

History, Lithology, and Groundwater Conditions in the Tulare Lake Basin



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Item #7

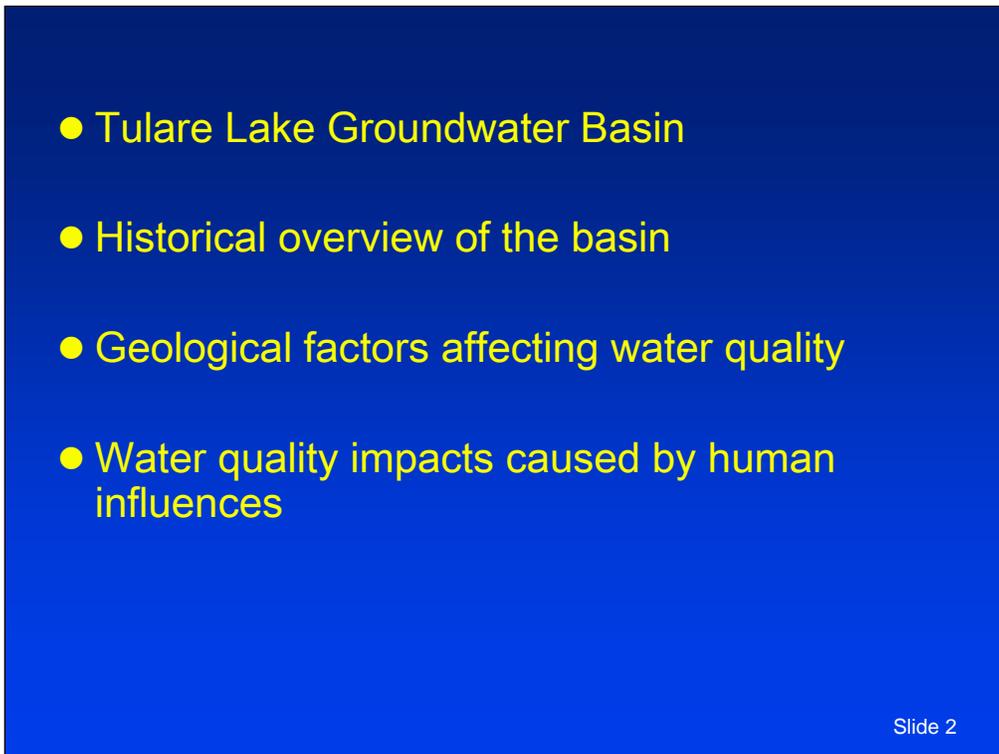
21 September 2006

Slide 1

Good morning Mr. Chairman and members of the board. I am David Sholes, a Senior Engineering Geologist in the Agriculture and Planning Unit at the Fresno Office.

In recent board meetings, issues regarding Groundwater quality in the Tulare Lake Basin have been brought forward. Today I am providing an overview of groundwater quality in the Tulare Lake Basin. Groundwater quality is largely determined by natural conditions, and modified human influences.

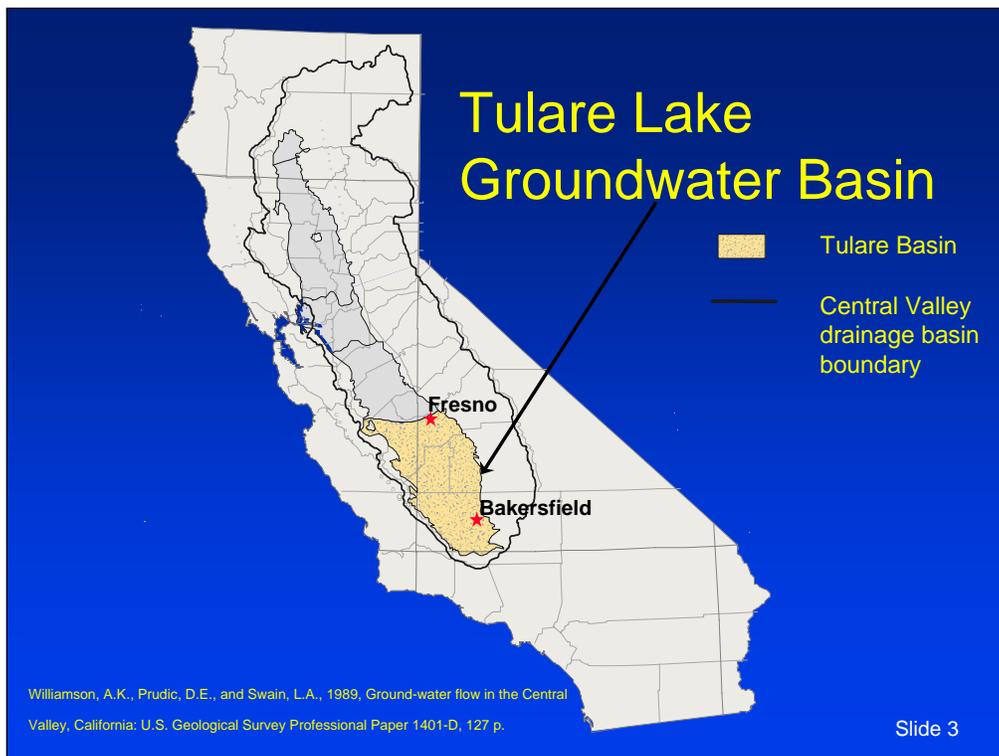
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- Tulare Lake Groundwater Basin
- Historical overview of the basin
- Geological factors affecting water quality
- Water quality impacts caused by human influences

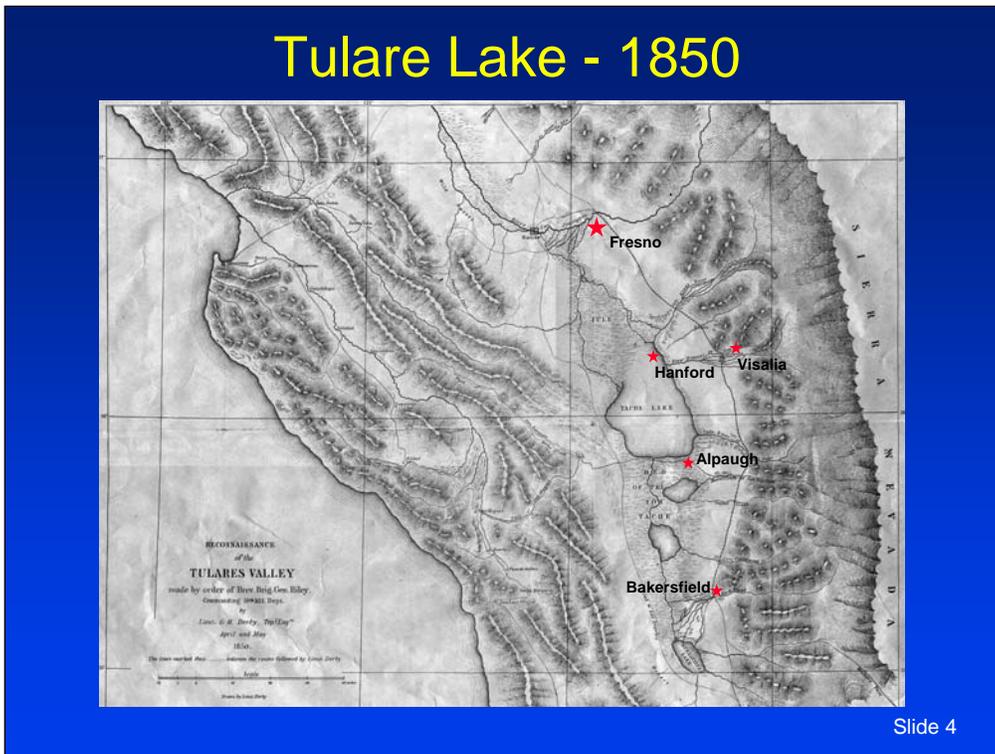
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I'll start with physical description of the basin. Next I will provide a historical overview of the basin prior to development. I will follow with a description of the geologic factors affecting water quality. And finally, conclude with a description of some of our impacts on groundwater quality.



The Tulare Lake groundwater basin comprises the southern half of the San Joaquin Valley. It is bounded in the east by the Sierra Nevada, on the west by the Coast Ranges, on the south by the Tehachapi and San Emegdio mountains, and it extends north to the San Joaquin River. It includes portions of Kern, Tulare, Kings, and Fresno counties.

