Prepared in Cooperation with the Utah Department of Environmental Quality

Quantifying Trends in Arsenic, Nitrate, and Dissolved Solids from Selected Wells in Utah

Scientific Investigations Report 2020–5047

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

Cover images: Left, Utah Valley, 1986, Google Earth
Right, Utah Valley, 2016, Google Earth.

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DAVID BERNHARDT, Secretary

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
acre-foot (acre-ft)	1,233	cubic meter (m^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F = (1.8 × °C) + 32.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Supplemental Information

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Abbreviations

EPA	U.S. Environmental Protection Agency
IQR	interquartile range
MCL	maximum contaminant levels
NTU	Nephelometric Turbidity Units
NWIS	National Water Information System
SDWA	Safe Drinking Water Act
SDWIS	Safe Drinking Water Information System
SMCL	secondary maximum contaminant level
USGS	U.S. Geological Survey

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Abstract

Groundwater makes up a primary portion of the water supply in many parts of Utah, with annual withdrawals estimated at more than 1,000,000 acre-feet per year. Increases to groundwater withdrawal and land use may negatively impact water availability. Ensuring availability of clean water requires understanding how water quality has changed over time and how natural and human activities and processes influence water quality. Changes in arsenic, nitrate, and dissolved-solids concentrations in the groundwater in basins with high groundwater withdrawals were evaluated between 1975 and 2015 as indicators of basinwide water quality and the suitability of water for drinking. Data were used from the U.S. Geological Survey's National Water Information System (NWIS) database and the Safe Drinking Water Information System (SDWIS) maintained by the Utah Department of Environmental Quality, Division of Drinking Water. Mann-Kendall trend tests were used to assess temporal trends in decadal and 5-year (sub-decadal) median analyte concentrations in basins. Trends also were assessed in smaller parts of larger basins to focus on changes occurring at a smaller spatial scale. To evaluate the relationship between land-use change and water-quality changes, trends also were evaluated for wells where land use has changed. Trends in decadal and sub-decadal median arsenic, nitrate, and dissolved-solids concentrations over time were identified throughout the basins and sub-basins in this study. For combined NWIS and SDWIS data, rates of median arsenic concentration change in basins and sub-basins ranged between decreases of –0.24 microgram per liter (ug/L) per year and increases of 0.48 ug/L per year. Rates of median nitrate-concentration change ranged between decreases of –0.08 milligram per liter (mg/L) per year and increases of 0.02 mg/L per year. Rates of median dissolved solids concentration change ranged between decreases of –5 mg/L per year and increases of 7 mg/L per year. The rates of change for nitrate and dissolved solids were similar to or less than rates of change observed in other parts of the country. Trends were not directly related to land-use change approximal to a well, although more data from wells where land use has changed would improve this evaluation. These findings highlight that water quality at a well is related to a range of factors including land, demographics, and water use over a larger area surrounding and up-gradient from the well; rates and direction of groundwater movement; and geologic and hydrologic conditions.

Introduction

Groundwater withdrawals in Utah have increased over time, mostly due to increased irrigation and industrial use (Burden, 2015). Groundwater also is used for public supply and serves as buffer for water suppliers when surface-water supplies decrease (for example, during summer months or drier years). Groundwater use is expected to play an even bigger role in meeting growing water demand as the population of Utah grows. The Utah Governor's Office of Planning and Budget estimates indicate that the population in Salt Lake County will nearly double from approximately 1 million people in 2010 to 1.8 million people by 2050 (Utah Governor's Office of Planning and Budget, 2012). Groundwater quality becomes increasingly important for supplying clean water to a growing population. Degradation of groundwater quality can have long-term negative implications for the viability of groundwater as a source of drinking water.

Groundwater has several advantages as a source for public water supply. Although surface-water supplies may be sensitive to precipitation and temperature variability on weekly to monthly timescales, groundwater integrates climatic conditions over multi-year timescales, making it a more constant supply. Groundwater also can be harder to contaminate than surface-water bodies because contaminants introduced at the land surface must travel through the subsurface to reach aquifers. Finally, groundwater withdrawal often occurs proximal to areas of demand, whereas surface water often requires conveyance over long distances (Price, 1985). These advantages, in addition to the relatively large volumes of groundwater relative to surface water, make groundwater an important source of water for future water use and management plans. However, for groundwater to continue to be a viable supply into the future, groundwater resources must be carefully managed by using knowledge of the groundwater conditions. Excessive withdrawals can result in declines in water levels leading to increased costs to drill wells, land-surface subsidence, water-quality deterioration, and conflicts over water rights.

This report investigates spatial and temporal trends in arsenic, nitrate, and dissolved-solids concentrations in basins that have experienced significant groundwater development in Utah. These analytes were selected for several reasons. Each analyte is regulated by the U.S. Environmental Protection Agency (EPA) and reflects different natural and anthropogenic processes. Increased concentrations of nitrate and dissolved solids, resulting from human activities, also are a common water-quality issues in the southwestern United States (U.S.; Thiros and others, 2010). Characterizing temporal and spatial patterns and trends in these analytes is important for regulatory compliance and for understanding impacts of different natural and anthropogenic influences.

Arsenic, a toxic element of concern for human and animal health, has been predicted to exceed drinking water standards in 43 percent of the area of basin-fill aquifers in the southwestern U.S. (Anning and others, 2012; Beisner and others, 2012). Arsenic often occurs naturally in aquifers from interactions between water and arsenic-bearing minerals in rocks. Generally, at local scales, human alteration of aquifer geochemical conditions such as pH or oxidation-reduction conditions can mediate arsenic concentrations in groundwater; this could occur through groundwater pumping or artificial recharge, or the addition or removal of an acid or base to the groundwater system. Increased loading of arsenic, through leaching of mining tailings, for example, also can impact groundwater arsenic concentrations.

Nitrate can occur naturally in groundwater through dissolution of geologic deposits or from desert legume soil processes; or it can be introduced to water by human activity through fertilizer use, manure production, and agricultural and urban land development (Anning and others, 2012). Nitrate can cause a range of negative human and animal health impacts.

Dissolved solids occur naturally in water through dissolution of geologic deposits, or through anthropogenic processes including land development, wastewater treatment plant discharge, and irrigation and other agricultural practices. Dissolved-solids concentrations can increase through water consumption (for example, diversion of clean water out of a basin or evapotranspiration), which reduces the amount of water available for dilution. High concentrations of dissolved solids can impact aquatic ecosystems, and agricultural, municipal, industrial, and domestic water users who require or prefer water with low dissolved solids.

Factors that Affect Water Quality

Natural and human factors can influence groundwater quality. In the southwestern U.S., several natural and human factors have been identified as important controls on groundwater quality including the quality of recharge water, the composition of geologic material in contact with water, land and water use, and chemical spills or leaks (Thiros and others, 2010). Bexfield and others (2011) described in detail common natural and human contamination sources to basin-fill aquifers in the southwestern U.S. Because these processes vary in time and space, and can work constructively or destructively, disentangling the effects of specific processes on water quality poses a unique challenge. In addition, assessment and process attribution of changing groundwater quality over time is further complicated by the multiyear to millennial timeframes of groundwater movement. The following paragraphs broadly describe natural and human factors, including changes to the hydrologic flow system and changes to constituent sources, that can influence arsenic, nitrate, and dissolved-solids concentrations in groundwater.

Natural factors can influence groundwater quality. The chemical composition and amount of recharge water can influence groundwater quality. The geologic composition of porous media through which water passes, the contact time, and geochemical conditions can greatly influence concentrations of dissolved solids and metals (for example, arsenic and uranium; Anning and others, 2007; Bexfield and others, 2011). In the Southwest, volcanic bedrock surrounding basin-fill aquifers, low rates of natural recharge from precipitation, high potential evapotranspiration, minimal basin outflow, and geochemical conditions all contribute to increased vulnerability of an aquifer to high arsenic concentrations (Anning and others, 2012). Recharge from mountain streams to basin-fill aquifers typically originates as snowmelt runoff and is generally of high quality (low dissolved solids). Dissolved-solids concentrations typically increase along flow paths through interactions with basin-fill sediments and evapotranspiration (Anning and others, 2007). Evapotranspiration and nitrate fixation by vegetation also can concentrate nitrate in soils, which can subsequently dissolve in recharge passing through soil and moving downward to aquifers.

Humans have influenced groundwater quality through alteration of the hydrologic flow system in Utah (Thiros and others, 2010). As groundwater pumping and use have increased, human-mediated recharge (for example, through infiltration of excess irrigation water and seepage from leaky canals, pipes, or ponds) has become an important component of the hydrologic system with potentially important impacts on groundwater quality. Increased pumping can alter flow patterns within an aquifer, leading to higher flows and thus higher connectivity, particularly from the land surface to shallow aquifers, thereby increasing the risk of contamination from the surface (Thiros and others, 2010). Recharge of water exposed to surface contamination can transport contaminants to aquifers. Historically, recharge has occurred through mountain block recharge or as infiltration through streams and alluvial fans at the base of mountains. However, as irrigation and development has increased, excess water from fields and yards and leaking canals and pipes has become a source of recharge to aquifers (Lambert, 1995). Excess irrigation and artificial recharge (for example, seepage from unlined canals, leaky pipes, or septic systems; or engineered recharge facilities including percolation ponds) can contribute substantially to increased concentrations of nitrate and dissolved solids in groundwater (Bexfield and others, 2011). Recharge of this kind poses a risk for degrading water quality in underlying aquifers because the water quality can be poor at the surface and this water is more susceptible to surface contamination. Recharge and flow rates, which also depend on sediment type and the presence of large fractures, control how quickly contaminated surface water moves into and through an aquifer. Coarser sediments with well-connected pore space allow for higher flows, whereas finer sediments with poorly connected pore space impede or even prevent flow. Flow rates determine the duration of contact between groundwater and aquifer material, and longer contact times can result in greater interaction between water and porous media, which controls constituent concentration.

Humans have also influenced groundwater quality through activities related to constituent source. Mining and mineral processing waste and leachate from landfills can contribute to increases in concentration of metals and dissolved solids in groundwater (Waddell and others, 1987). Commercial fertilizer application is the dominant source of nitrogen in agricultural areas of the western U.S. (Puckett, 1994) and in some urban areas (Hamlin and others, 2002). In agricultural areas, nitrate can be added to groundwater through infiltration of irrigation drainage containing nitrate (Edmonds and Gellenbeck, 2002), whereas in urban areas this can occur through recharge from leaky septic systems, water lines, septic systems, or lawn irrigation (Thiros, 2003). Regions with cropland and well drained soils are at greater risk for high nitrate levels in groundwater, particularly where irrigation is necessary (Spalding and Exner, 1993). Older or poorly constructed wells can exhibit increased nitrate in well water (Spalding and Exner, 1993). These processes also would contribute dissolved solids to groundwater.

Recharge of urban runoff and leaky infrastructure to aquifers can affect groundwater quality (Carlson and others, 2011). Road salt application has been proposed as a source of chloride in groundwater (Waddell and others, 1987). Broadly, numerous factors associated with urbanization could contribute to water-quality degradation, including changes in amount and type of water use, which could impact infiltrations patterns, irrigation with reclaimed wastewater, fertilizer and pesticide application, mining activities, septic system use, and water system infrastructure. Aging of urban water infrastructure such as sewage system pipes also makes it more susceptible to leaks, which can affect groundwater.

Effects and Regulation of Groundwater Contamination

Degradation of groundwater quality can result in human and animal health problems. Arsenic exposure can result in skin lesions, circulatory system problems, neuropathy, and increased risks of cancer and diabetes (Yu and others, 2003; Ahamed and others, 2006). Ingestion of nitrate in drinking water can cause methemoglobinemia (blue baby syndrome), which can be fatal for infants and livestock (Campbell and others, 1954; Ward and others, 2005). Nationally, nitrate is one of the most frequent anthropogenic contaminants to exceed human health standards in water from public-supply wells (Toccalino and others, 2010). High levels of dissolved solids in water can affect the taste and color of water, lead to mineral deposits on pipes and other infrastructures, and impact plants and animals that cannot tolerate saline water. Although dissolved solids can have limited impact on health, their presence can result in an aversion to the public water supply and be costly to treat.

To reduce the risks to human health arising from poor public-supply water quality, the EPA has defined Maximum Contaminant Levels (MCL) for a range of constituents in the National Primary Drinking Water Regulations, pursuant to the Safe Drinking Water Act (SDWA; U.S. Environmental Protection Agency, 2009). Primary drinking water regulations apply to a range of microorganisms, disinfectants and their byproducts, inorganic and organic chemicals, and radionuclides. Non-enforceable secondary maximum contaminant levels (SMCL), established in the National Secondary Drinking Water Regulations, have been developed to assist public water suppliers in managing water for color, taste, and odor qualities (U.S. Environmental Protection Agency, 2009). Secondary standards apply to dissolved solids, some metals and foaming agents, and pH. The State of Utah has primary and secondary standards consistent with federal regulations and has additional standards for dissolved solids (Utah Administrative Code, 2019; table 1).

Table 1. Primary and secondary drinking water standards.

[*Maximum total dissolveds solids levels are given in the Utah Primary Drinking Water Standards. Adapted from R309-200 (Monitoring and water quality: Drinking water standards, Utah Administrative Code) and U.S. Environmental Protection Agency (2009). **Abbreviations**: mg/L, milligrams per liter; >, greater than]

Contaminant	Maximum contaminant level (mg/L)	Secondary maximum contaminant level (mg/L)
Arsenic	0.010 (0.05 mg/L prior to 1/23/2006)	None
Nitrate	10 (as nitrogen)	None
Nitrite	1 (as nitrogen)	None
Total nitrate and nitrite	10 (as nitrogen)	None
Total dissolved solids*	2,000 (if concentration >1,000 mg/L, supplier must meet additional requirements)	500

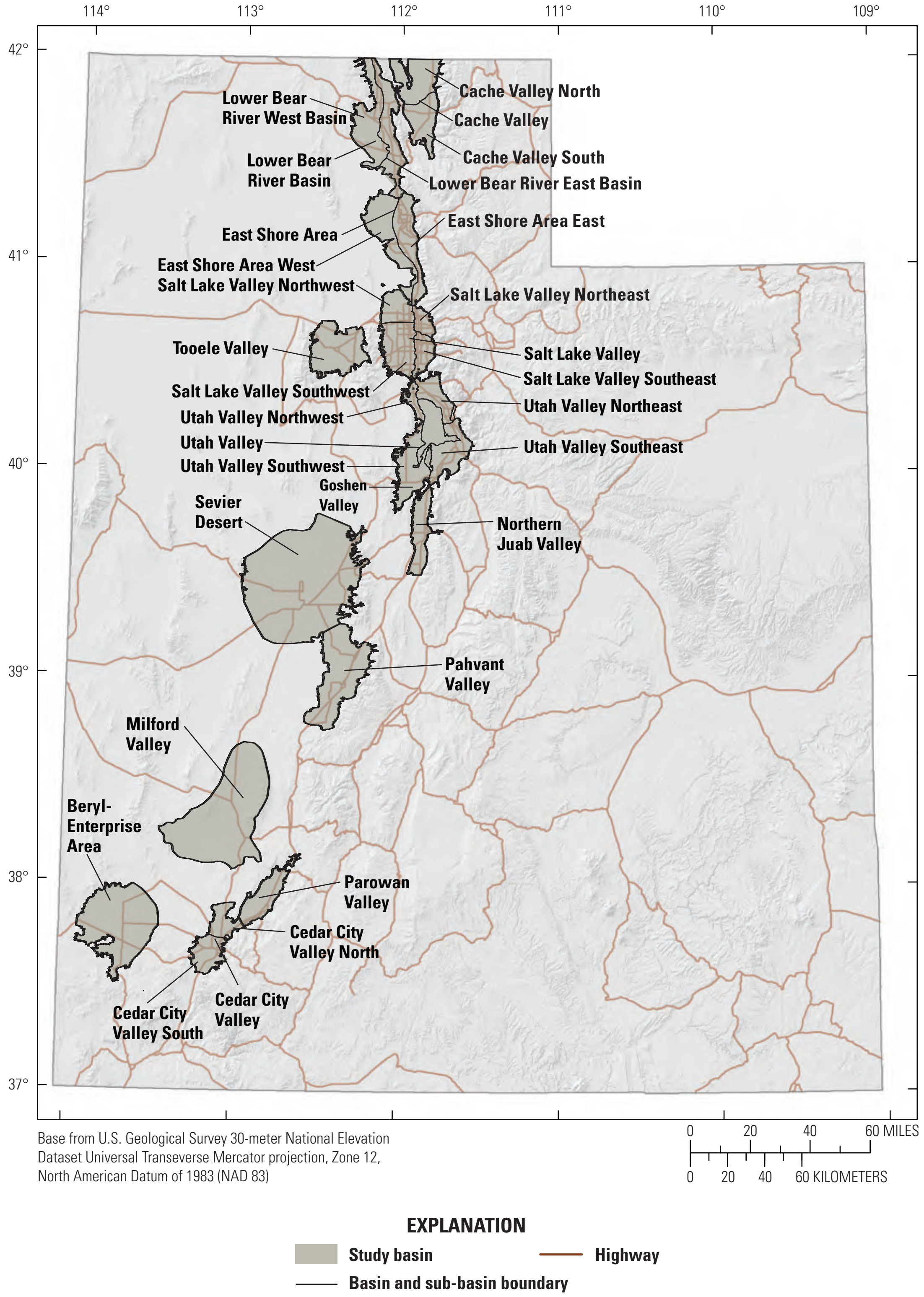
Prior work has been completed to analyze conditions and trends of arsenic, nitrate, and dissolved solids in groundwater at regional, well, or basin-specific scales in Utah. Since 1964, the U.S. Geological Survey (USGS) has published yearly reports describing annual groundwater conditions, including annual water levels and water-quality measurements, although temporal changes in water quality are not generally addressed (Burden, 2017). A few examples of prior work that focused on arsenic, nitrate, or dissolved solids conditions, conducted at either the regional or local scale, are described below. These studies tended to examine shorter periods (years to decades) than the analysis presented in this report.

