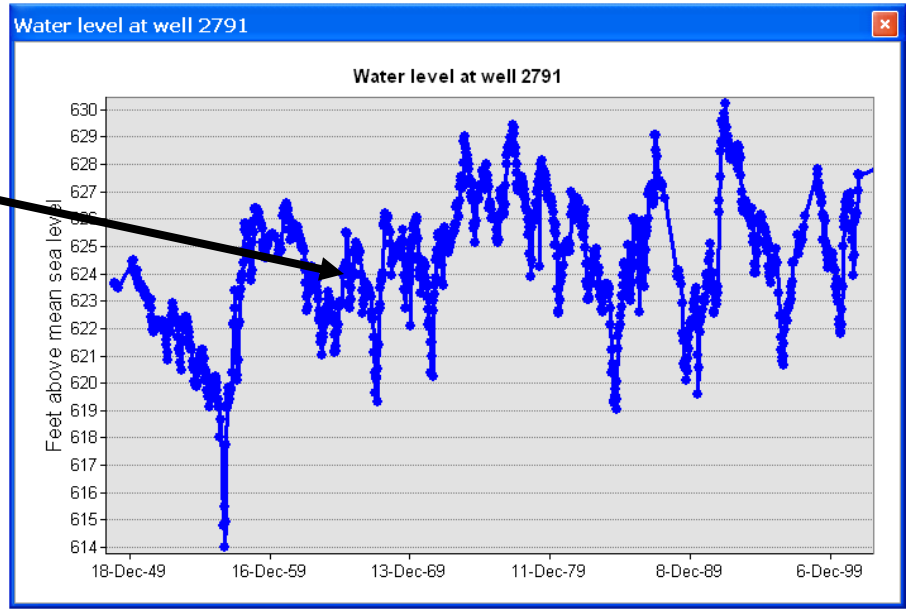
(FeatureID = 2791 VarID = 6875)



Time Series Views

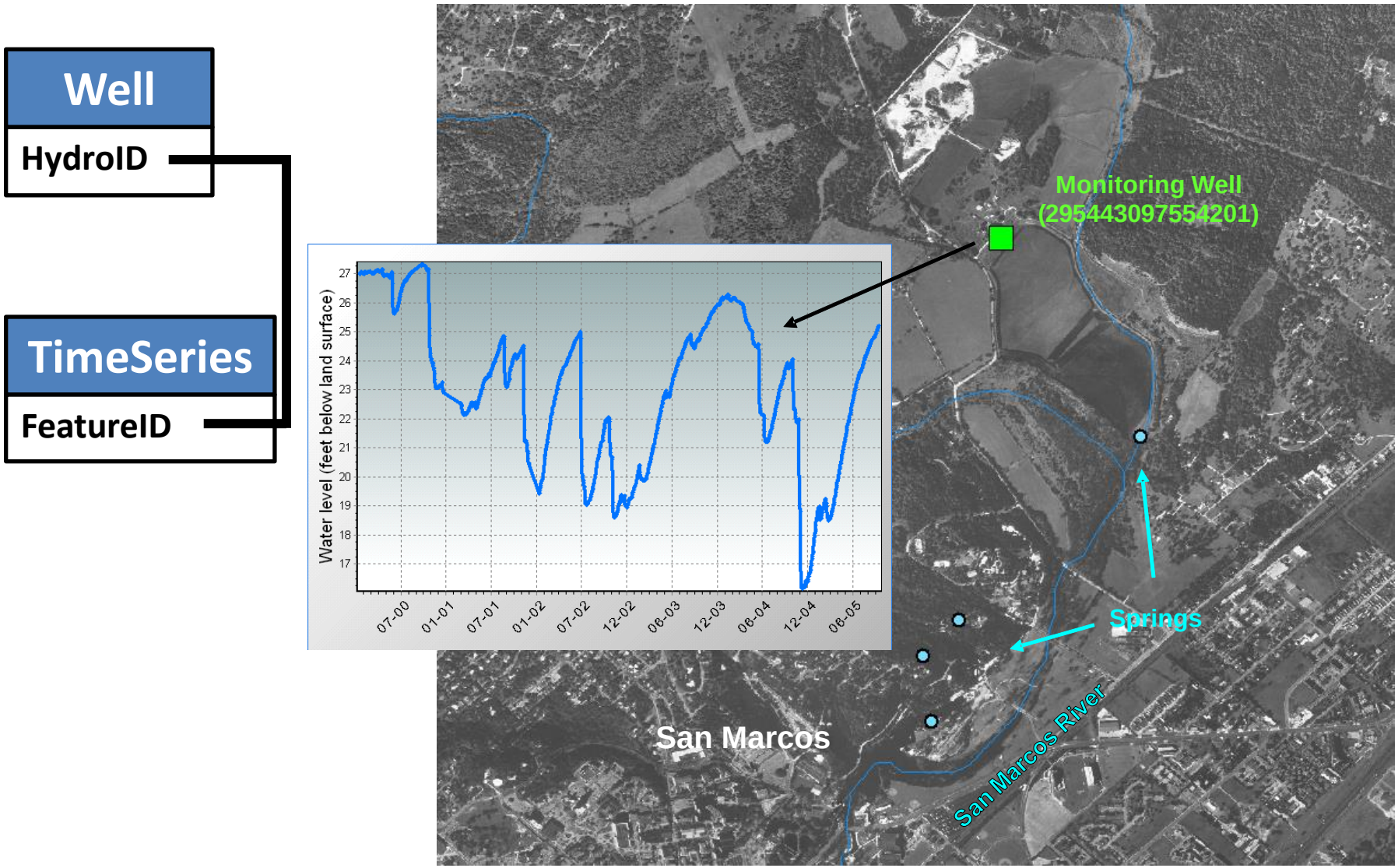


- Create a plot of time series related to a feature
- Get all the data of VarID 6875 measured at Feature 2791

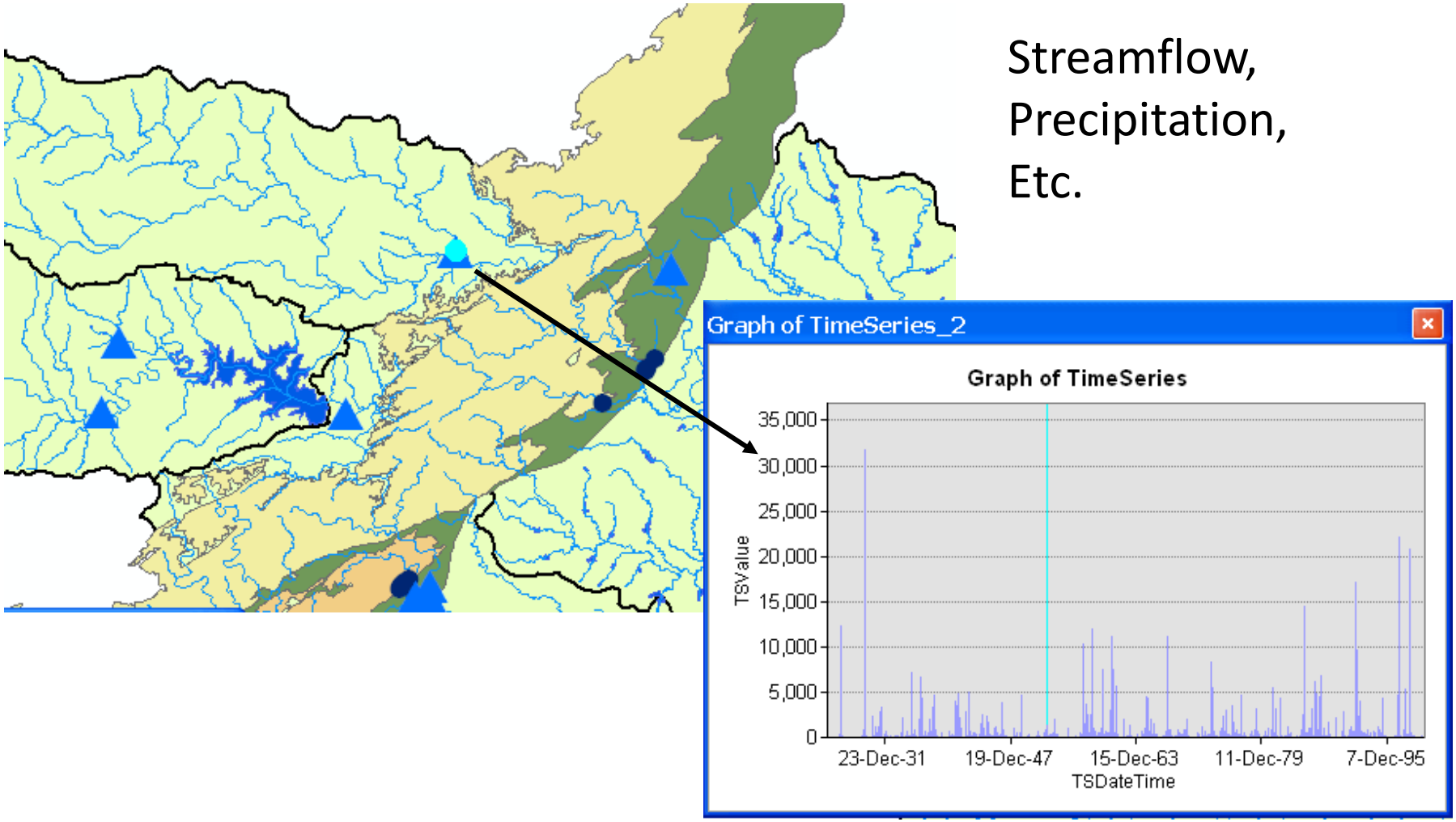


Wells and TimeSeries

Wells are related with time series (e.g., water levels, water quality)

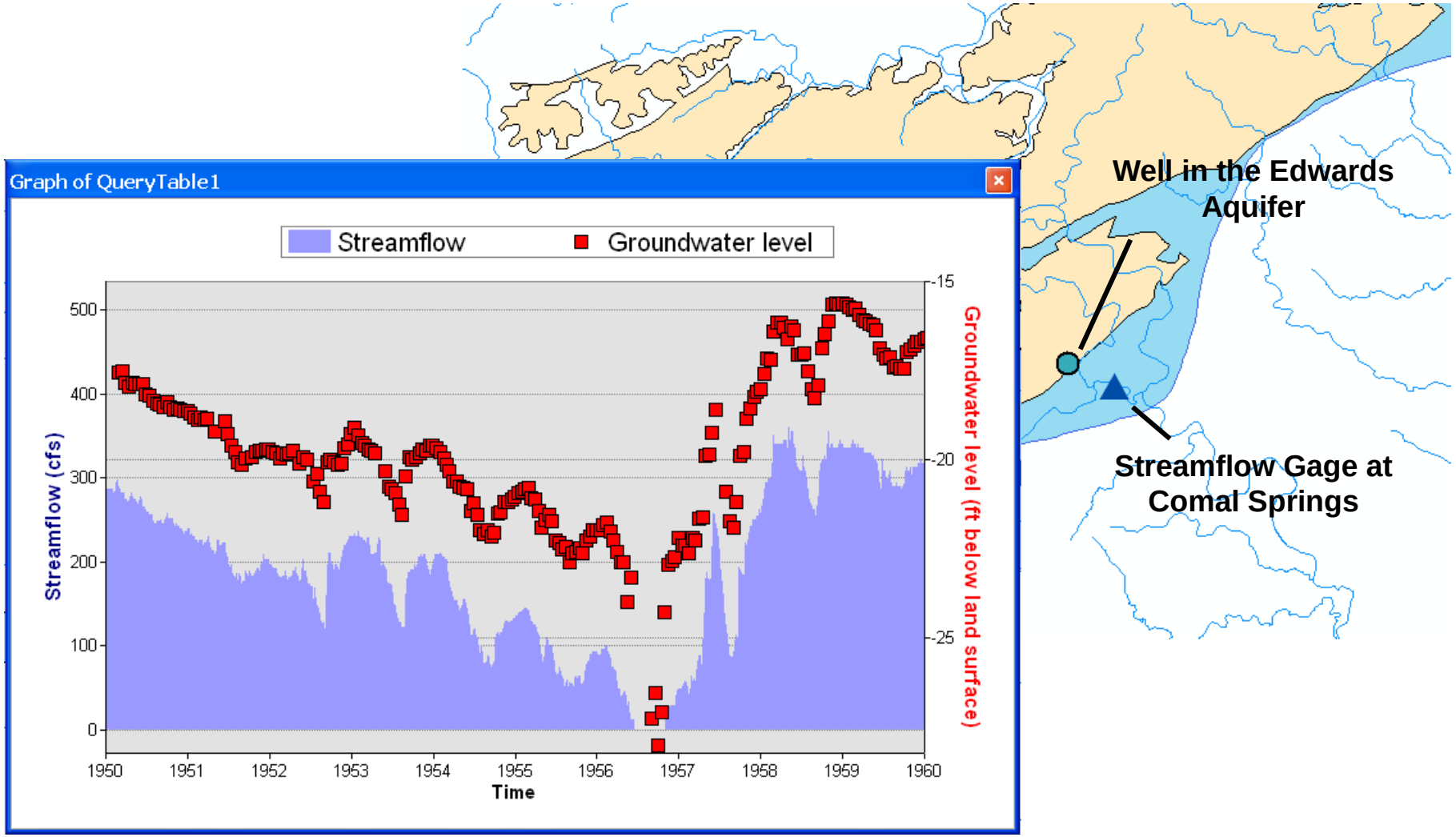


MonitoringPoints and Time Series



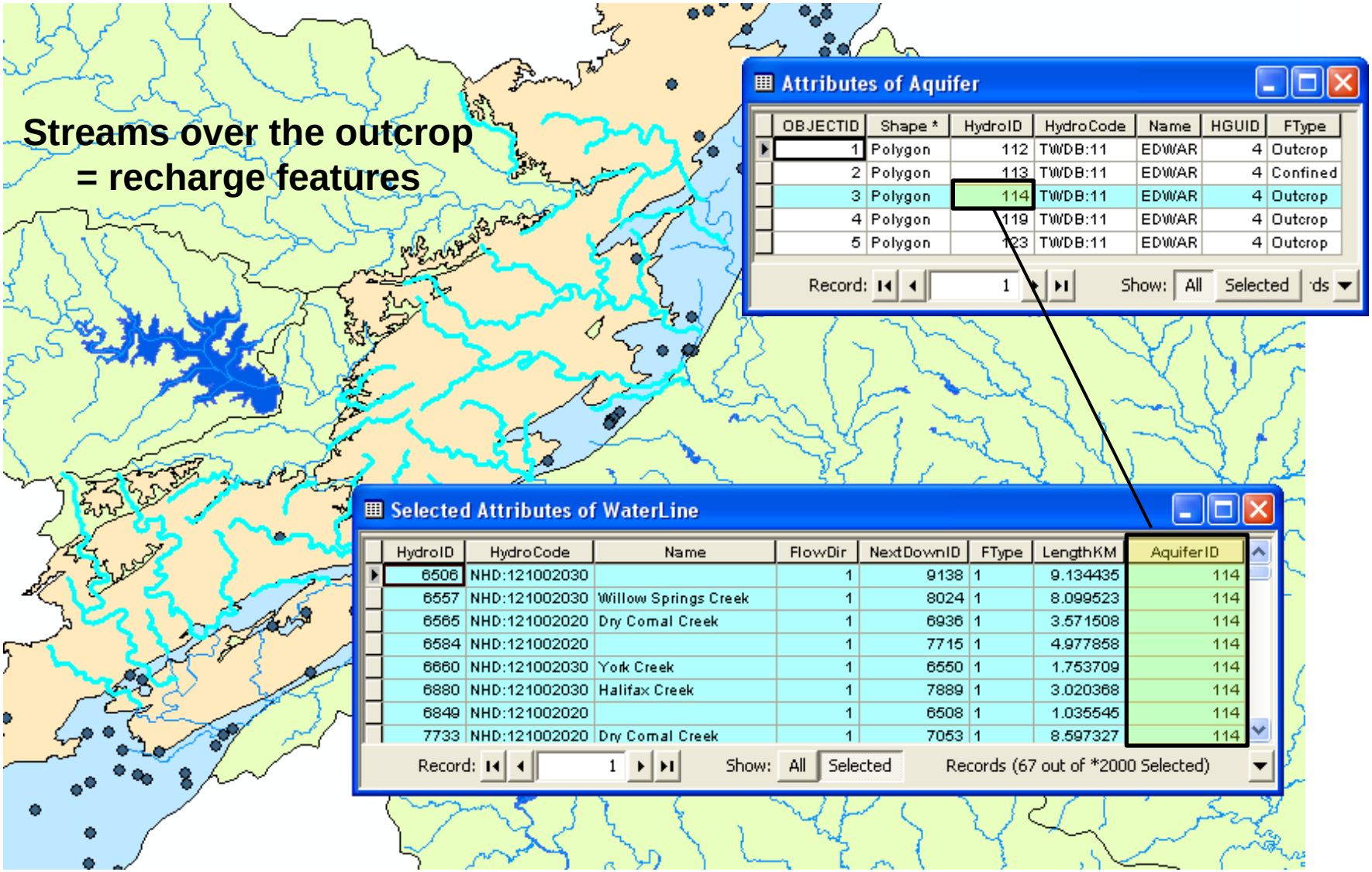
Streamflow,
Precipitation,
Etc.