In general, the Basin can be thought of as an essentially closed basin. This means that with the exception of some flows from the Kings River to the San Joaquin River, which flows north toward the Delta, rivers and groundwater do not flow out of the basin. Before development, there was some flow which flushed some salts from the basin.



As you can see from the Derby Survey of 1850, the central portion of the Tulare Lake basin was formerly occupied by large shallow lakes and associated marshes.

These lakes included Buena Vista Lake in what is now Kern County, and Tulare Lake and associated marshlands in what is now Kings and Tulare County. During wet years, the lakes would fill and spill northward to the San Joaquin River, and flow north to the Delta, carrying dissolved salts out of the basin. Tulare Lake was formerly the largest lake in the western states.

Early diversion of the surface waters that fed Buena Vista and Tulare lakes cut off their surface water recharge.

And Tulare Lake was essentially drying up by the end of the 19th century.

Today, Buena Vista Lake exist only as a small remnant, and Tulare Lake exist as a small remnant during wet years.

Surface waters were completely controlled with the completion of the dam in the Tule, Kaweah, Kings and Kern rivers by the middle of the last century.

For reference, the cities of Fresno, Visalia, Hanford, Alpaugh, and Bakersfield have been added for this presentation.

Four Factors Affecting Water Quality

- 1. The lithology (rocks) of the source area.**
- 2. Reducing conditions in the basin sediments (lakes and marshes).**
- 3. Interactions between minerals in aquifer sediments and the groundwater.**
- 4. Human influences.**

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Natural water quality can be affected by:

- The lithology (rocks) of the source area.
- Reducing conditions in the basin sediments (lakes and marshes).
- Interactions between minerals in aquifer sediments and the groundwater.

Combinations of the first three factors can largely explain the natural water quality observed in the Tulare Lake basin, and I will next show you where these factors affect water quality.

Human influences also affect water quality, and I will briefly describe some of these affects later in this presentation.



Lets take a look at the geologic factors that affect groundwater quality in the Tulare Lake Basin.

Groundwater starts out as precipitation, that falls on the mountain ranges and collects into streams and rivers.

The streams, flowing across the rocks of their mountainous source areas, dissolve salts and mineral constituents from the rocks, contributing these to the surface water.

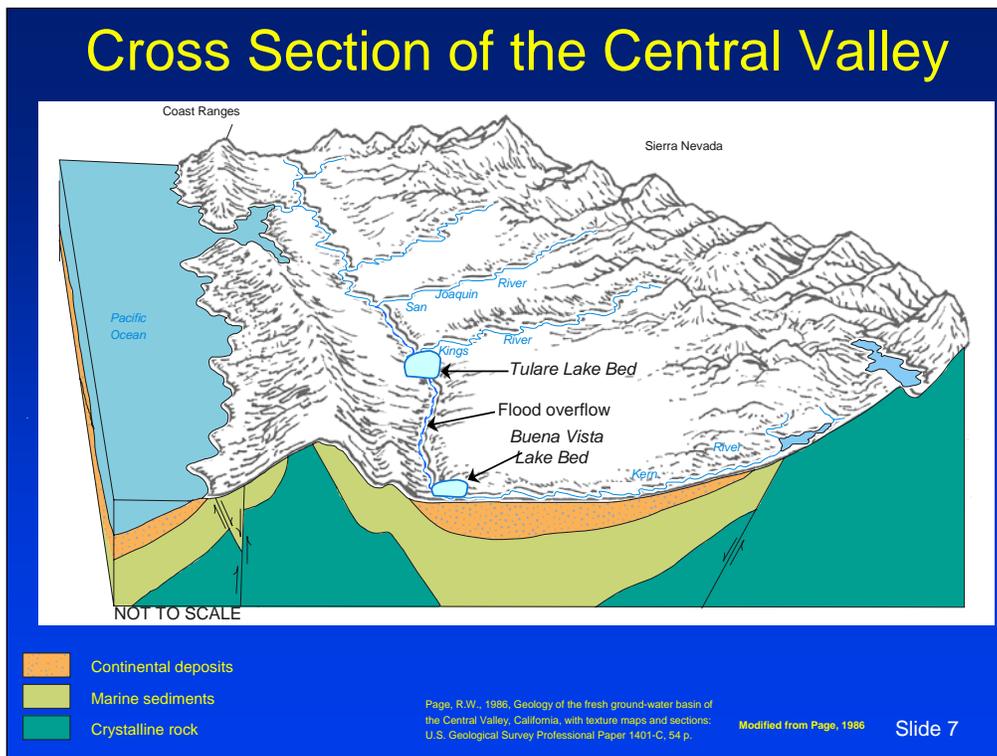
Under natural conditions groundwater aquifers in the Basin are fed by water from these streams that infiltrates into the sediments of the valley.

Thus surface and groundwater quality largely reflect the soluble mineral makeup of their source areas.

The Sierra Nevada and Tehachapis are composed of crystalline granitic rocks and some metamorphic rocks.

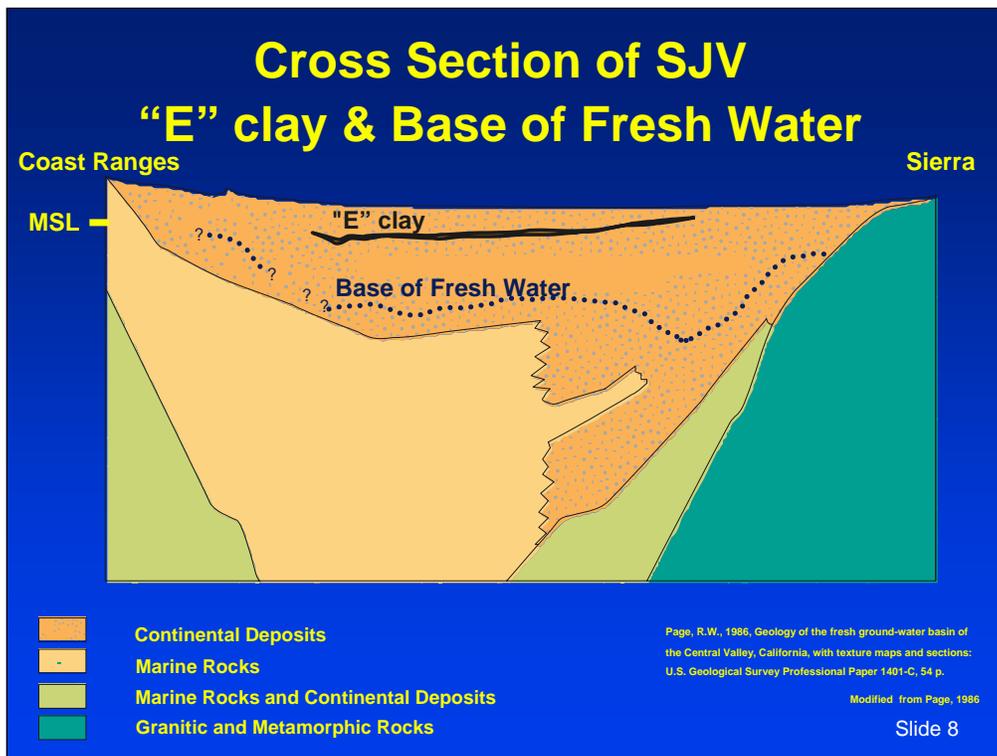
The coast ranges and the San Emegdios are composed of sedimentary rocks deposited in an ancient marine environment.

These different rock types, contribute different salts to the groundwater.



This diagram shows a portion of the Central Valley from just south of Bakersfield, north to the Sacramento Valley. It also shows a cross section through the Tulare Lake Basin just south of Bakersfield. A cross section shows a side view of the rocks and sediments beneath the basin. It is just as looking at a slice of cake from the side which lets you look at the interior of the cake beneath the frosting. The Tulare Lake Basin is part of a structural trough formed by the west tilted Sierran Block and the adjacent coast ranges. The westward tilt of the Sierran block means that the eastern side of the basin is shallower than in the western side. On the west side of the Central Valley, the sediments are considerably thicker than on the east side, and may be as thick as 20,000 feet in the Tulare Lake basin.