In a regional study of arsenic, Anning and others (2012) used statistical models to predict arsenic concentrations throughout basin-fill aquifers in the southwestern U.S. Of the total area of basin-fill aquifers in Utah, approximately 53 percent were predicted to have low arsenic concentrations (less than 10 micrograms per liter, µg/L), 24 percent were predicted to have concentrations between 10 and 24 µg/L, and 23 percent were predicted to have concentrations greater than or equal to 25 µg/L (Anning and others, 2012). Many of the high concentration areas were in western Utah.

A few studies have been conducted on arsenic conditions at the basin or well scale in Utah. For example, sources of arsenic have been investigated in Goshen Valley (in the Utah Valley basin in this study); geothermal springs had the highest arsenic concentrations, and groundwater interactions between alluvial or carbonate rocks also were associated with moderate arsenic concentrations (Selck and others, 2018). Arsenic in areas of residential development in the Salt Lake Valley was characterized, and no correlation between percentage of residential land use surrounding a well and arsenic concentration in well water was determined (Thiros, 2003). This study also reported higher arsenic concentration on the western and northwestern sides of the Salt Lake Valley than the eastern side, which were possibly related to sedimentology, redox conditions and reactions, proximity to faults and geothermal water, high concentrations of arsenic in canals, and the presence of volcanic rocks. Arsenic trends in the Great Salt Lake have been assessed and although mean concentrations were greater than 100 ug/L, consistent evidence for temporal trends was not identified (Adams and others, 2015).

In a regional study of nitrate concentrations in the Southwest, Anning and others (2012) used statistical models to predict nitrate concentrations throughout basin-fill aquifers. Nitrate concentrations were generally predicted to be less than 5 milligrams per liter (mg/L; Anning and others, 2012). Approximately 65 percent of the total area of basin-fill aquifers in Utah were predicted to have nitrate concentrations less than 0.5 mg/L, 10 percent were predicted to have concentrations between 0.5 and 0.99 mg/L, and 20 percent were predicted to have concentrations between 1.0 and 1.9 mg/L (Anning and others, 2012). Higher concentrations were predicted for shallower wells (Anning and others, 2012). A mapper also was developed to display spatio-temporal trends in nitrate in public-supply systems across the state (Wallace and Inkenbrandt, 2013).

Many studies have been conducted on nitrate conditions at the basin or well scale in Utah (fig. 1 shows a map of Utah). For example, geologic sources, septic-tank systems, and agricultural activities have been identified as potential sources of nitrate in groundwater in Cedar City Valley (Lowe and Wallace, 2001). Sources also were evaluated in Goshen Valley (part of Utah Valley in this study) where the highest nitrate concentrations occurred in agricultural areas, with manure being the major source (Selck and others, 2018). Nitrate conditions and sources in the Salt Lake Valley public-supply wells were characterized, and human influence (for example, from fertilizer application, or leaky septic systems or sewer pipes) was implicated in areas where nitrate concentrations were greater than 2–3 mg/L (39 percent of sampled public-supply wells; Thiros and Manning, 2004).



Base from U.S. Geological Survey 30-meter National Elevation Dataset Universal Transeverse Mercator projection, Zone 12, North American Datum of 1983 (NAD 83)

Figure 1. Study basins in Utah.

Nitrate occurrence and distribution in the Great Salt Lake Basins and Tooele Valley was described in Thiros (2000) and Susong (2005). Throughout the Great Salt Lake Basins, water from wells in agricultural or urban areas had higher nitrate concentrations than water from wells in rangeland areas, and in urban areas shallower wells had higher median nitrate concentrations than deeper wells. Groundwater quality in Cache Valley has been classified by nitrate concentration and shallower wells, and wells in discharge zones tended to have higher nitrate concentrations (Lowe and others, 2003). Nitrate concentrations and trends at several wells in Milford Valley were evaluated, and trends varied by well (Susong, 1996).

Anning and others (2007) conducted a regional study of dissolved-solids concentrations and trends in basin-fill aquifers and streams across the Southwest. Nearly 40 percent of the area of basin-fill aquifers in the southwestern U.S., including Utah, exceeded the SMCL for dissolved solids of 500 mg/L from the 1960s through the 1980s (Anning and others, 2007). Anning and others (2007) assessed dissolved solids trends in select wells in basin-fill aquifers across the Southwest for 1974–88, 1989–2003, and 1974–2003 and reported that concentrations of dissolved solids did not increase over time in most groundwater-quality monitoring wells. Of wells with trends, more showed increasing trends than decreasing trends (Anning and others, 2007).

Several studies have been conducted on dissolved solids conditions at the basin or well scale in Utah. For example, changes in dissolved-solids concentrations in wells in the Salt Lake Valley were determined (Waddell and others, 1987; Thiros and Manning, 2004; Thiros and Spangler, 2010). Among public-supply wells, dissolved-solids concentrations were generally lower on the eastern side of the valley than the western side, and the southeastern side of the valley had the lowest concentrations, although concentrations were increasing in some areas (Thiros and Manning, 2004; Thiros and Spangler, 2010). Increasing trends were identified in wells completed in the principal aquifer in the Salt Lake Valley between 1962 and 1984; seepage from reservoirs, evaporation ponds, and tailings piles contributed to increased dissolved-solids concentrations (Waddell and others, 1987). Dissolved solids have been used to classify groundwater in Cedar Valley, where 80 percent of the basin, primarily in the central and western parts, had concentrations less the 500 mg/L (Lowe and others, 2010). Although year-to-year fluctuations have occurred, few substantial changes in dissolved-solids concentrations over time were observed in the East Shore Area wells between 1960 and 1969 (Bolke and Waddell, 1972).

Purpose and Scope

This report presents the result of an analysis of trends in groundwater arsenic, nitrate, and dissolved-solids concentrations between 1975 and 2015 in selected basins characterized by high groundwater development. This analysis was conducted with support from the Utah Department of Environmental Quality, Division of Water Quality. The objectives of the analysis were to (1) compare data from two different databases and their combination to determine if samples from each database are comparable, and (2) identify and interpret trends in groundwater quality in select basins across Utah. Water-quality data come from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS) databases. This analysis provided a more temporally and spatially comprehensive assessment of the state of water quality in the selected basins throughout Utah.

Methods

A description of the study area, datasets used, data preparation, and statistical methods applied to the data are included in the following sections.

Study Area

Selected basins analyzed for this study included Cache Valley, Cedar City Valley, East Shore Area, Lower Bear River Basin, Milford Valley, Northern Juab Valley, Pahvant Valley, Parowan Valley, Salt Lake Valley, Sevier Desert, Tooele Valley, and Utah Valley (fig. 1). Milford Valley is similar to the area called the Milford area of Escalante Valley in the annual “Groundwater Conditions in Utah” reports (for example, Burden and others, 2017).

Data Sets Used

Water-quality data from two sources were used in this study: the USGS NWIS database and the EPA SDWIS database maintained by the Utah Department of Environmental Quality, Division of Drinking Water (Utah Division of Drinking Water, 2017). NWIS data were obtained from the USGS NWIS database (U.S. Geological Survey, 2017, https://waterdata.usgs.gov), and the SDWIS data were obtained from the SDWIS database (http://www.drinkingwater.utah.gov/).

The NWIS database contains water-quality data, beginning in 1911 through the time of this study from more than 6,000 wells in Utah, collected for local and regional studies or as part of an annual groundwater monitoring program in cooperation with the Utah Department of Natural Resources, Division of Water Rights, and Utah Department of Environmental Quality, Division of Water Quality. Wells were not necessarily sampled at regular time intervals. Data in NWIS represent samples taken at individual wells. Wells included had a wide range of depths and uses, from irrigation to monitoring to public supply; therefore, the source of water may have varied substantially.

The SDWIS database contains water-quality data from regular sampling of nearly 700 public-supply wells in accordance with the SDWA. Public-supply wells must be sampled every 3 years for inorganic and metal contaminants and sampled annually for nitrate unless a waiver is obtained. Samples for arsenic, total dissolved solids, nitrate, and nitrite are taken at the source. This study used SDWIS data from samples that were taken at single source wells before treatment or distribution. Data within the SDWIS database come from public-supply wells, which may bias the results toward cleaner water from potentially deeper wells, although exceptions may occur.

Data Preparation

Water-quality data from the NWIS and SDWIS databases were compiled (hereinafter referred to as NWIS samples and SDWIS samples). Data from the SDWIS database were limited to single source wells before treatment or distribution. Delineations of basin-fill aquifers (McKinney and Anning, 2009) were modified to focus on areas of substantial groundwater and agricultural development. Basins were further subdivided into sub-basins to evaluate trends on a smaller spatial scale. Subdivision was based on hydrologic unit code eight boundaries, and river and municipality locations.

For the trend analysis, datasets were limited to the years 1975–2015 for two reasons: (1) much of the SDWIS data were collected after the Safe Drinking Water Act of 1974 was enacted, and (2) to divide data into sub-decades of equal length. Arsenic data from 1,337 wells (598 NWIS wells and 739 SDWIS wells) were used. Nitrate data from 1,857 wells (1,051 NWIS wells and 806 SDWIS wells) were used. Dissolved solids data from 1,955 wells (1,173 NWIS wells and 782 SDWIS wells) were used.

Duplicate sample entries within datasets were excluded from the analysis. Additionally, some samples had multiple results reported for the same analyte (for example, dissolved solids reported as the sum of constituents and the residual on evaporation at 180 degrees Celsius; °C). For nitrate data, the order of preference was filtered nitrate, unfiltered nitrate, filtered nitrate plus nitrite, and finally unfiltered nitrate plus nitrite following Oelsner and others (2017). For dissolved solids data, values obtained from both methods were used, although the sum of a constituent's value was preferentially selected over the residual on evaporation value (Liebermann and others, 1989).

Data were manually and visually inspected for unlikely measurement values such as concentrations in multiple orders of magnitude above other values from the same well, samples collected during drilling operations, or probable typographical errors. Suspect data were compared to original lab reports and other concentration data for a given site and were eliminated if obvious errors were identified. In the SDWIS database, data from one site were sometimes assigned to multiple wells in a basin. Such group assignments are coded into the SDWIS dataset during data reporting. However, for older data (1980s and older), group assignment of measurements was not coded. To eliminate replication, and thus artificial weighting of data that were sampled at one site but assigned to multiple sites, identical concentrations taken on the same date in the same basin and stored in the same database were filtered out and only one value was retained.

Comparison Between Data Collection and Analysis Methods for Data from National Water Information System and Safe Drinking Water Information System Databases

The water data in the NWIS and SDWIS databases differ in several ways. In addition to the challenges of combining water-quality data described by Sprague and others (2017), including missing or ambiguous sample fraction, chemical form, parameter name, units of measurement, precise numerical value, or remark codes, several differences between NWIS and SDWIS data were identified. Sample collection and analysis methods differ for sample filtration and well purging and pumping practices for NWIS and SDWIS data. NWIS samples are collected in accordance with the sampling procedures described in the USGS National Field Manual (U.S. Geological Survey, 2006) and analyzed according to a range of standardized methods. The SDWIS samples are collected according to 40 CFR 141.23 (U.S. Environmental Protection Agency, 1996). Some sampling and laboratory methods have changed over time because of technology advances and improved method development.

NWIS and SDWIS samples have different practices for sample filtration, well purging and pumping, and potentially different depths of sample collection. NWIS samples are generally collected after well purging and then are filtered in the field. Some NWIS groundwater samples for smaller studies are collected with low-flow pumps following well purging. Purging is meant to ensure samples are representative of ambient formation water and filtering is done for analysis of dissolved ions in water. Explicit purging of wells may not occur before collection of SDWIS samples, although wells used for public supply are generally pumped more frequently and for longer duration, and samples are not field filtered, although some lab filtering may occur. NWIS samples come from wells with a wide range of uses, from irrigation to monitoring to public supply, and can therefore come from shallow or deep wells. The SDWIS samples come from public-supply wells, which can bias the results toward cleaner water, and in many cases, deeper wells. The main sampling differences (filtration, pumping rate, purging, and well depth) influence particulate matter or turbidity in water, which can alter constituent measurements. Specifically, constituents can interact with particulate matter, thereby altering measured concentrations.

Although variation in sample collection and laboratory analysis procedures between NWIS and SDWIS samples exists, comparing data from the NWIS and SDWIS databases is justified because the sampling differences generally result in lower-turbidity samples that are more comparable. According to R309-200 (Monitoring and Water Quality: Drinking Water Standards) of the Utah Administrative Code, turbidity in samples of groundwater for public supply must be below 5 Nephelometric Turbidity Units (NTU). This is lower than the 100 NTU that Puls and Powell (1992) observed contribute to significant metal concentration differences between filtered and unfiltered water samples. Therefore, samples in SDWIS are biased toward low turbidity (unless they are in violation of that standard) so they should be comparable to filtered NWIS samples even if the lab does not filter samples (Puls and Powell, 1992). For samples with low turbidity, difference in filtration should not bias contaminant measurements between the two databases. In a nationwide study of trends in rivers and streams, concentrations of nitrate and nitrate plus nitrite from filtered samples were indistinguishable from unfiltered samples (Oelsner and others, 2017).

Because the data from the two databases were determined to be comparable (in other words, an analyte from one database is comparable to the same analyte in the other database), combining the datasets was therefore justified. Data stored in the NWIS and SDWIS databases were combined to increase the number of samples available for analysis and expand the temporal and spatial data coverage. Using information about groundwater conditions from multiple sources improves the robustness of the analysis against biases arising from different sampling strategies and protocols and provides a more comprehensive analysis of water quality. Accounting for all the variation and temporal changes in sampling and analysis is beyond the scope of this report, but it should be acknowledged to potentially induce variability and bias into datasets, which can make trend determination more difficult.

Data Analysis

Before trend analysis, the data from each database, and the combination of datasets, were compared to understand differences between datasets and how that may influence trend results. The Mann-Kendall trend test was used to identify and quantify monotonic trends in decadal and sub-decadal median concentrations of arsenic, nitrate, and dissolved solids in groundwater over time. Monotonic trends were of interest because they identify overarching, consistent changes in water quality over time. Trends were identified in decadal and sub-decadal median concentrations within each basin and smaller portions of some basins (sub-basins). To evaluate the effect of land-use change on water quality, trends were identified among wells in each basin that had experienced different kinds of land-use change.

Water-quality data are often censored (reported as less than a certain value). Data can be reported at multiple censoring limits because labs and analysis techniques change. The purpose of sample collection can even determine censoring limit; some concentrations in the SDWIS database are reported as less than the MCL instead of reported as the measured value. Although censored values contain information about water quality, they complicate common statistical calculations. A range of statistical techniques have been employed by various researchers to deal with censored data including substitution, maximum likelihood, regression on order statistics, and nonparametric treatments.

Trends were evaluated using the Mann-Kendall trend test, which uses Kendall's tau, a nonparametric correlation coefficient statistic that indicates the monotonic association between two variables (in this study, time and analyte concentration). Water-quality data rarely follow a normal distribution, which is required for parametric trend tests (for example, linear regression). The nonparametric Mann-Kendall trend test can determine a trend regardless of whether or not the data follow a normal distribution. Kendall's Tau, which ranges from 1 to –1, depends on the number of increases and decreases in concentration over time. If all median concentrations increased over time, tau would equal +1 and if all median concentrations decreased over time, tau would be –1. Consequently, noise in the concentration data reduces tau toward zero (similar number of increase and decreases over time). The Theil-Sen slope estimate of the trend line, a nonparametric analog to linear regression commonly used in environmental analysis, also was used and can be interpreted in this study as the rate of median-concentration changes over time. Trends were considered significant at the 90-percent confidence level if the two-sided p-value was less than 0.1.

To identify basin-wide trends in groundwater quality, decadal and sub-decadal nonparametric Kaplan-Meier estimates of summary statistics for each basin were calculated using a single concentration per well per year (Helsel, 2012). At least three concentrations per basin per decade or sub-decade were required to calculate a median concentration. Calculation of summary statistics and trend tests all account for censoring at multiple levels through the application of survival analysis methods to water-quality data (Helsel, 2012; Lee, 2017). In this study, the recommended nonparametric Kaplan-Meier technique for datasets with up to 50 percent censored observations was used to calculate decadal and sub-decadal summary statistics (for example, medians; Helsel, 2012). The relatively short period of record, low sampling frequency, or frequent occurrence of censored values for some analytes in some basins made identifying trends using decadal medians difficult. To address this issue, sub-decadal medians were calculated and used for trend analysis. This increased the number of observations at the expense of increased variability.

Mann-Kendall trend tests were then applied to the decadal and sub-decadal median concentrations in each basin for each constituent to identify trends in groundwater quality. Some basins also were sub-divided and trends were assessed in sub-basins of larger basins to focus on changes in water quality at a smaller spatial scale (fig. 1). Results from trend tests on the combined NWIS and SDWIS data and the SDWIS data are presented. The SDWIS trend results are included because they represent drinking water sources (before any treatment) and may therefore be of interest to public water suppliers.

Identified trends were compared to land-use change in each basin. To identify the connection between surface practices and groundwater quality, trends in wells where land use has changed in each basin were evaluated to determine the relationship between land-use change and trends in concentrations of arsenic, nitrate, and dissolved solids. Land-use changes in each basin were identified throughout the study area by comparing land use in 2012 to land use in 1974. The USGS National Water-Quality Assessment Wall-to-Wall Anthropogenic Land Use Trends dataset contains national 60-meter, 19-class mapping of anthropogenic land uses for five periods between 1974 and 2012 (Falcone, 2015). The dataset contains six broad land-use classes including water, developed, semi-developed, production, low use, and very low use/conservation. Developed land includes the built environment such as residences, places of employment, and recreation. Production land includes areas where natural resources are produced such as agricultural or natural resource extraction. These classes were lumped so that urban included developed and semi-developed land, and low use included low use and very low use/conservation in order to increase the number of wells in each class. Wells were classified based on the kind of land-use change (including no change) that had occurred directly at the well location (within 60-m grid cell) from 1974 to 2012. Mann-Kendall trend tests were then applied to decadal and sub-decadal medians in each basin for each constituent for all land-use change classes.