The common framework supports analysis of surface water and groundwater data together



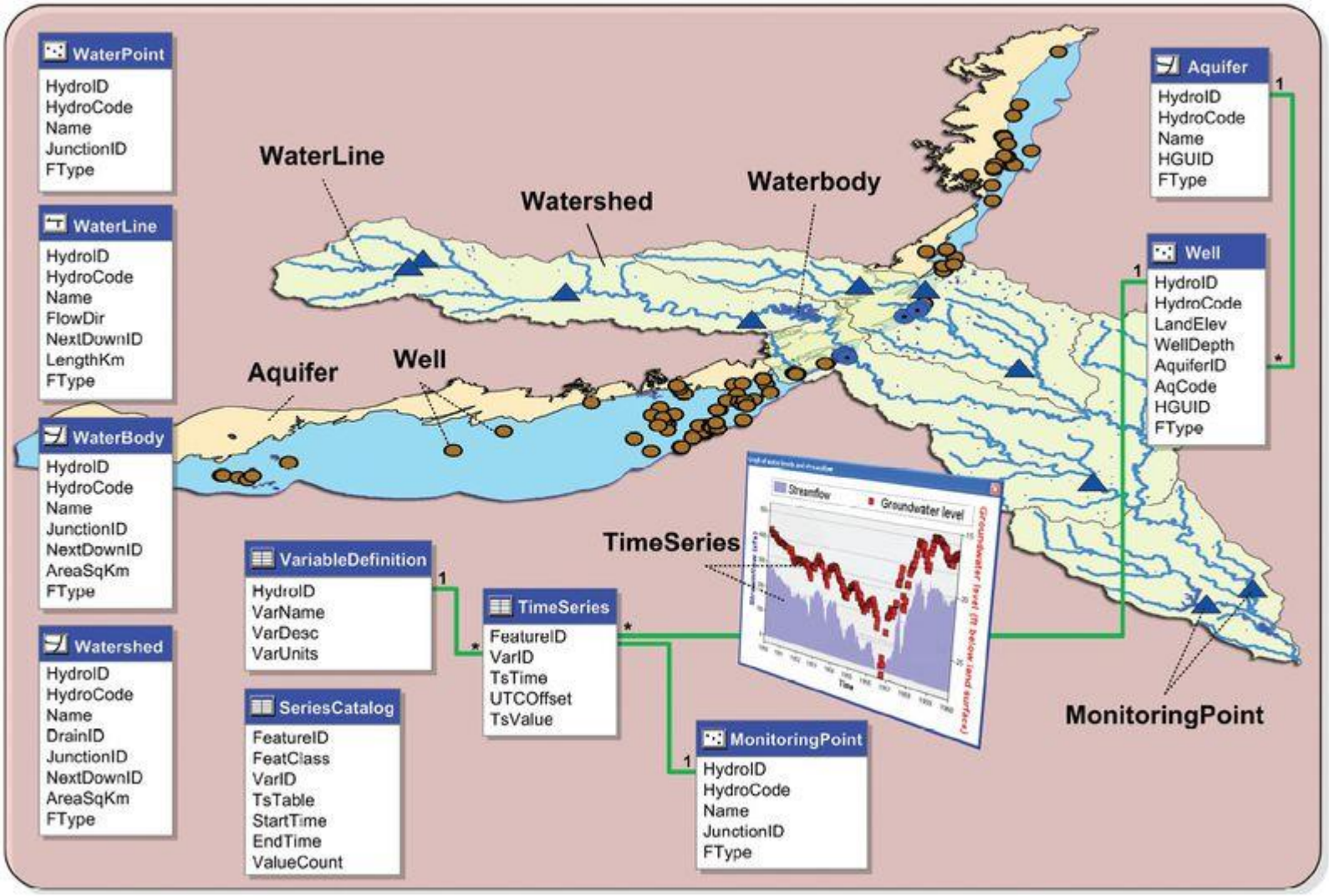
Surface water - groundwater linkage

Relationships between surface water and aquifer enable analysis based on spatial and hydrologic relationships



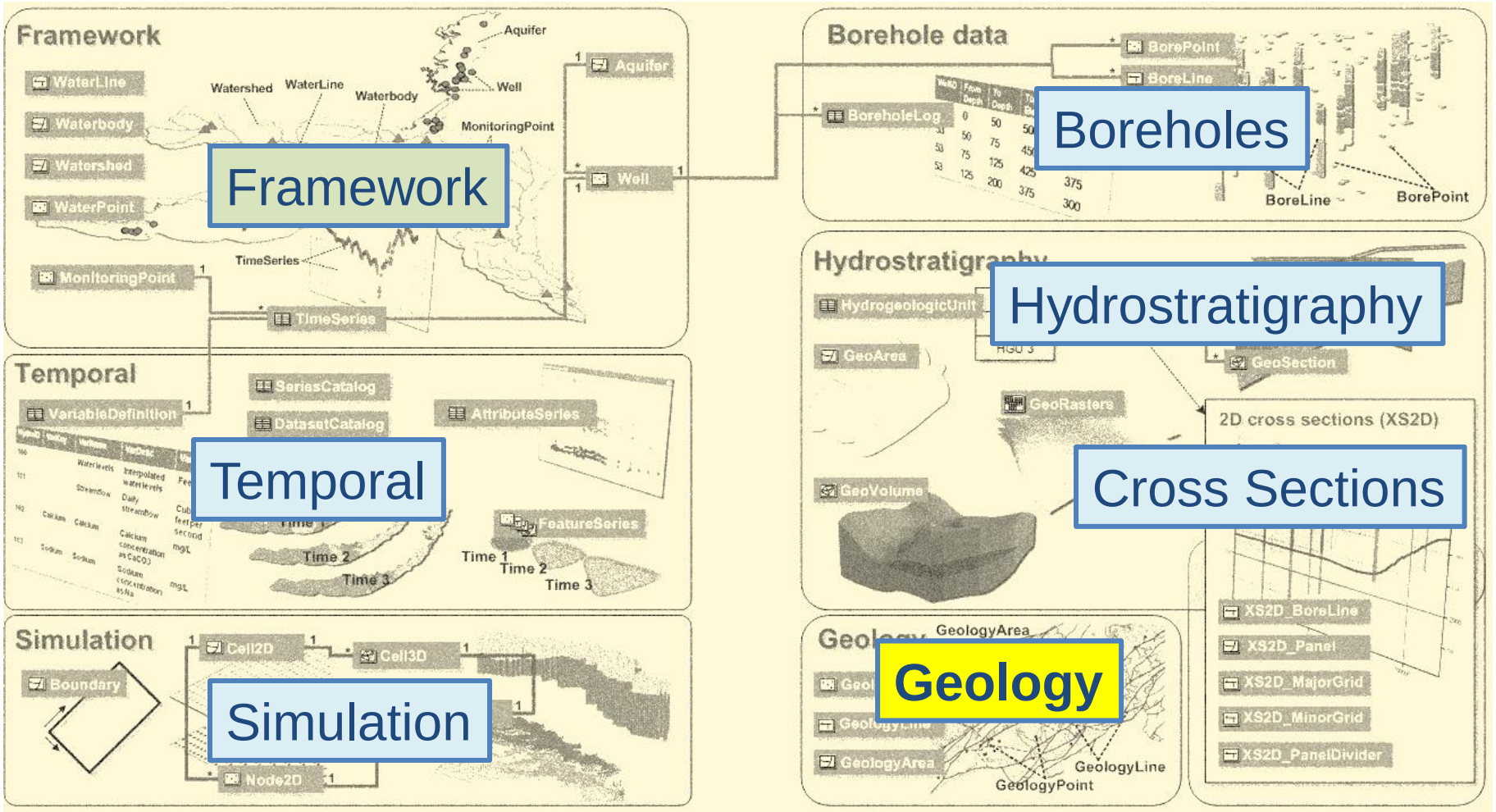
Arc Hydro Framework - Review

Note the relationships (the lines connecting the boxes)



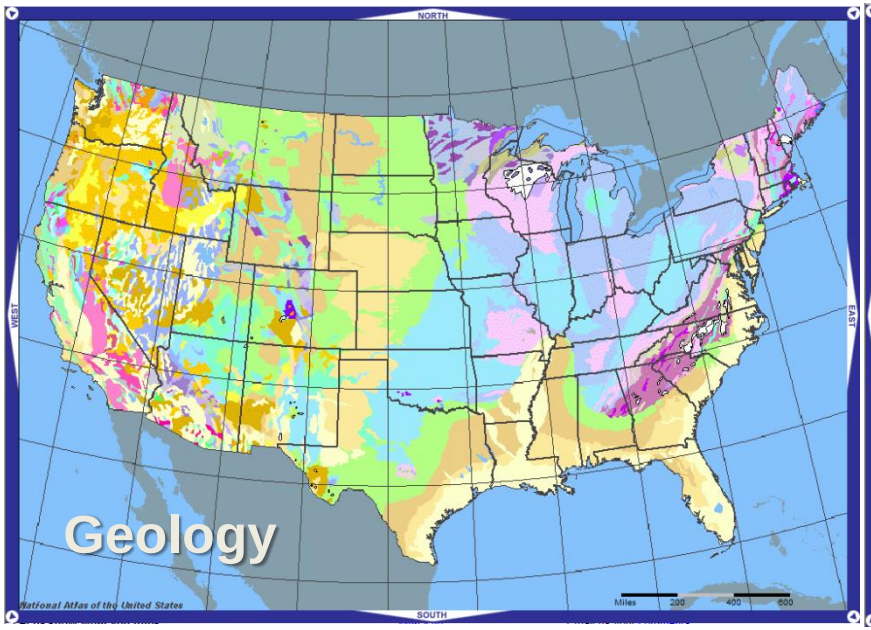
http://www.archydrogw.com/File:Archydrogw_framework.JPG

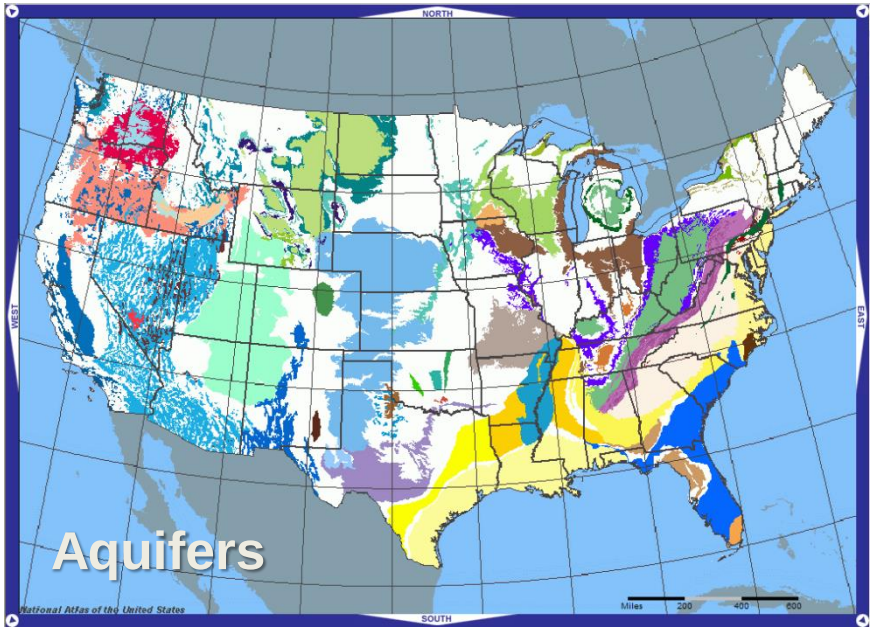
Arc Hydro Groundwater Data Model



Geologic maps

- Are closely tied to geology
- Vary in scale (continental, regional, local)

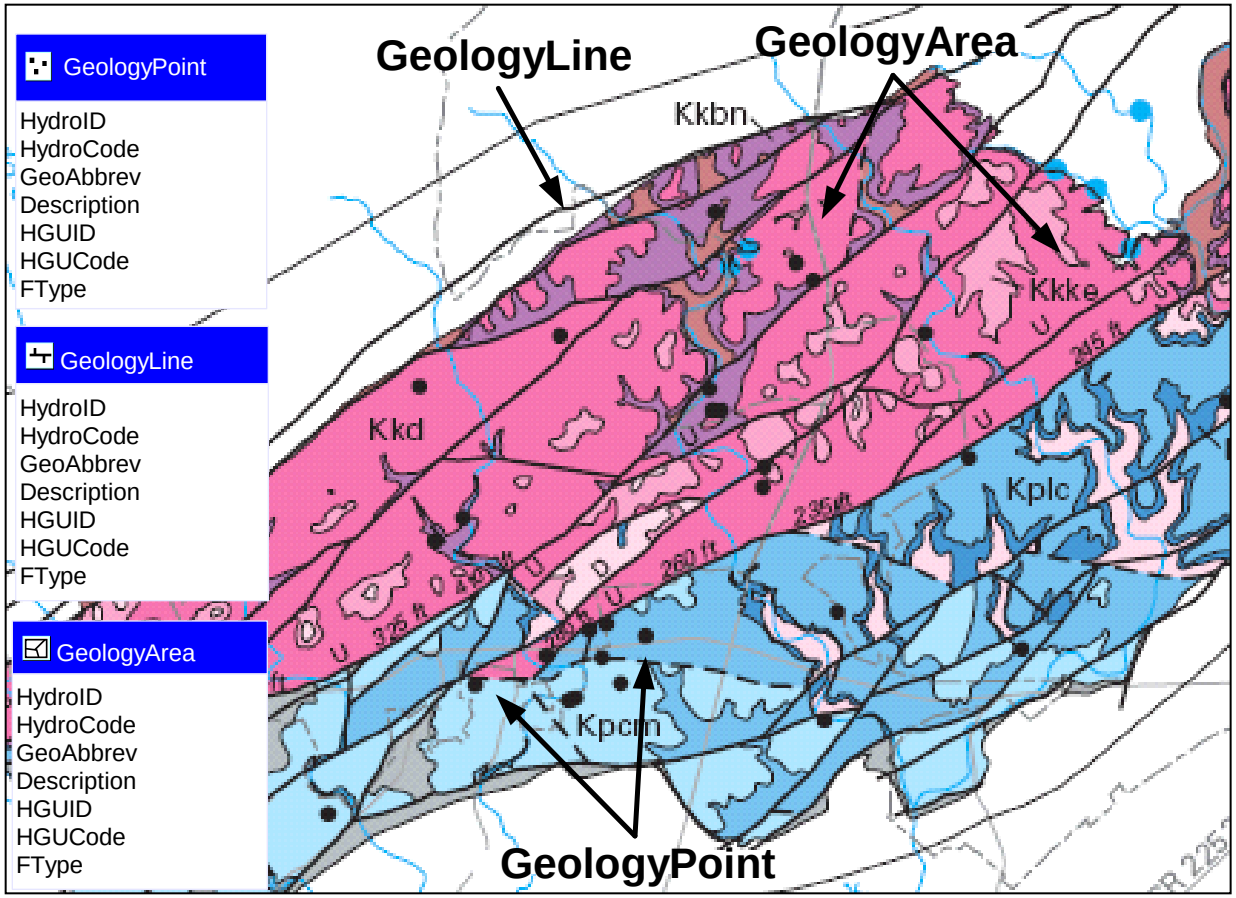




maps from http://nationalatlas.gov

Arc Hydro Geology Component

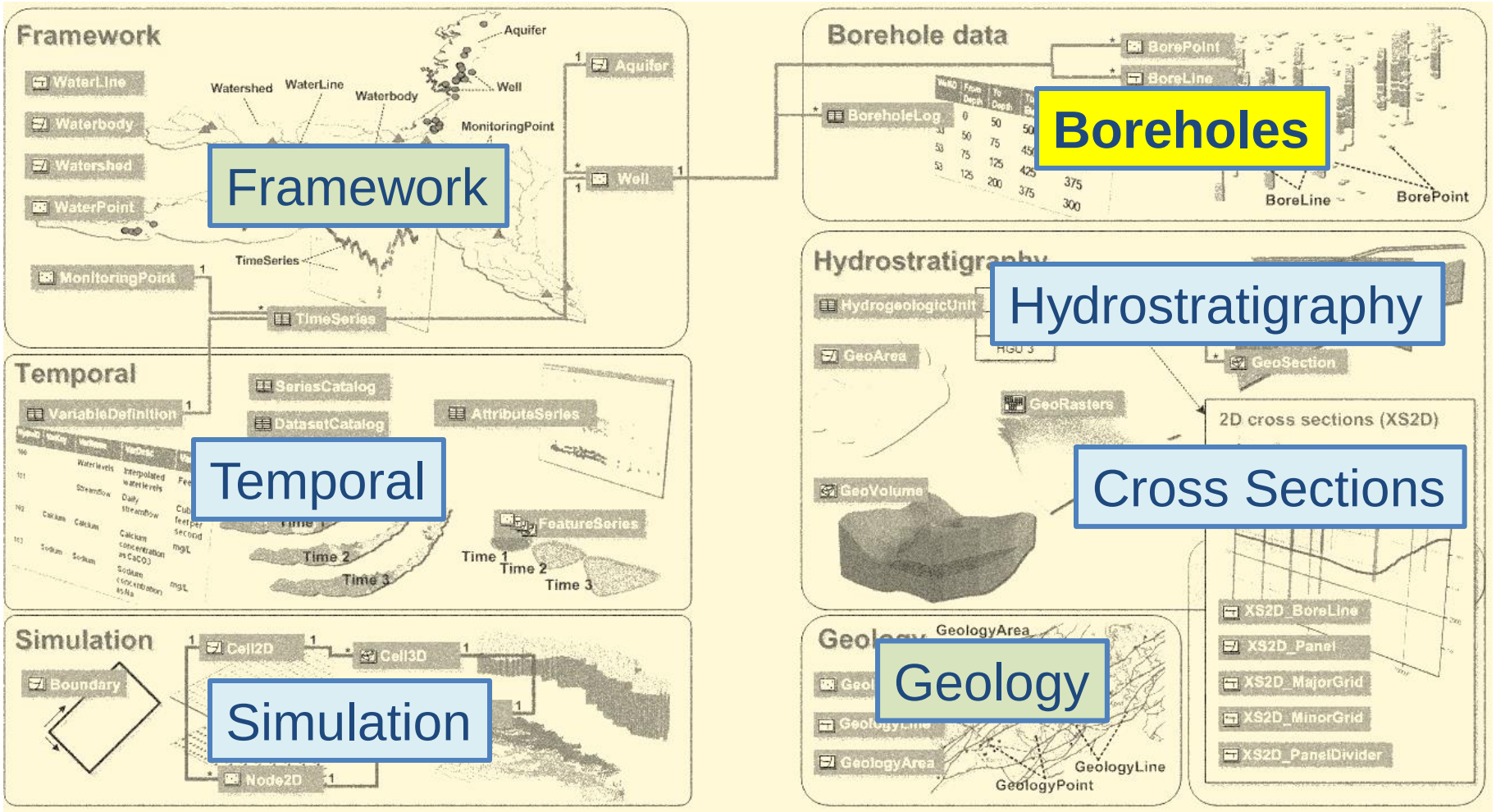
GeologyPoint: e.g., springs, caves, sinks, observation points
GeologyLine: e.g., faults, contacts
GeologyArea: e.g., outcrops



A simple data model to support geologic maps

Map modified from: Geologic map of the Edwards Aquifer recharge zone, south-central Texas. U.S. Geological Survey SIM 2873

Arc Hydro Groundwater Data Model



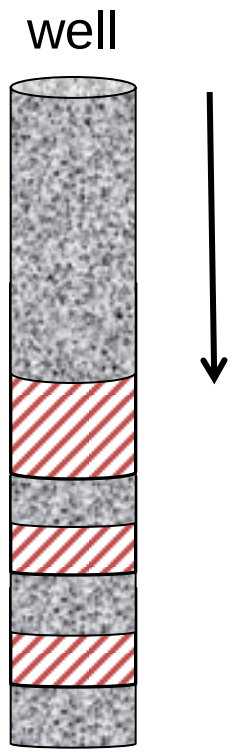
Borehole data

- Vertical data (screens, stratigraphy) referenced along the well
- From depth (top), To depth (bottom), and Description

From (ft)	To (ft)	Description and color of formation material

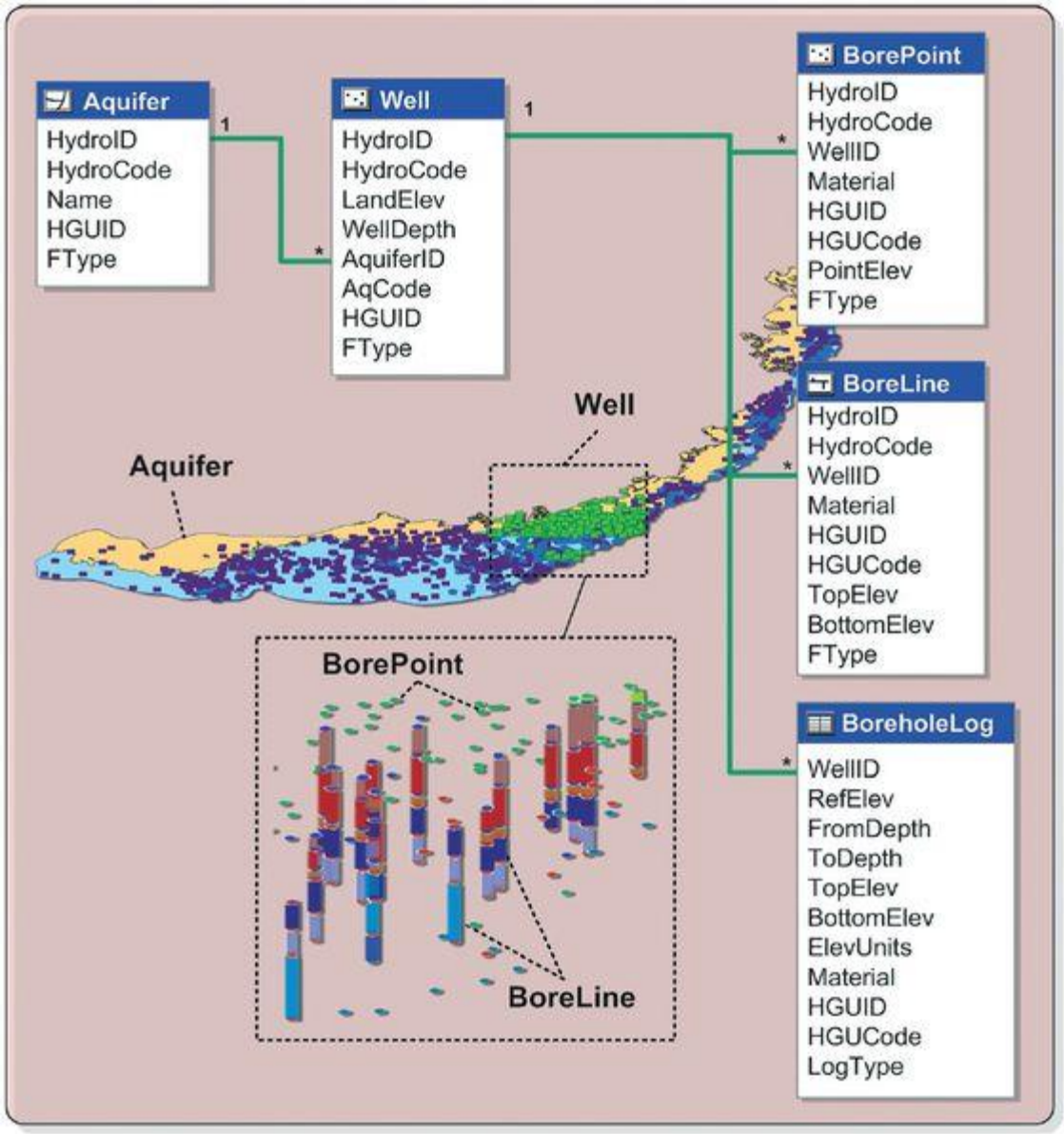
Casing, Blank Pipe, and Well Screen Data