The sediments that fill the Central Valley and Tulare Lake Basin have accumulated through geologic ages (since the Cretaceous). Most of it was shed west from the ancestral Sierra, and for most of the time, those sediments were shed into the Pacific ocean before the coast ranges formed. The Coast Ranges formed from folded marine sediments during the last geologic era, and the area that became the Central Valley was once an inland sea which gradually filled with sediment, shed from both the Sierra in the east, and the coastal ranges in the west, until the inland sea disappeared. The southern portion of the Central Valley, including the area now known as the Tulare Lake basin, filled last. That most of the sediments that fill the basin were deposited in a marine environment is important because ancient sea water exists in those sediments today, and the fresh water we use exists within a thin layer of Recent continental sediments deposited on top of those marine layers. The thickness of the fresh water aquifers varies from about 1,500 feet to about 4,500 feet at its thickest, and averages about 2,000 feet. The cost of drilling wells and pumping from those depths often preclude the use of the entire section for freshwater extraction. Below this level the ancient marine waters trapped in the sediments are too salty for use.



This cross section through the Tulare Lake basin shows the freshwater aquifer system. The base of the fresh water system is indicated by the dotted line. Below this line, groundwaters are generally too salty for use.

A thick section of organic rich fine-grained sediments exists in the central portion of the Tulare Lake Basin. These organic-rich silts and clays were deposited in a series of lakes and marshes that occupied this area through geologic time. Tulare Lake was simply the latest of these lakes.

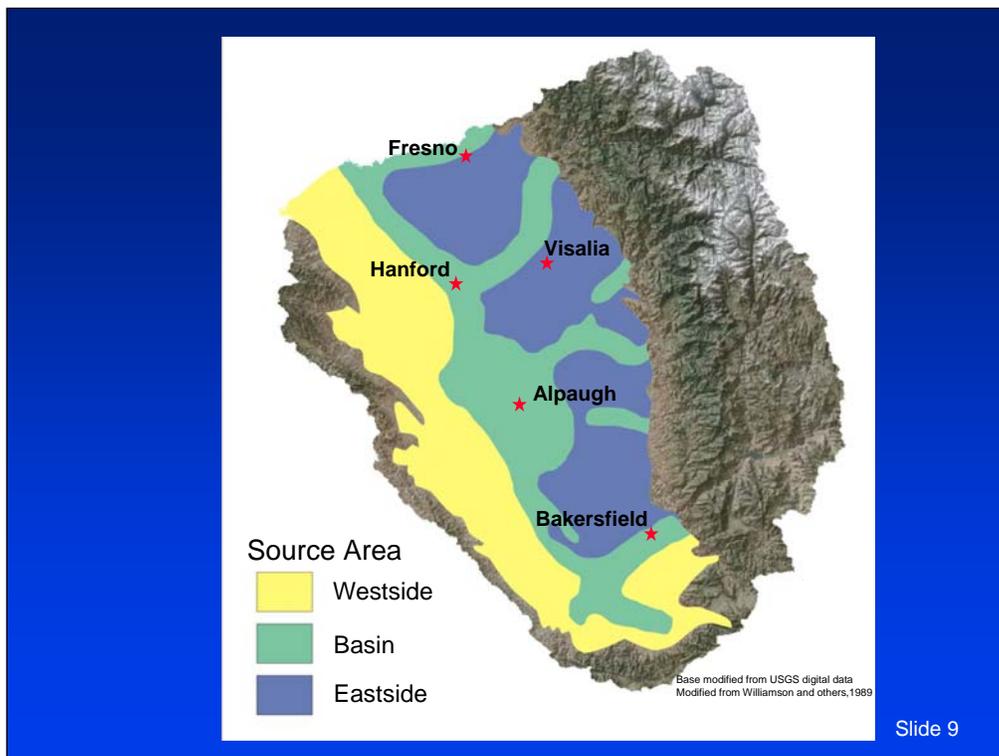
Groundwater within these organic-rich fine grained sediments are generally reduced (low oxygen content) which causes some metals normally bound to soil particles to become soluble, affecting water quality.

The E Clay

Three really extensive fine grained layers, have been found when drilling multiple wells throughout the Tulare Lake Basin. Only the oldest and lowest of these, the E clay, is shown here.

Pre-development, and to some extent today, the E clay separated the fresh water into a confined aquifer below the E clay, and a semi-confined and unconfined aquifer above the E clay. The deeper waters below the E clay are generally older than the shallower waters above, and are often of excellent quality, though enriched with sodium with respect to calcium.

This sodium enrichment is thought to result from cation exchange where calcium in the water has been exchange for sodium in the aquifer sediments.



Based on geologic factors, natural groundwater quality can be approximately grouped into:

- EASTSIDE – originating from the Sierra
- WESTSIDE – originating from the Coast Ranges and San Emegdio Mountains
- Valley Trough or basin – areas formerly occupied by ancient lakes and marshes and overbank sediments from streams
- Confined or below the E-Clay which is not represented here

I will now briefly describe water quality in each of these areas.

Eastside Water Quality

- **Source in the granitic/metamorphic crystalline rocks of the Sierra**
- **Major cations are Ca & Mg**
- **Major anion is HCO₃**
- **TDS is low (100-300 mg/L)**

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Eastside waters largely reflect their source in the crystalline granitic rocks of the Sierra

Due to the mineralogy of these rocks, major cations are calcium and magnesium and the major anion is bicarbonate.

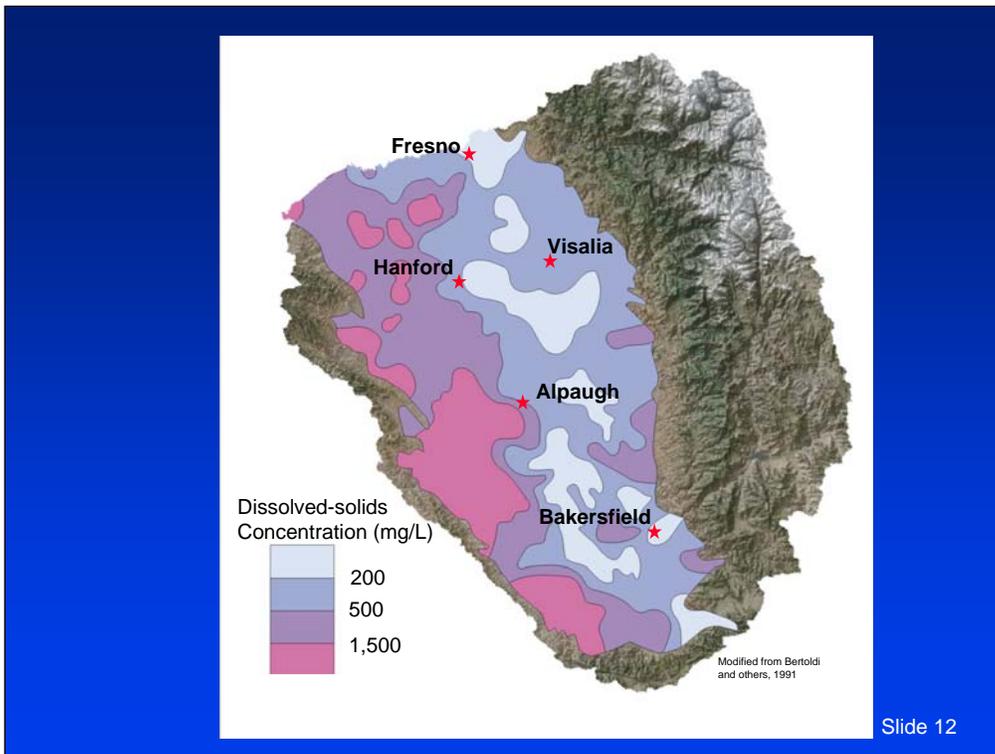
Total dissolved solids are low.

Westside Water Quality

- Source in the marine sediments of the coast ranges.
- Major cations (Ca & Na)
- Major anions (SO₄ & Cl)
- TDS up to several 1,000 mg/L

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Westside groundwaters are also greatly affected by their source, which is the marine sediments of the coast ranges. High sulfate concentrations can impart a objectionable taste and odor to these waters, and the high sodium makes these waters soft, sometimes imparting a slimy feel when soap will not wash off.



This slide depicts typical dissolved solids, or salt, concentration in the unconfined aquifer. Note the elevated TDS on the west side of the basin compared to the lower concentration of salt on the eastside. This difference is due to the salts dissolved from the different source rocks (marine sediments on the west, granitic on the east).