Well characteristics can change as land-use changes. For example, as more development of an area occurs, water demand may increase, prompting an increase in the number of wells or in the depth to which wells are drilled. Water quality can change with depth in a well. To avoid the confounding effects resulting from a potential increase in deeper wells as an area develops over time, NWIS wells shallower than 200 feet depth also were tested. Depth data was not available for many SDWIS wells and so SDWIS data was therefore not used for this part of the analysis. These shallow wells were expected to be the first to experience possible impacts from land-use change as well.

Results: Identification and Quantification of Groundwater-Quality Trends

Results of a comparison of data from each database and the combination of datasets is presented below, followed by a description of the trends analysis, and a comparison of trends to land-use change patterns.

Data Summary and Database Comparison

Generally, there are more data from the SDWIS database than the NWIS database. These results show differences and similarities between datasets from each database and how these differences may influence trend results. Variability across datasets introduces variability into the trend tests, which makes trend identification more difficult.

Arsenic

Widespread measurement of arsenic concentrations in wells began in the mid to late 1970s, roughly coincident with enactment of the Safe Drinking Water Act of 1974 (fig. 2; table 2). The SDWIS database contained more arsenic concentration data than the NWIS database, and generally covered a longer period of record. The number of measurements varied greatly by basin. Some sub-basins had fewer than 10 wells and fewer than 20 samples, and the period of record may only have extended back to the late 1980s, which increases the uncertainty in interpreting results for those areas.

Generally, the percentage of censored data in each basin and sub-basin was low, although many basins had between 30 and 50 percent censored data (table 2). The SDWIS data had a higher percentage of censored values than NWIS arsenic data and several basins had more than 50 percent censoring. This violates the recommendations for fewer than 50 percent censoring for the methods used in this study and therefore the results for these data are less reliable. When combining the NWIS and SDWIS data, there were fewer than 50 percent censored data in each basin except the East Shore Area. The NWIS data have fewer censored values than the SDWIS data.

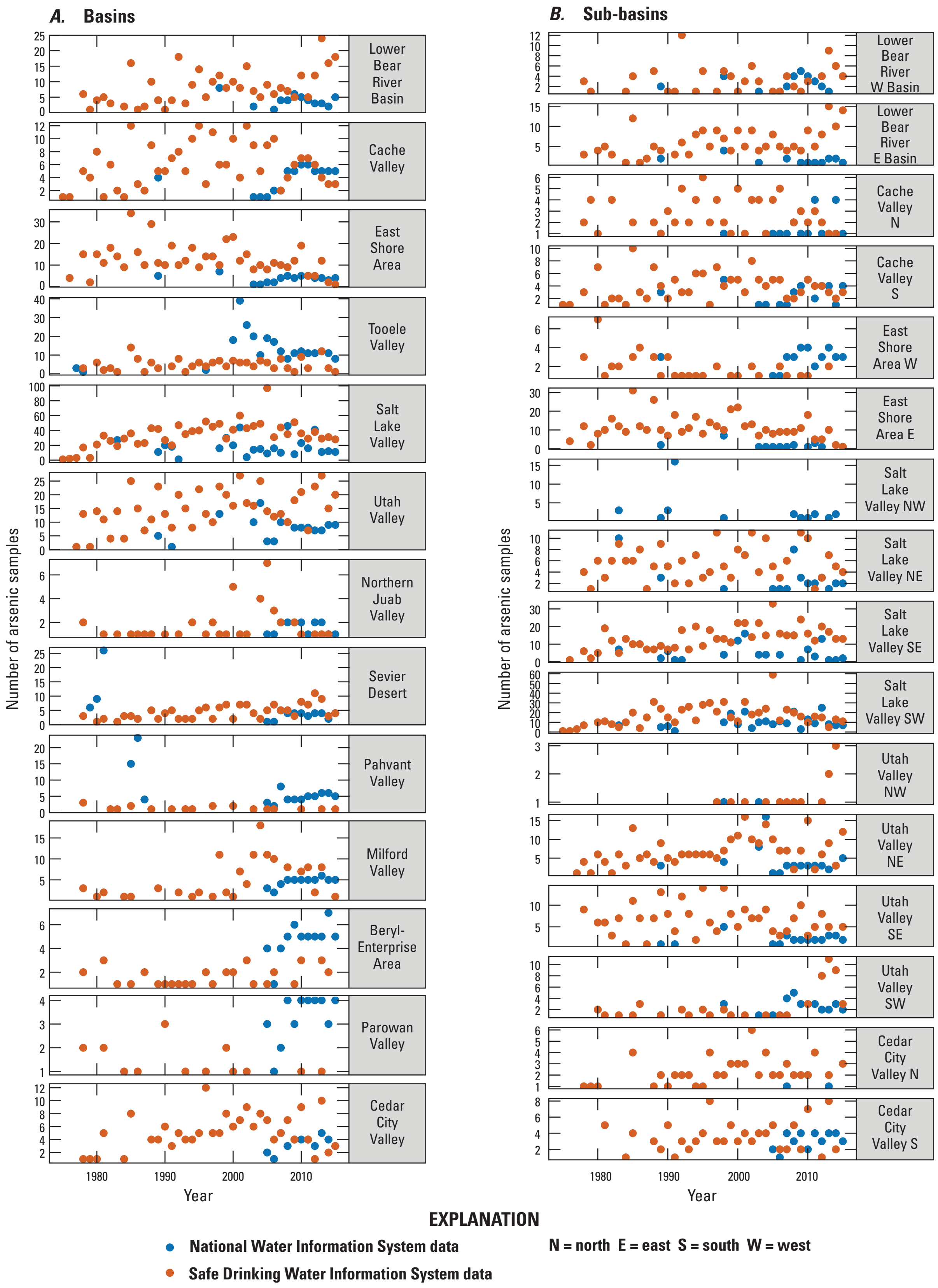


Figure 2. Number of arsenic samples over time in select Utah *A*, basins and *B*, sub-basins in the National Water Information System and Safe Drinking Water Information System datasets.

Table 2. Number of wells and arsenic samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS), Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.

[Number in parentheses indicates the total number of wells. **Abbrevations**: µg/L, micrograms per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (µg/L)	Maximum concentration (µg/L)	Median concentration (µg/L)
Basins									
NWIS and SDWIS data combined (1,337)									
Beryl-Enterprise Area	23	1978	2015	90	15	17	0.04	95.7	3.8
Cache Valley	74	1975	2015	293	116	40	0.02	42.4	0.9
Cedar City Valley	58	1978	2015	212	70	33	0.1	15.7	2
East Shore Area	150	1976	2015	544	306	56	0.1	50	0.7
Lower Bear River Basin	80	1978	2015	356	116	33	0.1	106	2
Milford Valley	43	1978	2015	176	6	3	1	39	6.6
Northern Juab Valley	21	1978	2015	63	27	43	0.19	10	0.7
Pahvant Valley	61	1978	2015	115	17	15	0.21	19	2
Parowan Valley	17	1978	2015	53	6	11	0.5	11.3	3.8
Salt Lake Valley	412	1975	2015	1,814	499	28	0.005	360	2.1
Sevier Desert	78	1978	2015	231	20	9	0.08	730	8
Tooele Valley	125	1977	2015	421	108	26	0.005	206	1.5
Utah Valley	195	1977	2015	704	286	41	0.1	72.9	1.1
NWIS data (598)									
Beryl-Enterprise Area	18	2005	2015	52	1	2	0.04	95.7	3.9
Cache Valley	25	1989	2015	59	7	12	0.02	23.5	1
Cedar City Valley	11	2005	2015	38	0	0	0.3	6.4	0.88
East Shore Area	24	1989	2015	56	6	11	0.1	44	3.7
Lower Bear River Basin	29	1989	2015	51	2	4	0.1	95	1
Milford Valley	23	2005	2015	50	0	0	1.4	34.7	3.2
Northern Juab Valley	9	2005	2015	17	0	0	0.19	2.2	0.68
Pahvant Valley	54	1985	2015	94	7	7	0.21	19	2.3
Parowan Valley	12	2005	2015	36	0	0	1.5	11.3	4
Salt Lake Valley	182	1983	2015	423	48	11	0.005	360	5
Sevier Desert	51	1979	2015	79	2	3	0.08	730	8
Tooele Valley	87	1977	2015	251	30	12	0.005	206	1.8
Utah Valley	73	1989	2015	128	6	5	0.1	18	2.1
SDWIS data (739)									
Beryl-Enterprise Area	5	1978	2014	38	14	37	0.1	10	2.9
Cache Valley	49	1975	2015	234	109	47	0.3	42.4	0.8
Cedar City Valley	47	1978	2015	174	70	40	0.1	15.7	2.4
East Shore Area	126	1976	2015	488	300	61	0.1	50	0.7
Lower Bear River Basin	51	1978	2015	305	114	37	0.2	106	2.3
Milford Valley	20	1978	2015	126	6	5	1	39	9
Northern Juab Valley	12	1978	2014	46	27	59	0.4	10	0.7
Pahvant Valley	7	1978	2015	21	10	48	0.5	10	1
Parowan Valley	5	1978	2013	17	6	35	0.5	8	2

Table 2. Number of wells and arsenic samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS), Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbrevations**: µg/L, micrograms per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (µg/L)	Maximum concentration (µg/L)	Median concentration (µg/L)
Basins—Continued									
SDWIS data (739)—Continued									
Salt Lake Valley	230	1975	2015	1,391	451	32	0.1	50	1.9
Sevier Desert	27	1978	2015	152	18	12	0.5	62	8
Tooele Valley	38	1978	2015	170	78	46	0.1	23	1.1
Utah Valley	122	1977	2015	576	280	49	0.1	72.9	0.9
Sub-basins									
NWIS and SDWIS data combined (969)									
Cache Valley N	22	1978	2015	105	41	39	0.02	42.4	2.0
Cache Valley S	52	1975	2015	188	75	40	0.09	25.0	0.7
Cedar City Valley N	21	1978	2015	74	27	36	0.5	11.7	3.0
Cedar City Valley S	37	1981	2015	138	43	31	0.1	15.7	1.6
East Shore Area E	124	1976	2015	462	282	61	0.1	50.0	0.6
East Shore Area W	26	1978	2015	82	24	29	0.5	42.5	3.1
Lower Bear River Basin E	48	1978	2015	231	84	36	0.1	106.0	1.7
Lower Bear River Basin W	32	1978	2015	125	32	26	0.2	95.0	2.2
Salt Lake Valley NE	66	1978	2015	259	108	42	0.1	60.0	0.8
Salt Lake Valley NW	23	1983	2014	33	4	12	1	360.0	20.0
Salt Lake Valley SE	153	1976	2015	634	233	37	0.1	60.0	0.9
Salt Lake Valley SW	170	1975	2015	888	154	17	0.005	110.0	6.0
Utah Valley NE	97	1977	2015	325	145	45	0.1	72.9	1.0
Utah Valley NW	7	1997	2014	17	1	6	0.5	34.0	4.0
Utah Valley SE	72	1978	2015	272	137	50	0.1	53.0	0.7
Utah Valley SW	19	1980	2015	90	3	3	0.5	18.0	9.2
NWIS data (344)									
Cache Valley N	7	1989	2015	20	3	15	0.02	17.3	5.9
Cache Valley S	18	1989	2015	39	4	10	0.09	23.5	0.9
Cedar City Valley N	2	2007	2013	4	0	0	2	3.0	2.3
Cedar City Valley S	9	2005	2015	34	0	0	0.3	6.4	0.9
East Shore Area E	12	1989	2015	22	6	27	0.1	44.0	0.7
East Shore Area W	12	1989	2015	34	0	0	0.84	42.5	14.0
Lower Bear River Basin E	10	1989	2015	18	2	11	0.1	7.3	1.7
Lower Bear River Basin W	19	1989	2015	33	0	0	0.66	95.0	1.0
Salt Lake Valley NE	26	1983	2015	52	6	12	0.34	60.0	1.1
Salt Lake Valley NW	23	1983	2014	33	4	12	1	360.0	20.0
Salt Lake Valley SE	59	1983	2015	115	13	11	0.12	60.0	1.0

Table 2. Number of wells and arsenic samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS), Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbrevations**: µg/L, micrograms per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (µg/L)	Maximum concentration (µg/L)	Median concentration (µg/L)
Sub-basins—Continued									
NWIS data (344)—Continued									
Salt Lake Valley SW	74	1983	2015	223	25	11	0.005	110.0	8.0
Utah Valley NE	40	1989	2015	61	3	5	0.1	6.0	1.7
Utah Valley NW	3	1998	2004	3	0	0	0.8	4.0	2.7
Utah Valley SE	15	1989	2015	30	3	10	0.4	11.0	0.6
Utah Valley SW	15	1989	2015	34	0	0	0.93	18.0	6.4
SDWIS data (625)									
Cache Valley N	15	1978	2014	85	38	45	0.5	42.4	1.5
Cache Valley S	34	1975	2015	149	71	48	0.3	25.0	0.7
Cedar City Valley N	19	1978	2015	70	27	39	0.5	11.7	3.4
Cedar City Valley S	28	1981	2014	104	43	41	0.1	15.7	2.0
East Shore Area E	112	1976	2015	440	276	63	0.1	50.0	0.6
East Shore Area W	14	1978	2013	48	24	50	0.5	34.0	1.0
Lower Bear River Basin E	38	1978	2015	213	82	38	0.3	106.0	1.6
Lower Bear River Basin W	13	1978	2015	92	32	35	0.2	62.0	3.2
Salt Lake Valley NE	40	1978	2015	207	102	49	0.1	11.0	0.7
Salt Lake Valley SE	94	1976	2015	519	220	42	0.1	23.0	0.9
Salt Lake Valley SW	96	1975	2015	665	129	19	0.1	50.0	5.0
Utah Valley NE	57	1977	2015	264	142	54	0.5	72.9	0.7
Utah Valley NW	4	1997	2014	14	1	7	0.5	34.0	10.8
Utah Valley SE	57	1978	2015	242	134	55	0.1	53.0	0.7
Utah Valley SW	4	1980	2015	56	3	5	0.5	14.8	10.6

The maximum concentration in most basins and all sub-basins was at or above the arsenic MCL of 10 ug/L for NWIS and SDWIS data combined. The NWIS data in several basins including Sevier Valley, Salt Lake Valley, and Tooele Valley had maximum concentrations of more than 100 ug/L. However, for NWIS data, SDWIS data, and combined data, the median concentration in all basins was below 10 ug/L and most were below 5 ug/L. A paired two-sided t-test indicated that the medians of the NWIS and SDWIS datasets, the SDWIS and combined datasets, and the NWIS and combined datasets were not significantly different (p-value greater than 0.05). Among NWIS data, some sub-basins had maximum concentrations below the MCL such as Cedar City Valley North, Cedar City Valley South, Lower Bear River Basin East, Utah Valley Northeast, and Utah Valley Northwest. Among SDWIS data, all sub-basins had maximum concentrations above the MCL.

The distribution of concentrations in individual and combined datasets is shown for each basin and sub-basin in figure 3. Most concentrations in each basin fell below the MCL. However, concentrations in the Sevier Desert, Milford Valley, and Beryl-Enterprise Area were generally elevated relative to the other basins and had more regulatory exceedances. The distribution of concentrations in individual and combined datasets was generally similar within a given basin. However, in some basins the distributions vary; for example, in Milford Valley, the NWIS interquartile range (IQR) was completely below and outside the IRQ of the SDWIS and combined datasets, indicating that the NWIS data was distinctly lower than the SDWIS and combined datasets in this area. The NWIS distribution extended higher than the SDWIS distribution in some basins (for example, the East Shore Area) and lower in others (for example, Milford Valley and Cedar City Valley); the differences between datasets were not systematic across basins. The variability of concentrations also differed by basin. For example, Parowan Valley had a much narrower range of concentrations than the Salt Lake Valley.

The distribution of arsenic concentrations of NWIS, SDWIS, and combined NWIS and SDWIS data is shown for each sub-basin in figure 3. There are several sub-basins that had IQRs that exceed the MCL including the East Shore Area East, Salt Lake Valley Northwest, Salt Lake Valley Southwest, Utah Valley Northwest, and Utah Valley Southwest.

Arsenic concentration data in each basin for each dataset over time are shown in figure 4; concentrations varied substantially by basin. At the time of this study, widespread exceedance of the MCL of 10 ug/L occurred in the studied basins (figs. 3, 4). Some basins had many exceedances (for example, Lower Bear River Basin, East Shore Area, Utah Valley, and Milford Valley), whereas some basins had concentrations that exceeded the regulatory standard by a factor of ten (for example, Tooele Valley, Salt Lake Valley, and Sevier Desert). In some basins, regulatory exceedances were rare (for example, Northern Juab Valley, Pahvant Valley, and Parowan Valley). The MCL changed in 2002 from 50 to 10 ug/L. Many basins had data that exceeded the old standard as well. The locations of wells with samples that exceeded the MCL are shown in figure 5. The Salt Lake Valley had many instances of regulatory exceedance. The greater number of samples taken may account for some of the high number of regulatory exceedances relative to the other basins.

Arsenic concentration data in each sub-basin for each dataset over time are shown in figure 4. In Cache Valley, Cache Valley North had higher concentration data than Cache Valley South, although the high concentration data is generally only from 2000 to 2015; whereas in Cache Valley South, more regulatory exceedances occurred in the period from 1975 to 2000 than in Cache Valley North. In Cedar City Valley, the number, magnitude, and timing of regulatory exceedances was similar. In the East Shore Area, the western sub-basin had more exceedances among NWIS data. Lower Bear River Basin East had fairly regular regulatory exceedances, and the concentrations could be greater than 50 ug/L. In Lower Bear River Basin West, regulatory exceedances were rare, but they could be greater than 50 ug/L when they did occur. In the Salt Lake Valley, the Northwest sub-basin had the highest arsenic concentrations, followed by the southwestern sub-basin. Higher arsenic concentrations on the western and northwestern part of the Salt Lake Valley were consistent with the findings of Thiros (2003); the Northeast and Southeast had similar concentrations, with a few high concentration regulatory exceedances in the mid-1980s and a few infrequent exceedances between the 1980s and 2010s. In Utah Valley, the northeastern part had the highest concentrations, followed by the southeastern part; the northwestern sub-basin has a much shorter period of record compared to the rest of the basin.

