ABSTRACT

Upper Colorado River (West Texas) and Petronila Creek (Texas Coastal Plain) salinities exceed state regulatory standards. For a recent study, airborne conductivity surveys located points of saline influx. Hydrochemical analyses defined salinity trends and potential sources. Both streams comprise Na-Cl hydrochemical facies and are near hydrocarbon production operations.

Upper Colorado River salinity decreases downstream overall (8,430-1,540 mg/L total dissolved solids [TDS], during this study) with local trend reversals. Stream-proximal shallow Permian groundwaters are sulfate enriched from evaporite dissolution. Stream-water chloride predominance is mitigated downstream by sulfate-enriched base flow. Anomalous chloride increases along the stream path correlate with proximity to anomalously saline water wells and oil fields. Conservative (Br/Cl) mixing models suggest hydraulic connection between saline wells, deep-basin brines, and saline streams.

Petronila Creek salinity increases downstream (233-15,180 mg/L TDS). The highest salinity (28,100 mg/L) in the study area is observed in a tributary ditch that previously was used for oil-field brine discharge. Conservative mixing models suggest that either Tertiary-age oil-field brine or seawater might constitute the source of salinity. However, boron and chloride data suggest that oil-field brine is probably the source. Sulfate (relative to chloride) is more concentrated in surface water than is expected from evaporation of oil-field brine or seawater and probably reflects soil-gypsum dissolution.

INTRODUCTION

Upper Colorado River (West Texas) salinities frequently exceed regulatory standards. For example, the 15,893-acre E. V. Spence Reservoir in Coke County impounds surface water from the Upper Colorado River (Fig. 1). The watershed upstream of the reservoir includes 15,278 sq. mi in Texas and New Mexico, although 10,260 sq. mi of the area is part of the High Plains system and does not generally contribute runoff to the main stream of the river. With increasing frequency, constituent concentrations in the reservoir have exceeded Texas Commission on Environmental Quality (TCEQ) standards for chloride (950 mg/L), sulfate (450 mg/L), and total dissolved solids (1,500 mg/L) (TCEQ, 2003). During this study (2005) of the Upper Colorado River in the Spence Reservoir area, maximum concentrations (mg/L) measured 3,950 for chloride, 1,500 for sulfate, and 8,430 for total dissolved solids (TDS). At the sample location immediately downstream of Spence Reservoir, concentrations of these same constituents respectively measured 1,505, 861, and 3,830 mg/L. Time-series data that report daily fluctuations of salinity in terms of specific electrical conductivity (SC) indicate that SC values at
Figure 1. Water-level map of the Upper Colorado River study area based on most recent well data collected since January 1, 2000. Also shown are well locations and stream-sample locations. County names shown in Figure 8. Data from Texas Water Development Board (2006).
one continuously monitored station on the Upper Colorado at Ballinger are frequently near or greater than 4,000 mS/cm (Fig. 2), which corresponds to greater than 2,000 mg/L TDS. In this example, lower SC values often occur during flooding events that dilute the normal dissolved constituent load.

There have been several investigations of factors affecting relatively poor surface- and groundwater quality along this segment of the Colorado. The most recent include Slade and Buszka (1994) and Paine et al. (1999). Most previous studies suggest that saline surface and groundwater in the upper Colorado River area has been affected by (a) dissolution of Permian-age strata-bound and recent soil-zone evaporites and (b) formation water released from oil-field operations in the Permian Basin.

Petronila Creek in Nueces and Kleberg counties on the Texas Gulf Coastal Plain (Fig. 3) has long exceeded quality standards since brine discharge from oil-field operations began in the 1950s. In analyses conducted between 1980 and 1986, salinities were observed to be equal to or greater than those of the ocean, and ionic proportions diverged from both fresh upstream and ocean waters (Fig. 4) (Shipley, 1991). Hydrocarbons were present in water and sediment, normal biological communities were reduced, and salinity-tolerant communities normally observed in estuarine environments were present far upstream of their expected niches. After brine discharges were discontinued in 1987, several fish species expanded their habitats from more upstream locations as salinities decreased.

Salinities of Petronila Creek water remain above acceptable levels. During this study (2005) of Petronila Creek and tributaries in Nueces County, maximum concentrations (mg/L) measured 14,780 for chloride, 2,630 for sulfate, and 28,100 for TDS. However, chloride concentrations measured during fall 2004 for the present study had fallen from levels measured in fall 1982, as reported in Shipley’s study (1991) (Fig. 4). Shipley proposed that dilution by groundwater caused the decrease in salinity downstream of the highest-salinity sample location nearest the Clara Driscoll Field (station 3 in Figure 4). In the 19 years since cessation of brine discharge to the stream, the salinity profile along the creek has been reduced (Fig. 4). Currently salinity gradually increases.