Basin Water Quality

- Variable sources
- Reducing conditions, soluble metals (As, Fe, Mn)
- Major cations (Ca & Na)
- Major anions (SO₄, Cl, & HCO₃)
- TDS varies from 100s to 1,000s mg/L

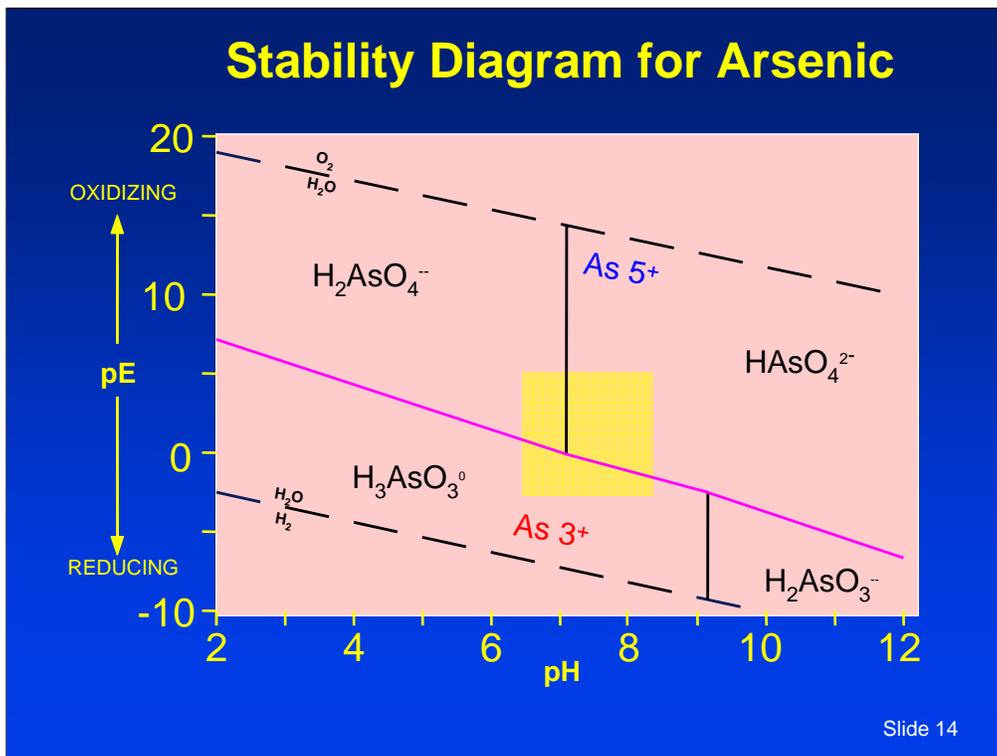
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Groundwater in the valley trough can have variable source areas, either from the Sierra or Coast ranges.

The organic-rich fine grained sediments in these areas exhibit reducing conditions, which cause some metals such as arsenic, iron, and manganese to become soluble.

These metals may exist at concentrations exceeding California drinking water standards.

Major cations include calcium and sodium. Major anions are sulfate, chloride and bicarbonate. Total dissolved solids vary from 100s to 1000s of mg/L.



This diagram shows dissolved forms of arsenic, and the conditions under which they are stable in the environment.

- The yellow box represents typical groundwater conditions with respect to Oxidation Potential (pe) and pH.
- Under reducing conditions common to the basin deposits, As is soluble.
- Fe and Mn are soluble under these conditions as well.
- Soluble forms of As, Mn, and Fe may be naturally occurring components of groundwater in areas where reducing conditions exist. Waters obtained from these areas may exceed MCLs, and these waters may also have esthetic issues such as color, and unusual taste and odor.

Confined Aquifer Water Quality

- **Source**
- **Groundwater – sediment interactions**
- **Mixing with deeper saline waters**
- **TDS is very low (100 mg/L)**

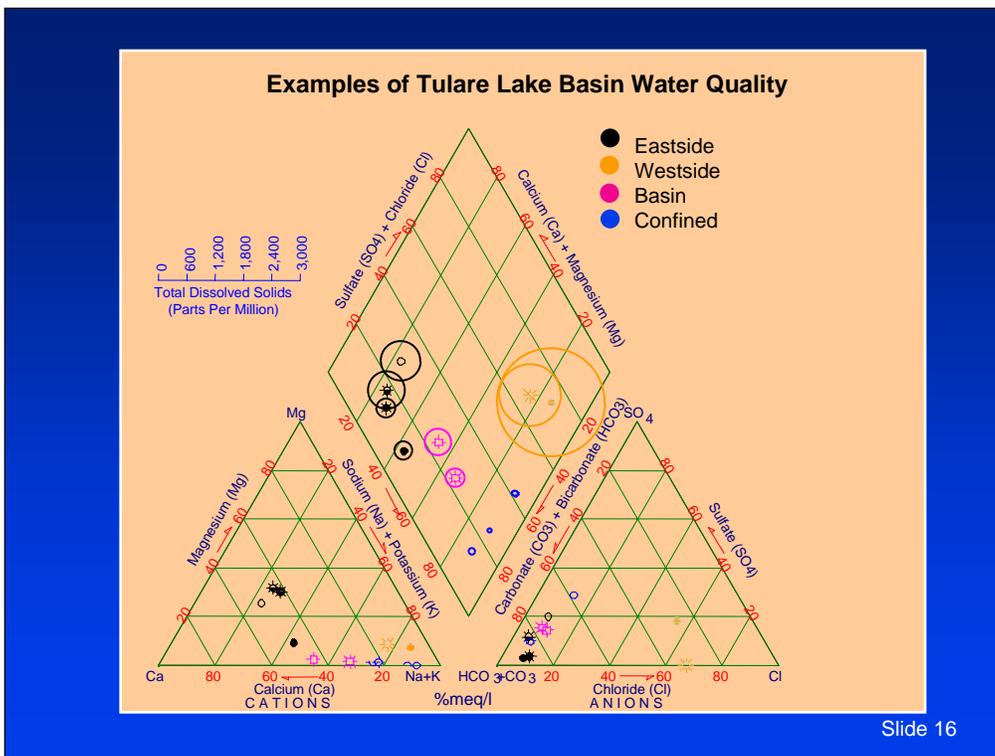
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Water Quality in the Confined aquifer reflects its source which is usually Sierran.

Groundwater – sediment interactions account for the proportional increase in Na concentration.

TDS may be very low, around 100 mg/L.

Salinity (TDS) increases with depth due to mixing with deeper saline waters.



Water scientists often depict water quality using tools such as this trilinear diagram, which helps us visualize differences in water quality and relationships between waters.

In a trilinear diagram the percentages of cations and anions are plotted in the lower triangles and then combined in the diamond field above. Major Cations include Ca, Mg, Na and K. Major Anions include HCO₃, SO₄, and Cl. The size of the circle in the diamond field denotes the concentration of TDS. The larger the circle, the higher the concentration, and the saltier the water.

To summarize our discussion of water quality in the Tulare Lake Basin;

- Eastside water quality reflects the relatively insoluble mineral makeup of the granitic source area. The waters depicted here are Ca-HCO₃ type waters. These two, with the larger TDS circles represent areas affected by wastewater discharges.
- Westside water quality reflects the marine sedimentary rocks of their source area, exhibiting higher salt concentrations and containing more Na, SO₄ and Cl than east side waters. The high SO₄ may impart objectionable odor and taste, and the elevated TDS may affect agricultural uses. The examples here are Na-Cl waters with high total dissolved solids.
- Basin water quality chemically may look like either eastside or west side waters. The examples here are Ca,Na-HCO₃ waters with low TDS. Reducing conditions in the basin sediments cause As, Fe, and Mn to become soluble, which may affect its use for municipal or domestic supply.
- Confined aquifer waters are Na rich, but low in TDS. The examples here are Na-HCO₃ type waters. These grade vertically into the saline waters trapped in the underlying marine sediments. Eventually, TDS become so high that the waters are unusable.

Human Influences

- **Surface water diversions & imports**
- **Groundwater extraction**
- **Fertilizer & chemical use**
- **Increased population**
- **Wastewater disposal**

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That completes my review of natural geologic processes that affect water quality,...

I would now like to turn to water quality issues within the Basin related to human influences.

Our use of surface and groundwater resources in the Tulare Lake Basin has profoundly changed the basin in many ways.