The decadal and sub-decadal medians for each dataset and combined datasets are shown for each basin and sub-basin in figure 6. In general, the medians for individual and combined datasets were similar over time; there was no obvious systematic bias. The medians for NWIS, SDWIS, and combined data largely agreed, and the sub-decadal medians were more variable over time, whereas the decadal medians were smoother over time. Several basins had median concentrations that exceeded the MCL. The NWIS medians were consistently higher than the other medians in several basins (for example, the East Shore Area and Salt Lake Valley). The variation among medians was greatest in the Sevier Desert area. In Milford Valley, the NWIS period of record was much shorter than the SDWIS records and so the medians were less comparable to other medians.

In Cache Valley North, the NWIS data had a much shorter period of record than the SDWIS data. In the East Shore Area West, the NWIS medians were consistently higher than the SDWIS or combined data medians. In Utah Valley Northwest there were fewer data and the period of record was shorter, resulting in fewer medians than in other sub-basins, over a shorter period of time. There were only NWIS data in the Salt Lake Valley Northwest.

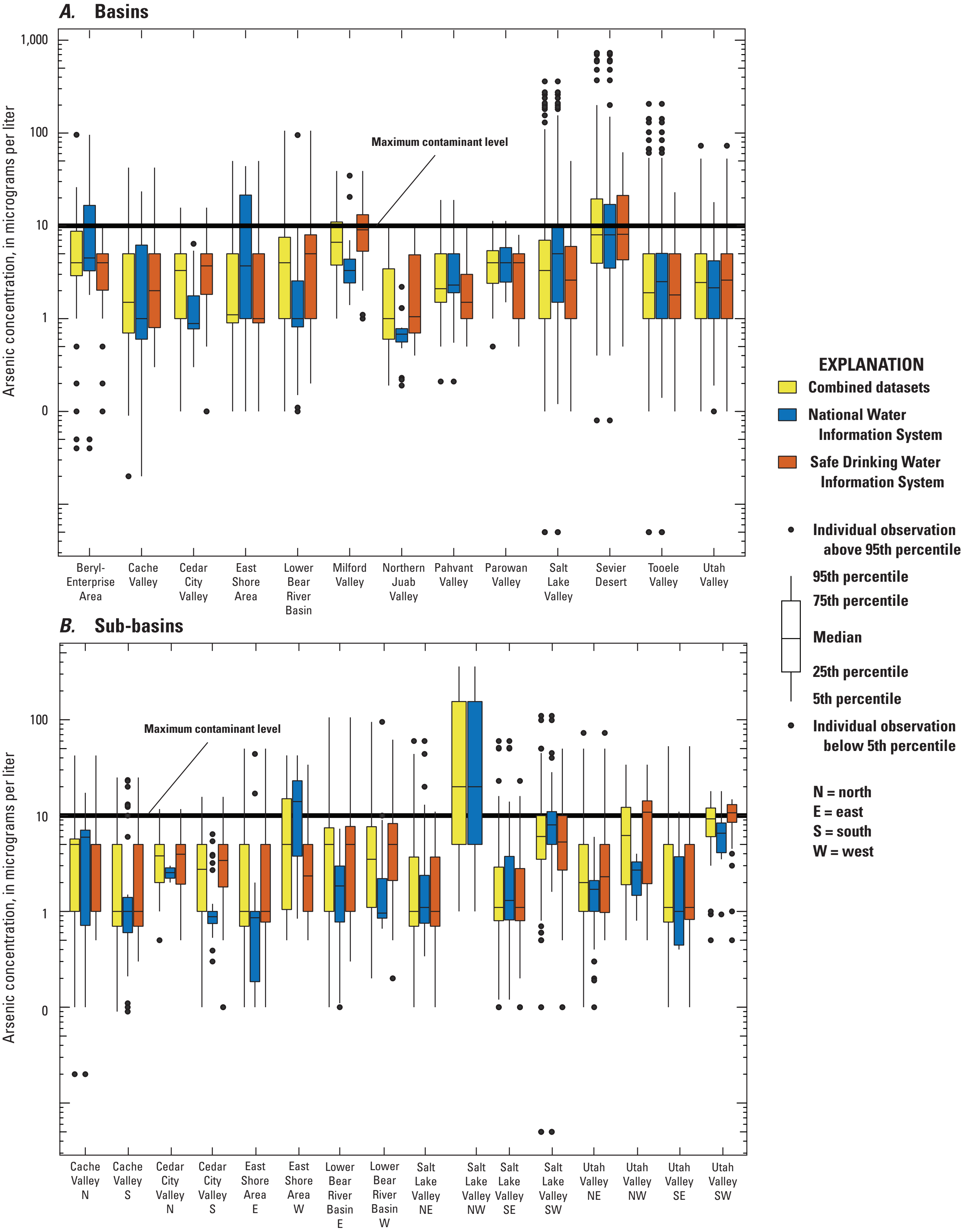


Figure 3. Arsenic concentrations in select Utah *A,* basins and *B,* sub-basins for data from the National Water Information System and Safe Drinking Water Information System, and combined datasets.

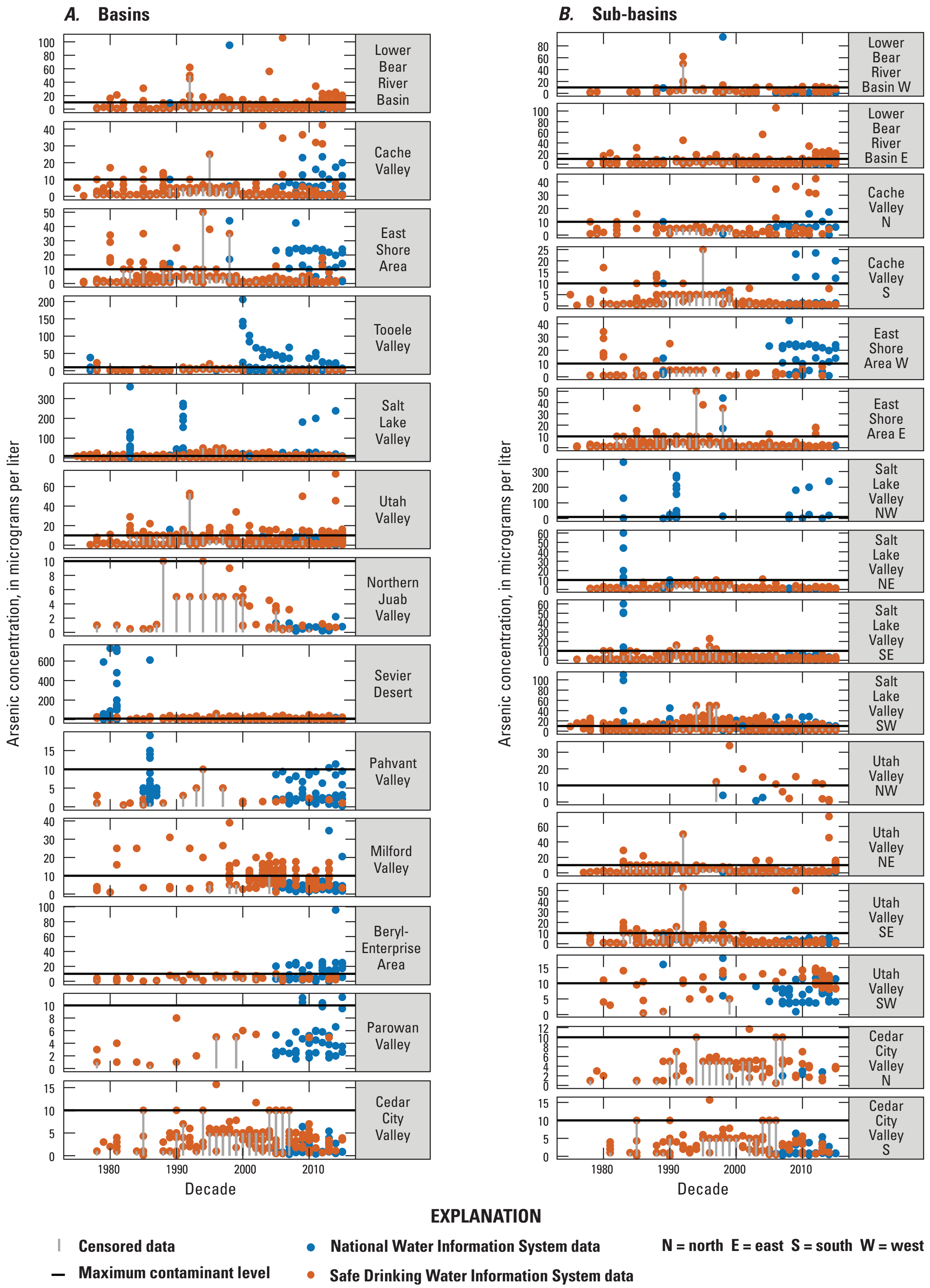
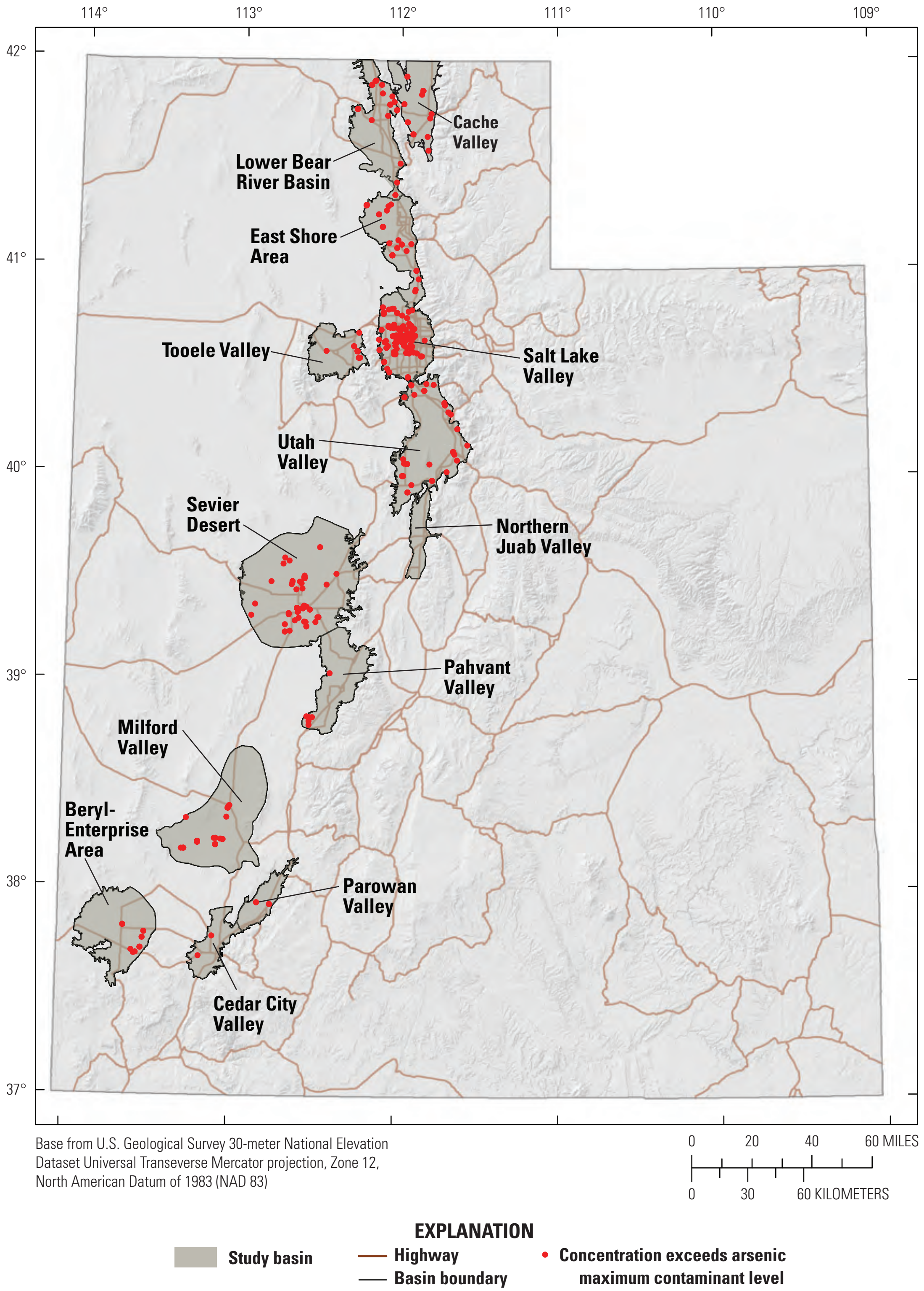


Figure 4. Arsenic concentrations over time by database in select Utah *A,* basins and *B,* sub-basins.



Base from U.S. Geological Survey 30-meter National Elevation Dataset Universal Transeverse Mercator projection, Zone 12, North American Datum of 1983 (NAD 83)

Figure 5. Location of wells with sample concentrations that exceed the maximum contaminant level for arsenic in select basins in Utah.

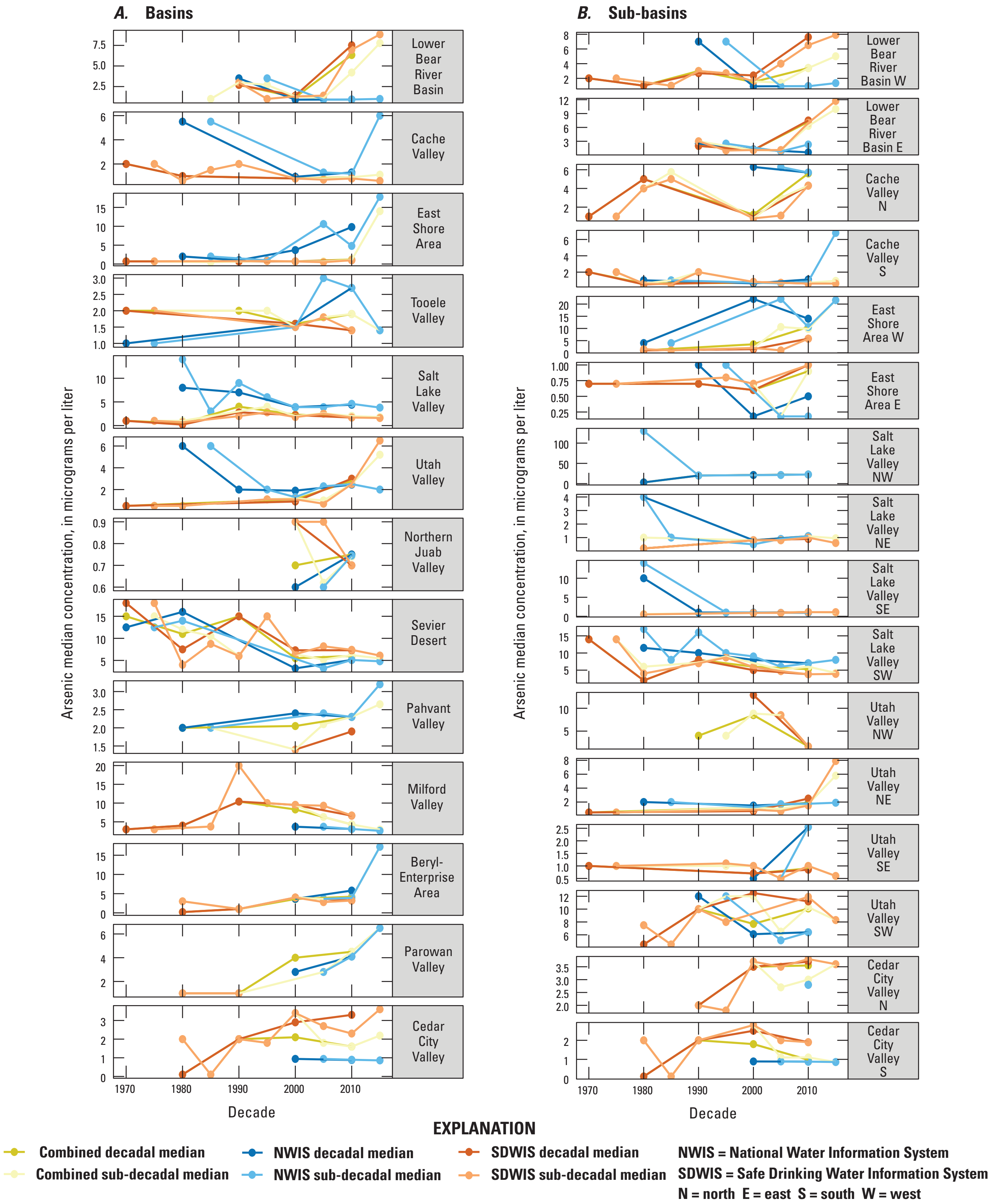


Figure 6. Decadal and sub-decadal median arsenic concentration in select *A,* basins and *B,* sub-basins in Utah.

Nitrate

Widespread measurement of nitrate concentrations in wells began in the mid to late 1970s, roughly coincident with enactment of the Safe Drinking Water Act of 1974, although the purpose of many USGS studies (NWIS data) at that time was to document the suitability of water resources for use (table 3; fig. 7). The SDWIS database contained more nitrate concentration data than the NWIS database, although there were more NWIS data in some basins including the Beryl-Enterprise Area, Pahvant Valley, and Parowan Valley. The number of wells and measurements varied greatly by basin and sub-basin. Several sub-basins had fewer than 10 wells including Utah Valley Northwest (combined NWIS and SDWIS data, NWIS data, and SDWIS data), and Utah Valley Southwest (SDWIS data only); this reduces the ability to detect trends in these areas. Generally, unfiltered nitrate samples from the SDWIS database, filtered nitrate plus nitrite samples from the NWIS database, and unfiltered nitrate plus nitrite samples from the SDWIS database were the most numerous sample types in each basin (fig. 7).

Generally, the percentage of censored measurements in each basin and sub-basin was low and was below 50 percent in all basins (table 3). For the combined datasets, the Sevier Desert had the highest percentage of censored values with 19 percent censored values.