![Figure 2](image-url)  

Figure 2. Average daily stream discharge and specific electrical conductivity data for the Colorado River at Ballinger, Texas, collected between July 1, 2003, and July 1, 2005. Note general correspondence between low-flow conditions and elevated electrical conductivity. Data from U.S. Geological Survey (2006).
Figure 3. Location map of Petronila Creek study area. Also shown are topographic contours, oil-field locations, stream-sample sites, and Stiff diagrams for samples. Stiff diagrams have been normalized to emphasize variations in ionic ratios (meq/L units) rather than salinity. TDS values indicated below each diagram. Key to diagrams is provided with Stiff diagrams for (B) seawater and (C) Driscoll oil-field brine. Location 5 is tributary drainage ditch across Driscoll Field, and sample 9 is from a tributary that crosses Luby Field.
Figure 4. Plot of chloride concentrations for Petronila Creek measured at same locations in early 1980s (squares) and during recent investigation in 2005 (diamonds). Sample station numbers are keyed to present study. Extremely elevated values measured in 1980s reflected surface disposal of oil-field brine that was discontinued later in the decade. Note that most upstream and downstream values appear to have remained stable.

along the flow path (Figures 3 and 4). Notably salinity at the most downstream station, common to both studies, is approximately unchanged. The currently elevated salinity of surface water suggests that base flow with significant residual brine content still affects the creek. The evolving salinity profile might be explained as reflecting down-gradient migration of a saline plume in the near-stream subsurface.

RECENT STUDY

During fall 2004 and spring 2005, airborne conductivity surveys were coordinated with targeted hydrochemical sampling during an investigation of stream salinities in the Upper Colorado River in West Texas (Paine et al., 2005a) and Petronila Creek in south-central Texas on the Gulf Coastal Plain (Paine et al., 2005b). Objectives of the investigation were to identify (1) particularly saline reaches of the streams, (2) locations of above-average saline influxes, and (3) likely sources of fluids that contributed to stream salinity or otherwise influenced stream hydrochemistry. In addition, methods of investigation were brought to bear in the present effort that either were not utilized in previous studies or were more focused geographically in our study. This paper reports the results of hydrochemistry component of the project.

STUDY AREA AND METHODS

The Upper Colorado River study area is in the semiarid Rolling Plains and Edwards Plateau regions of Texas and includes the near-uppermost extent of the stream from Thomas Reservoir in Scurry County to Ivie Reservoir
in Concho County (Fig. 1). Distance along the valley included in this study is approximately 100 mi (not thalweg distance). Also included are parts of Beals and Elm Creeks, the most prominent tributaries of the Upper Colorado. Prominent municipalities on these streams include Colorado City (Mitchell County), Big Spring (Howard County), Robert Lee (Coke County), and Ballinger (Runnels County). Surface-geologic and hydrogeologic units include rocks whose ages range from middle Permian to Neogene age, as well as Holocene alluvium along some stream segments (Fig. 5) (Mear, 1963; Eifler et al., 1974; Eifler et al., 1975; Kier et al., 1976; Johnson, 2002).

The Petronila Creek study area is on the humid, subtropical Texas Gulf Coastal Plain and includes 11 mi of the stream from its uppermost extent to a location immediately southeast of a tributary stream that transects Luby Field (Fig. 3). Petronila Creek discharges into Alazan Bay, approximately 19 mi southeast of Driscoll, Texas. Driscoll, a small rural community (pop. 788) on State Highway 77, is the only community near the creek in the study area. Clara Driscoll and North Clara Driscoll fields, located on the south and north sides of Petronila Creek, respectively, are located a few miles southeast and northeast of Driscoll (Fig. 3).

Identical hydrochemical investigative methods were applied in both field areas. Measurements of pH, water temperature, and specific electrical conductivity were made at all the sample sites with a Hydrolab Quanta multisensor probe that was lowered into the water and allowed to equilibrate prior to recording measurements. The instrument was calibrated before the day’s measurements were made and at the end of the day. The calibrations were to check for instrument drift with calibration solutions that had been previously cross checked with laboratory desktop instruments. Instrument stability was excellent with regard to pH, and electrical conductivity calibration drift was insignificant compared with salinity levels observed in samples.