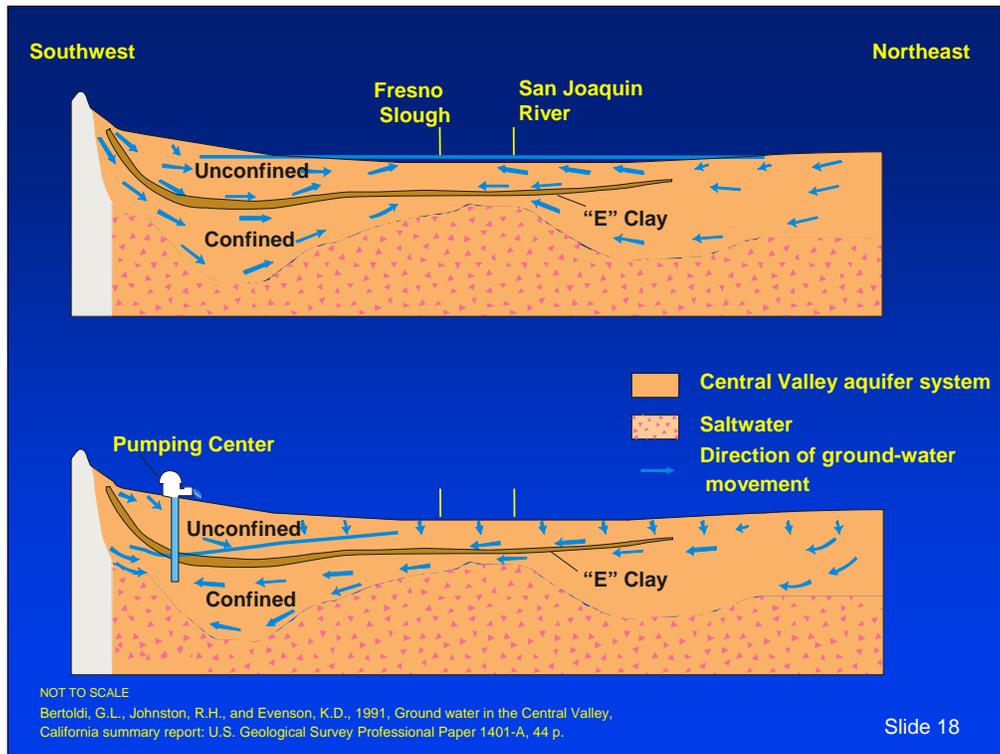
Human influences include:

- diversion of the basin’s surface waters and importation of surface water,
- increased extraction of groundwater,
- increased use of fertilizers and chemicals, and
- increased population and its use, reuse, and disposal of wastewater

And, certainly, there are many other issues that this board deals with continually.

This morning though, I am going to focus on two aspects that affect groundwater quality in the Basin. They are:

1. Changes in surface and groundwater flow patterns, and
2. The importation of water and salt from outside the basin



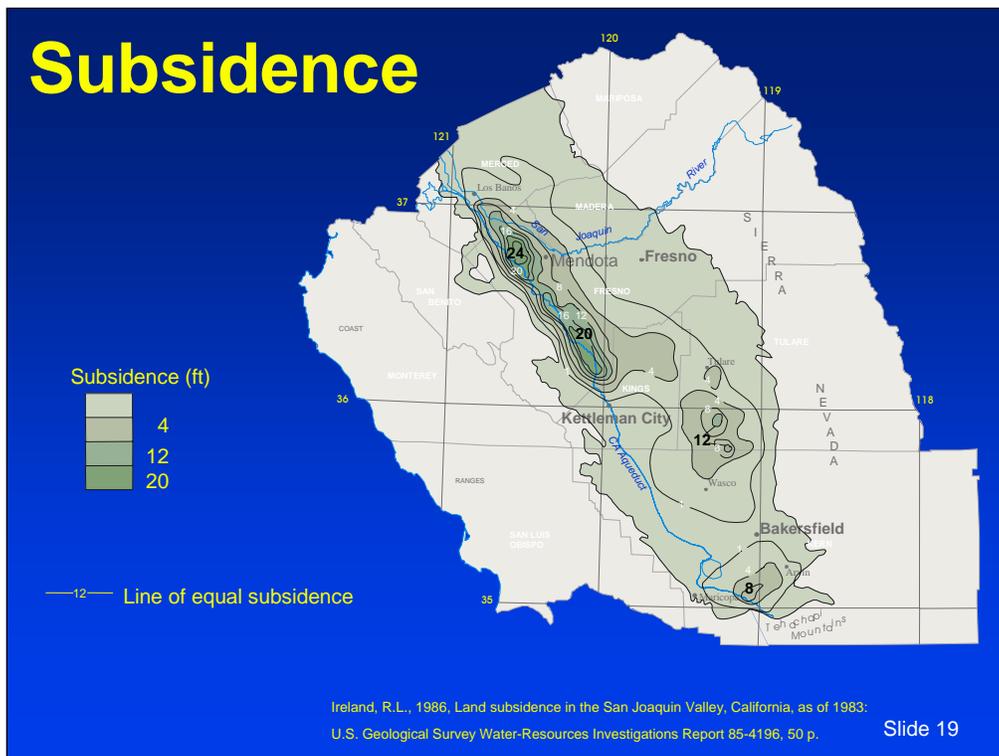
Starting at the end of the 19th century, extraction of groundwater began to change the way groundwater flows in the Tulare Lake Basin.

These are cross sections through the Central valley just north of the Tulare Lake basin. The coast ranges are on your left, and the Sierra are on your right. The salt water below the freshwater system is shown by the hachured area, and the blue arrows show the direction of water movement. The E Clay is present in each.

The upper cross section shows the natural pre-development groundwater flow system.

Formerly, infiltrating surface waters from streams originating in the coast ranges and the Sierra moved from the higher foothill areas of recharge to the center of the valley where it surfaced and was discharged as evaporation and evapotranspiration from Tulare lake and associated marshlands, or during wet years was discharged to the San Joaquin River and out to the Delta.

The lower cross section shows the current flow pattern. Groundwater recharge now is largely made up of infiltrated irrigation waters, carrying some fraction of the salts contained down into the groundwater. Groundwater discharge now is largely from pumpage of wells. Because there is no outflow from the basin, salts are recycled and concentrated within the basin.



Groundwater development in the late 19th and early to mid 20th century led to lowering of groundwater tables in the east side of the Basin, and land subsidence over large areas in the southern and western portion of the basin. This map shows where subsidence occurred most severely, largely centered on the western and southern portions of the basin.

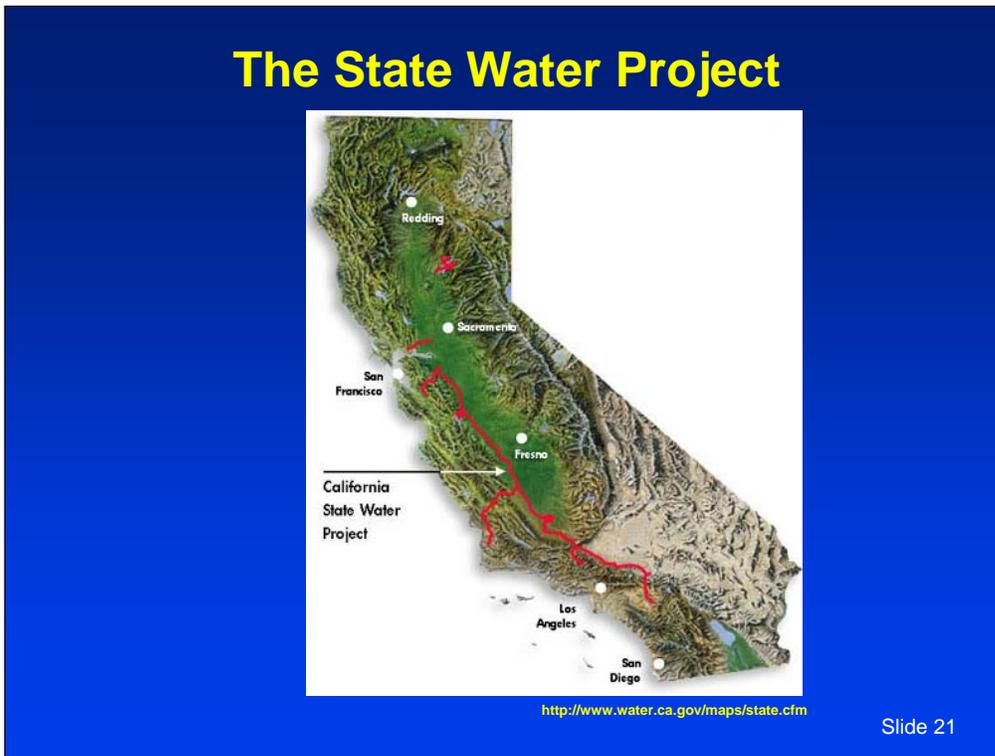
San Joaquin Valley Subsidence from 1925-1977