Maximum concentrations exceeded the nitrate MCL of 10 mg/L in all basins except Parowan Valley for NWIS and SDWIS combined data. The NWIS maximum concentration was above the nitrate MCL in most basins, whereas the SDWIS maximum concentration was above the MCL in 6 out of 13 basins. The median concentrations in all basins for NIWS data, SDWIS data, and combined NWIS and SDWIS data were below 5 mg/L. Many sub-basins had maximum concentrations that exceeded the MCL, although the median in all basins for all datasets was well below the MCL. A paired two-sided t-test indicated that the medians of the NWIS and SDWIS datasets and the SDWIS and combined datasets are statistically different (p-value less than 0.05). The medians of the NWIS and combined datasets were not significantly different (p-value greater than 0.05).

The distribution of concentrations in individual and combined datasets is shown for each basin in figure 8. The IQR of concentrations in each basin and for individual and combined datasets fell below the MCL. The distribution of concentrations for individual and combined datasets was generally similar within a given basin. In some basins, the distributions of datasets varied. In Cache Valley and the East Shore Area, the NWIS IQR extended much lower than the IQR of SDWIS or combined datasets. Northern Juab Valley and Pahvant Valley had the highest IQRs relative to the other basins, whereas the Salt Lake Valley had the highest outlier values. The variability of concentrations also differed by basin. For example, the Beryl-Enterprise Area had a much narrower range of concentrations than the Sevier Desert.

The distribution of nitrate concentrations of NWIS, SDWIS, and combined NWIS and SDWIS data also is shown for each sub-basin in figure 8. The IQR of all data types fell below the MCL except NWIS data in Utah Valley Southwest. Most basins had some data above the MCL. The IQR for each data type within a sub-basin were generally similar with a few notable exceptions. The IQR of NWIS data in Cache Valley North and East Shore Area West was much lower than the SDWIS or combined datasets. The IQR of NWIS and combined datasets in the Salt Lake Valley Northwest were the same because there is no SDWIS data from this area. The Salt Lake Valley Northeast had the highest concentration data.

Nitrate concentration data in each basin and sub-basin for each database over time are shown in figure 9. Concentrations varied substantially by basin. Some basins had many or severe MCL exceedances (for example, Cache Valley, Tooele Valley, Salt Lake Valley, Utah Valley, and Pahvant Valley). In some basins, regulatory exceedances were rare or non-existent (for example, Northern Juab Valley, Beryl-Enterprise Area, and Parowan Valley). Exceedances occur in SDWIS and, more commonly, NWIS data. The locations of wells with nitrate samples that exceeded the MCL are shown in figure 10.

Concentrations exceeded the MCL in nearly every sub-basin except Cache Valley South, Cedar City Valley South, Salt Lake Valley Northwest, Utah Valley Northeast, and Utah Valley Northwest. In Cache Valley, Cache Valley North had more high concentration data than Cache Valley South. In Cedar City Valley, the concentration data were similar except for some higher concentration NWIS data from the early 2000s in the northern sub-basin. In the East Shore Area, the West sub-basin had overall lower concentration data, and both areas had very few samples that exceeded the MCL. In the Lower Bear River Basin, the West sub-basin had more data that exceeds the MCL, although these samples were NWIS data that may not represent water used for drinking water. In the Salt Lake Valley, the Northeast and Southwest sub-basins had the highest nitrate concentration data, although these data were from only a few samples. The data in the Northwest sub-basin were all below the MCL. The Southeast sub-basin had some data that exceeded the MCL, although it was all NWIS data that may not represent water used for drinking water. In Utah Valley, the Southwest and Southeast sub-basins had the highest concentrations. All of the data that exceeded the MCL in the Southwest sub-basin came from the NWIS database and may not represent drinking water.

The decadal and sub-decadal median nitrate concentrations for individual and combined datasets in each basin and sub-basin are shown in figure 11. Medians were below the MCL of 10 mg/L in all basins, although they were above the MCL in several sub-basins (Cache Valley North, Utah Valley Southwest, and Cedar City Valley North). In general, the medians for individual and combined datasets were similar within a basin or sub-basin. The NWIS medians were higher than the other medians in several basins (for example, Milford Valley and Cedar City Valley). The variation among medians for different datasets was greatest in Pahvant Valley.

Table 3. Number of wells and nitrate samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.

[Number in parentheses indicates the total number of wells. **Abbrevations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
NWIS and SDWIS data combined (1,857)									
Beryl-Enterprise Area	35	1975	2015	306	2	1	0.04	10.0	1.93
Cache Valley	97	1975	2015	818	41	5	0.01	18.9	1.26
Cedar City Valley	107	1975	2015	720	15	2	0.02	19.5	1
East Shore Area	212	1975	2015	1,731	212	12	0.01	18.0	1
Lower Bear River Basin	96	1975	2015	809	45	6	0.001	27.9	1.08
Milford Valley	55	1975	2015	377	23	6	0.01	40.3	0.77
Northern Juab Valley	40	1975	2015	208	1	0	0.01	42.0	3.4
Pahvant Valley	78	1975	2015	363	4	1	0.02	43.3	3.2
Parowan Valley	44	1975	2015	160	20	13	0.01	6.4	1.35
Salt Lake Valley	486	1975	2015	3,934	262	7	0.01	86.0	1.4
Sevier Desert	87	1975	2015	412	79	19	1.00E–06	22.0	0.37
Tooele Valley	223	1975	2015	1,032	12	1	0.02	36.9	1.7
Utah Valley	297	1975	2015	2,344	153	7	9.00E–04	46.0	0.83
NWIS data (1,051)									
Beryl-Enterprise Area	29	1975	2015	206	0	0	0.04	10.0	1.96
Cache Valley	37	1979	2015	86	14	16	0.02	8.9	0.6
Cedar City Valley	58	1975	2015	149	0	0	0.035	19.5	2.02
East Shore Area	77	1975	2015	171	54	32	0.01	18.0	0.3
Lower Bear River Basin	42	1975	2015	120	17	14	0.01	27.9	1.68
Milford Valley	34	1975	2015	177	1	1	0.08	40.3	2.49
Northern Juab Valley	28	1975	2015	88	0	0	0.46	42.0	4.9
Pahvant Valley	71	1975	2015	297	3	1	0.05	43.3	3.2
Parowan Valley	39	1975	2015	109	3	3	0.04	6.4	1.71
Salt Lake Valley	239	1976	2015	626	86	14	0.01	86.0	1.43
Sevier Desert	58	1975	2015	127	5	4	0.01	22.0	0.58
Tooele Valley	175	1975	2015	437	8	2	0.02	36.9	2.53
Utah Valley	164	1975	2015	321	36	11	0.02	46.0	1.3
SDWIS data (806)									
Beryl-Enterprise Area	6	1978	2015	100	2	2	0.1	7.2	1.64
Cache Valley	60	1975	2015	732	27	4	0.01	18.9	1.35
Cedar City Valley	49	1977	2015	571	15	3	0.02	10.6	0.9
East Shore Area	135	1976	2015	1,560	158	10	0.01	11.6	1.02
Lower Bear River Basin	54	1977	2015	689	28	4	0.001	15.6	1
Milford Valley	21	1978	2015	200	22	11	0.01	6.4	0.4
Northern Juab Valley	12	1978	2015	120	1	1	0.01	9.7	2.9
Pahvant Valley	7	1978	2015	66	1	2	0.02	9.1	3.2
Parowan Valley	5	1978	2015	51	17	33	0.01	1.2	0.2
Salt Lake Valley	247	1975	2015	3,308	176	5	0.01	70.0	1.4

Table 3. Number of wells and nitrate samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbreviations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
SDWIS data (806)—Continued									
Sevier Desert	29	1978	2015	285	74	26	1.00E–06	6.2	0.3
Tooele Valley	48	1977	2015	595	4	1	0.02	5.3	1.15
Utah Valley	133	1976	2015	2,023	117	6	9.00E–04	23.1	0.8
Sub-basins									
NWIS and SDWIS data combined (1,295)									
Cache Valley N	28	1977	2015	318	23	7	0.01	18.85	1.7
Cache Valley S	69	1975	2015	500	18	4	0.01	8.84	0.88
Cedar City Valley N	37	1977	2015	291	3	1	0.035	19.5	1.1
Cedar City Valley S	70	1975	2015	429	12	3	0.02	8.98	0.9
East Shore Area E	176	1975	2015	1,549	156	10	0.01	11.6	1.1
East Shore Area W	36	1975	2015	182	56	31	0.01	18	0.2
Lower Bear River Basin E	60	1977	2015	563	42	7	0.001	15.6	0.8
Lower Bear River Basin W	36	1975	2015	246	3	1	0.05	27.9	2.25
Salt Lake Valley NE	82	1976	2015	615	42	7	0.01	86.0	1.6
Salt Lake Valley NW	25	1976	2014	41	29	71	0.01	5.0	0.0
Salt Lake Valley SE	179	1976	2015	1,715	64	4	0.01	21.0	1.2
Salt Lake Valley SW	200	1975	2015	1,563	127	8	0.01	70.0	1.7
Utah Valley NE	165	1976	2015	1,020	47	5	9.00E–04	5.9	0.8
Utah Valley NW	9	1980	2015	32	1	3	0.06	4.6	1.1
Utah Valley SE	92	1975	2015	1,151	89	8	0.01	23.1	0.8
Utah Valley SW	31	1975	2015	141	16	11	0.01	46.0	1.5
NWIS data (617)									
Cache Valley N	10	1979	2015	31	7	23	0.02	8.9	0.1
Cache Valley S	27	1979	2015	55	7	13	0.037	6.7	1.2
Cedar City Valley N	18	1977	2013	39	0	0	0.035	19.5	1.5
Cedar City Valley S	40	1975	2015	110	0	0	0.25	9.0	2.1
East Shore Area E	57	1975	2015	109	17	16	0.01	11.2	1.0
East Shore Area W	20	1975	2014	62	37	60	0.01	18.0	0.0
Lower Bear River Basin E	19	1977	2015	57	16	28	0.01	11.0	0.4
Lower Bear River Basin W	23	1975	2015	63	1	2	0.05	27.9	2.6
Salt Lake Valley NE	39	1976	2015	94	8	9	0.019	86.0	4.3
Salt Lake Valley NW	25	1976	2014	41	29	71	0.01	5.0	0.0
Salt Lake Valley SE	77	1976	2015	208	12	6	0.01	21.0	1.2
Salt Lake Valley SW	98	1976	2015	283	37	13	0.03	25.0	1.9
Utah Valley NE	102	1976	2015	166	24	14	0.02	4.4	0.9
Utah Valley NW	5	1980	2004	5	1	20	0.06	3.1	2.0
Utah Valley SE	30	1975	2015	74	8	11	0.02	15.4	1.5
Utah Valley SW	27	1975	2015	76	3	4	0.05	46.0	4.3

Table 3. Number of wells and nitrate samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbrevations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
Sub-basins—Continued									
SDWIS data (678)									
Cache Valley N	18	1977	2015	287	16	6	0.01	18.9	2.0
Cache Valley S	42	1975	2015	445	11	2	0.01	8.8	0.8
Cedar City Valley N	19	1977	2015	252	3	1	0.07	10.6	1.1
Cedar City Valley S	30	1977	2015	319	12	4	0.02	6.8	0.7
East Shore Area E	119	1976	2015	1,440	139	10	0.01	11.6	1.1
East Shore Area W	16	1977	2015	120	19	16	0.01	5.4	0.7
Lower Bear River Basin E	41	1977	2015	506	26	5	0.001	15.6	0.8
Lower Bear River Basin W	13	1978	2015	183	2	1	0.2	4.0	2.2
Salt Lake Valley NE	43	1977	2015	521	34	7	0.01	31.7	1.4
Salt Lake Valley SE	102	1976	2015	1,507	52	3	0.01	6.0	1.2
Salt Lake Valley SW	102	1975	2015	1,280	90	7	0.01	70.0	1.7
Utah Valley NE	63	1977	2015	854	23	3	9.00E–04	5.9	0.8
Utah Valley NW	4	1997	2015	27	0	0	0.1	4.6	1.1
Utah Valley SE	62	1976	2015	1,077	81	8	0.01	23.1	0.8
Utah Valley SW	4	1977	2014	65	13	20	0.01	2.2	1.1

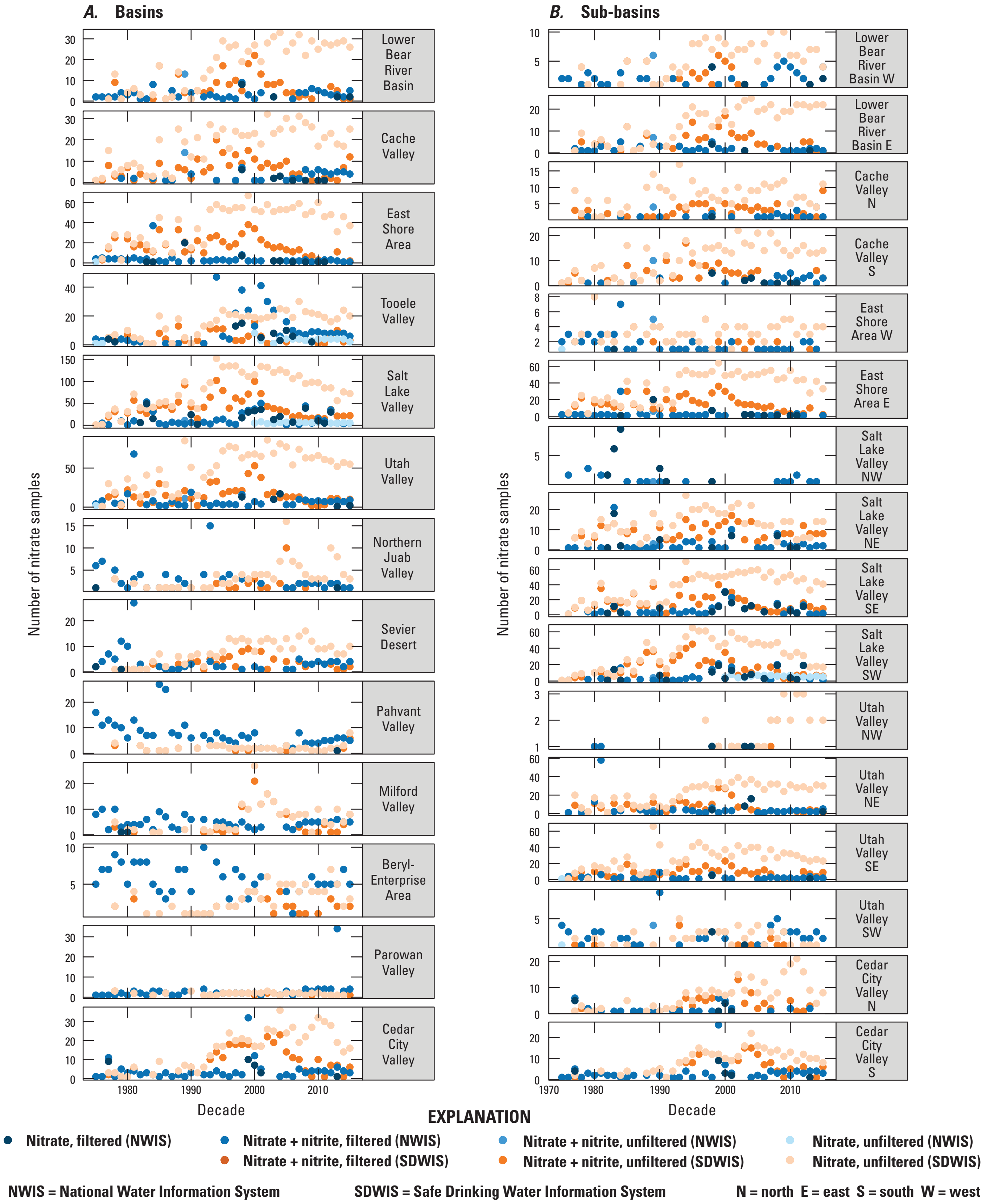


Figure 7. Number of nitrate samples over time in select Utah *A*, basins and *B*, sub-basins in the National Water Information System and Safe Drinking Water Information System datasets.

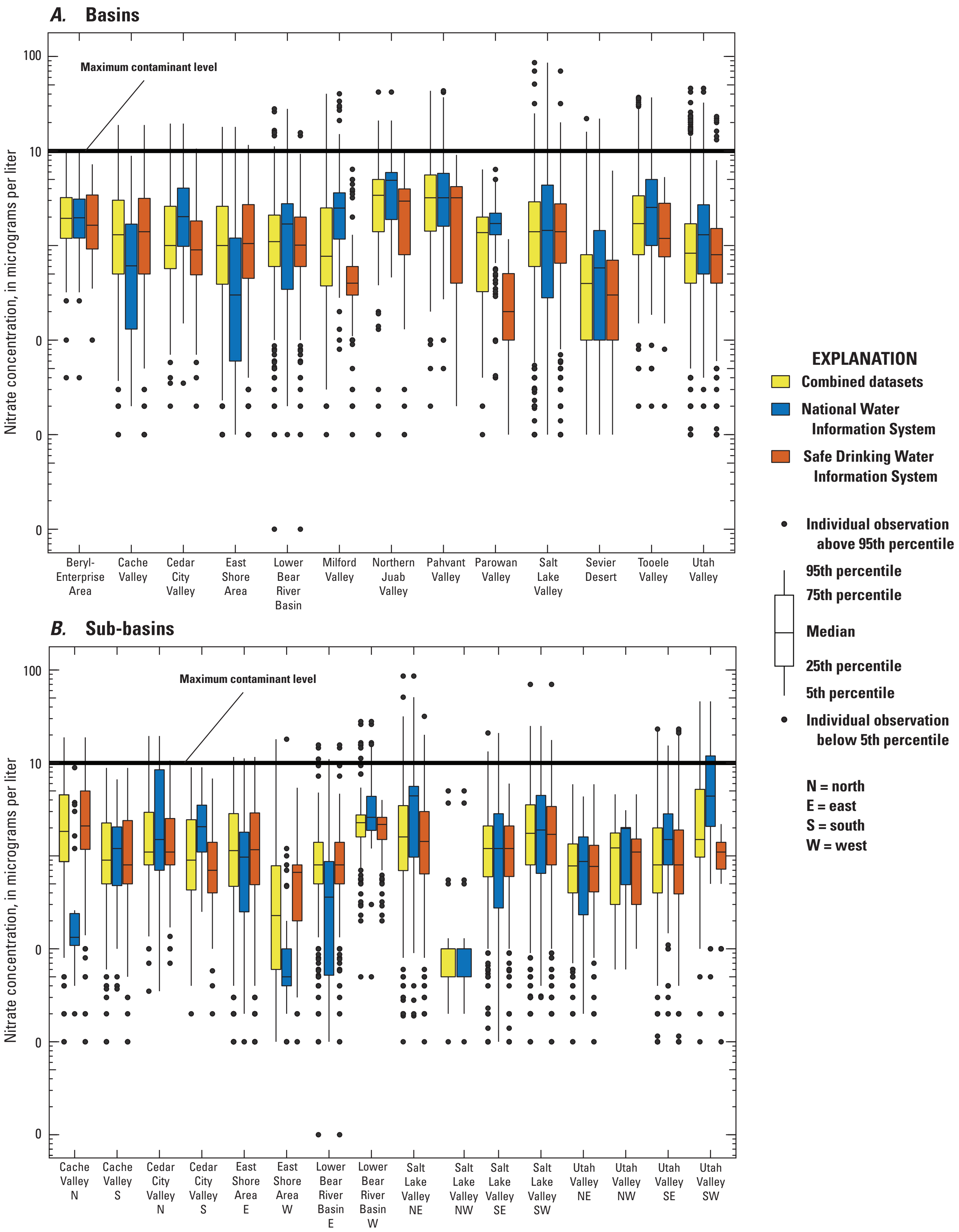


Figure 8. Nitrate concentrations in select Utah *A,* basins and *B,* sub-basins for data from the National Water Information System and Safe Drinking Water Information System, and combined datasets.