Dia. (in.)	New Or Used	Steel, Plastic, etc. Perf., Slotted, etc Screen Mfg., if commercial	Setting (ft) From	Setting (ft) To	Gage Casing Screen



Arc Hydro Borehole Component

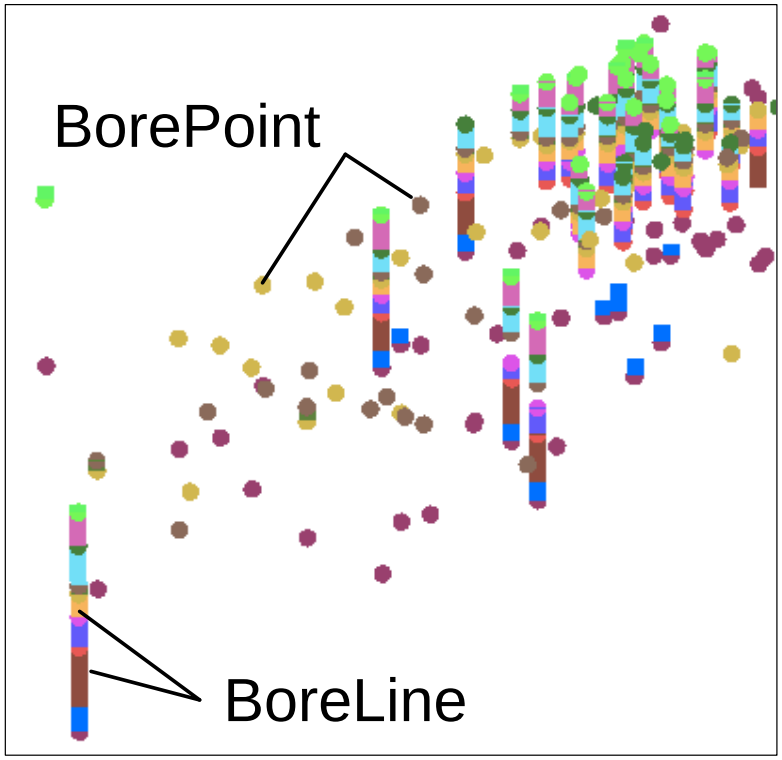
Stores borehole data and represents data in 3D

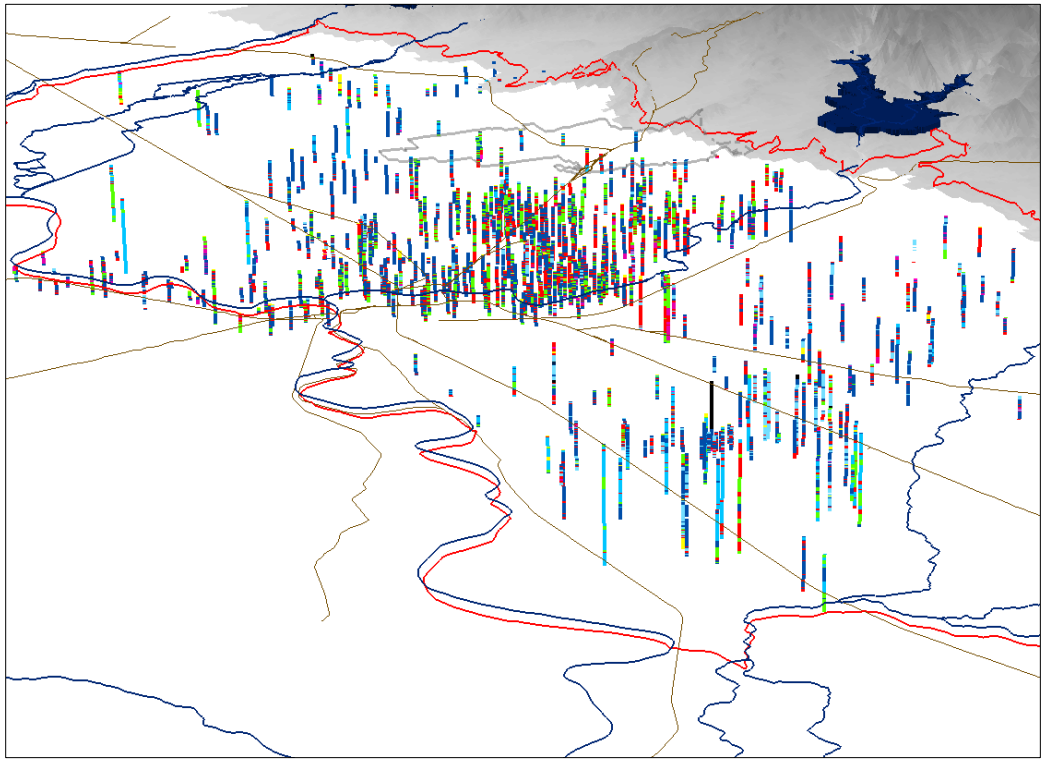


http://www.archydrogw.com/File:Archydrogw_wellsandboreholes.JPG

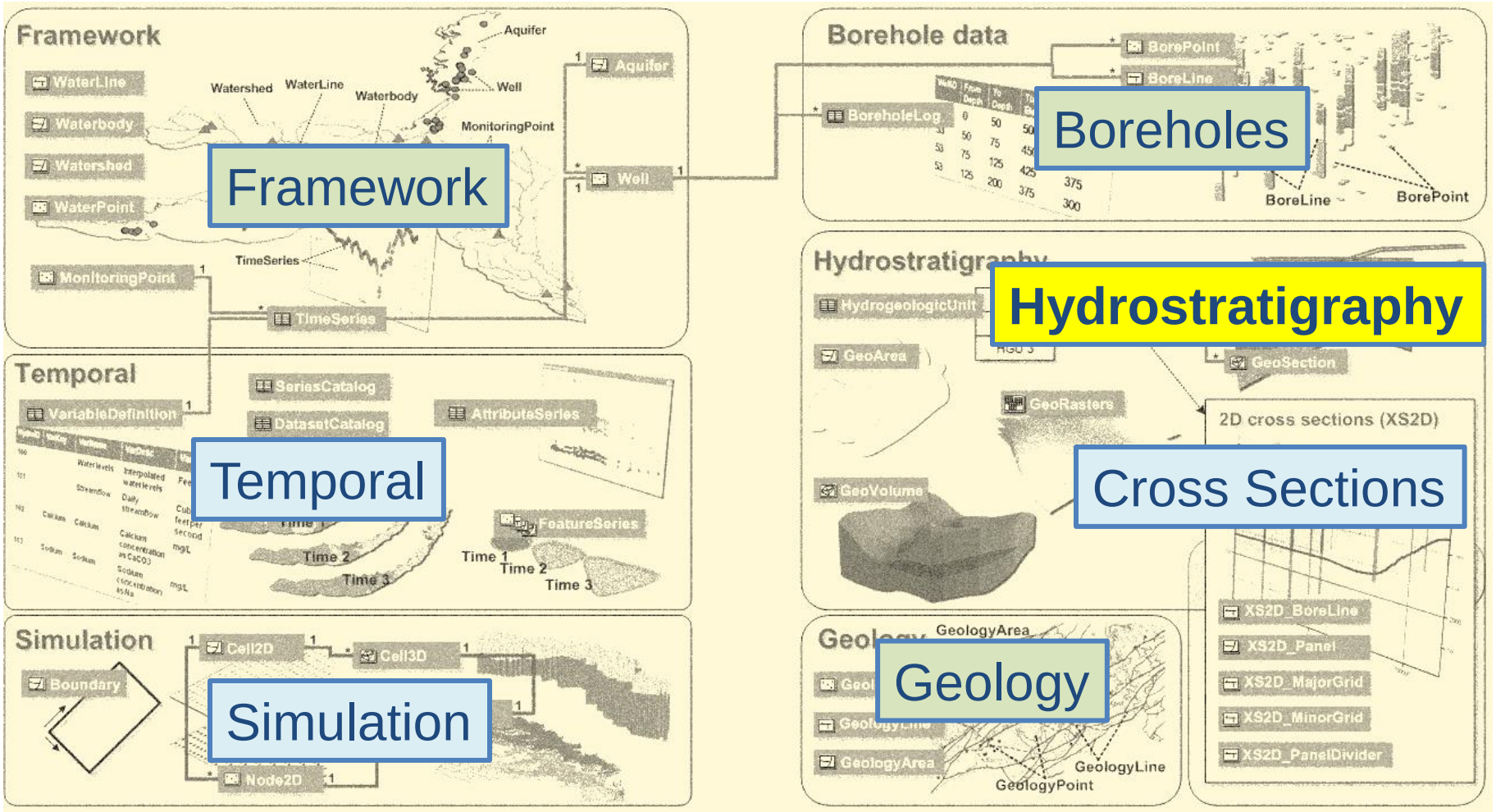
BorePoints and BoreLines

- 3D features representing data in the BoreholeLog table
- BorePoint is a 3D point feature class for representing point locations along a borehole (e.g., geologic contacts, samples)
- BoreLine is a 3D line feature class for representing intervals along a borehole





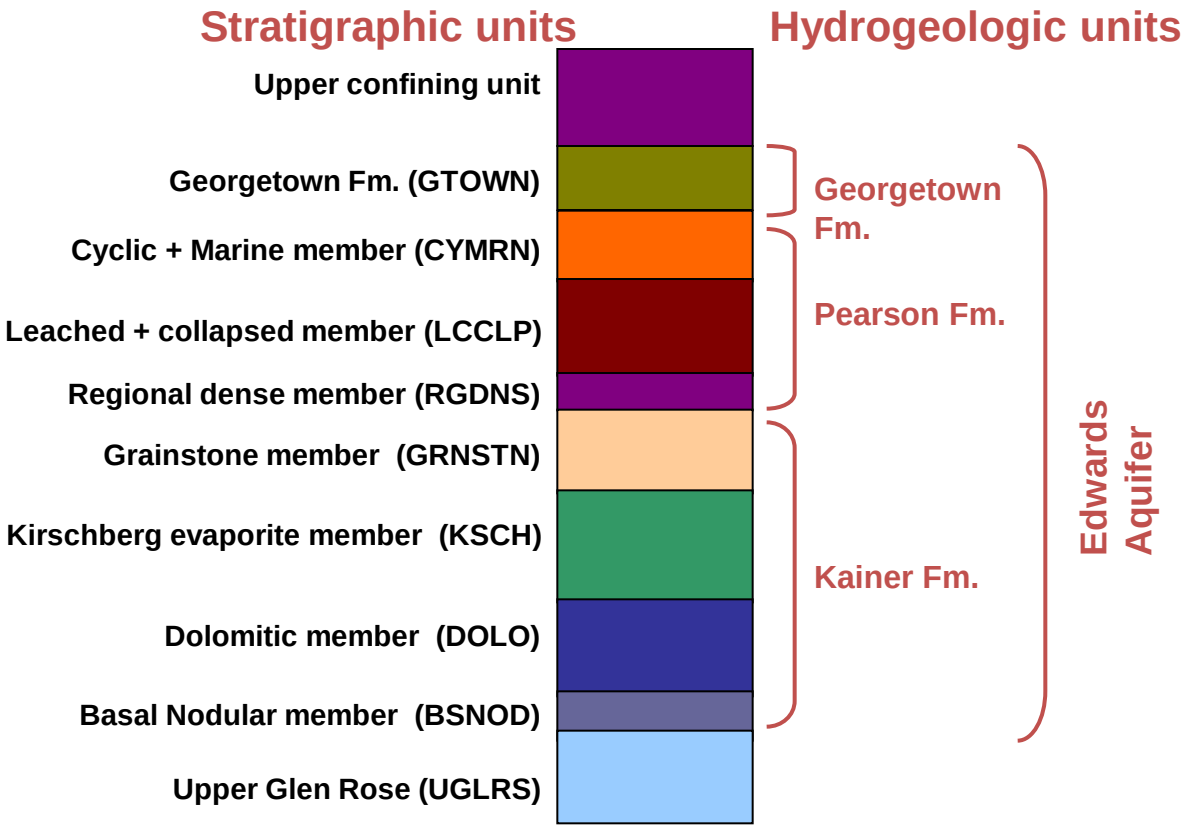
Arc Hydro Groundwater Data Model



Hydrogeologic units

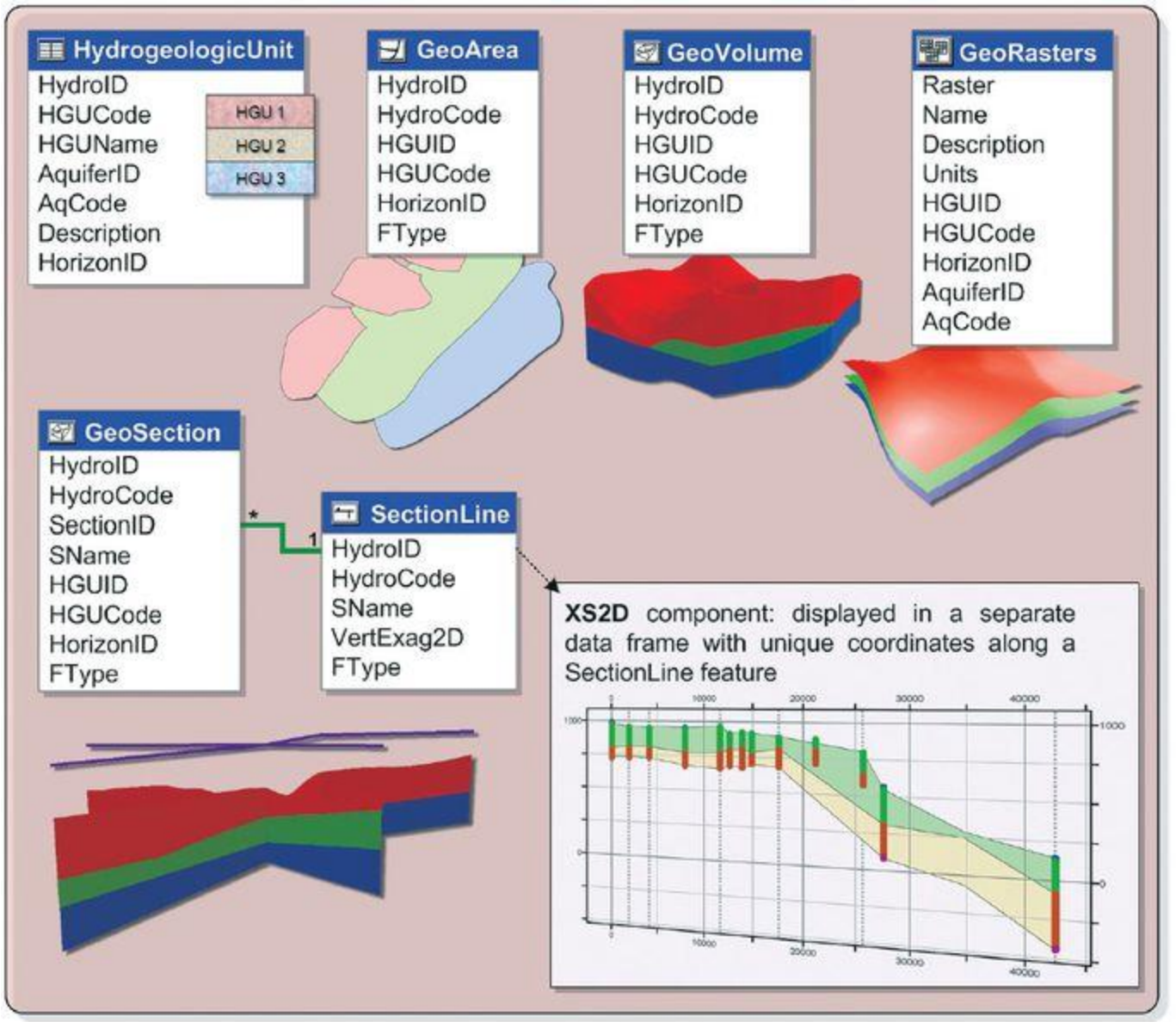
"Hydrogeologic unit is any soil or rock unit or zone which by virtue of its hydraulic properties has a distinct influence on the storage or movement of ground water" (USGS glossary of hydrologic terms)

Hydrogeology can be derived by classifying stratigraphic units



Arc Hydro Hydrostratigraphy

Hydrogeologic units in 2D and 3D



http://www.archydrogw.com/File:Archydrogw_hydrostratigraphy.JPG

Hydrogeologic unit table

- Provides a conceptual description of hydrogeologic units
- Units are indexed with an HGUID
- Units can be grouped into an aquifer via AquiferID