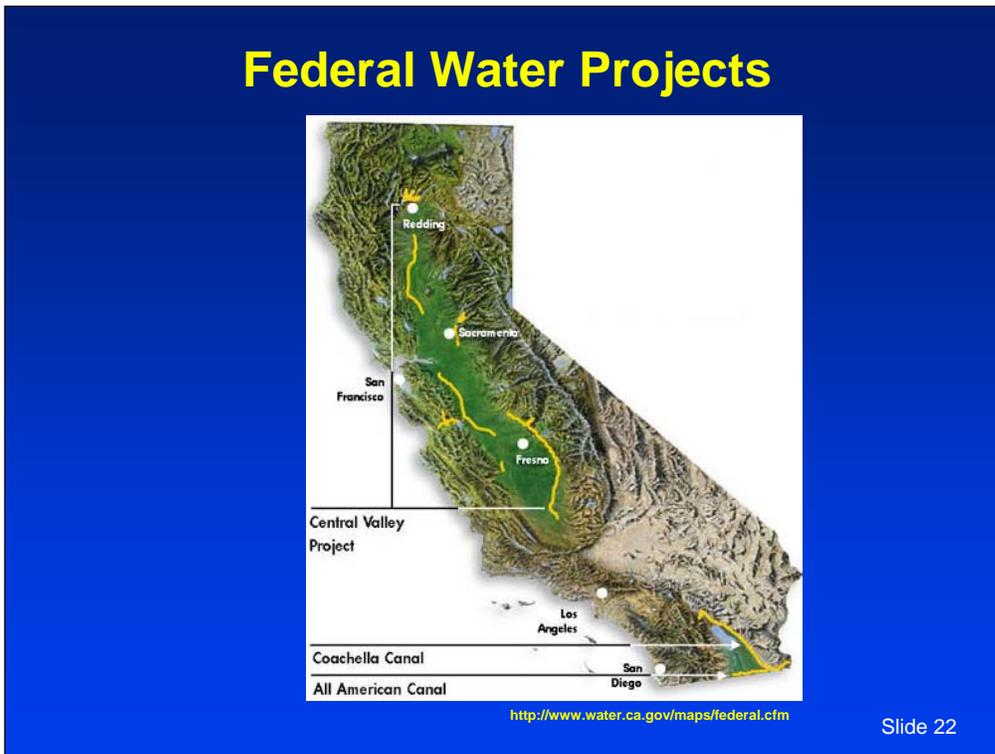
R. Ireland, U.S. Geological Survey

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Subsidence of over 20 feet occurred in several places, including near Mendota in western Fresno County where this famous photograph was taken.

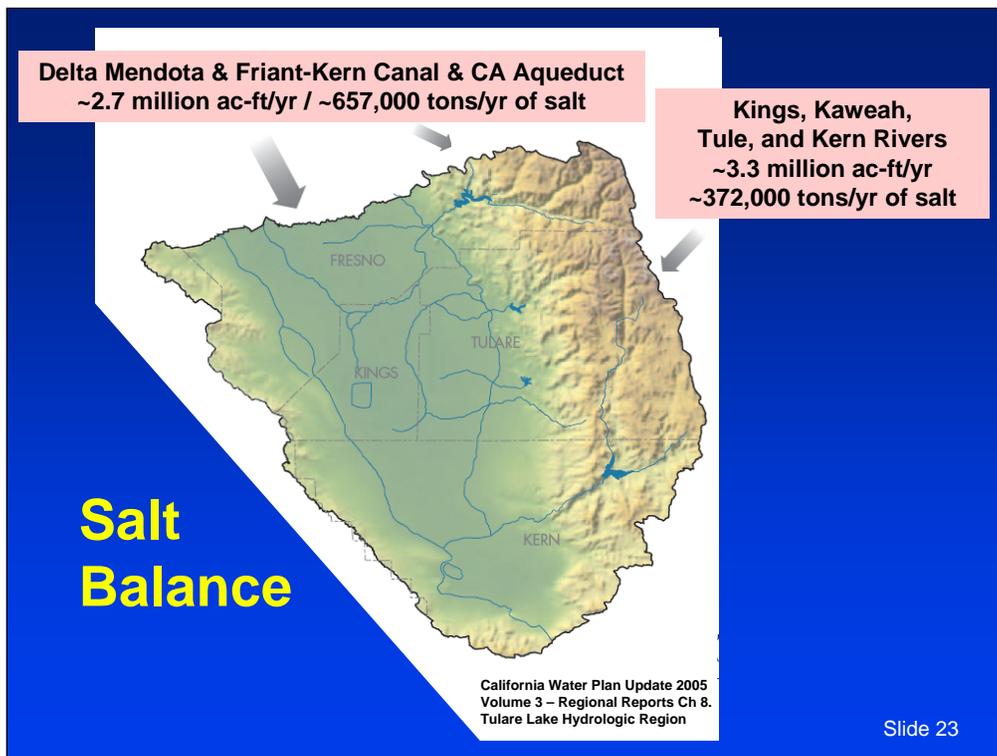


The State Water Project brought water from Northern California to San Joaquin Valley farmers and Southern California.



The Central Valley Project also brought Northern California water south. Part of the CVP transferred San Joaquin water to eastside farmers and Kern County.

Subsidence has largely stopped with the importation of surface water and the attendant decrease in groundwater pumpage on the west side of the basin.



However, imported water contains salts.

This slide shows the water and salt inputs into the Tulare Lake groundwater basin.

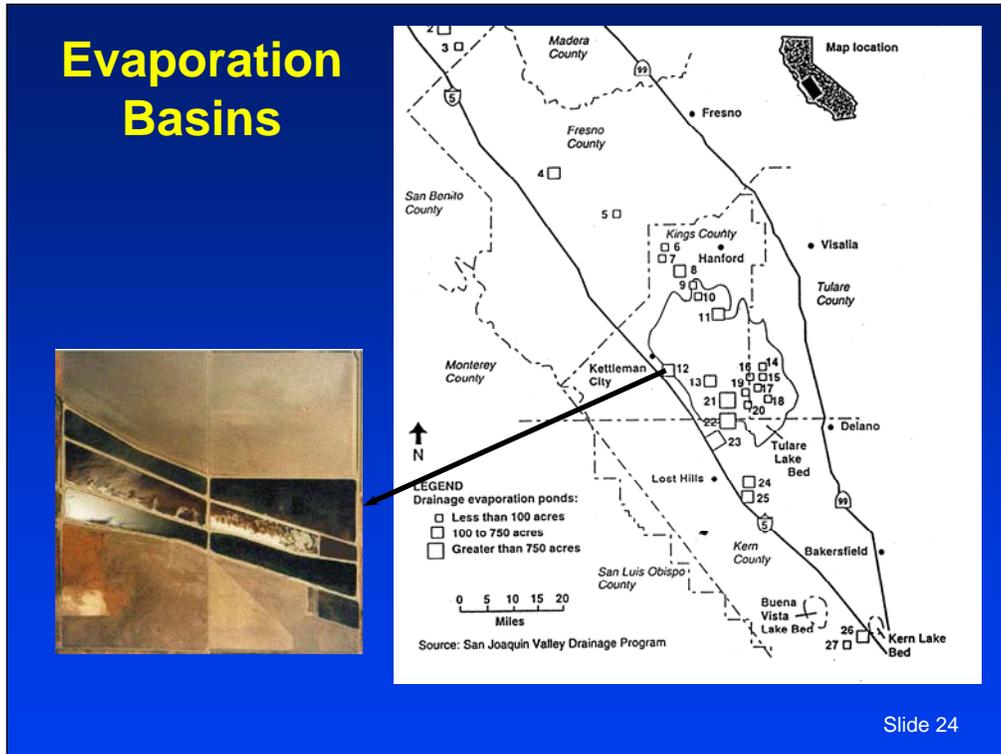
About 9 million acre feet per year of water enters the Tulare Lake groundwater basin from Sierran streams, contributing about 370,000 tons salt/year from the Kings, Kaweah, Tule, and Kern rivers.