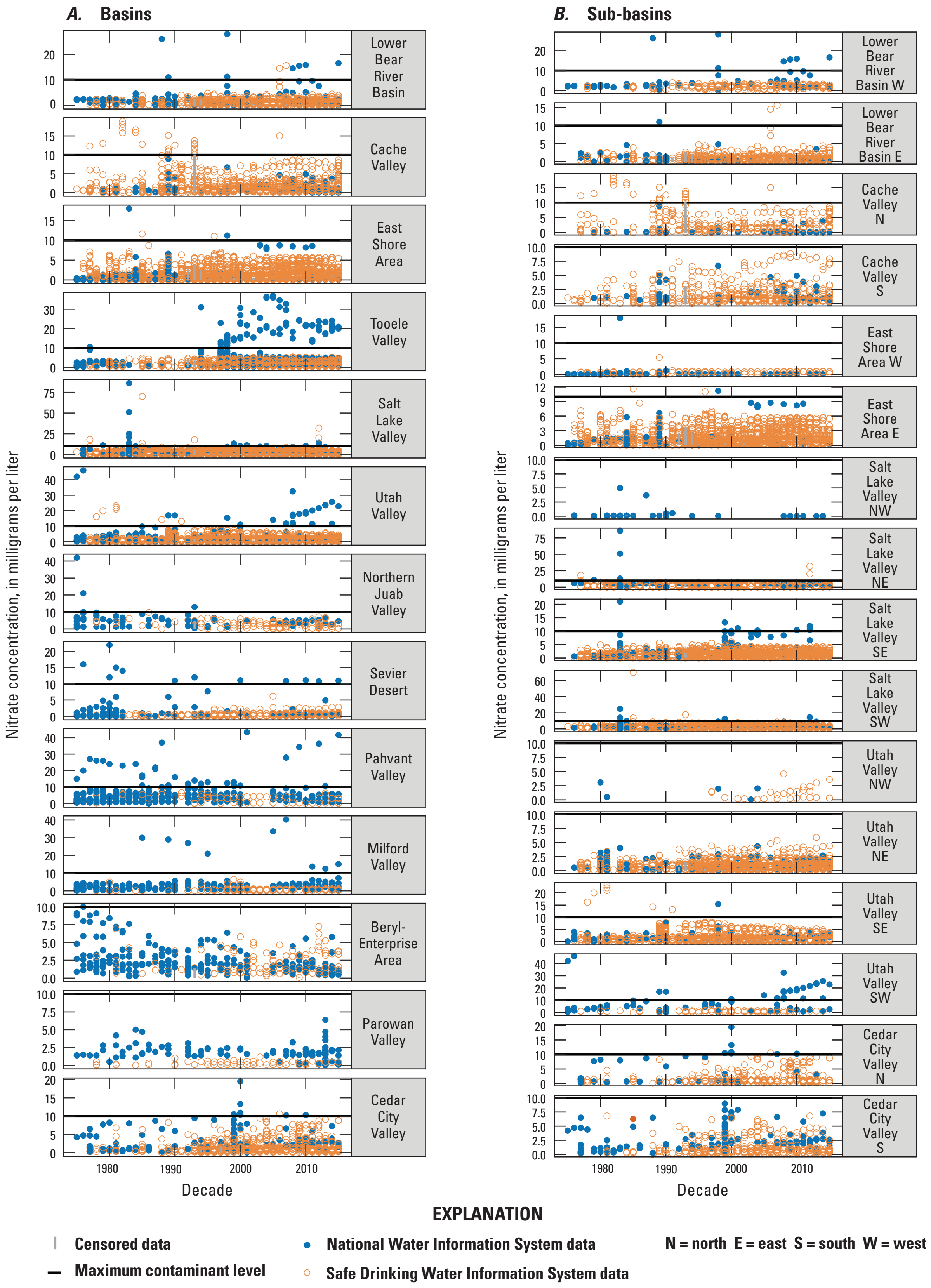
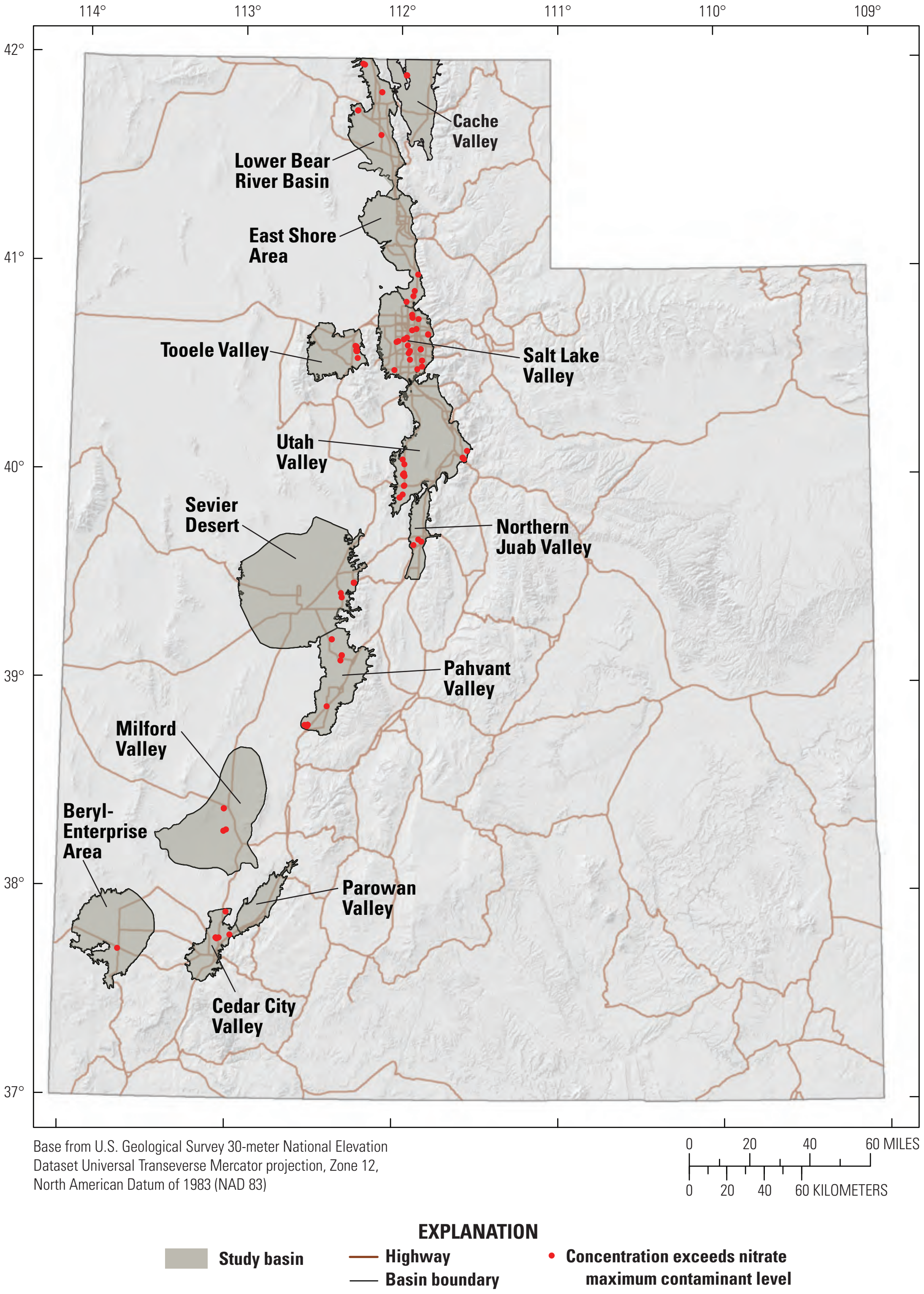


Figure 9. Nitrate concentrations over time by dataset in select Utah *A*, basins and *B*, sub-basins.



Base from U.S. Geological Survey 30-meter National Elevation Dataset Universal Transverse Mercator projection, Zone 12, North American Datum of 1983 (NAD 83)

Figure 10. Location of wells with samples that exceed the Maximum Contaminant Level for nitrate in select basins in Utah.

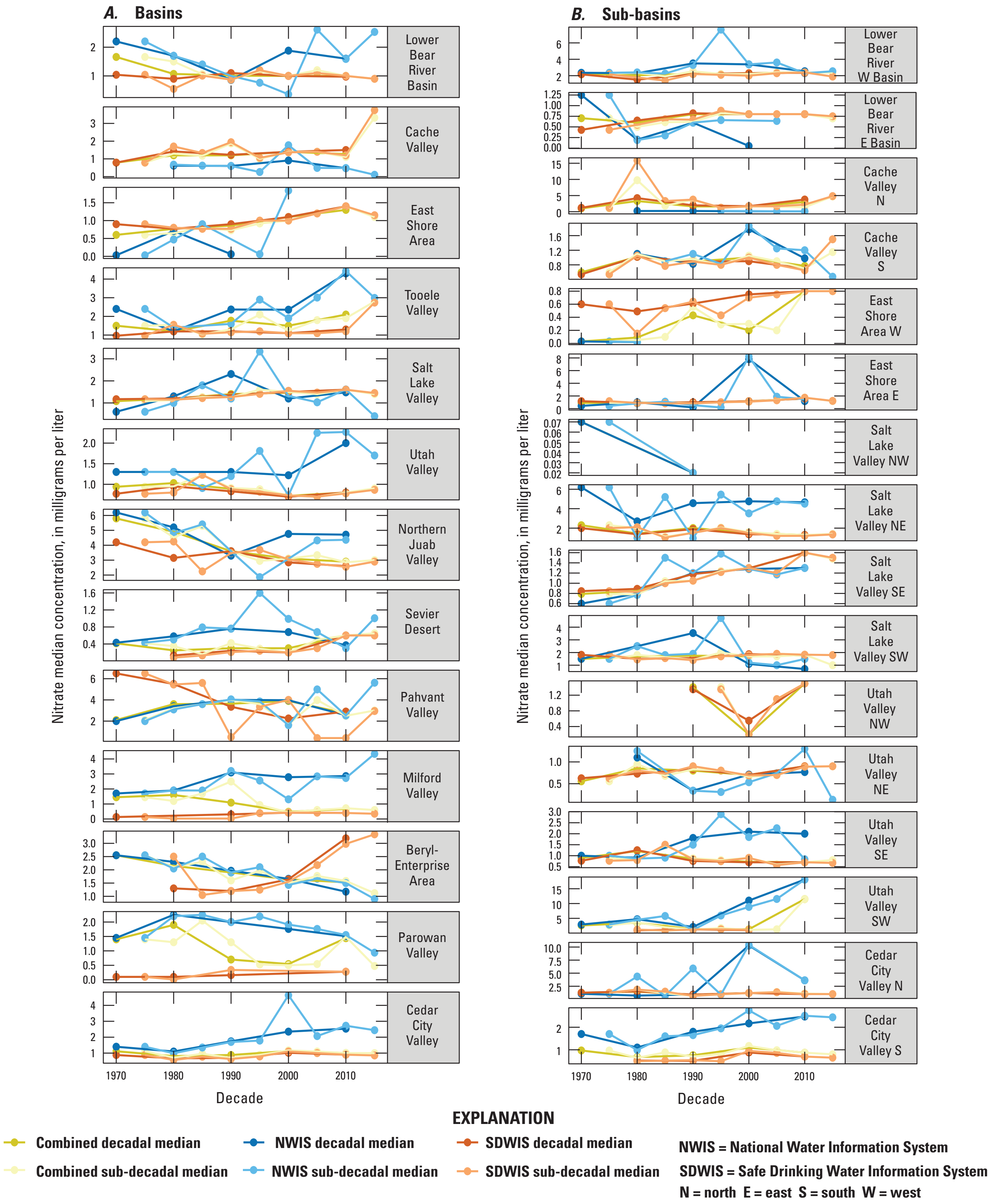


Figure 11. Decadal and sub-decadal median nitrate concentration in select *A*, basins and, *B* sub-basins in Utah.

Dissolved Solids

The period of record and number of measurements of dissolved-solids concentrations in wells is shown in table 4 and figure 12. The SDWIS database contained more dissolved solids concentration data than the NWIS database, although there were more NWIS measurements in some basins including the Beryl-Enterprise Area, Milford Valley, Northern Juab Valley, Pahvant Valley, Parowan Valley, Sevier Desert, and Tooele Valley. Utah Valley Northwest was the only sub-basin with fewer than 10 wells for combined NWIS and SDWIS data, and there were only 18 samples in this area. This makes trend identification more difficult. The number of measurements varied greatly by basin. Generally, dissolved solids as the residual of evaporation from the SDWIS database and as the sum of constituents from the NWIS database were the most numerous sample types in each basin (fig. 12). The sum of constituents depends on the number of constituents measured.

None of the dissolved solids data were censored (table 4). The maximum concentration in all basins was above the dissolved solids SMCL of 500 mg/L. However, the median concentration in many basins was below 500 mg/L. Among NWIS data, eight basins had medians greater than the SMCL of 500 mg/L, whereas among SDWIS data, no basins had medians greater than 500 mg/L. A paired two-sided t-test indicates that the medians of the NWIS and SDWIS datasets, the NWIS and combined datasets, and the SDWIS and combined datasets were statistically different (p-value less than 0.05). The increased variability this introduces makes trend identification more difficult when combining NWIS and SDWIS data.

For combined NWIS and SDWIS data, the maximum dissolved solids concentration in each sub-basin was greater than 500 mg/L. The median in each sub-basin was below the SMCL in all basins except 6 out of 16 sub basins, and the highest median was below the MCL of 2,000 mg/L at 1,270 mg/L in the Salt Lake Valley Northwest. The distribution of concentrations in individual and combined datasets is shown for each basin in figure 13. The IQR of concentrations in each basin and for individual and combined datasets fell below the MCL except in Pahvant Valley. The IQR exceeded the supplier requirements level of 1,000 mg/L in Lower Bear River Basin, Tooele Valley, Sevier Desert, and Pahvant Valley although this was often only for NWIS samples, which are taken from wells with a range of purposes, not just drinking-water supply. Lower water quality may be acceptable when the water is not used for public supply. The IQRs of all basins exceeded the SMCL except in Cache Valley and Parowan Valley, where no IQR exceeded the SMCL. For SDWIS data, the IQR exceeded the SMCL in Cedar City Valley, Northern Juab Valley, Salt Lake Valley, and Tooele Valley. The distribution of concentrations in individual and combined datasets was generally similar within a given basin.

However, in some basins, the distributions of particular datasets vary. The NWIS IQR often extended higher than the SDWIS IQR. This is generally expected because SDWIS samples come from wells used for public supply, and may therefore be biased toward higher quality, whereas NWIS samples come from wells used for a range of purposes including agriculture irrigation or industrial applications where quality considerations are different.

Among sub-basins, the distributions of dissolved-solids concentrations varied substantially, although within each basin the distributions for NWIS, SDWIS, and combined datasets generally aligned (fig. 13). The IQRs for all sub-basins were below the MCL of 2,000 mg/L except in the Salt Lake Valley Northeast. The Salt Lake Valley Northwest had the highest IQR and highest concentration (20,900 mg/L from a shallow well near the Great Salt Lake). The SDWIS IQRs for many sub-basins were below the MCL of 500 mg/L, except in Lower Bear River Basin West; Salt Lake Valley Northeast and Southwest; Utah Valley Northwest and Southwest; and Cedar City Valley South. The NWIS IQR often extended higher than the SDWIS IRQ, although exceptions occurred and there was often substantial overlap.

Dissolved solids concentration data in each basin for each database over time are shown in figure 14. Concentrations varied substantially by basin and sub-basin. Some basins had many or severe MCL exceedances (for example, Tooele Valley, Salt Lake Valley, Sevier Desert, and Pahvant Valley). In some basins, concentrations exceeding the MCL were rare or non-existent (for example, Northern Juab Valley, Beryl-Enterprise Area, and Parowan Valley). Exceedances occurred in SDWIS and, more commonly, NWIS data. The locations of wells with dissolved solids samples that exceeded the MCL are shown in figure 15.

Within and among sub-basins, dissolved-solids concentrations varied (fig. 14). In Cache Valley, the northern sub-basin had more high-concentration data than the southern part. In Cedar City Valley and East Shore Area, both sub-regions had relatively few concentrations greater than 2,000 mg/L. There were a few concentrations greater than 2,000 mg/L in Lower Bear River West and none in Lower Bear River East. In the Salt Lake Valley, the Northwest and Northeast had several samples with concentrations of more than 10,000 mg/L; these were all NWIS data. In the Salt Lake Valley Southeast, all SDWIS data were below 2,000 mg/L and in the Salt Lake Valley Southwest there were only a few SDWIS concentrations greater than 2,000 mg/L. Concentrations were generally lower than 1,000 mg/L in Utah Valley sub-basins, although there were limited data over a shorter period of record in the northeastern area.