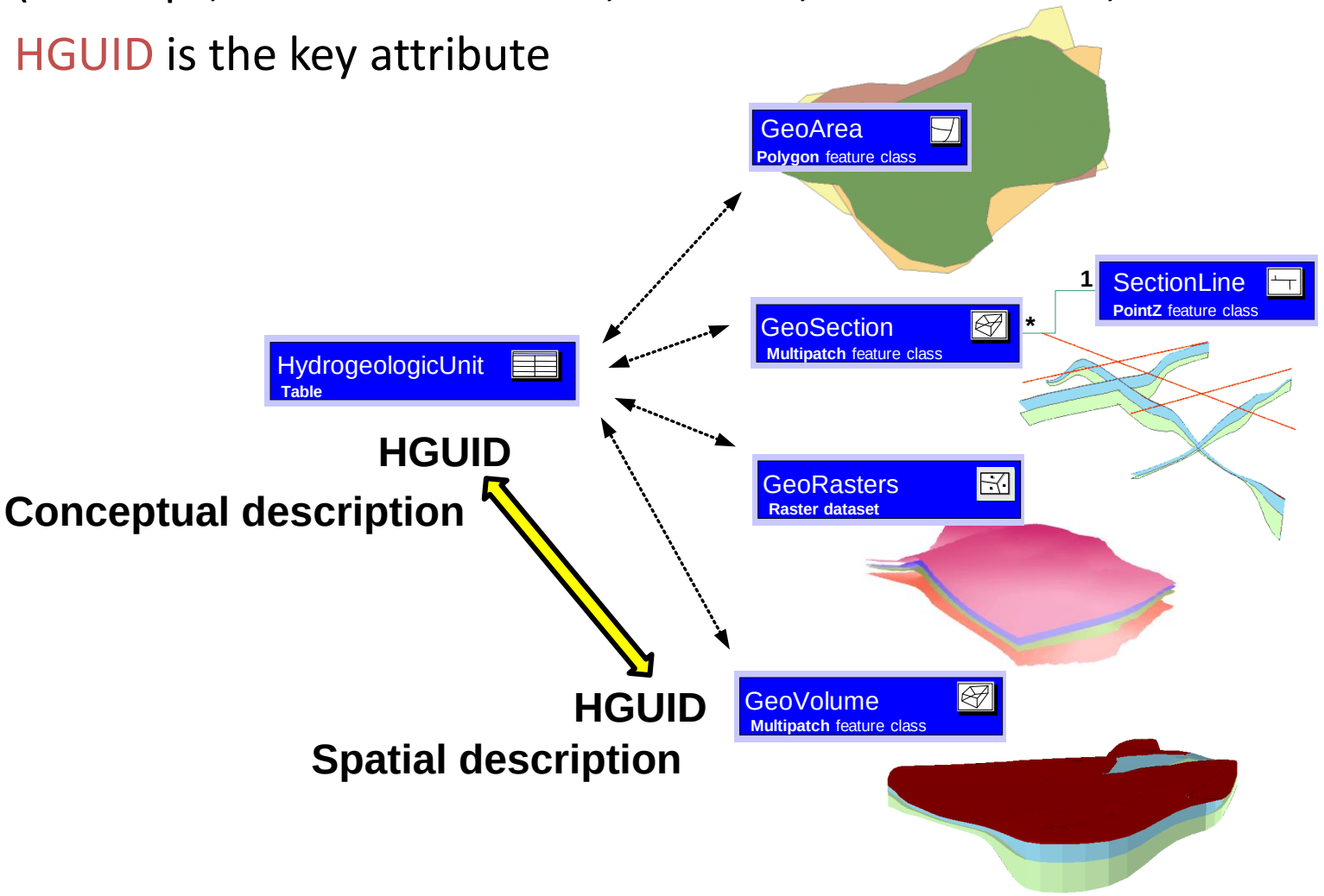
Attributes of HydrogeologicUnit

HGUID	HGUCode	HGUName	AquiferID	AqCode	Description
1	GTOWN	Georgetown Formation	4761	Edwards	Georgetwown formation is the upper formation in the Edwards aquifer
2	PERSON	Person Formation	4761	Edwards	Pearson formatin includes the following fomrations: CYMRN, LCCLP, RGDNS
3	KAINER	Kainer Formation	4761	Edwards	Kainer formation includes the foolowing formations: GRNSTN, KSCH, DOLO, BSNOD
4	UGLRS	Upper Glen Rose	<Null>		Glen Rose limestone
5	<Null>	Edwards Aquifer	4761	Edwards	Edwards Aquifer

Record: 0 Show: All Selected Records (0 out of 5 Selected) Options

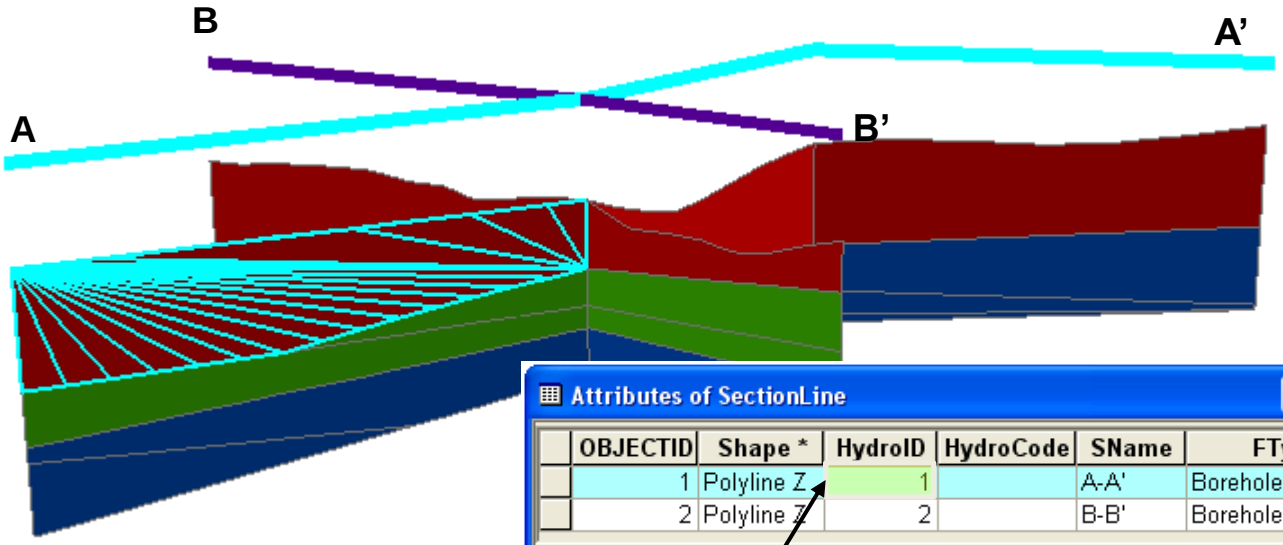
Hydrogeologic unit table

- Hydrogeologic units are described with different spatial instances (outcrops, borehole intervals, surfaces, cross sections, and volumes)
- HGUID is the key attribute



3D Representation of Cross Sections

- SectionLine defines the location of the 2D cross section
- GeoSection represent 3D sections as 3D features
- SectionID of a GeoSection feature relates back to the section line



Attributes of SectionLine

OBJECTID	Shape *	HydroID	HydroCode	SName	FType
1	Polyline Z	1		A-A'	Borehole Section
2	Polyline Z	2		B-B'	Borehole Section

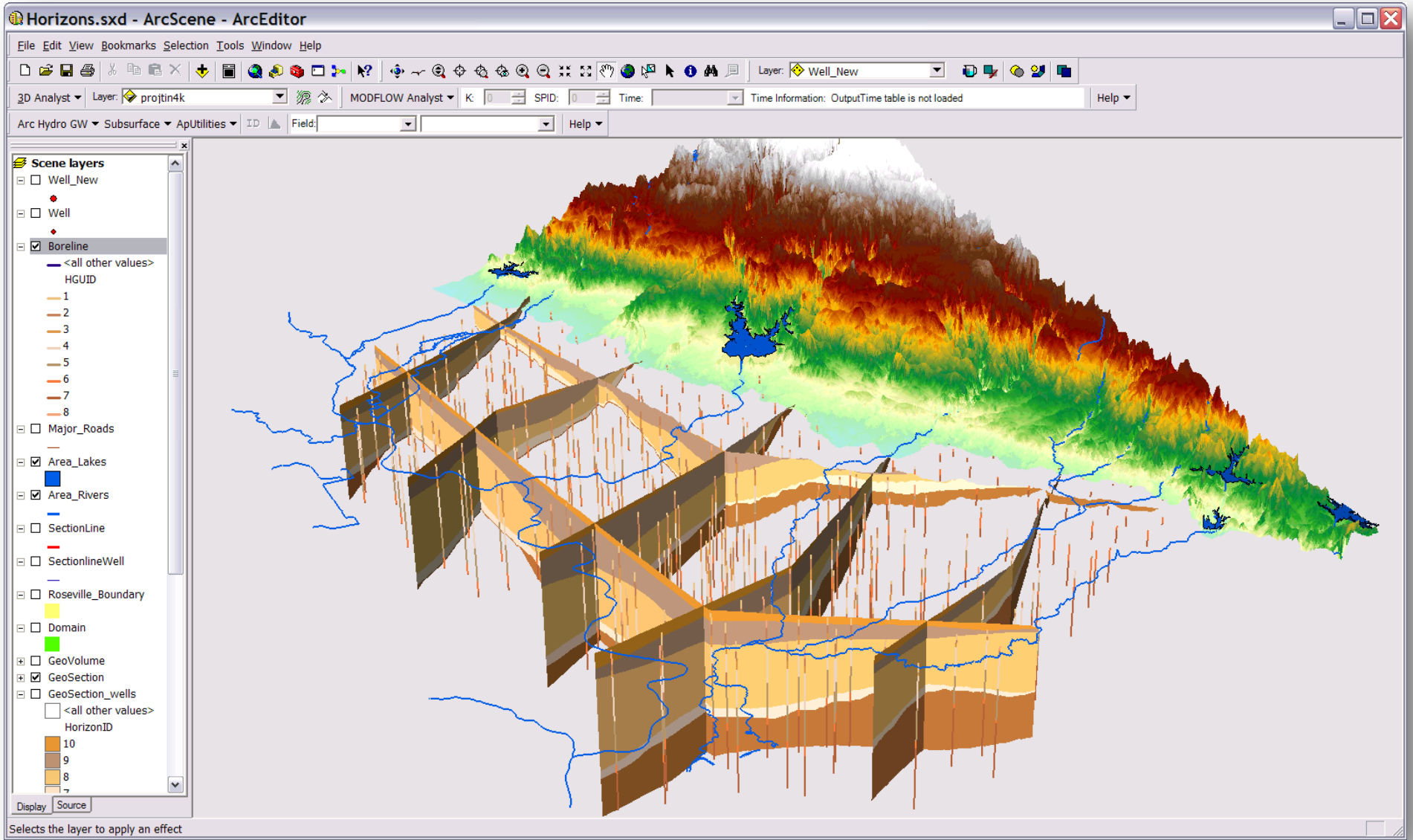
Record: 0 Show: All Selected Records (1 out

Attributes of GeoSection

Object ID	Shape *	HydroID	HydroCode	SectionID	SName	HGUID	HGUCode	FType
15	Polygon ZM	3000014		1	A-A'	1	HGU 1	Borehole Sections
20	Polygon ZM	3000019		1	A-A'	1	HGU 1	Borehole Sections
29	Polygon ZM	3000028		2	B-B'	1	HGU 1	Borehole Sections
11	Polygon ZM	3000010		1	A-A'	1	HGU 1	Borehole Sections
25	Polygon ZM	3000024		2	B-B'	1	HGU 1	Borehole Sections

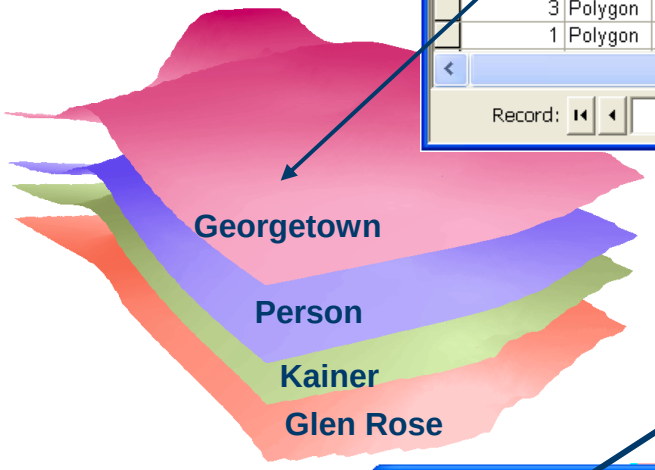
Record: 0 Show: All Selected Records (1 out of 23 Selected) Options

GeoSections



GeoRasters

- Raster catalog for storing and indexing raster datasets
- Can store top and bottom of formations
- Each raster is related with a HGU in the hydrogeologic unit table



Attributes of GeoRasters

OBJECTID	Shape *	Raster	Name	Description	RasterUnits	HGUID	HGUCode	AquiferID	AquiferCode
4	Polygon	<Raster	gtown_surface	top of formation	feet from mean sea level	1	GTOWN	<Null>	
2	Polygon	<Raster	person_surface	top of formation	feet from mean sea level	2	PERSON	<Null>	
3	Polygon	<Raster	kainer_surface	top of formation	feet from mean sea level	3	KAINER	<Null>	
1	Polygon	<Raster	uglrs_surface	top of formation	feet from mean sea level	4	GLEN ROSE	<Null>	

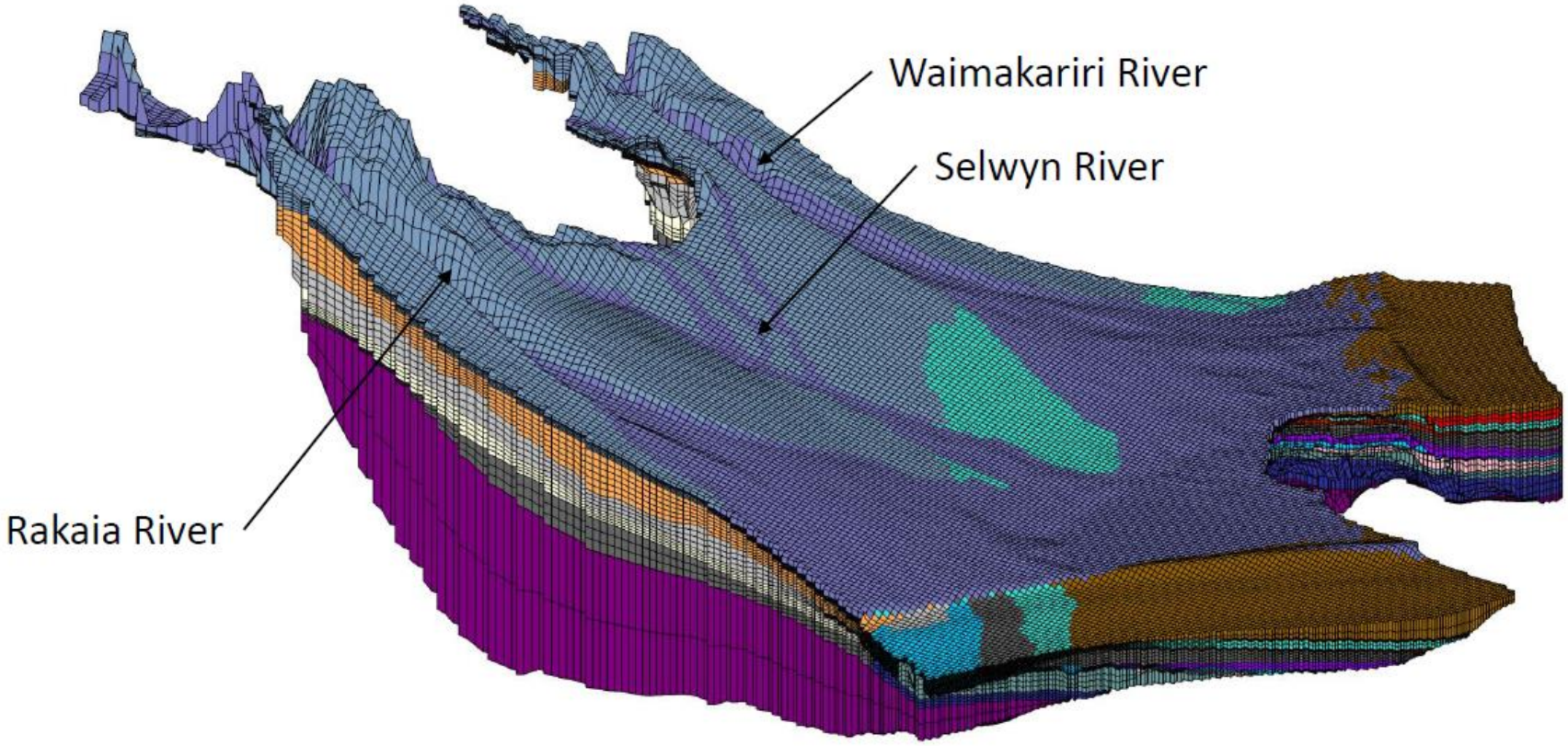
Record: 0 Show: All Selected Records (1 out of 5 Selected) Options

Attributes of HydroGeologicUnit

HGUID	HGUName	HGUCode	AquiferID	AqCode	Description
1	Georgetown Formation	GTOWN	11	Edwards	Georgetwown formation is the upper formation in the Edwards aquifer
2	Person Formation	PERSON	11	Edwards	Pearson formatin includes the following fomrations: CYMRN, LCCLP, RGDNS
3	Kainer Formation	KAINER	11	Edwards	Kainer formation includes the foolowing formations: GRNSTN, KSCH, DOLO, BSNOD