The SWP and the CVP net import is approximately 2.7 million acre feet per year of water, containing about 660,000 tons per year of salt.

This means that the imported water which is about 1/3 of the natural flow into the basin contains almost twice the salt as the natural flows,

The water leaves as evaporation and evapotranspiration.

The salts stay in the basin.



Cultivation and irrigation of valley trough (basin) and west side lands has mobilized salts stored in these soils and moved them toward the groundwater,

Often creating conditions of shallow perched water of poor quality where soils are clayey.

Many acres of basin and west side farmland have been impacted by shallow saline groundwater.

An interim solution to this problem is disposal to evaporation basins

Currently, 4,800 acres of evaporations basins serve 46,000 acres of tile drained land in the Tulare Lake Basin.

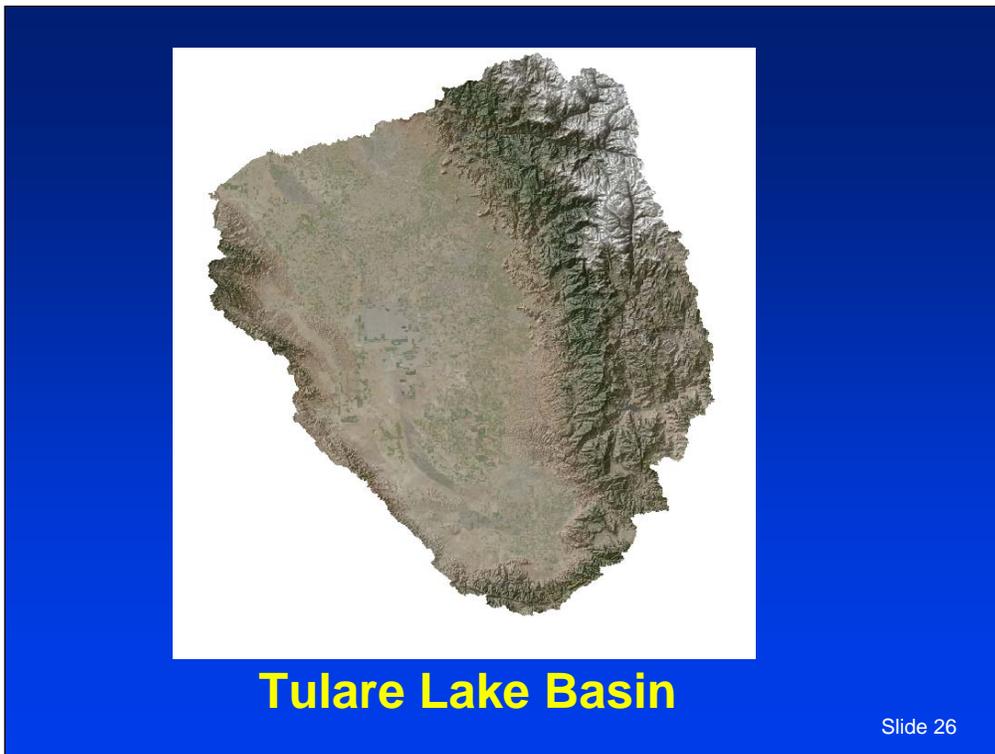
Evaporation Basin - Salt



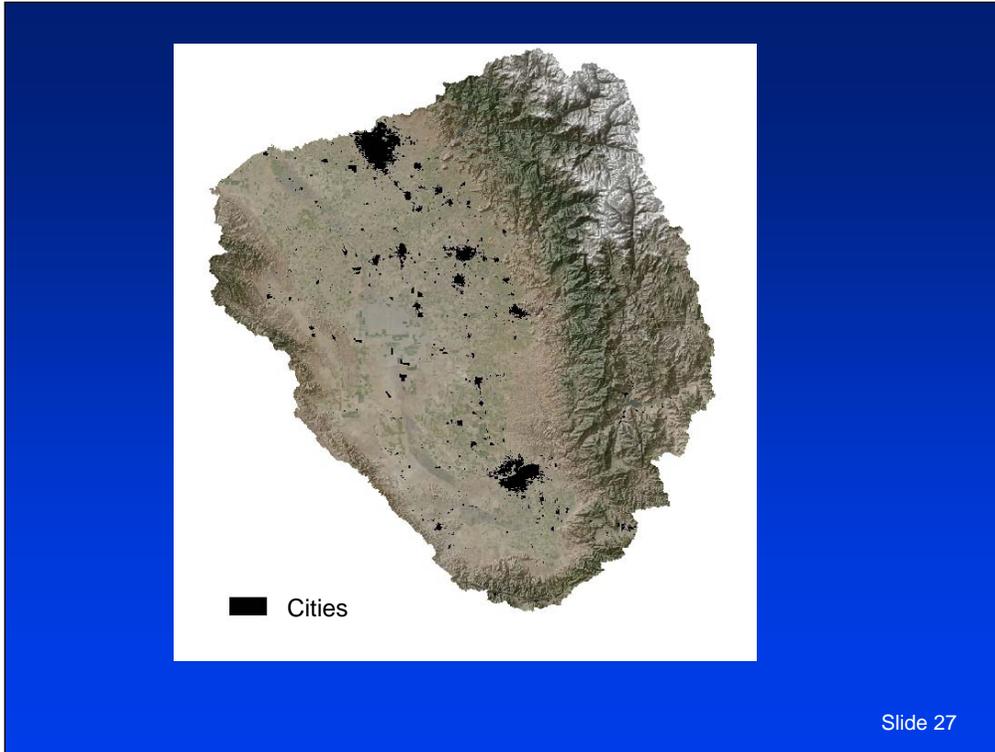
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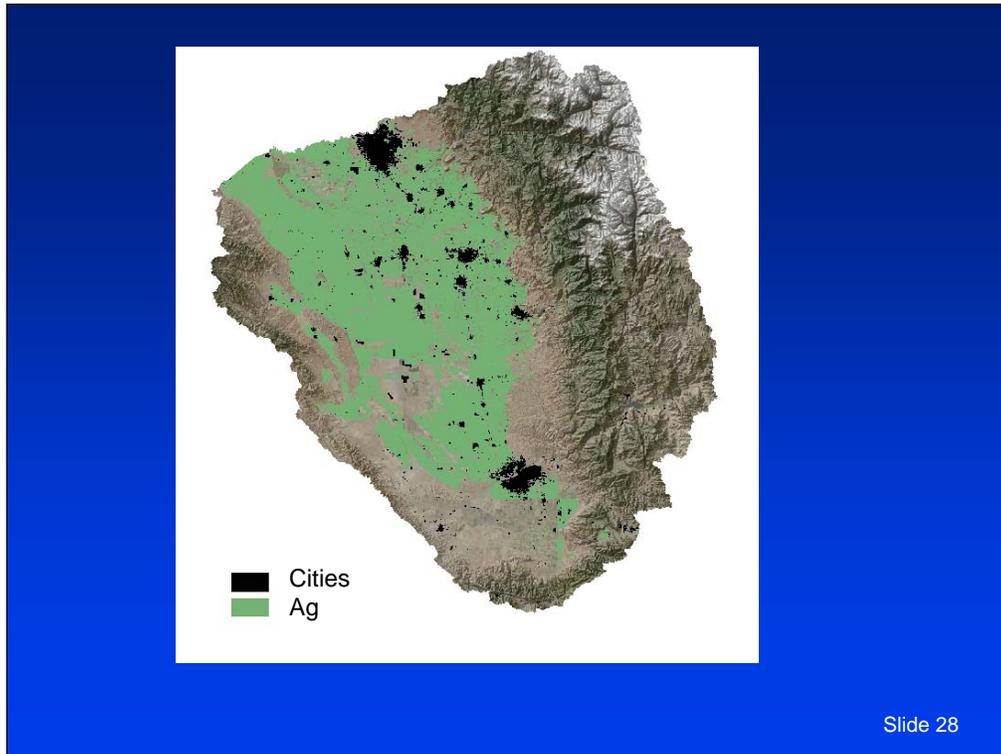
This young man is standing in a hollow salt crust in a dry evaporation basin on the west side of Kings County.