Samples were taken at 18 locations on the Colorado River, Beals Creek, and Elm Creek (Fig. 1); and 9 locations on Petronila Creek, a tributary ditch previously used for oil-field brine discharge (sample 5), and a tributary that transects Luby Field (sample 9) (Fig. 3). Location coordinates were determined with a hand-held Garmin GPS III unit. Two samples were taken at each location: (1) 500 mL, filtered with a 0.45-mm filtering syringe assembly and (2) 200 mL, filtered with a 0.45-mm filtering syringe assembly and stabilized with 2mL 6N HCl. The samples were stored on ice for 24 hrs and then shipped by overnight express to laboratories at the Kansas Geologic Survey, University of Kansas at Lawrence. Under the supervision of Donald Whittemore, samples were analyzed for major ions, TDS, laboratory alkalinity and pH, bromide, and boron. Samples were also collected from one oil-field brine separation tank at each location. Brine samples were analyzed for iodide as well as a cross-check for accuracy of the bromide measurements. Charge balance variances between cations and anions were less than 5%.

Interpretations of salinity sources were based on classical hydrochemical techniques that included cross-plotting concentrations of chemical constituents and development of end-member mixing models that use measurements of concentrations and calculated ratios of conservative constituents analyzed from water samples. Similar methods were described by Richter et al. (1993) and Whittemore (1995). Some of these methods were applied to the Upper Colorado study area by Slade and Buszka (1994) and to the Petronila Creek area by Shipley (1991). The present study differs from the previous effort in the Upper Colorado River area in that it is more locally focused and explores hydrochemical variability of stream water as a function of base-flow hydrochemistry. This study differs from the previous effort in the Petronila Creek area by Shipley (1991) in that it uses cross plots of conservative-ion constituents and conservative-ion end-member mixing models to discriminate between potential sources of stream salinity.

RESULTS

Upper Colorado River

The Upper Colorado is an overall gaining stream (Fig. 1). Base flow in the study area is from Triassic and Permian aquifers (Fig. 5), whose hydrochemistry significantly affects that of the streams, as will be discussed later. The study area is on the Eastern Shelf of the Permian Basin, where stratal dip is toward the west. Aquifer host-rock age thus increases to the east, in the downstream direction. Locally, ground- and surface waters co-mingle in Quaternary stream alluvium (Fig. 5). Stream depths vary irregularly along the Colorado River, and scarcity of surface water in some reaches suggests that flow is largely through stream alluvium locally. Several
Figure 5. Stratigraphic chart for the Upper Colorado River study area (modified after Paine et al., 2005a). Note increasing importance of evaporites and carbonates in older parts of the succession. Aquifer rock types exert strong control on groundwater and surface-water chemistry (see text for discussion).
prominent Permian Basin oil fields are located along the river and may be a source of high-chloride groundwater and, ultimately, surface water.

Dissolved solids, chloride, and sulfate content in Colorado River water decreases overall downstream, with several trend reversals in the vicinity of prominent oil fields (Figs. 6 and 7). In terms of meq/L, all surface-water samples are Na-Cl type (Na and Cl compose >50% of the cation and anion fractions, respectively), with one notable exception (sample 10) (Fig. 6).

Although 17 of the 18 surface-water samples are Na-Cl dominated, SO₄/Cl and Ca/Cl values increase overall in the downstream direction, with a few trend reversals. One sample that shows such a reversal is in the vicinity of the Wendkirk Field (sample 8) (Figs. 6 and 7). It is best explained as the accumulating effects of base flow of SO₄- and Ca-enriched groundwater, with a local source of Cl-enriched ground water in the Wendkirk vicinity (Fig. 8).

Base-flow groundwater is sulfate-rich (in terms of mass units) along most of the stream within the study area, whereas groundwater in areas 10 mi or more from the stream are dominated by chloride. The primary control on quality distribution is the aquifer system from which groundwater from a given location is abstracted (Fig. 9). On a regional basis, for example, average SO₄/Cl is significantly higher in Triassic and Paleozoic aquifer systems than in the Cretaceous and Ogallala systems (Fig. 10). Ogallala and Cretaceous strata characterize highlands, whereas older strata predictably are exposed in topographically lower areas. The overall increase in SO₄/Cl along the stream flow path is a direct result of stream contact mainly with Triassic and Paleozoic rocks. Sulfate attains dominance (>50% of anions, in terms of mass) in the surface water along the most downstream reach in the study area, beginning at the Coke/Runnels county line (Fig. 8), although the water maintains its Na-Cl-type facies character (Fig. 6).