Record: 1 Show: All Selected Records (1 out of 3 Selected) Options

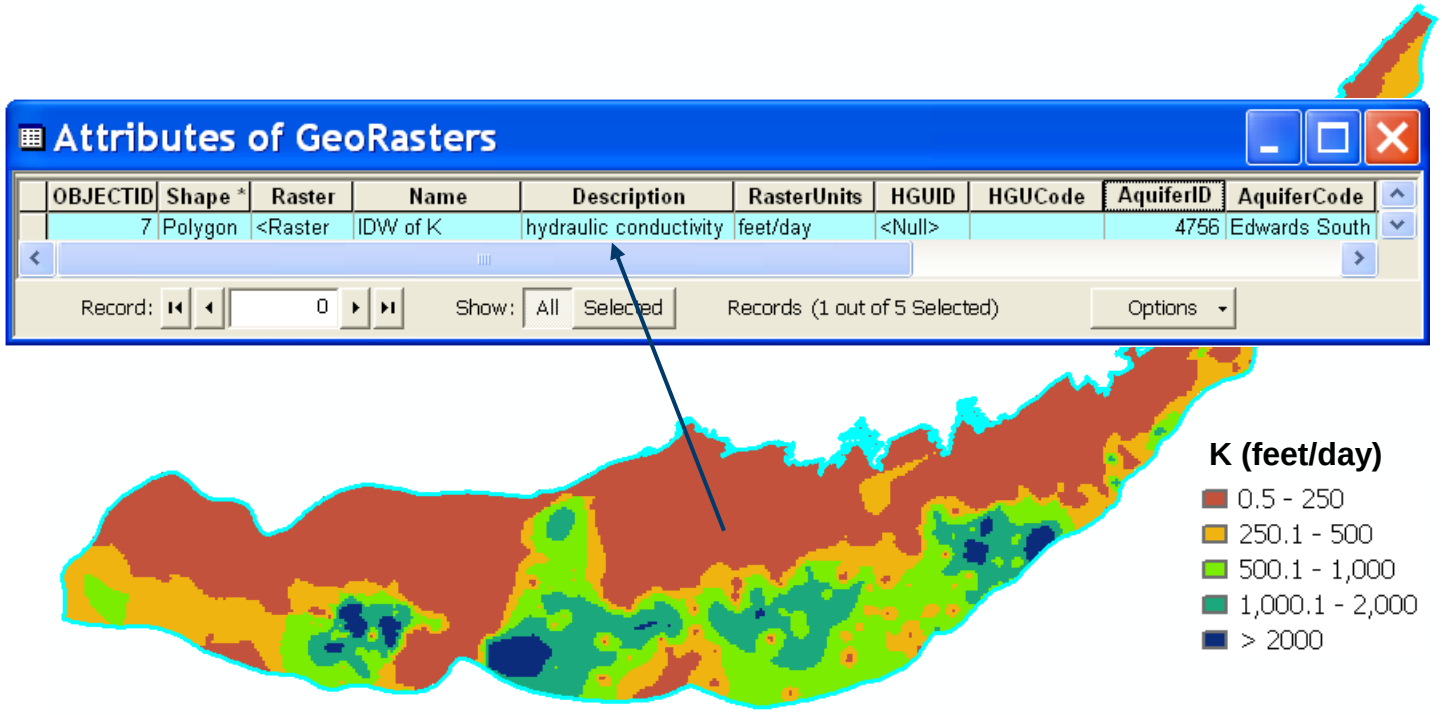
Selwyn Hydrogeological Strata



Source: Julian Weir, Aqualinc

GeoRasters

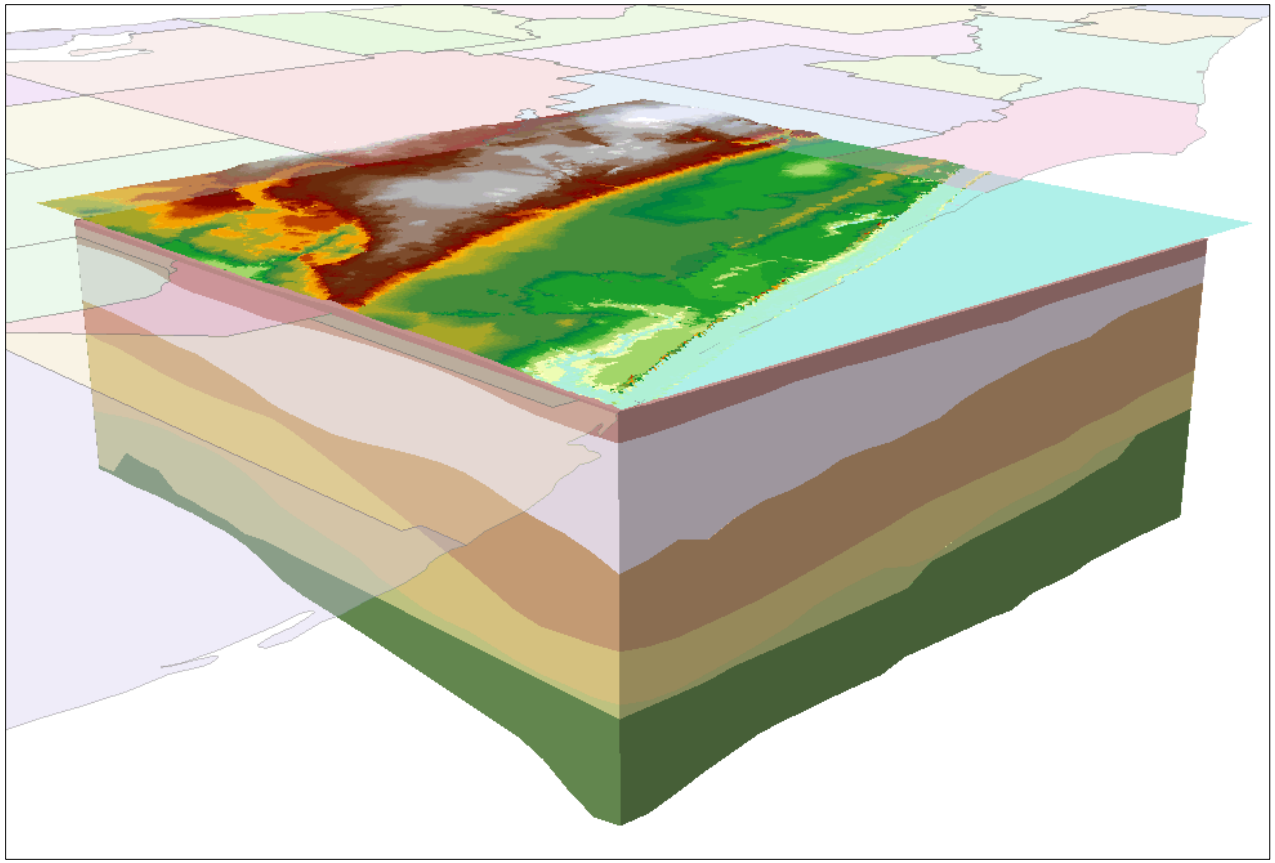
- GeoRasters also store hydraulic properties such as transmissivity, conductivity, and specific yield



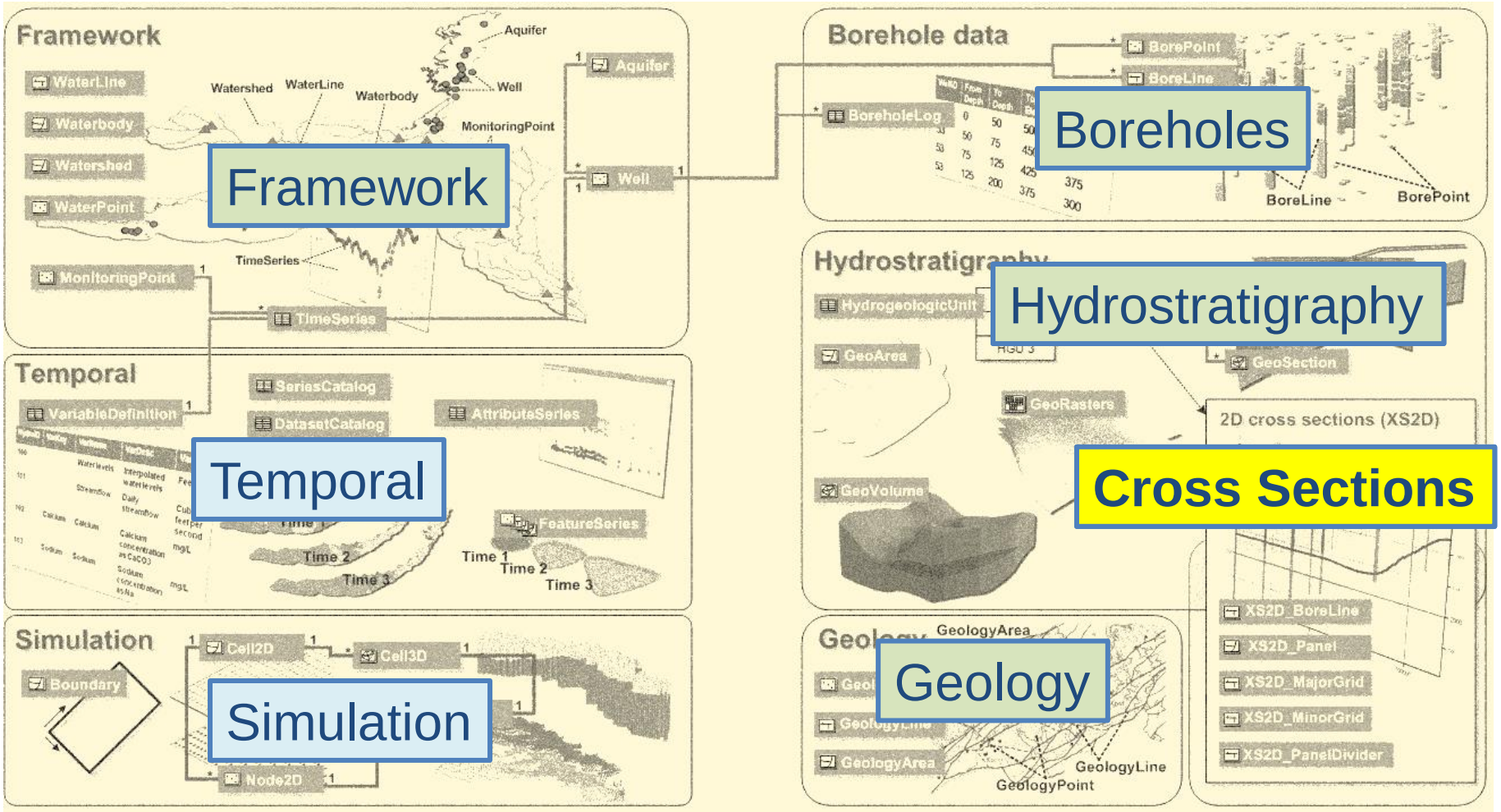
Raster of hydraulic conductivity in the Edwards Aquifer

GeoVolume

- Features representing 3D volume objects
- Geometry is multipatch



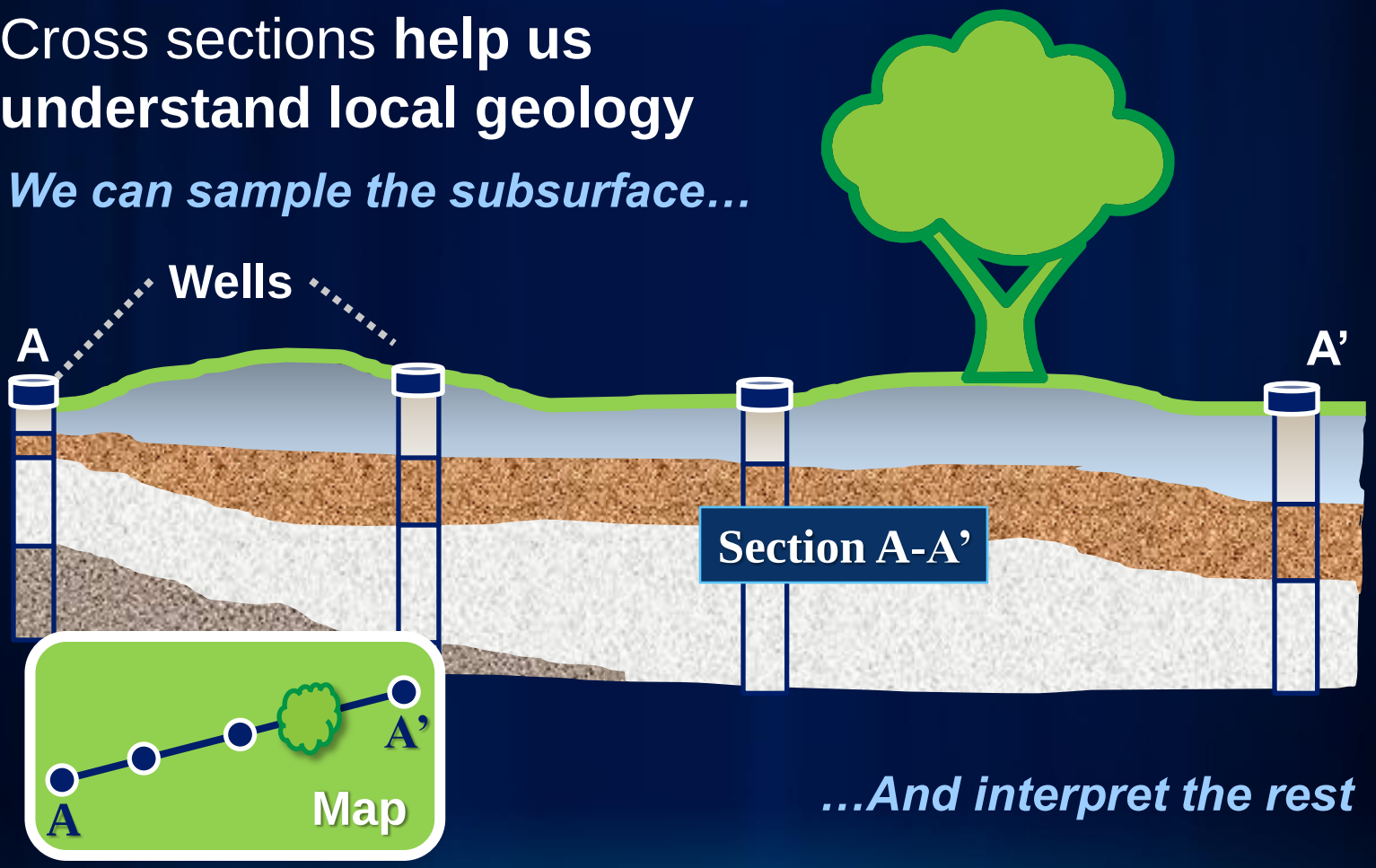
Arc Hydro Groundwater Data Model



Cross sections

Cross sections **help us understand local geology**

We can sample the subsurface…

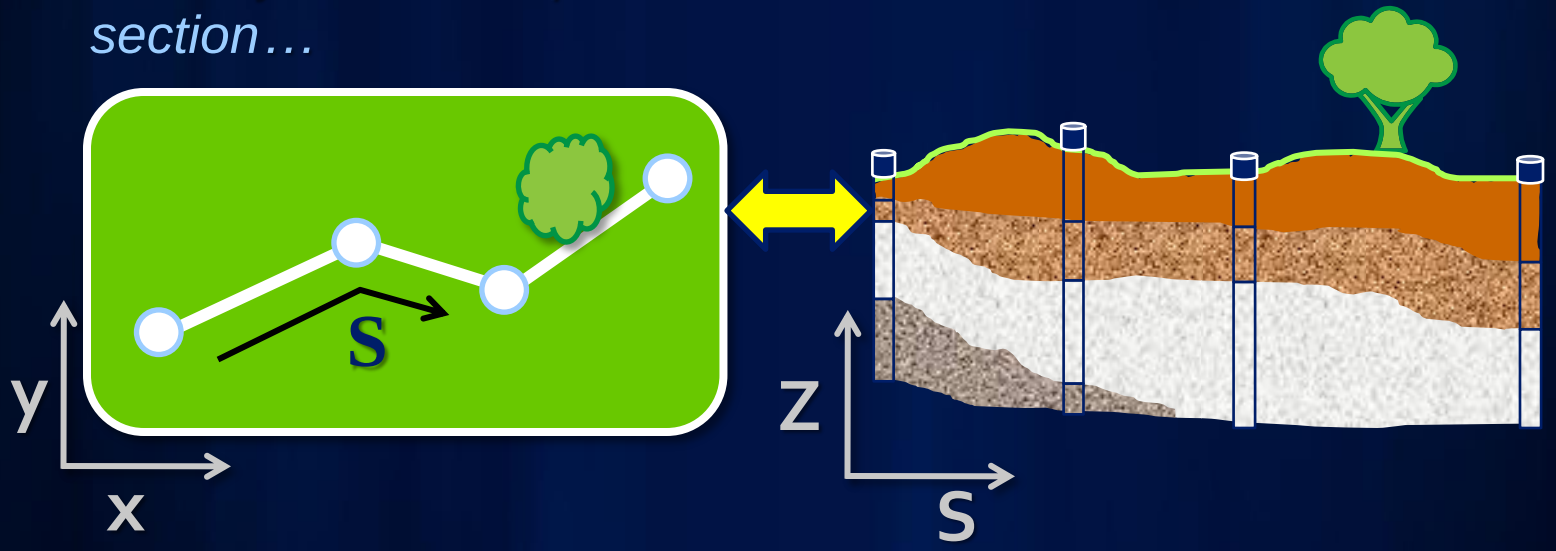


…And interpret the rest

Cross section coordinates

Cross sections use a (Distance, Elevation) coordinate system

Each system is unique to the cross section…

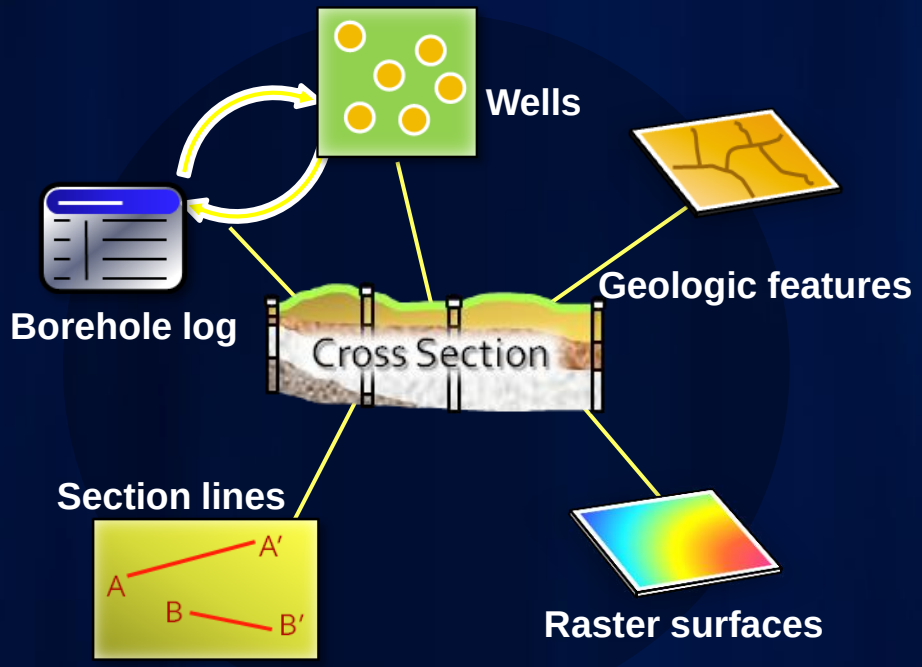


And includes vertical exaggeration…

GIS datasets

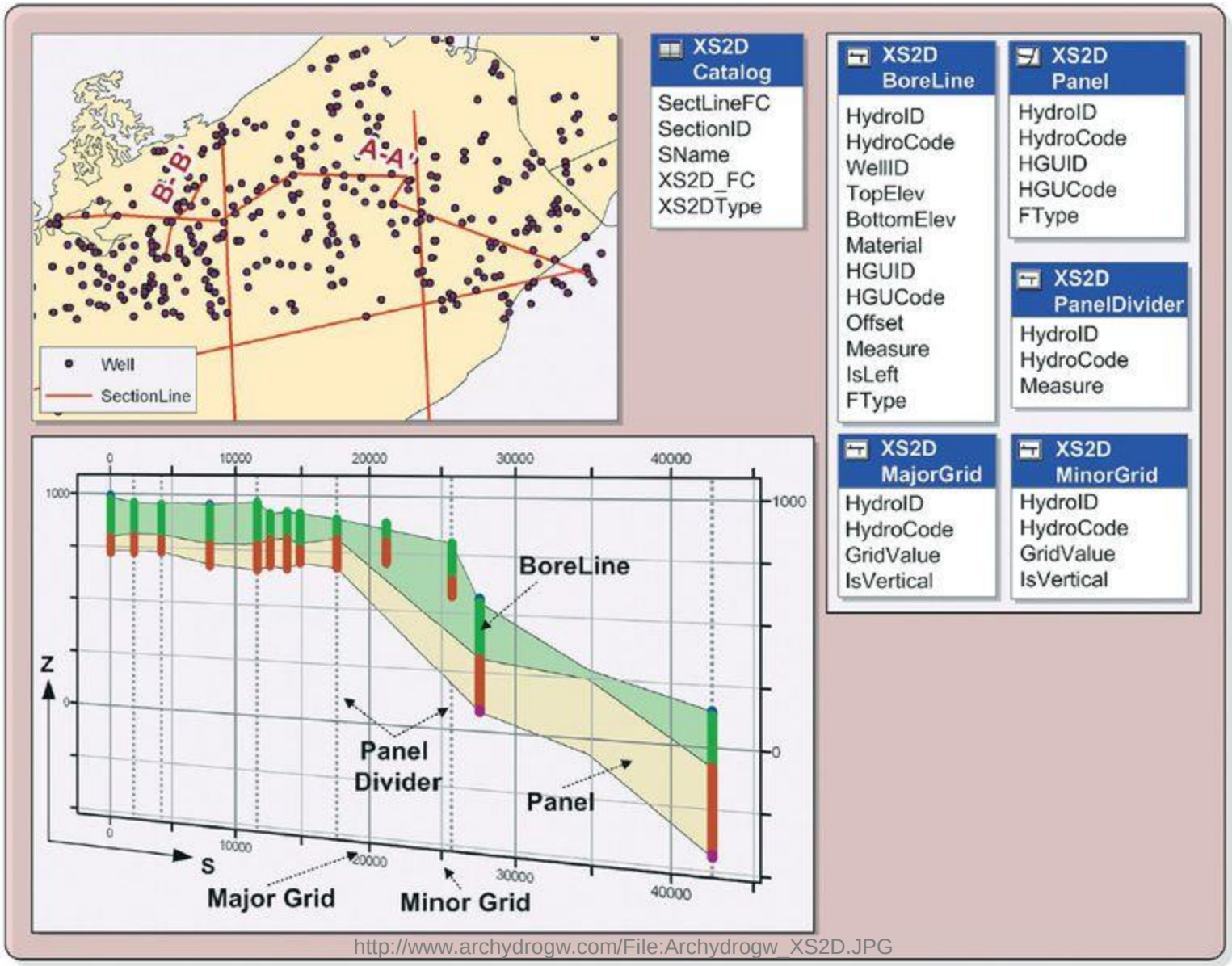
We'd like to create cross sections **from GIS datasets**