Table 4. Number of wells and dissolved solids samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.

[Number in parentheses indicates the total number of wells. **Abbreviations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
Basins									
NWIS and SDWIS data combined (1,955)									
Beryl-Enterprise Area	36	1975	2015	262	0	0	125	1,950	410
Cache Valley	88	1975	2015	352	0	0	150	1,986	288
Cedar City Valley	104	1975	2015	386	0	0	110	3,070	426
East Shore Area	248	1975	2015	958	0	0	28	4,000	298
Lower Bear River Basin	95	1975	2015	414	0	0	88	2,360	324
Milford Valley	57	1975	2015	370	0	0	156	10,200	456
Northern Juab Valley	40	1975	2015	165	0	0	18	2,940	794
Pahvant Valley	79	1975	2015	340	0	0	10	6,520	961
Parowan Valley	46	1975	2015	134	0	0	135	672	310
Salt Lake Valley	511	1975	2015	2,719	0	0	10	20,900	512
Sevier Desert	96	1975	2015	286	0	0	162	24,300	352
Tooele Valley	246	1975	2015	678	0	0	143	17,000	652
Utah Valley	309	1975	2015	1,083	0	0	55	2,560	314
NWIS data (1,173)									
Beryl-Enterprise Area	31	1975	2015	224	0	0	125	1,950	432
Cache Valley	38	1979	2015	91	0	0	174	1,730	295
Cedar City Valley	60	1975	2015	160	0	0	183	3,070	541
East Shore Area	112	1975	2015	245	0	0	122	4,000	371
Lower Bear River Basin	42	1975	2015	130	0	0	118	1,920	521
Milford Valley	36	1975	2015	194	0	0	189	10,200	547
Northern Juab Valley	28	1975	2015	106	0	0	262	2,940	827
Pahvant Valley	72	1975	2015	311	0	0	305	6,520	1,050
Parowan Valley	41	1975	2015	115	0	0	148	672	304
Salt Lake Valley	265	1976	2015	692	0	0	71	20,900	701
Sevier Desert	69	1975	2015	159	0	0	193	24,300	553
Tooele Valley	201	1975	2015	454	0	0	143	17,000	771
Utah Valley	178	1975	2015	369	0	0	91	2,560	355
SDWIS data (782)									
Beryl-Enterprise Area	5	1978	2014	38	0	0	160	723	304
Cache Valley	50	1975	2015	261	0	0	150	1,986	286
Cedar City Valley	44	1977	2015	226	0	0	110	2,720	368
East Shore Area	136	1976	2015	713	0	0	28	1,656	288
Lower Bear River Basin	53	1977	2015	284	0	0	88	2,360	288
Milford Valley	21	1978	2015	176	0	0	156	948	385
Northern Juab Valley	12	1978	2015	59	0	0	18	1,040	436
Pahvant Valley	7	1978	2015	29	0	0	10	882	380
Parowan Valley	5	1978	2013	19	0	0	135	504	402

Table 4. Number of wells and dissolved solids samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbrevations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
Basins—Continued									
SDWIS data (782)—Continued									
Salt Lake Valley	246	1975	2015	2,027	0	0	10	2,222	445
Sevier Desert	27	1978	2015	127	0	0	162	1,520	280
Tooele Valley	45	1977	2015	224	0	0	196	2,970	410
Utah Valley	131	1976	2015	714	0	0	55	1,290	298
Sub-basins									
NWIS and SDWIS data combined (1,355)									
Cache Valley N	27	1977	2015	124	0	0	156	1,986	260
Cache Valley S	61	1975	2015	228	0	0	150	576	295
Cedar City Valley N	35	1977	2015	131	0	0	112	2,510	385
Cedar City Valley S	69	1975	2015	255	0	0	110	3,070	485
East Shore Area E	200	1975	2015	785	0	0	28	2,960	296
East Shore Area W	48	1975	2015	173	0	0	158	4,000	308
Lower Bear River Basin E	59	1977	2015	269	0	0	88	1,142	249
Lower Bear River Basin W	36	1975	2015	145	0	0	307	2,360	896
Salt Lake Valley NE	81	1976	2015	463	0	0	84	16,800	582
Salt Lake Valley NW	40	1976	2014	68	0	0	336	20,900	1,270
Salt Lake Valley SE	182	1976	2015	1,046	0	0	10	2,430	268
Salt Lake Valley SW	208	1975	2015	1,142	0	0	10	8,550	696
Utah Valley NE	172	1976	2015	581	0	0	55	1,110	282
Utah Valley NW	9	1980	2014	18	0	0	387	1,510	949
Utah Valley SE	94	1975	2015	375	0	0	96	1,970	325
Utah Valley SW	34	1975	2015	109	0	0	348	2,560	719
NWIS data (695)									
Cache Valley N	11	1979	2015	33	0	0	218	1,730	258
Cache Valley S	27	1979	2015	58	0	0	174	539	307
Cedar City Valley N	18	1977	2013	42	0	0	276	2,510	503
Cedar City Valley S	42	1975	2015	118	0	0	183	3,070	570
East Shore Area E	81	1975	2015	139	0	0	122	2,960	339
East Shore Area W	31	1975	2015	106	0	0	158	4,000	374
Lower Bear River Basin E	19	1977	2015	60	0	0	118	835	236
Lower Bear River Basin W	23	1975	2015	70	0	0	342	1,920	1,020
Salt Lake Valley NE	39	1976	2015	97	0	0	204	16,800	706
Salt Lake Valley NW	40	1976	2014	68	0	0	336	20,900	1,270
Salt Lake Valley SE	82	1976	2015	216	0	0	71	2,430	434
Salt Lake Valley SW	104	1976	2015	311	0	0	206	8,550	778
Utah Valley NE	109	1976	2015	192	0	0	91	1,110	312
Utah Valley NW	5	1980	2004	5	0	0	387	1,510	960

Table 4. Number of wells and dissolved solids samples; period of record; and minimum, maximum, and median concentration in select Utah basins and sub-basins for data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS), and combined NWIS and SDWIS data.—Continued

[Number in parentheses indicates the total number of wells. **Abbrevations**: mg/L, milligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
Sub-basins—Continued									
NWIS data (695)—Continued									
Utah Valley SE	34	1975	2015	87	0	0	196	1,970	340
Utah Valley SW	30	1975	2015	85	0	0	354	2,560	807
SDWIS data (660)									
Cache Valley N	16	1977	2014	91	0	0	156	1,986	262
Cache Valley S	34	1975	2015	170	0	0	150	576	290
Cedar City Valley N	17	1977	2015	89	0	0	112	1,630	320
Cedar City Valley S	27	1977	2015	137	0	0	110	2,720	423
East Shore Area E	119	1976	2015	646	0	0	28	1,350	290
East Shore Area W	17	1977	2013	67	0	0	178	1,656	274
Lower Bear River Basin E	40	1977	2015	209	0	0	88	1,142	256
Lower Bear River Basin W	13	1978	2014	75	0	0	307	2,360	772
Salt Lake Valley NE	42	1977	2015	366	0	0	84	1,056	540
Salt Lake Valley SE	100	1976	2015	830	0	0	10	1,710	248
Salt Lake Valley SW	104	1975	2015	831	0	0	10	2,222	636
Utah Valley NE	63	1977	2015	389	0	0	55	998	275
Utah Valley NW	4	1997	2014	13	0	0	392	1,290	949
Utah Valley SE	60	1976	2015	288	0	0	96	1,200	320
Utah Valley SW	4	1977	2013	24	0	0	348	954	444

The decadal and sub-decadal dissolved solids medians for each database grouping are shown in figure 16. Median concentrations did not exceed the MCL of 2,000 mg/L in any basin or sub-basin except the Salt Lake Valley Northwest, although medians in many basins exceeded the SMCL of 500 mg/L. In general, the medians for individual and combined datasets were similar within a basin or sub-basin. The NWIS medians were higher than the other medians in several basins (for example, Lower Bear River Basin, Salt Lake Valley, and Sevier Desert). The variation among medians for different databases was greatest in Pahvant Valley. Variations among medians for different datasets were low in Cache Valley, Utah Valley, and Parowan Valley. Agreement among medians increased with time in the Pahvant Valley, Milford Valley, and Beryl-Enterprise Area.

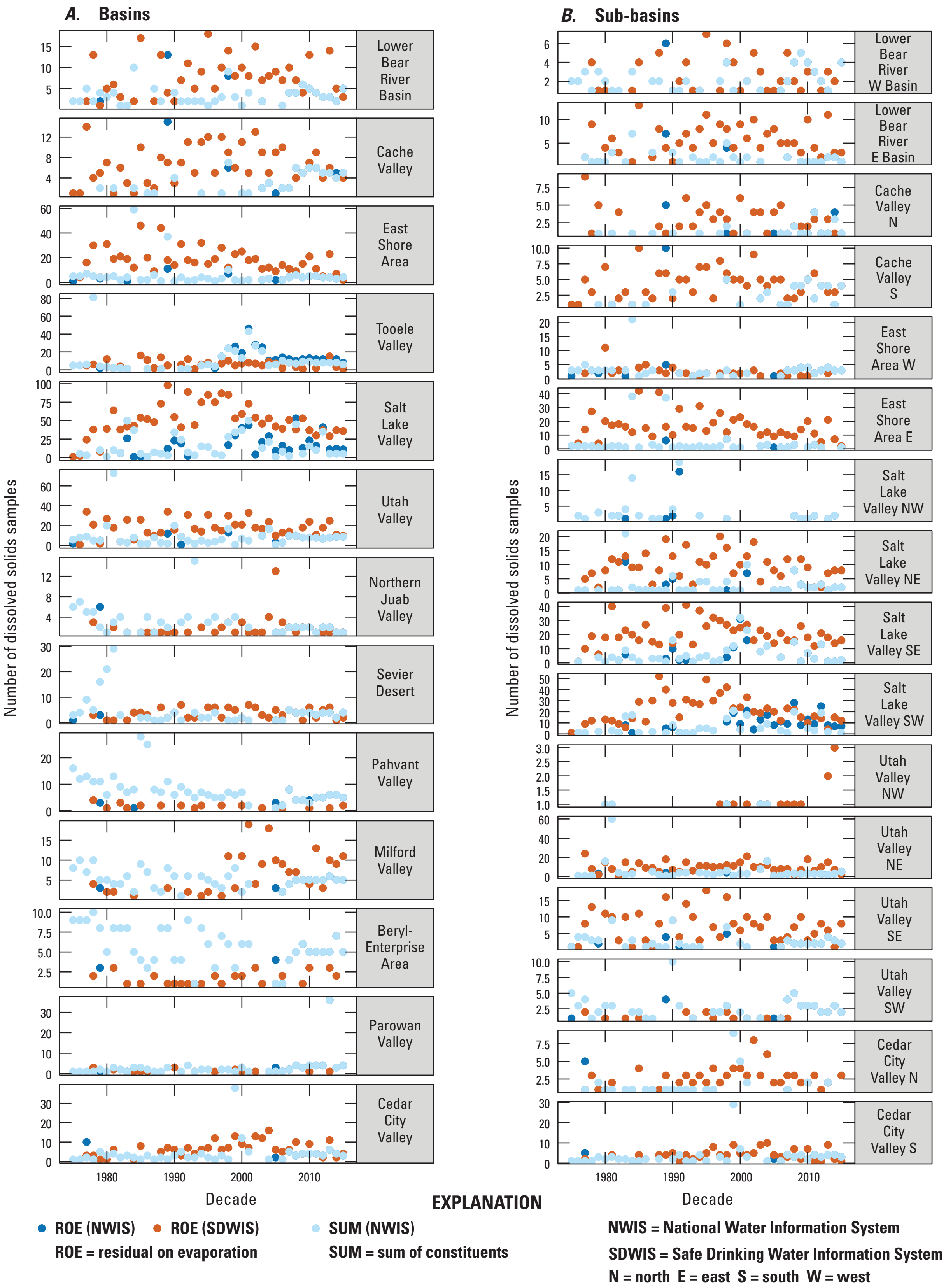


Figure 12. Number of dissolved solids samples over time in select Utah *A*, basins and *B*, sub-basins in the National Water Information System and Safe Drinking Water Information System datasets.

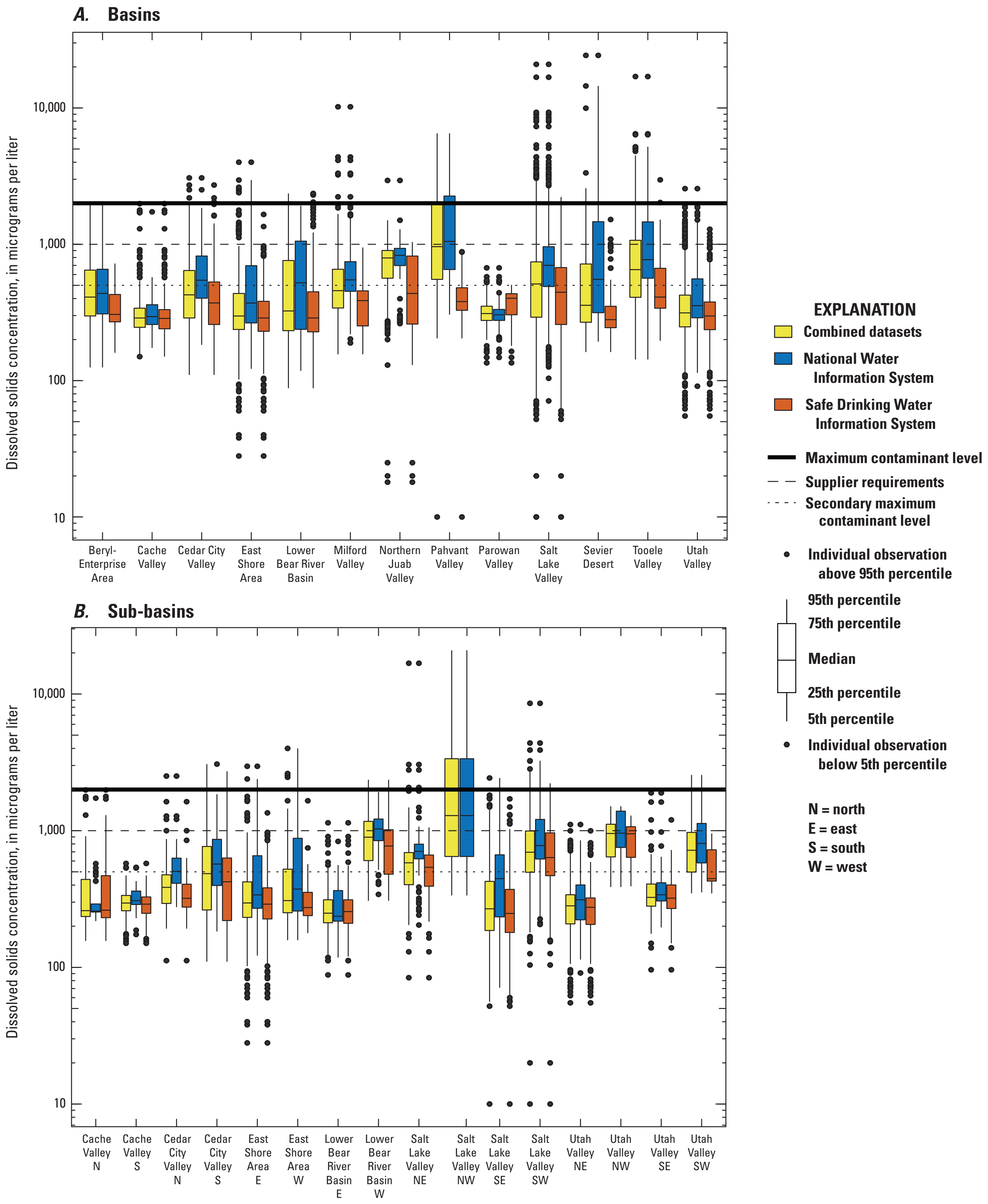


Figure 13. Dissolved-solids concentrations in select Utah *A*, basins and *B*, sub-basins for data from the National Water Information System and Safe Drinking Water Information System, and combined datasets.