Ca/Cl values increase overall downstream, as mentioned earlier. The spatially abrupt increase in Ca/Cl values in stream water at the Coke/Runnels county line reflects a compositional change in base flow arising from aquifer mineralogical variability that marks the change from dominantly sandstones, shales, and minor evaporites in upstream positions to a significant abundance of carbonate-bearing and evaporate-bearing rocks in more downstream positions. The increasing importance of carbonate in progressively older aquifer rocks is evident in the HCO₃/SO₄ values.

Conservative mixing models utilizing Br and Cl concentrations are consistent with the proposition that Upper Colorado River water composition reflects mixing of local fresh groundwater and deep-aquifer brines similar to those produced in local oil wells that have been completed in local Pennsylvanian reservoirs. Figure 11A demonstrates that the Br/Cl compositions of most stream-water samples fall within a mixing envelope constructed between local groundwaters with the lowest chloride concentrations and deep-aquifer brines sampled from local oil fields. The mixing envelopes allow for a ±5% analytical error for the end-members. Samples that fall outside the mixing envelope are the most upstream samples that are farthest from the oil wells where produced brines were sampled; and the most upstream of these samples deviate the most from the mixing envelope. This development does not prove that stream salinization is caused by contamination from oil-field operations, but it strongly suggests that similar deep-aquifer brines occur within the shallow aquifers that supply stream base flow. Stream water enters the study area from the northwest with high concentrations of chloride, and its relative concentration of chloride decreases overall along the flow path. However, a local increase in TDS and chloride, and a corresponding decrease in the SO₄/Cl value occur in the immediate vicinity of Wendkirk Field (sample 8) (Figs. 6-8). Although the model is not presented here, groundwater from an anonymously saline shallow well near Wendkirk Field plots on a Br/Cl mixing line between Wendkirk brine and sample 8. Such a relationship is not shown for other nearby, more upstream stream samples and strongly suggests a hydrochemical affinity between the three samples. It appears that either (1) deep Pennsylvanian brines have a highly-localized natural conduit to the shallow aquifer in this area or (2) brines are leaking from oil-field operations. It is not clear that anything short of testing oil wells for brine leaks or identifying leaking, abandoned brine pits can indicate conclusively that oil-field operations are responsible for stream contamination.

**Petronila Creek**

Petronila Creek is incised into Pleistocene-age strata of the Beaumont Formation (Brown et al., 1975) of the Chicot aquifer system, which extends along the entire Gulf Coastal Plain. The Beaumont is composed mainly of muddy, unconsolidated sediments with a few groundwater-productive sand layers. Along Petronila Creek in the
Figure 6. Stiff diagrams of selected sample locations along the Upper Colorado River study area. Diagrams have been normalized to emphasize variations in ionic ratios (meq/L units) rather than salinity. TDS values are also shown. Note overall increase in (Ca+Mg)/Na and SO₄/Cl downstream, although stream water remains an Na-Cl type in all but sample 10. Dominance of Ca and increase in (Ca+Mg)/Na in sample 10 reflects base flow from Clear Fork carbonate aquifer that crops out near location 10.
study area, the upper 5.5 m of the soil profile is characterized by a 0.5-m cap of dry silty clay and an underlying 5 m of wet, highly electrically-conductive silty clay, with a 0.2-m-thick sand bed in an intermediate position (Fig. 12). The highly-conductive interval is underlain by a significantly less conductive sandy interval. The base of the creek generally corresponds to the transition zone from highly conductive to less-conductive soil near the 5-m-depth level. The highly-conductive interval is best explained as recording the presence of groundwater with elevated salinity. The salinity profile appears to be inverted, in that one would expect salinity to increase with depth. The inverted salinity profile is consistent with influx of brine into the near-surface environment.

The stream continues to flow, even in times when there has been no recent precipitation. Therefore, the creek is maintained by base flow, which is maintained by meteoric recharge. It is reasonable to expect that movement of meteoric recharge through the highly conductive soil interval is responsible for maintenance of high salinity in the creek. The primary question concerns the ultimate cause of elevated salinity in the soil profile. The two obvious candidates are (1) seawater, because the study area is near the Gulf of Mexico, and (2) oil-field brine, because the study area contains several oil fields.