Spatial and attribute relationships tie features together …



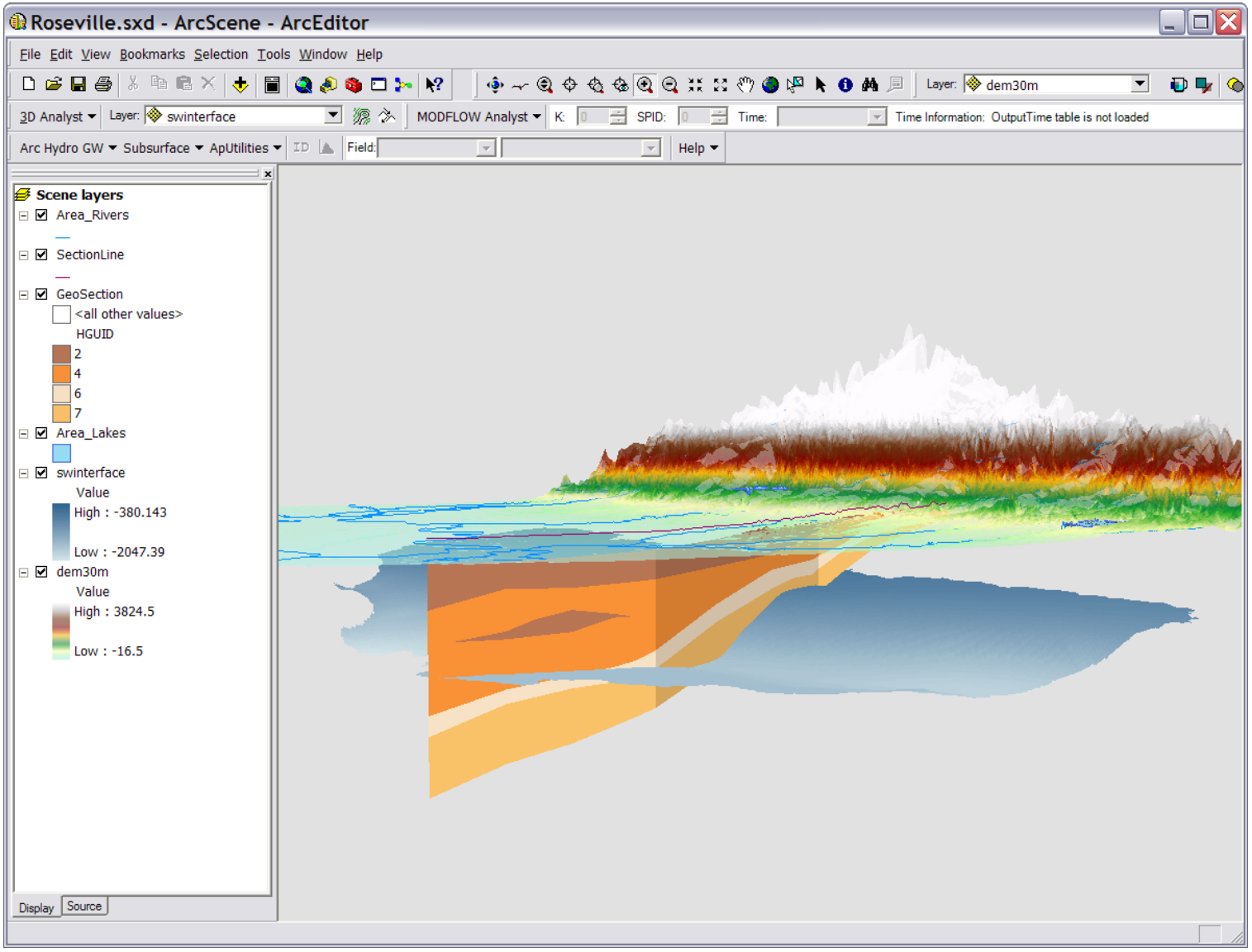
…Creating the connectivity we need to construct meaningful cross sections

XS2D Component

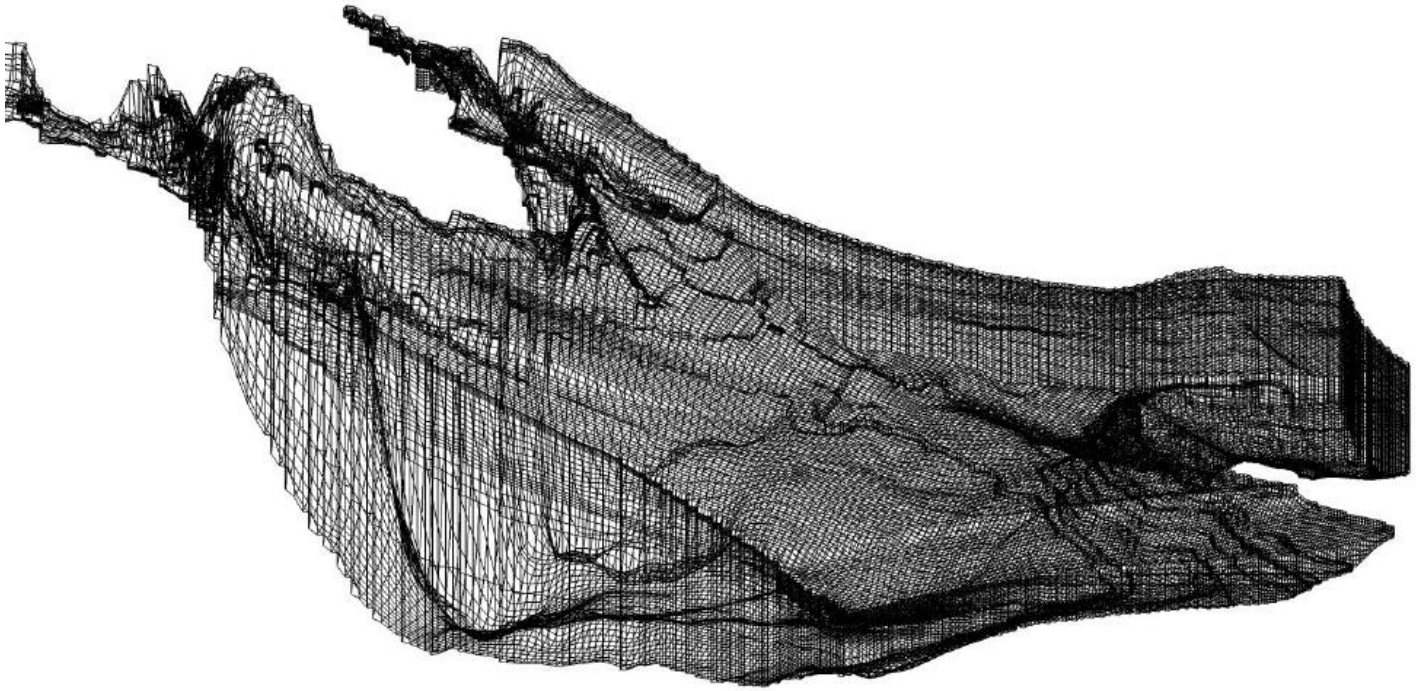


http://www.archydrogw.com/File:Archydrogw_XS2D.JPG

Transform to 3D GeoSection

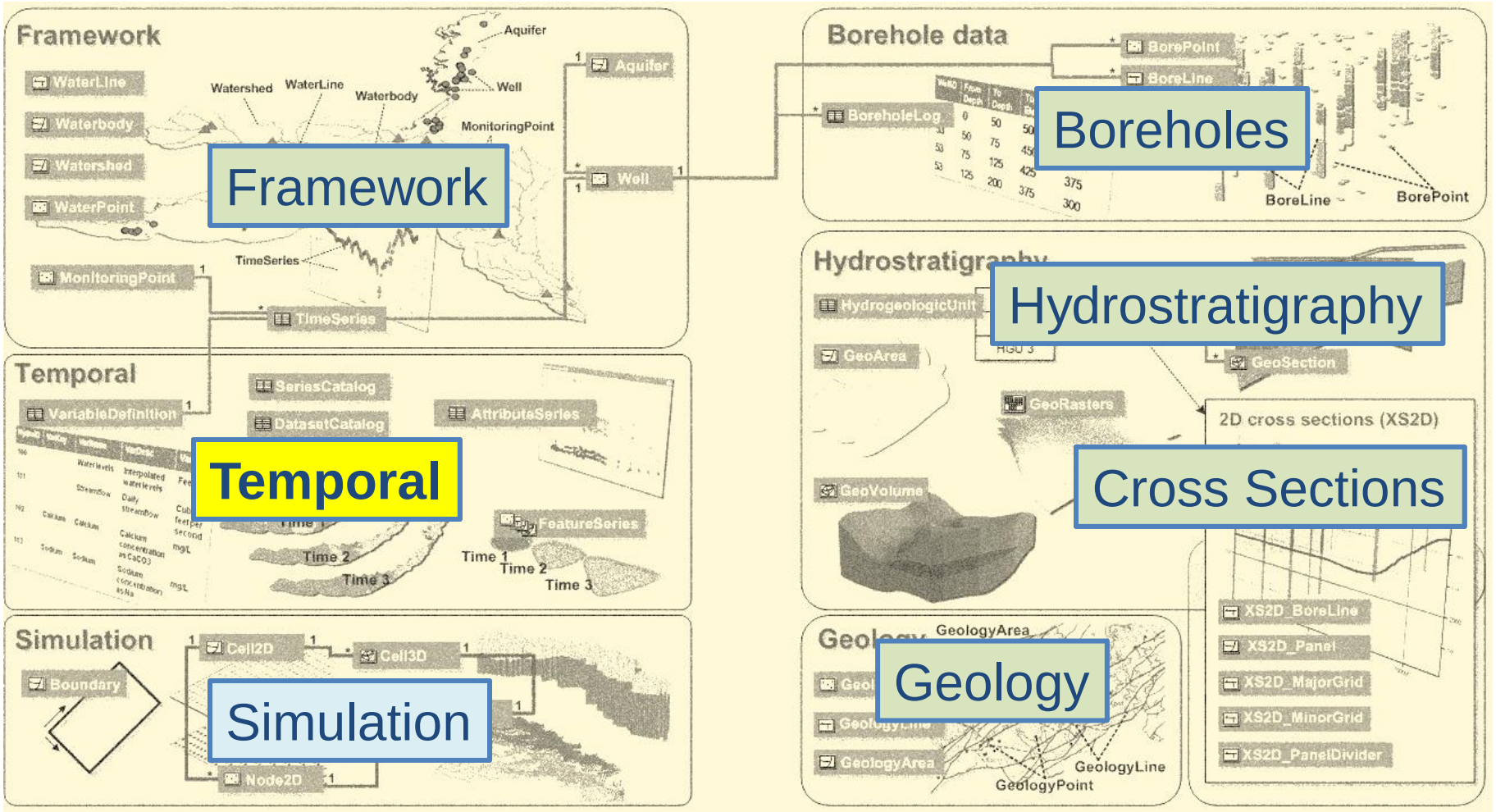


3D Model of Selwyn Groundwater

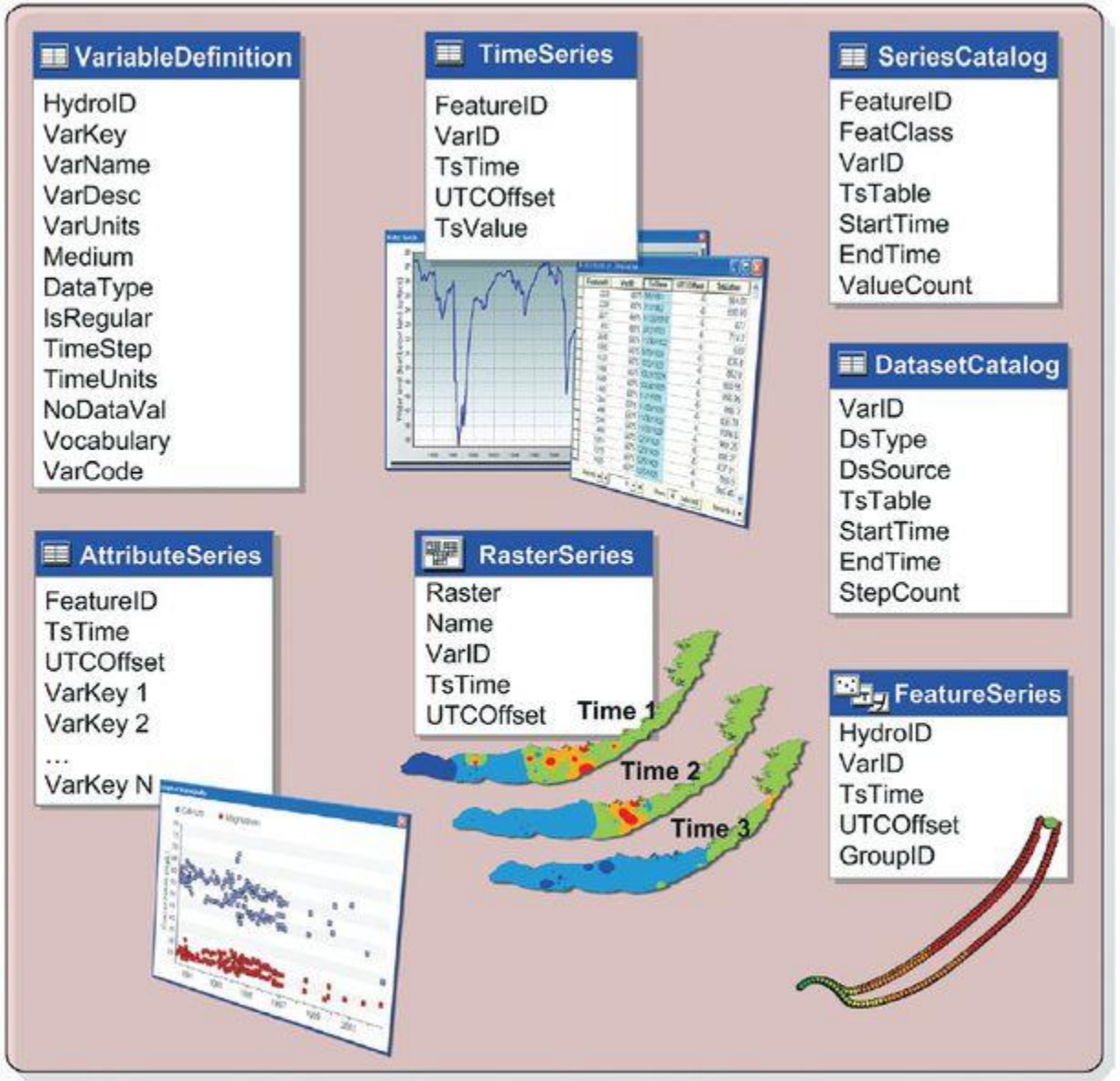


Source: Julian Weir, Aqualinc

Arc Hydro Groundwater Data Model

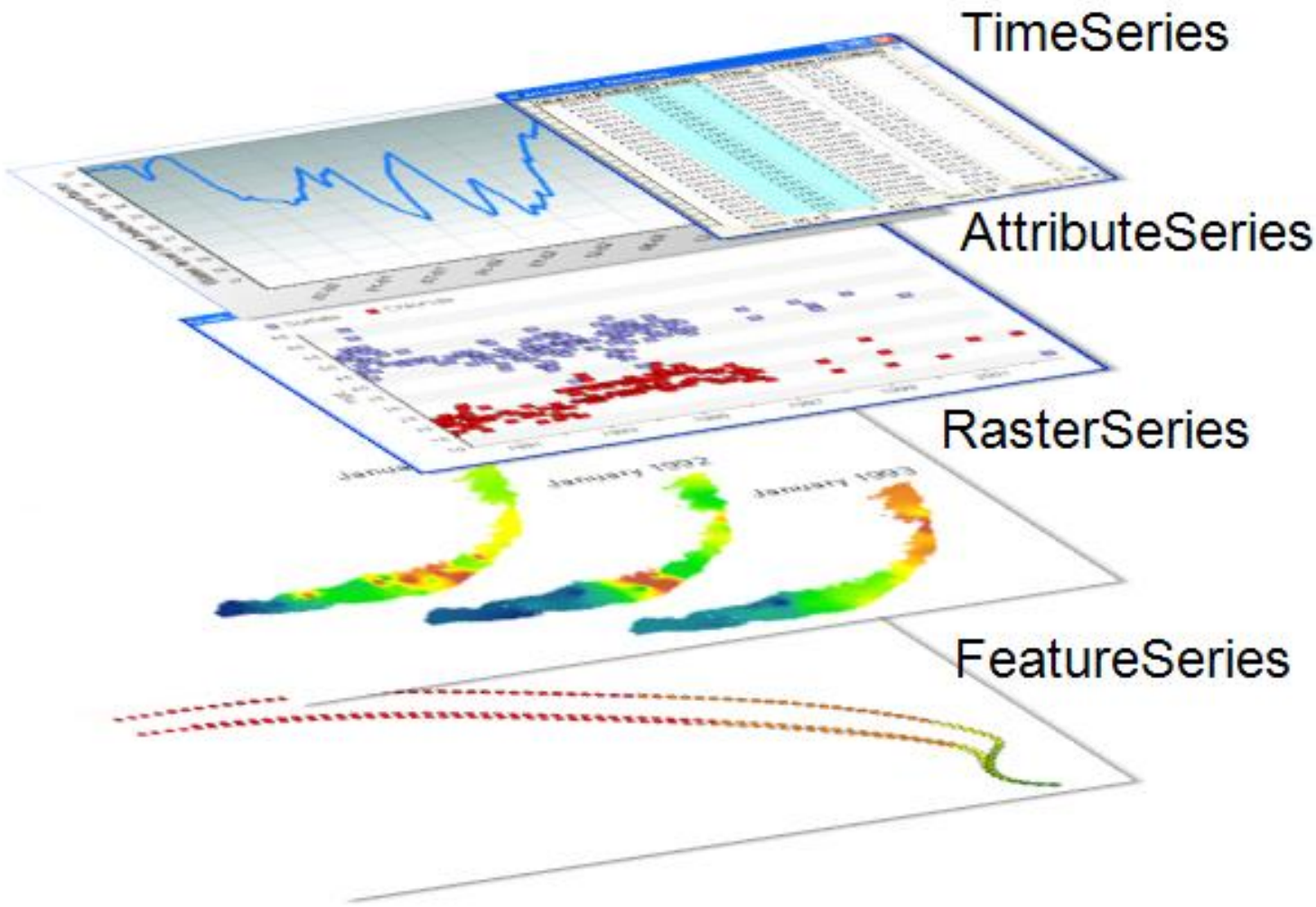


Temporal Component



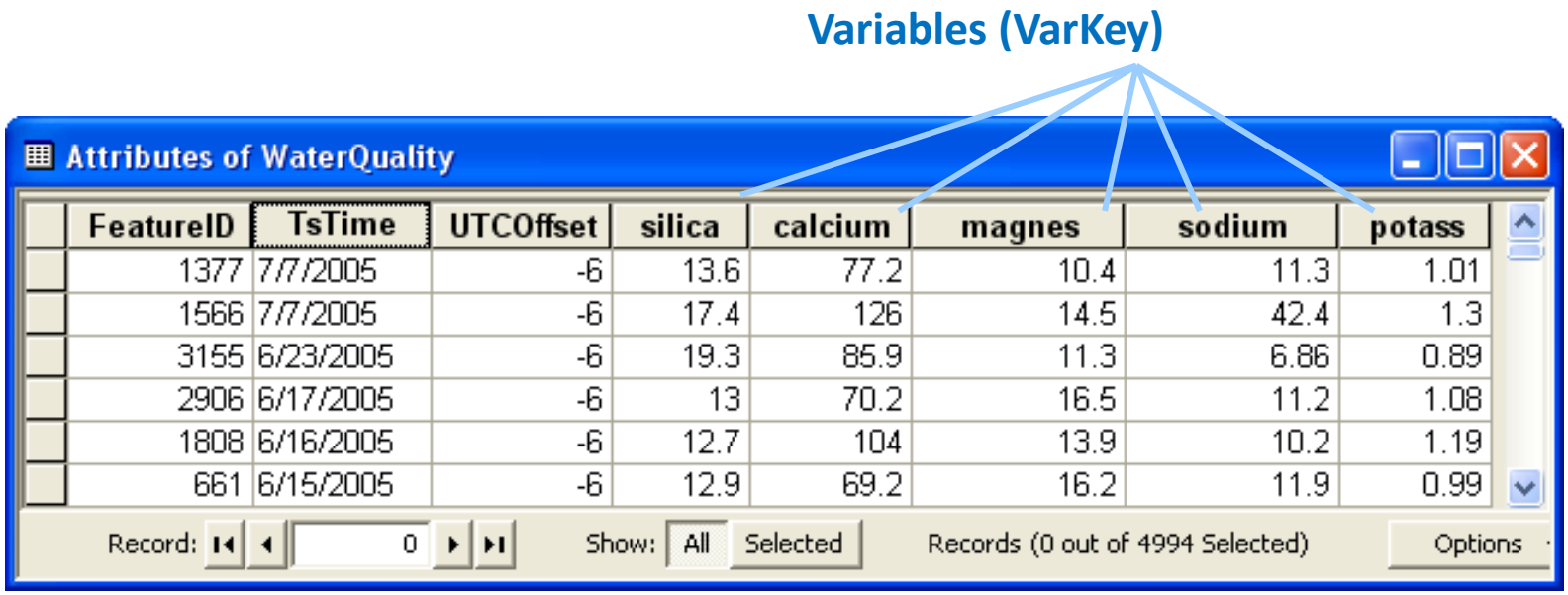
http://www.archydrogw.com/File:Archydrogw_XS2D.JPG