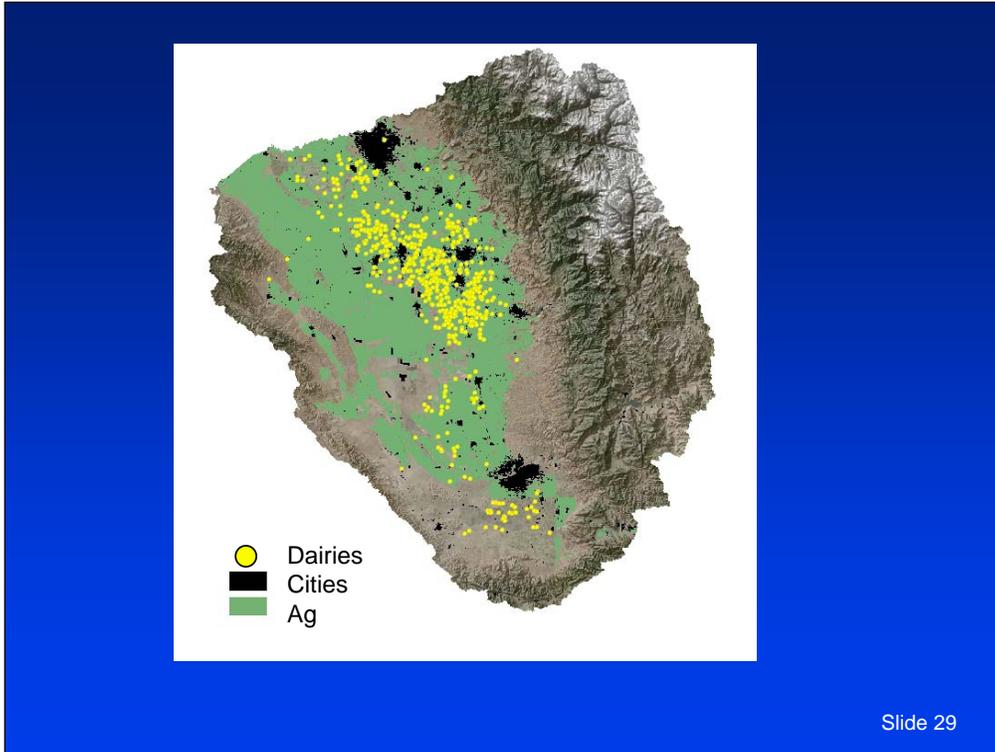
In summary with respect to Human Influences...



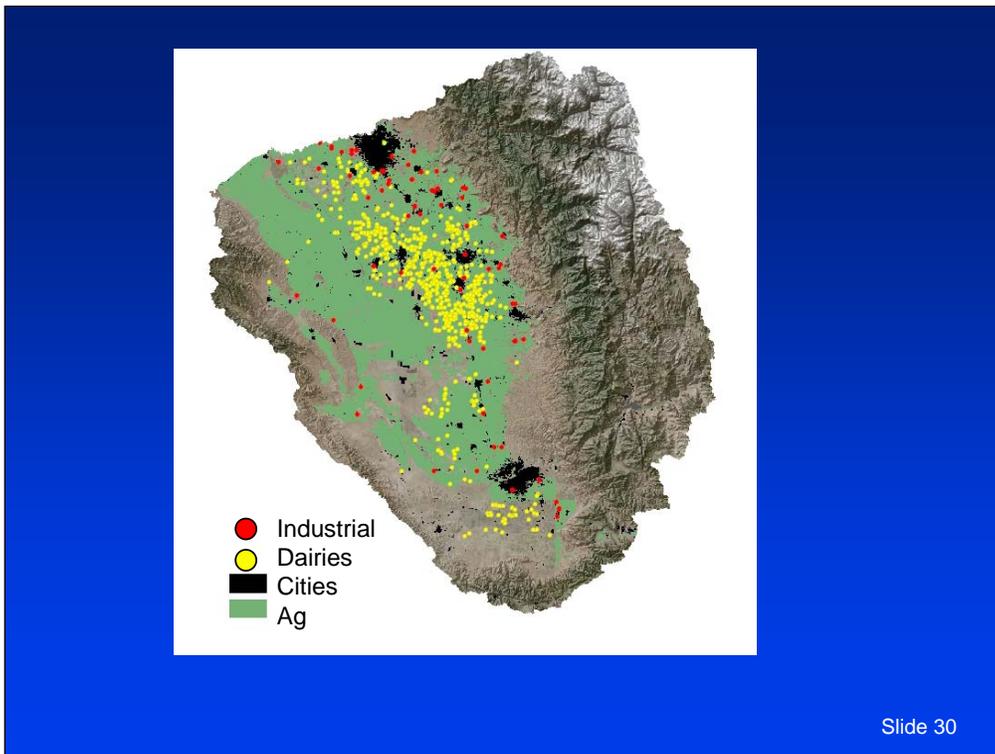
Today, the Tulare Lake Basin is home to approximately 3 million people



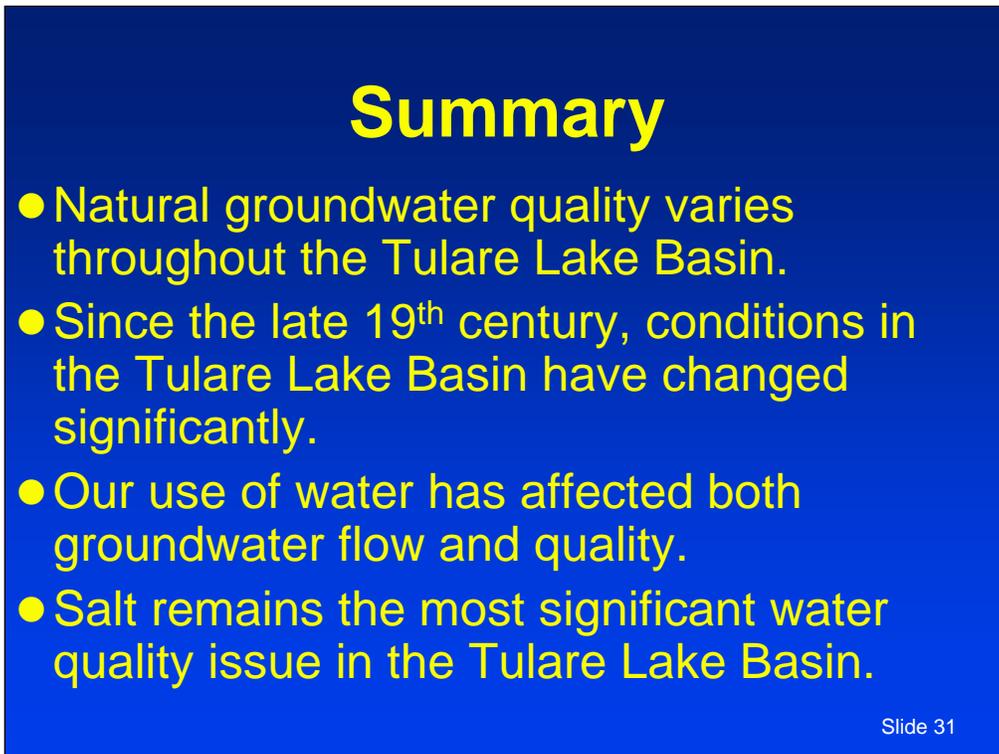
Approximately 3 million acres of land are under cultivation. Much of it irrigated with imported water.



There are 671 dairies, housing over 1,000,000 milk cows in the Tulare Lake Basin,



And approximately 100 facilities process the bounty grown or produced in the Tulare Lake Basin. All of these are sources of salt and other materials that accumulate in the Tulare Lake Basin, affecting or having the potential to affect, groundwater quality.



Summary

- Natural groundwater quality varies throughout the Tulare Lake Basin.
- Since the late 19th century, conditions in the Tulare Lake Basin have changed significantly.
- Our use of water has affected both groundwater flow and quality.
- Salt remains the most significant water quality issue in the Tulare Lake Basin.

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In summary:

- Natural groundwater quality varies throughout the Tulare Lake Basin.
- Since the late 19th century, conditions in the Tulare Lake Basin have changed significantly.
- Our use of water has affected both groundwater flow and quality.
- Salt remains the most significant water quality issue in the Tulare Lake Basin.



That concludes my presentation.

I would be happy to answer any questions as time permits.