Dissolved solids, chloride, and sulfate contents in Petronila Creek water increase downstream (Fig. 13). The most elevated salinity in the study area is found in a tributary ditch (sample 5) that transects Clara Driscoll Field (Fig. 13A). In terms of meq/L, all surface-water samples are Na-Cl type, except for the most upstream sample (sample 1), which is Ca-HCO₃ type (Fig. 3). The change from the hydrochemical-facies type observed in sample 1 to the thoroughly Na-Cl type observed in sample 3 is transitional, as documented in sample 2. Sample 2 has a Ca component that is intermediate in concentration between samples 1 and 3 (Fig. 3). Input from the tributary ditch, whose hydrochemistry is characterized by sample 5, does not greatly affect creek-water salinity because absolute discharge from the ditch was very low during the sampling period, when only isolated pools were present.
Figure 8. Map of SO₄/Cl values for shallow groundwater and stream water in the Upper Colorado River study area. Ratios are based on mg/L units. Stream-sample locations and corresponding SO₄/Cl values also shown. Curves connect river samples. Groundwater that is in proximity to the Colorado River and Beals Creek is generally enriched in sulfate compared with groundwater in less proximal areas. Mapped hydrochemistry generally reflects aquifer rock constituents (see Figure 10). Base flow from groundwater causes the river water to become generally more sulfate-rich downstream (see Figure 7); however, river water remains relatively elevated in chloride (compared with nearby aquifers) throughout most of the study area. River water achieves SO₄/Cl>1 near the Coke/Runnels county line.
Figure 9. Completion intervals for shallow-water wells in Upper Colorado River study area. Data from these wells provided values upon which SO₄/Cl map (Fig. 8) is based. Stream segments are shown only from which samples were collected.
Figure 10. Histogram showing average values of SO$_4$/Cl from prominent aquifer systems in the study area. Colorado River and near-river tributary segments are preferentially located in Triassic and Paleozoic rocks.

Conservative-ion two-end-member mixing models that use Br and Cl suggest that mixtures between water similar to that sampled in the tributary ditch (sample 5) and that sampled near Hwy. 77 (sample 2) show the best fit with other surface-water samples (Fig. 11E). However, the ultimate source of elevated salinity has to be in the soils in the recharge areas from which base flow acquires its hydrochemical character.

As mentioned earlier, the most likely candidates for providing salinity to the soil in the study area include seawater and oil-field brine. The Br-Cl mixing model does not provide a means for discriminating between these two potential salinity sources because seawater falls within the mixing envelope (Fig. 11B-E). Similar Br-Cl cross plots further document the difficulty of discriminating between seawater and oil-field sources of salinity (Fig. 13B). On the other hand, surface-water samples with elevated salinities (nos. 2-9) have elevated SO$_4$ concentrations (Fig. 13A), which would tend to eliminate oil-field brine because its sulfate fraction is exceeding low (Fig. 3). However, local soils have gypsum within the upper 5 m (Paine et al., 2005B), and surface water is close to gypsum saturation (Log SI = 0.02 to 0.38 in the seven more saline samples), according to hydrochemistry models generated in WebPhreeq (NDSU, 2006). These factors suggest that dissolution of soil gypsum is the primary source of sulfate in the surface water and seawater is not required to supply sulfate to the system directly, although it is possible that evaporated sea spray, or even evaporated oil-field brine, may be contributing sources of sulfate found in the soil.

Fortunately, cross plots of boron with chloride provide a means of discriminating between the two potential sources of salinity (Fig. 13C). In Figure 13C, surface-water samples and Driscoll oil-field brine define an approximate linear trend in the Br-Cl cross plot, whereas the boron concentration for mean seawater is relatively depleted compared with the expected value for a sample of comparable chloride concentration on the linear trend defined by the surface-water samples.