Types of time varying datasets



Multi-variable time series (attribute series)

- Multiple variables recorded simultaneously at the same location
- Example – water quality parameters
- Indexed by location (FeatureID) and time (TsTime)
- Relationship to the VariableDefinition table is through the VarKey



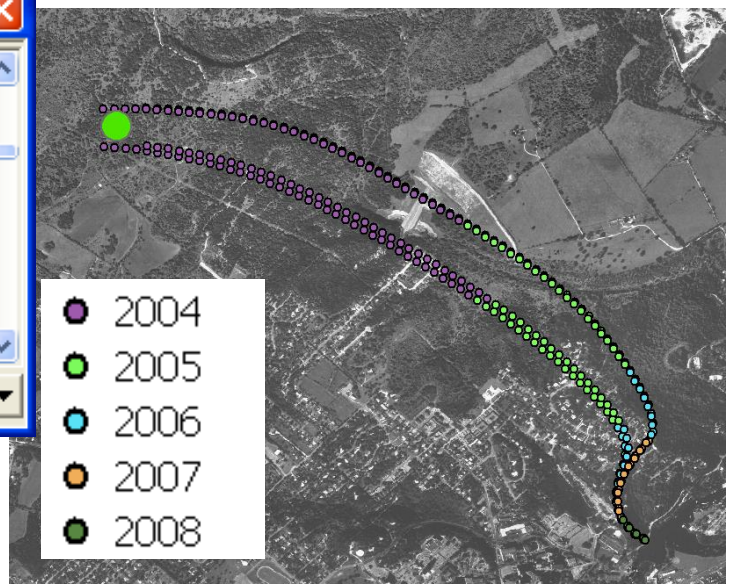
Feature Series

- A collection of features indexed by time
- Example - particle tracks
- Features are indexed by VarID, TsTime, and GroupID
- Each group of features creates a track over time

Attributes of Particles

Shape	HydroID	VarID	TsTime	GroupID	Z_value
Point	6689	6882	2/21/2005	1	138.404
Point	6699	6882	8/13/2005	1	138.577
Point	6698	6882	7/23/2005	1	138.556
Point	6697	6882	7/3/2005	1	138.536
Point	6696	6882	6/14/2005	1	138.517
Point	6695	6882	5/27/2005	1	138.499
Point	6694	6882	5/10/2005	1	138.482

Record: 1 Show: All Selected



Time Series Catalogs

- Like a library's card catalog, but for time series
- Series Catalog
  - For a single variable at a single feature
  - E.g., a summary of all water level measurements for a well
- Dataset Catalog
  - For an entire temporal dataset
  - E.g., a summary of raster series representing water level across the entire aquifer
- Both catalogs include start time, end time, and count

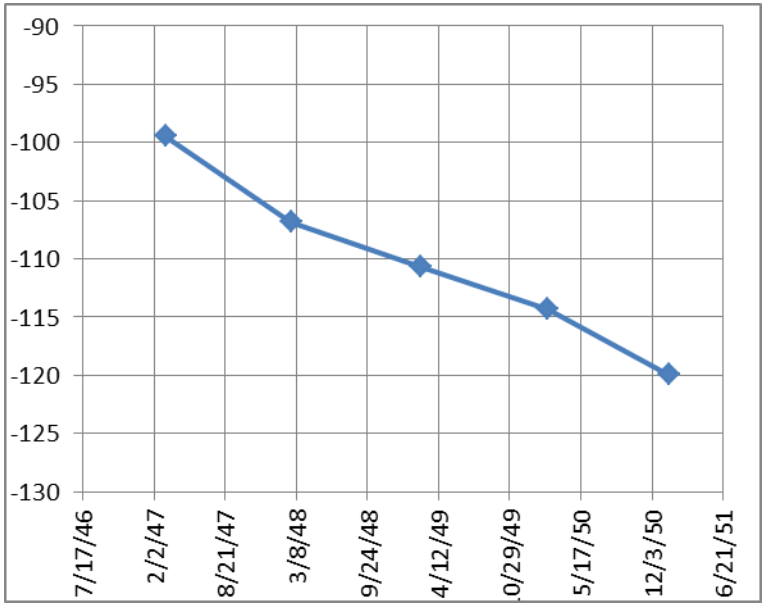
Series Catalog Example

TimeSeries

FeatureID	VarID	TsTime	TsValue
2310802	1	3/7/1947	-99.43
2310802	1	2/23/1948	-106.8
2310802	1	2/22/1949	-110.7
2310802	1	2/13/1950	-114.29
2310802	1	1/19/1951	-119.91
2311401	1	1/14/1966	-177.35
2311401	1	1/7/1967	-184.95
2311401	1	1/9/1969	-184.98
2311401	1	1/16/1970	-184.11
2311401	1	1/12/1971	-189.65

1 (5 out of 46 Selected)

water depth in a well

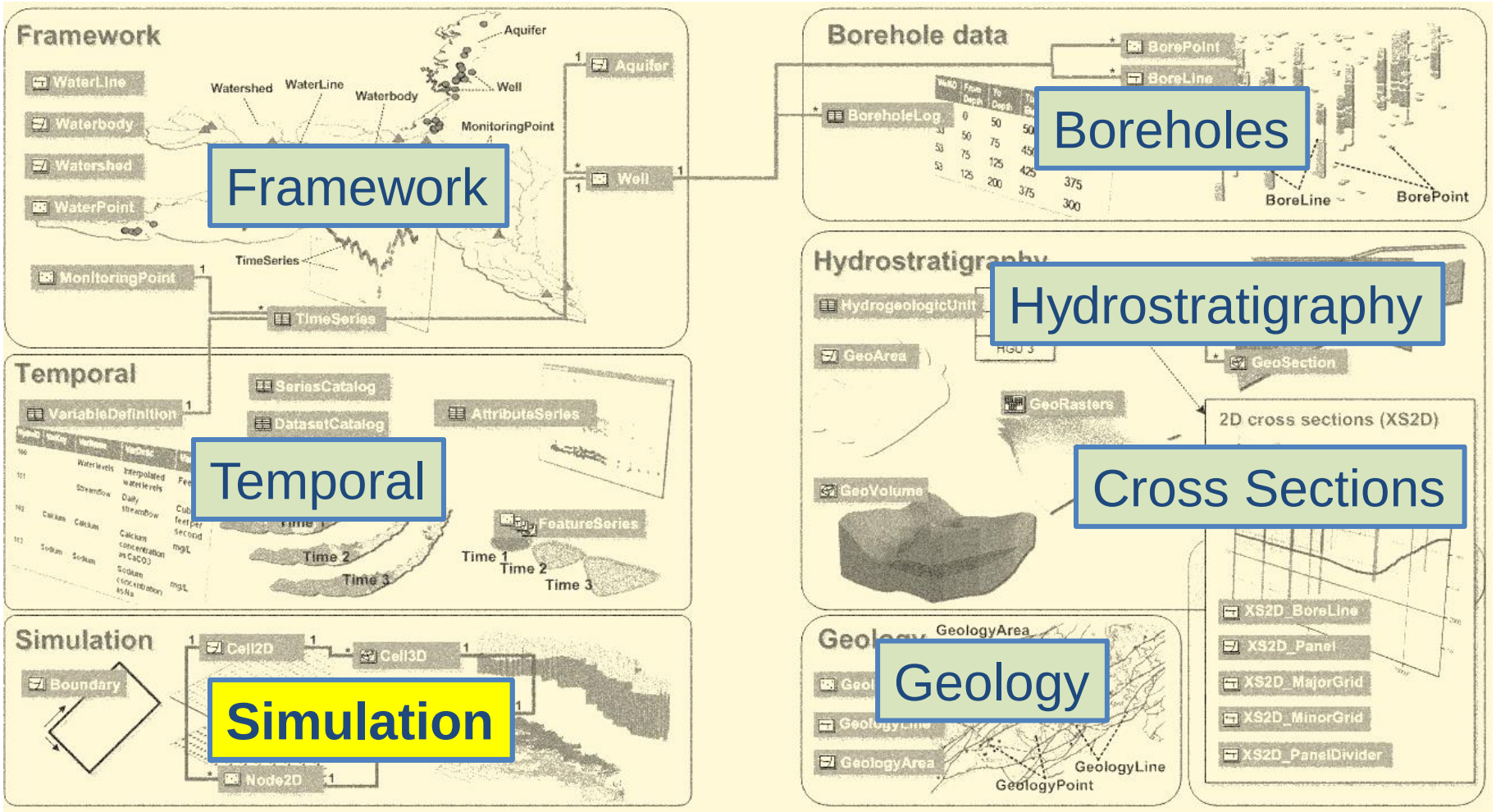


SeriesCatalog

FeatureID	FeatClass	VarID	TsTable	StartTime	EndTime	ValueCount
2310802	Well	1	TimeSeries	3/7/1947	1/19/1951	5
2311401	Well	1	TimeSeries	1/14/1966	1/18/2007	41

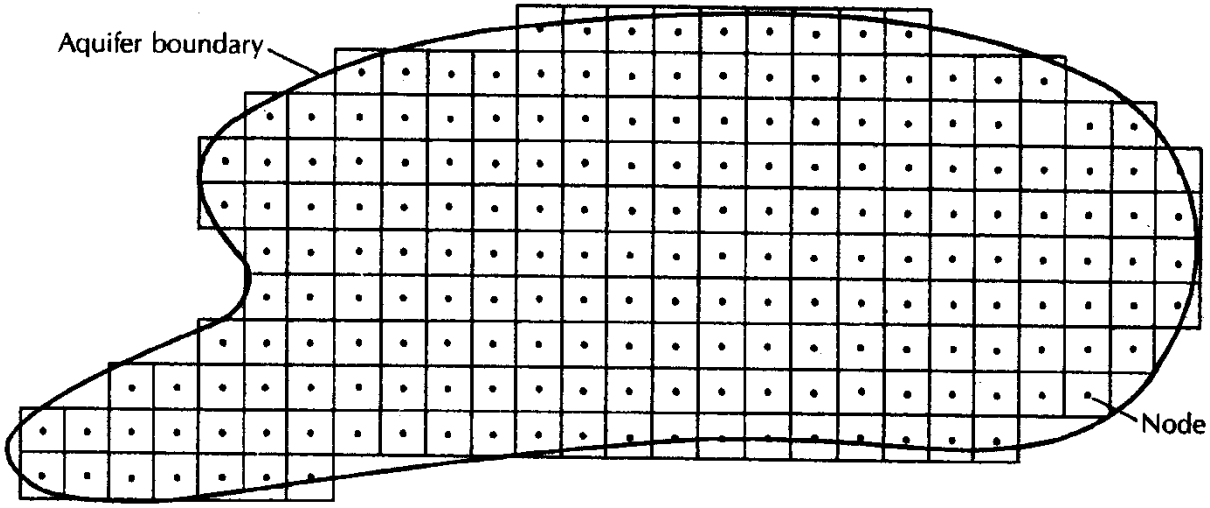
1 (1 out of 2 Selected)

Arc Hydro Groundwater Data Model



Representing simulation models

- Georeference model inputs and outputs (in space and time)
- Focus on MODFLOW, block centered finite difference grid (nodes are in the center of the cells)
- Represent 2D and 3D models



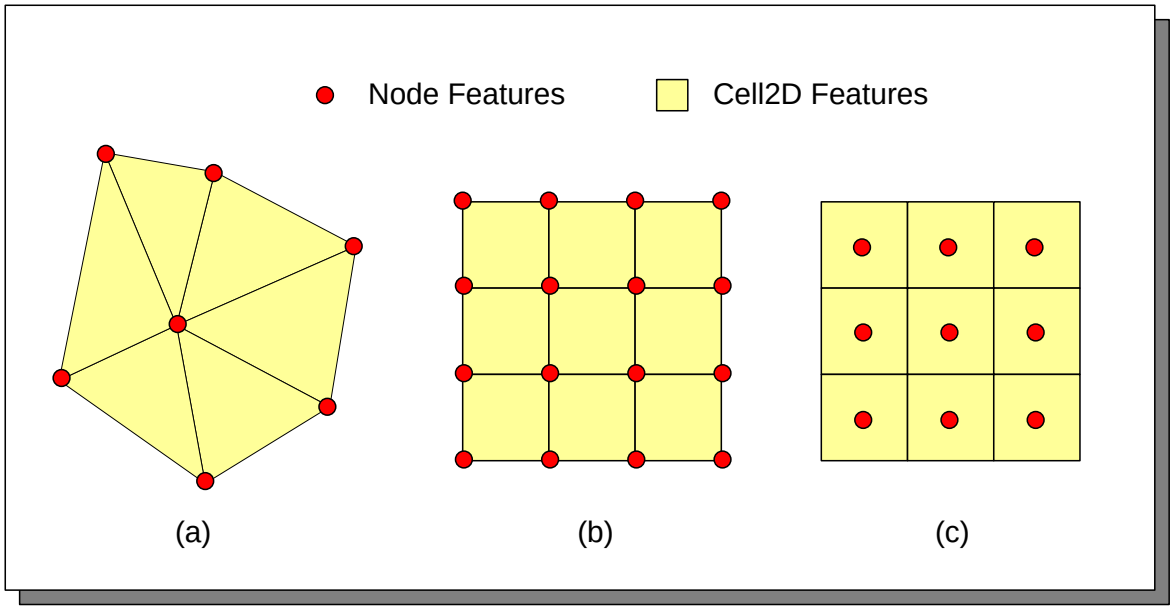
Block-centered finite difference grid

Cell2D and Node

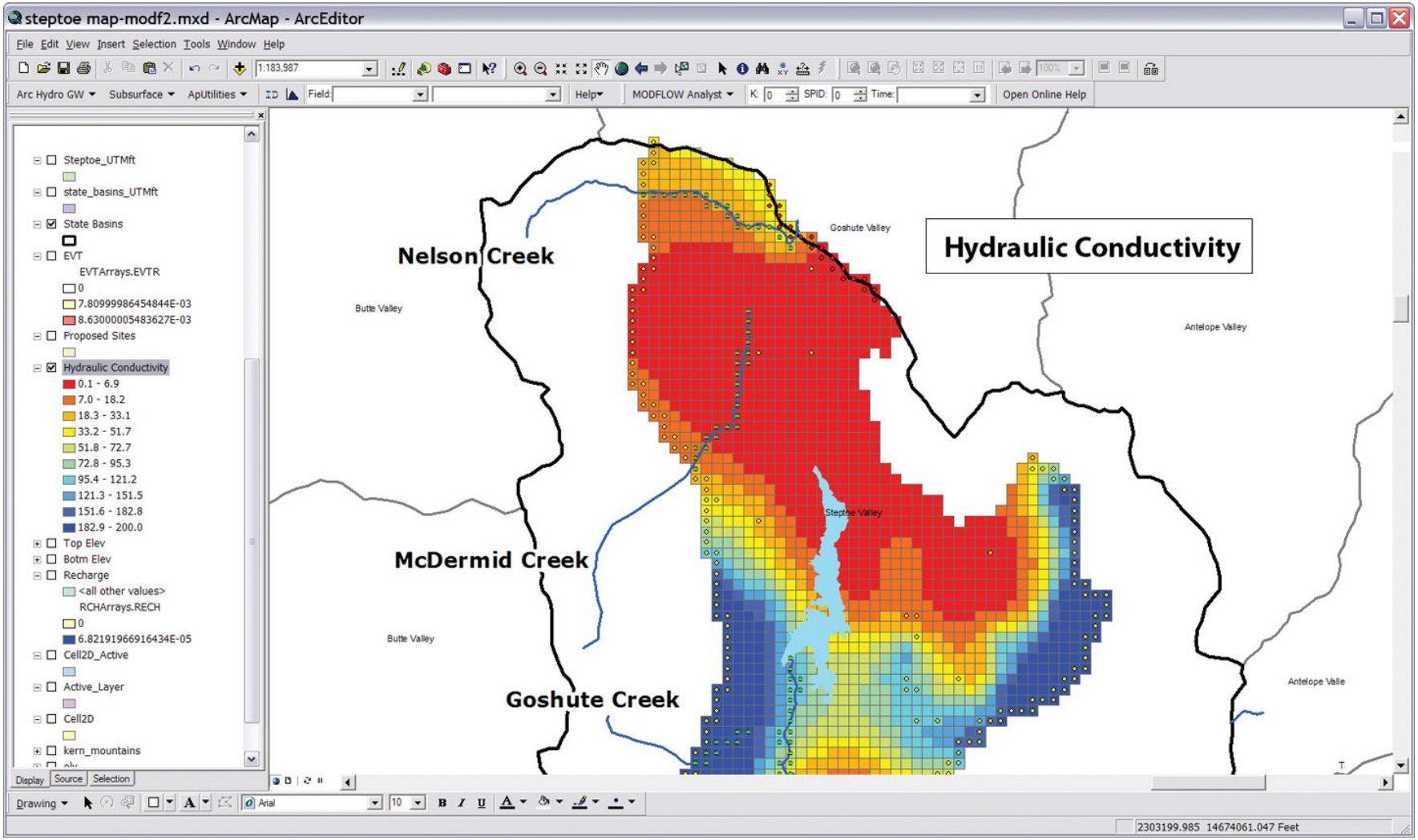
Cell2D: polygon feature class that represents cells or elements associated with a two-dimensional simulation model or a single layer of a three-dimensional model

Node: point feature class used in combination with Cell2D to represent the model's mesh/grid.

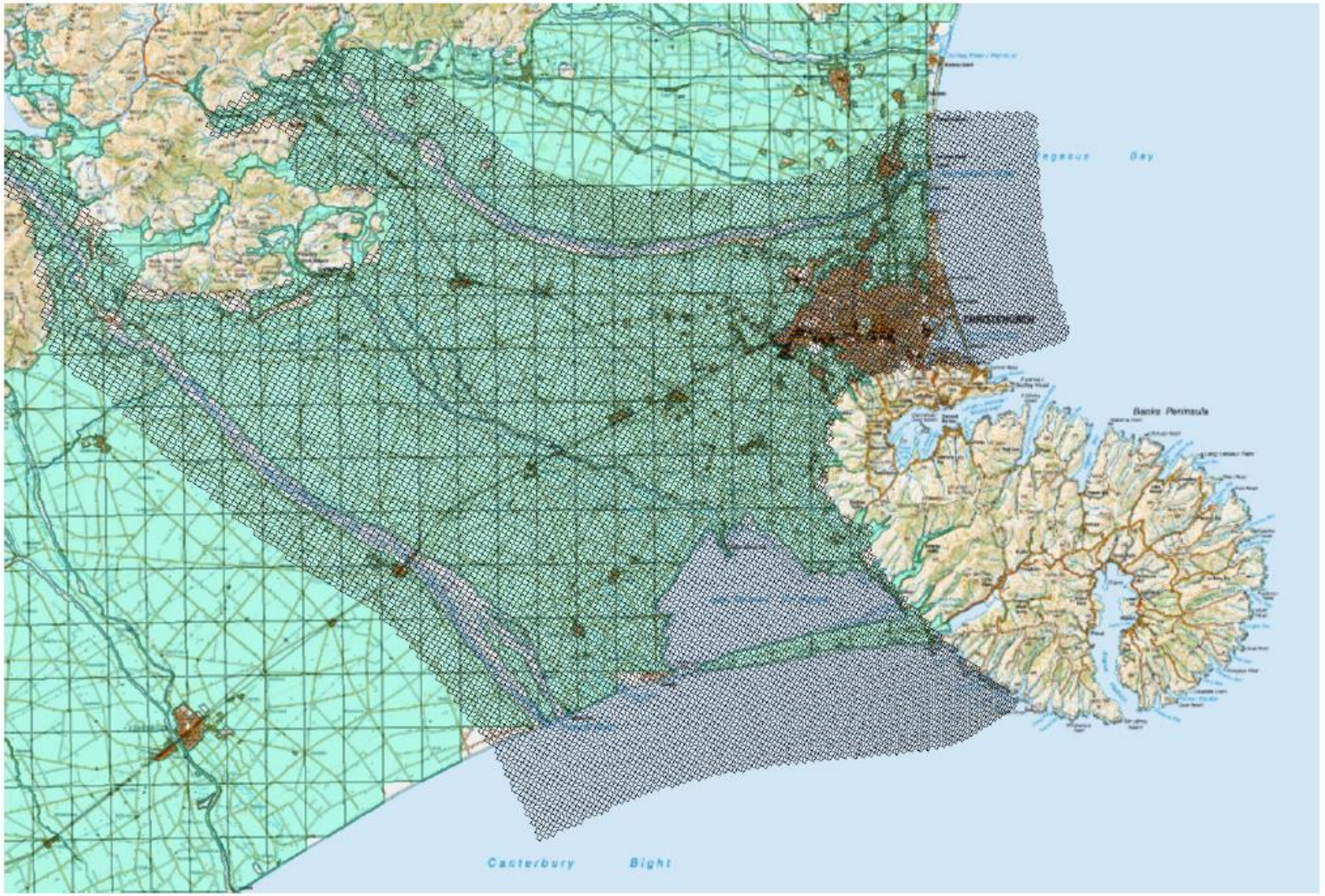
a) Finite element mesh
b) Mesh centered finite difference grid
c) Cell centered finite difference grid



Cell2D and Node for Mapping

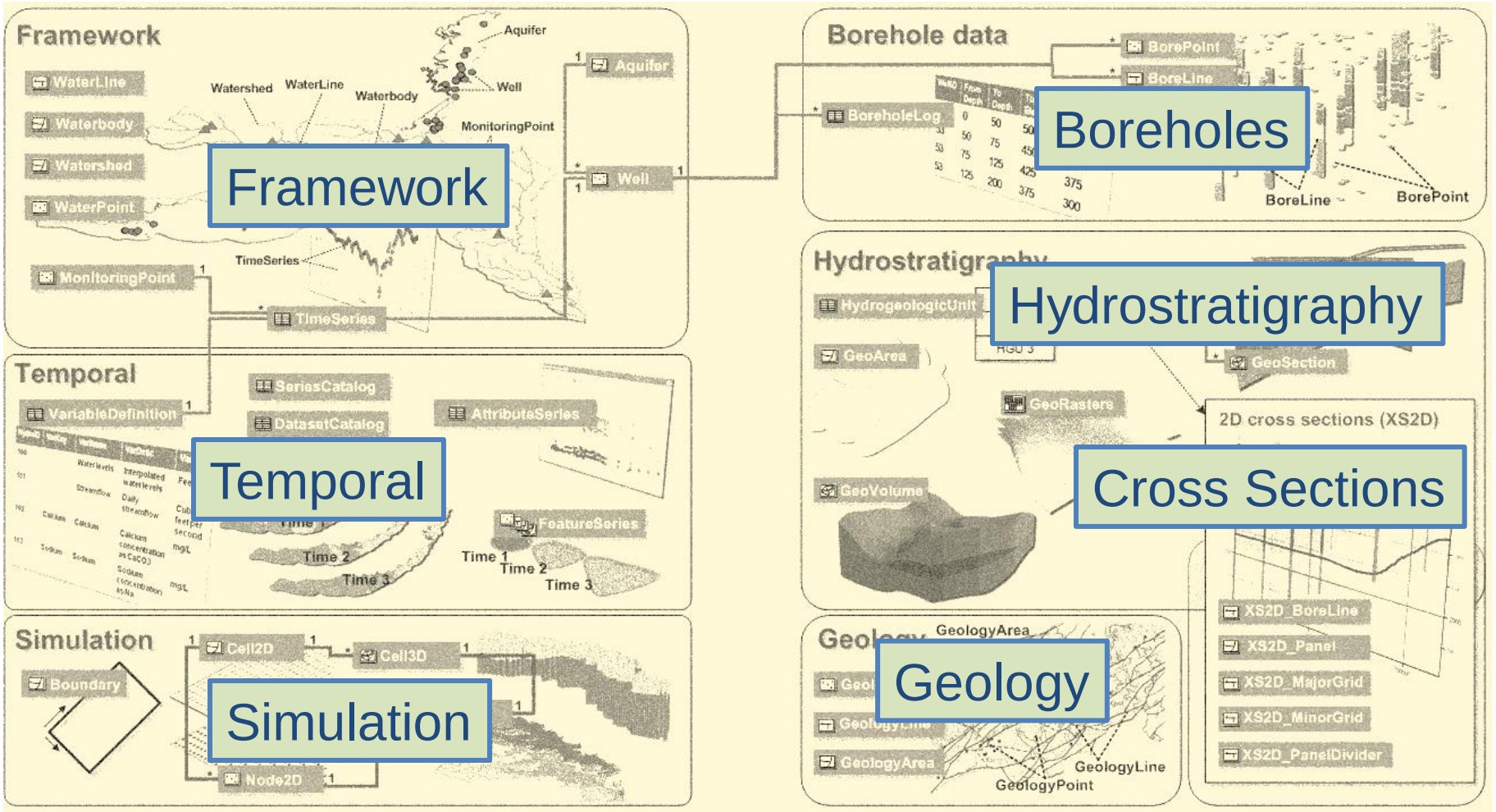


Selwyn Groundwater Model



Source of Data: Julian Weir, Aqualinc

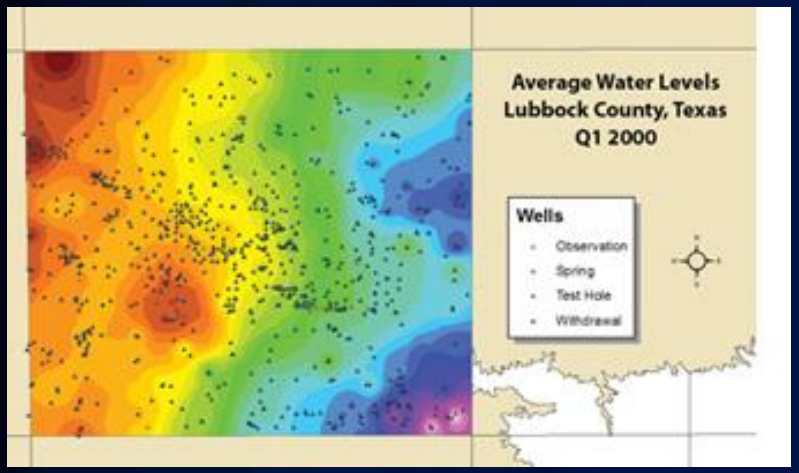
Arc Hydro Groundwater Data Model



Arc Hydro Groundwater Tools

- Groundwater Analyst
- MODFLOW Analyst
- Subsurface Analyst
  - 3D Features
  - 2D Cross Sections

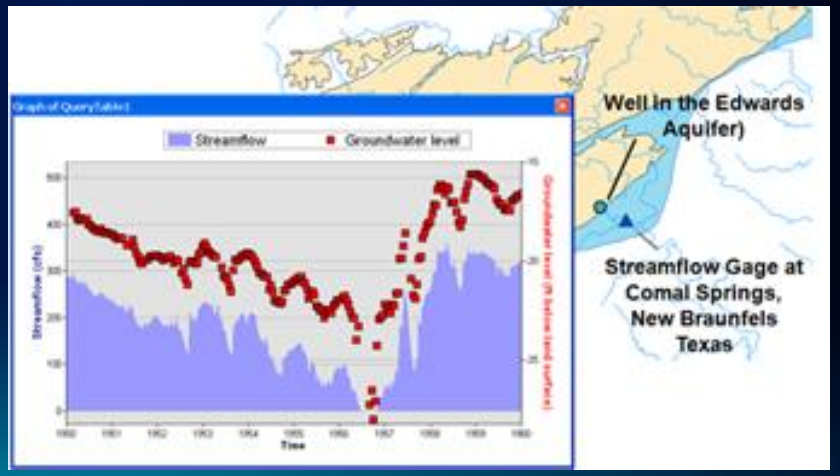
Groundwater Analyst



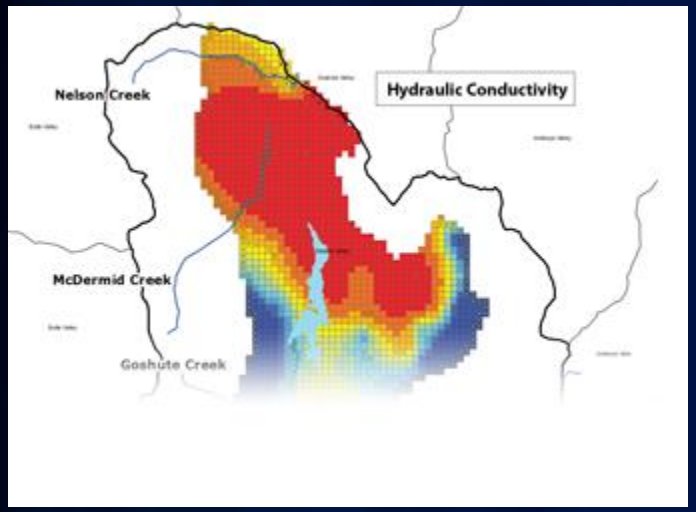
Import and Manage Well Data

Compute Time Series Statistics

Point and Click Graphing Tool

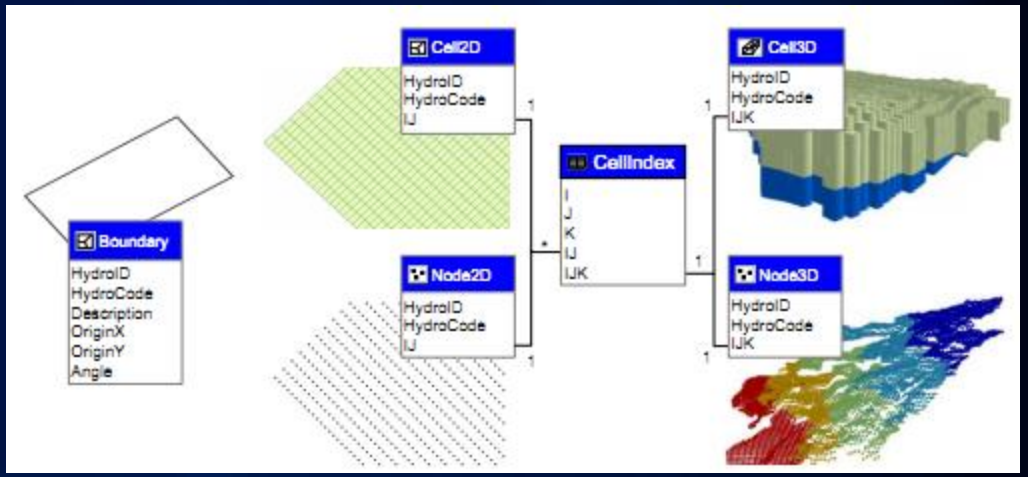


MODFLOW Analyst

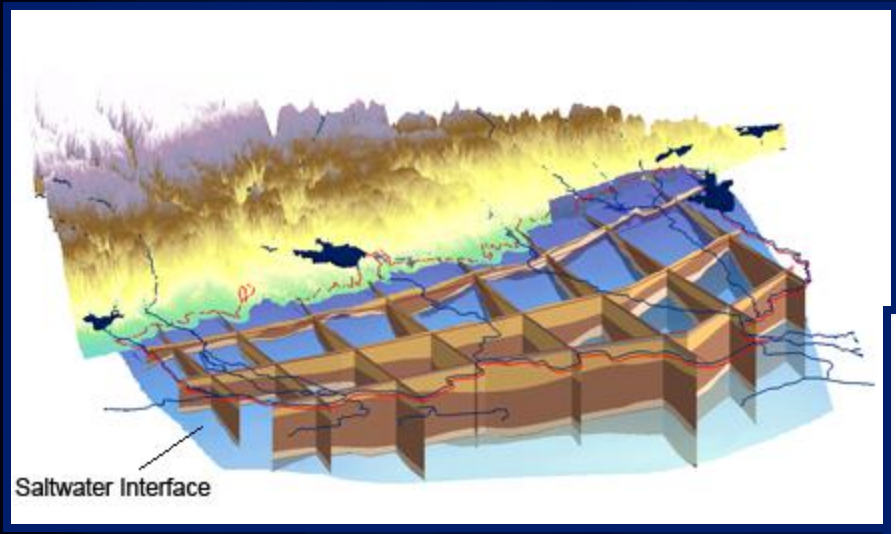


Import and Export MODFLOW models

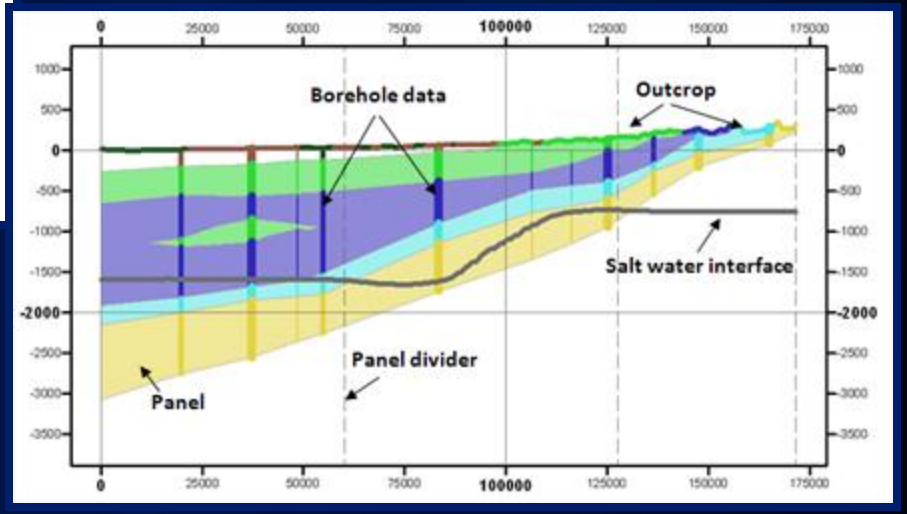
Run MODFLOW from ArcGIS



Subsurface Analyst

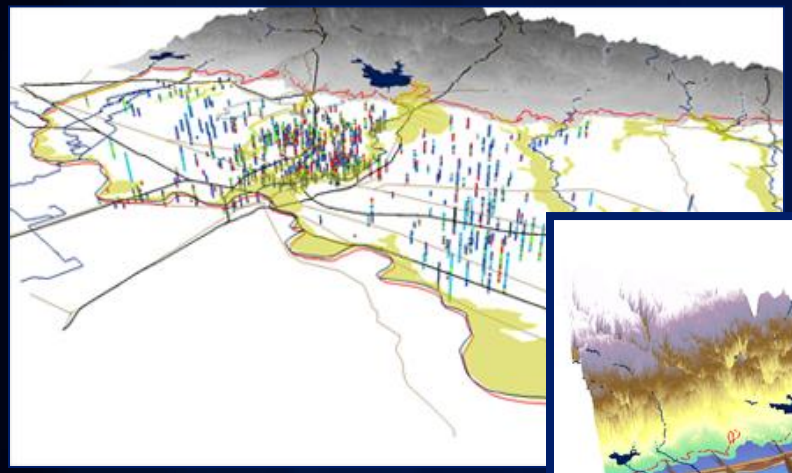


3D Features

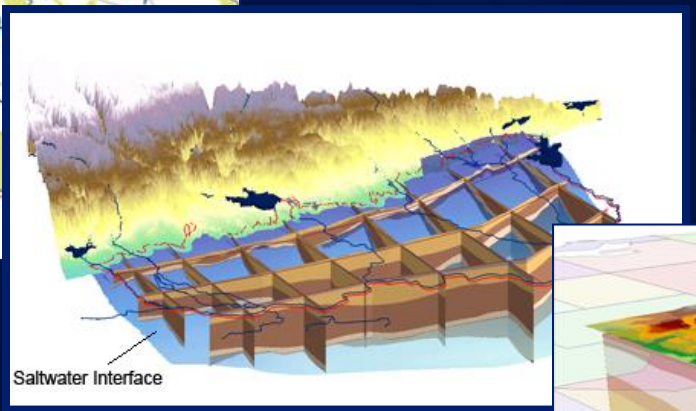


Create 2D Cross Sections

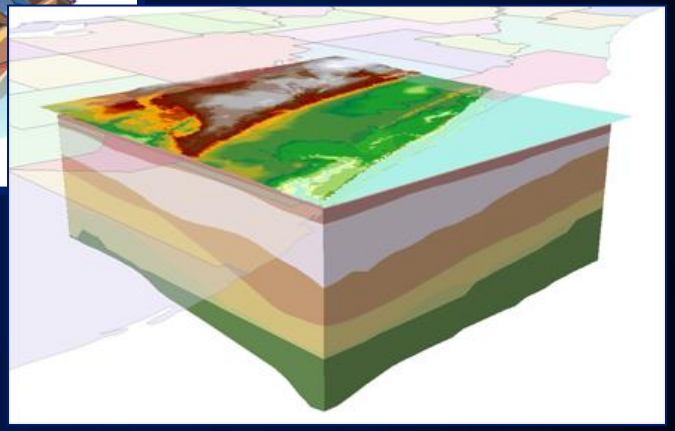
Subsurface Analyst – 3D



Create and Edit Borehole Data



Create GeoSections



Create GeoVolumes

Arc Hydro Groundwater Summary Concepts

- Arc Hydro helps us represent surface and groundwater systems in GIS
- The groundwater data model includes aquifers, wells, hydrogeologic features, time series, and simulation model features
- Relationships connect features with geologic data, aquifers, and time series