The brine sample does not, however, fall exactly on the linear trend defined by the surface-water samples, whereas the tributary ditch sample does fall close to a linear trend defined by the other surface-water samples. This slight misfit of the brine sample with the linear trend is best explained by the observation that the tributary ditch is currently receiving discharge of saline fluids that were placed in the soils during a previous time, when
Figure 11. Two-end-member Br/Cl mixing models: (A) in Upper Colorado River area, between oil-field brines and lowest-chloride groundwater samples; note that most of the surface-water samples lie within the mixing envelope. Most-upstream samples are either just below the mixing envelope (samples 1, 2, 4, and 5) or near the upper limit (sample 3) and are upstream of the Wendkirk oil-field area discussed in the text; in Petronila Creek area (B) oil-field brine and most-upstream creek sample; (C) between seawater and most-upstream sample; (D) tributary ditch sample and most-upstream creek sample; and (E) between tributary ditch sample and second-most-upstream creek sample, which is the best-fitting model for the highly saline creek samples. Tributary ditch had previously been used for oil-field brine discharge, and its present hydrochemistry probably reflects average composition of historical discharge that currently affects creek constituent composition. It is not possible with Br/Cl mixing models to distinguish between oil-field brine and seawater as potential salinity sources.
Figure 12. Soil profile on Petronila Creek floodplain near Driscoll, Texas, located near sample location 4 (Fig. 3), showing generalized soil types and apparent electrical conductivity (modified after Paine et al., 2005b). Distribution of conductivity values suggests that a plume of saline water is perched on fresher water. The base of the creek corresponds approximately with the transition from saline to fresher water. Sandy zone at 3 m depth may provide conduit for flux of saline fluid to the stream.
Figure 13. Hydrochemical cross plots for Petronila Creek samples: (A) concentrations of dissolved solids, chloride, and sulfate along flow path, including brine-discharge-ditch and Luby-area tributaries; lines connect Petronila Creek data points; (B) bromide versus chloride; and (C) boron versus chloride. Note that salinity and concentrations of major anions consistently increase along flow path. Boron/chloride plot suggests that oilfield brine, rather than seawater, is the source of salinity to the surface water.
oil-field brines were being disposed of at the surface. The local oil-field brine sampled for this study, however, was just one sample of local brines that may range in composition, depending on the specific well being sampled and the specific stratigraphic intervals from which brines are produced. The tributary ditch sample is probably more representative of the average composition of the original brines that continue to contaminate the creek.

**CONCLUSIONS**

Similar classical hydrochemical analytical methods were used to interpret sources of elevated salinity in two Texas stream systems that were located in profoundly different hydrogeological environments: the Upper Colorado River in the semiarid Rolling Plains and Edwards Plateau region, and Petronila Creek on the humid Gulf Coastal Plain.

**Upper Colorado River**

1. The Upper Colorado is an overall gaining stream that receives base flow from shallow aquifers developed in Paleozoic and Mesozoic strata.

2. All surface-water samples but one are Na-Cl-type.

3. Dissolved solids and major-ion concentrations decrease overall in the downstream direction.

4. Surface water maintains dominance by chloride (>50% of anions, in terms of mass) throughout most of its course in the study area, although SO4/Cl values increase along the flow path as a result of sulfate-enriched base flow.

5. Base-flow groundwater is sourced from sulfate-rich (in mass units) Permian and Triassic aquifers along most of the stream within the study area, whereas groundwater in areas 16 km (10 mi) or more from the stream are produced mainly from Cretaceous and Ogallala aquifers that have overall lower groundwater SO4/Cl values.

6. Chloride-enriched base flow locally interrupts the pattern of downstream sulfate enrichment in areas with prominent hydrocarbon-producing operations.

7. Spatially abrupt increase in SO4/Cl and Ca/Cl values in stream water reflects a compositional change in base flow that arises from aquifer mineralogical transition from siliciclastic-dominated, evaporate-bearing matrix to carbonate- and evaporate-dominated matrix. Increasing importance of carbonates is also reflected in increasing HCO3/SO4 values along the flow path.

8. Conservative mixing models utilizing Br and Cl analyses are consistent with the proposition that Upper Colorado River water composition reflects mixing of local fresh groundwater and deep-aquifer brines similar to those produced from local oil wells that are completed in Pennsylvanian reservoirs of the Eastern Shelf hydrocarbon province.

**Petronila Creek**

1. Salinity increases along the Petronila flow path, whereas it previously decreased along the flow path from high values in the Driscoll field area during times when oil-field brines were being discharged at the surface in the area.

2. Soil-conductivity profiles indicate a perched column of saline groundwater at and above creek level.
3. The mixing envelope produced by mixing a tributary ditch sample with sample 2 (Hwy. 77 bridge) shows the best fit with other surface-water samples, thereby suggesting that all the waters are related through mixing of common end-members.

4. Cross plots of boron with chloride suggest that oil-field brine is the primary source of salinity to surface water in the study area.

5. The highly saline tributary ditch was used until the 1960s for brine disposal, and its hydrochemistry more probably represents brines that are entering the stream through base flow than does the recently produced oil-field brine collected for this study.

6. Elevated SO₄ in the surface water probably records contributions from dissolved gypsum that occurs in the soil.

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