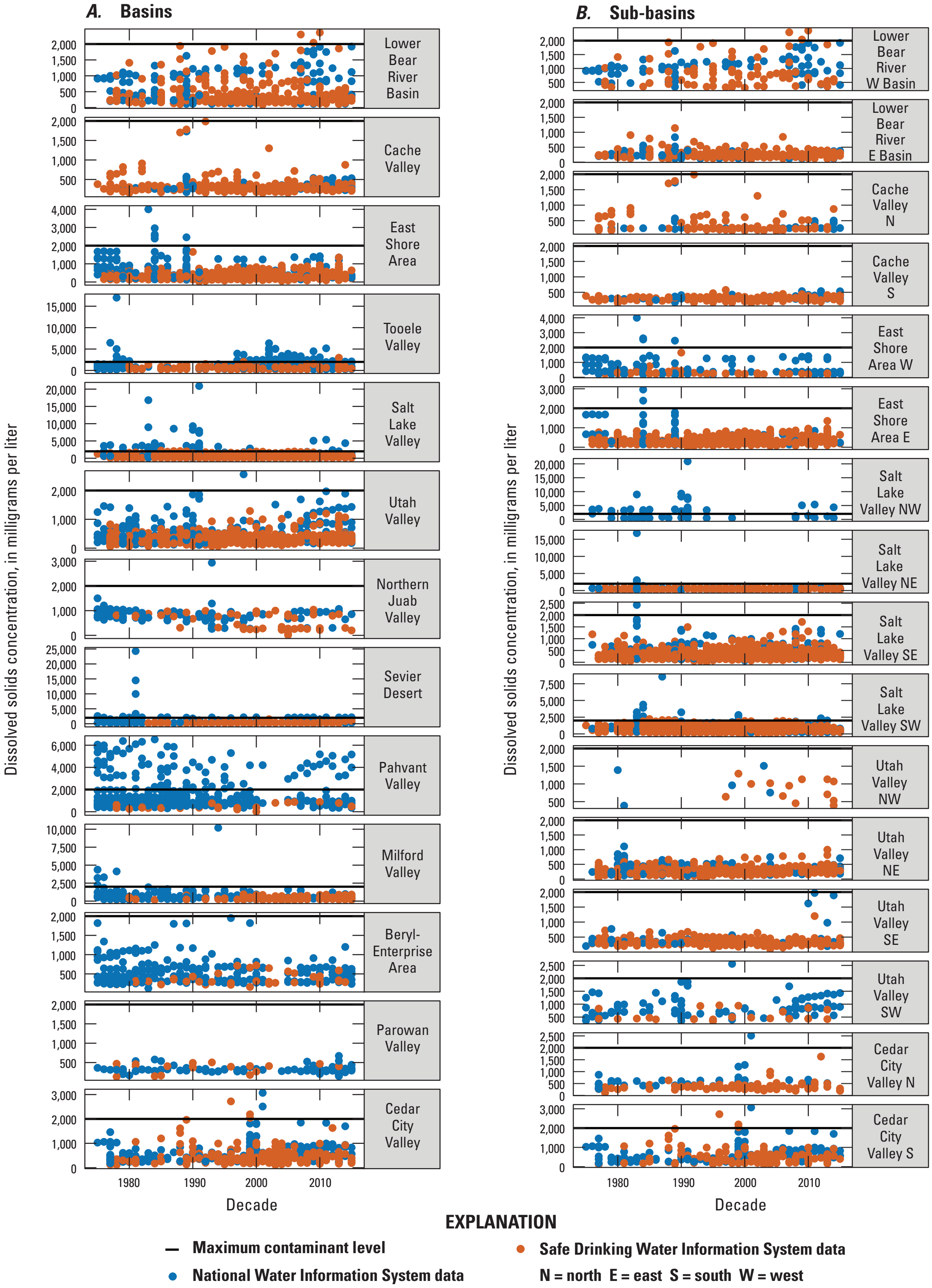
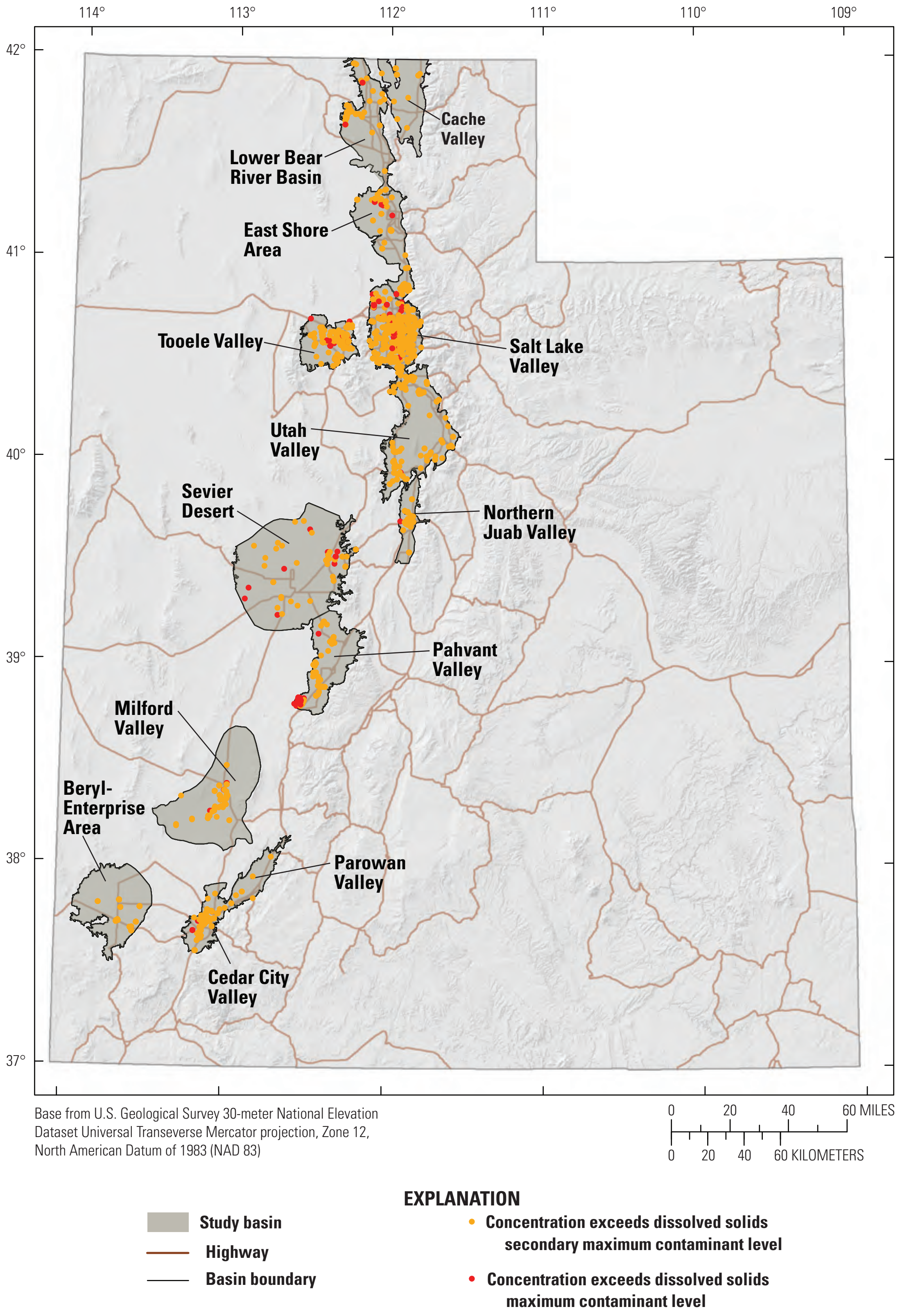


Figure 14. Dissolved-solids concentrations over time by dataset in select Utah *A*, basins and *B*, sub-basins.



Base from U.S. Geological Survey 30-meter National Elevation Dataset Universal Transeverse Mercator projection, Zone 12, North American Datum of 1983 (NAD 83)

Figure 15. Location of wells with samples that exceed the secondary maximum contaminant level and maximum contaminant level for dissolved solids in select basins in Utah.

Figure 16. Decadal and sub-decadal median dissolved-solids concentration in select *A*, basins and *B*, sub-basins in Utah.

Trends in Arsenic, Nitrate, and Dissolved Solids from Combined Datasets

Overall, despite differences between the NWIS and SDWIS databases, the increased understanding of general basin-wide conditions justifies combining the datasets. In addition, combining the datasets generally reduces the percentage of censored values in each basin. Combining the NWIS and SDWIS datasets also increases the number of samples, which increases precision in estimates characterizing water-quality conditions. However, combining the datasets also can introduce variability because the range in concentrations can increase, particularly when there are larger differences between the datasets. Further, because there are generally more SDWIS data than NWIS data, the combined dataset results can be dominated by patterns in the SDWIS data.

Long-term trend analysis of groundwater arsenic, nitrate, and dissolved solids evaluated in basins that have experienced increased development and groundwater use show widespread changes in water quality. Trends evaluated in smaller regions of some basins highlight local water-quality conditions.

When there was an insufficient number of decadal medians, trend tests were often only possible using sub-decadal medians. Comparing results of trend tests on decadal and sub-decadal medians indicated that often sub-decadal medians have greater variability than decadal medians. This additional variability can make trend identification more difficult, although analysis of sub-decadal median data more frequently yielded significant groundwater-quality trends compared to analysis of decadal median data. This is in part because of the larger number of sub-decadal median data compared to decadal median data. In these cases, the magnitude and sign of Kendall’s tau (nonparametric correlation coefficient measuring the monotonic association between the dependent and independent variable) for both tests were generally similar, indicating that the additional data available in the sub-decadal median analysis provided additional statistical power without adding noise. This similarity between decadal and sub-decadal analyses supports the robustness of this analysis.

In a few cases, trends were identified in decadal medians, but not in sub-decadal medians. This may be due to the increased variability introduced in some cases by more frequent median calculations. The Mann-Kendall trend test identifies monotonic trends, which are obscured by increased variability. Increasing and decreasing trends were identified in all basins for some constituents except Tooele Valley. Results are presented below and comparisons to trends identified in other areas are described where applicable.

Sample replicate variability can influence the concentrations from which a decadal or sub-decadal median is calculated. Replicate variability of samples taken following USGS sampling and lab protocols has been assessed. For samples with dissolved-solids concentrations between 14 and 1,000 mg/L, the standard deviation of replicates was 7 mg/L and for concentrations between 1,000 and 9,015 mg/L the relative standard deviation was 3 percent (Gross and others, 2012). For samples with nitrate concentrations between 0.05 and 1.0 mg/L, the standard deviation of replicates was 0.043 mg/L and for concentrations between 1 and 58 mg/L the relative standard deviation was 2.9 percent (Mueller and Titus, 2005). The replicate variability is generally less than the variability among different samples from a single site or samples from different sites. The trend test looks at changes in median values over time and so replicate variability or even temporal changes in concentrations must be big enough to influence the median to contribute to a monotonic trend.

Evaluating trends in comparison to land-use change provides some insights into understanding trend drivers. However, when considering land-use change at a well, the number of wells in each land-use change category decreased relative to the number of wells in each basin, and the number of samples and period of record were also often smaller, making trend detection more difficult. Trends, specifically for nitrate and dissolved solids, can occur in areas of increased population and urbanization. However, land use directly surrounding wells is not always useful in identifying trends. Trends in arsenic, nitrate, and dissolved solids were commonly identified among wells in areas where land use did not change. This is in part because there were more wells in areas where land use did not change than there were in areas where land use changed.

Although land use is expected to have a substantial impact on water quality, these results highlight a more complex relationship between land use and water quality, with various spatial and temporal factors influencing surface to subsurface connectivity. Among wells where land use did not change over time, trends in arsenic, nitrate, and dissolved solids were still identified, indicating that factors other than land use directly at the well location impact water quality, including the combination of activities farther away from the well, groundwater travel time, and the timing of land-use transitions. For example, a lag in the time between conversion of land from low use to farming and an increase in nitrate concentration at a well several miles away is expected due to the time required for a sufficient nitrate load, from increased fertilizer application, to enter the groundwater system and move to the well. Changes in nitrate loads upgradient from a well may take decades or more to travel to a well and register as a change in concentration. Even land-use change occurring at a well can have a lag time as nitrate moves through the unsaturated zone.

Arsenic

Evidence for statistically significant increases in decadal or sub-decadal median arsenic concentrations between 0.02 and 0.17 µg/L per year was identified in the Beryl-Enterprise Area, East Shore Area, Utah Valley, Pahvant Valley, and Parowan Valley (table 5; fig. 17). Evidence for decreasing median concentrations of –0.24 µg/L per year was identified in the Sevier Desert. Within sub-basins, evidence for statistically significant increases in decadal or sub-decadal median arsenic concentrations between 0.01 and 0.48 µg/L per year was identified in the East Shore Area West, Salt Lake Valley Northwest, Salt Lake Valley Southeast, and Utah Valley Northeast (table 5; fig. 17). Evidence for decreasing median concentrations of –0.17 µg/L per year was identified in the Salt Lake Valley Southwest. Overall, the sub-basin trend results highlight areas that drive basinwide trends. The increasing trend in the East Shore Area West drove the basinwide increasing trend. The opposing trends in the Salt Lake Valley (increases in the Northwest and Southeast and a decrease in the Southwest) result in an overall result of no trend basinwide. The increase in Utah Valley Northeast drove the basinwide increasing trend.

Nitrate

Evidence for statistically significant increases between 0.01 and 0.02 mg/L per year in decadal or sub-decadal median nitrate concentrations was identified in the East Shore Area and Salt Lake Valley (table 6; fig. 17). Evidence for decreasing median concentrations between –0.005 and –0.08 mg/L per year was identified in the Beryl-Enterprise Area, Milford Valley, Lower Bear River Basin, Northern Juab Valley, and Utah Valley. Within sub-basins, evidence for statistically significant increases between 0.01 and 0.02 mg/L per year in decadal or sub-decadal median nitrate concentrations was identified in the East Shore Area East and West, and Salt Lake Valley Southeast (table 6; fig. 17). Evidence for decreasing median concentrations of –0.01 mg/L per year was identified in Utah Valley Southeast. The increasing trend in the East Shore Area occurred in both the East and West sub-basins. The increasing trend in the Salt Lake Valley Southeast and the decreasing trend in Utah Valley Southeast drove the respective basinwide trends.

Nitrate trend results are similar to or smaller in magnitude than trends identified elsewhere using similar methods. Significant increases in median nitrate concentrations ranged from 0.01 to 0.02 mg/L per year and concentration decreases ranged from 0.005 to 0.08 mg/L per year. The rate of change for all trends was smaller in magnitude than nitrate trends identified in the Columbia Basin, Washington, where wells with high (greater than 10 mg/L) nitrate concentrations had median slopes of 0.35 and 0.46 mg/L per year (Helsel and Frans, 2006) and on a similar order of magnitude as trends in the Central Valley, California, where increases between 0.005 and 0.06 mg/L per year were detected (Burow and others, 2013). The rates of change are within the ranges of increases and decreases calculated in a range of well networks representing a range of land-use and principal aquifers across the U.S., where between 1988 and 2010 nitrate concentrations increased between less than 0.01 and 0.28 mg/L per year and decreased between –0.42 and –0.01 mg/L per year (Lindsey and Rupert, 2012). For a comparison of trends in the southwestern region in this study, no statistically significant trend was identified in alluvial aquifers in the Upper Colorado River Basin, a significant increasing trend of 0.01 mg/L per year was identified in the Nevada Basin and Range basin-fill aquifers, and no significant trend and a decreasing trend of –0.01 mg/L per year were identified in different parts of the Rio Grande Aquifer System (Lindsey and Rupert, 2012). The period of record varies between these studies, but the comparison is meant to give some general context for the slope of the trend line.

Dissolved Solids

Evidence for statistically significant increases of 1 mg/L per year in decadal or sub-decadal median dissolved-solids concentrations was identified in Cache Valley (table 7; fig. 17). Evidence for decreasing median concentrations between –4 and –5 mg/L per year was identified in Milford Valley. The larger differences between NWIS and SDWIS dissolved solids data may make trend identification more difficult, resulting in fewer trends detected.

Within sub-basins, evidence for statistically significant increases between 1 and 7 mg/L per year in decadal or sub-decadal median dissolved-solids concentrations was identified in Cache Valley South, Salt Lake Valley Northeast and Southeast, and Utah Valley Southwest (table 7; fig. 17). Evidence for decreasing median concentrations of between –1 and –3 mg/L per year was identified in the East Shore Area West and Utah Valley Southeast. Although no basinwide trend was identified in the East Shore Area, the western part of the basin had a decreasing trend. Similarly, no trend was identified in the Salt Lake Valley, although the eastern half of the basin had increasing trends. In Utah Valley Southeast and Southwest sub-basins, the opposing signs of trends may account for the lack of overall trend.

Table 5. Arsenic trend test results for National Water Information System and Safe Drinking Water Information System data combined in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: µg/L, micrograms per liter; —, no data; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
Basins										
Beryl-Enterprise Area	1.00	6	9	[1]0.089	0.15	0.60	9	28	0.133	0.15
Cache Valley	–0.67	–4	9	0.308	–0.02	–0.07	–2	63	0.900	–0.01
Cedar City Valley	0.33	2	9	0.734	0.03	0.07	2	63	0.900	0.00
East Shore Area	0.83	5	8	0.149	0.01	0.67	14	43	[1]0.048	0.02
Lower Bear River Basin	—	—	—	—	—	0.43	9	44	0.230	0.13
Milford Valley	0.40	4	17	0.462	0.07	–0.21	–6	65	0.536	–0.19
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	0.80	8	17	[1]0.086	0.05
Parowan Valley	0.83	5	8	0.149	0.13	0.90	9	16	[1]0.043	0.17
Salt Lake Valley	0.20	2	17	0.806	0.03	0.07	2	63	0.900	0.01
Sevier Desert	–0.50	–5	16	0.312	–0.25	–0.58	–21	91	[1]0.036	–0.24
Tooele Valley	–0.50	–3	8	0.470	0.00	–0.53	–8	27	0.181	–0.01
Utah Valley	—	—	—	—	—	0.76	16	43	[1]0.023	0.06
Sub-basins										
Cache Valley N	0.67	4	9	0.308	0.07	0.20	3	28	0.707	0.07
Cache Valley S	–0.17	—	8	1.000	–0.02	–0.18	–5	64	0.618	–0.01
Cedar City Valley N	—	—	—	—	—	0.47	7	28	0.260	0.06
Cedar City Valley S	0.00	0	9	1.000	0.00	–0.19	–4	43	0.649	–0.03
East Shore Area E	0.33	2	9	0.734	0.00	0.10	1	16	1.000	0.00
East Shore Area W	—	—	—	—	—	0.73	11	28	[1]0.060	0.48
Lower Bear River Basin E	—	—	—	—	—	0.20	3	28	0.707	0.28
Lower Bear River Basin W	0.40	4	17	0.462	0.03	0.36	10	65	0.266	0.04
Salt Lake Valley NE	—	—	—	—	—	0.10	1	16	1.000	0.00
Salt Lake Valley NW	1.00	6	9	[1]0.089	0.39	0.00	0	9	1.000	–1.75
Salt Lake Valley SE	—	—	—	—	—	0.80	8	17	[1]0.086	0.01
Salt Lake Valley SW	–0.40	–4	17	0.462	–0.17	–0.61	–17	64	[1]0.046	–0.17
Utah Valley NE	—	—	—	—	—	0.80	8	17	[1]0.086	0.09
Utah Valley NW	—	—	—	—	—	–0.33	–2	9	0.734	–0.11
Utah Valley SE	—	—	—	—	—	–0.33	–5	20	0.367	0.00
Utah Valley SW	0.67	4	9	0.308	0.17	0.18	5	64	0.618	0.06

[1] Significant result.

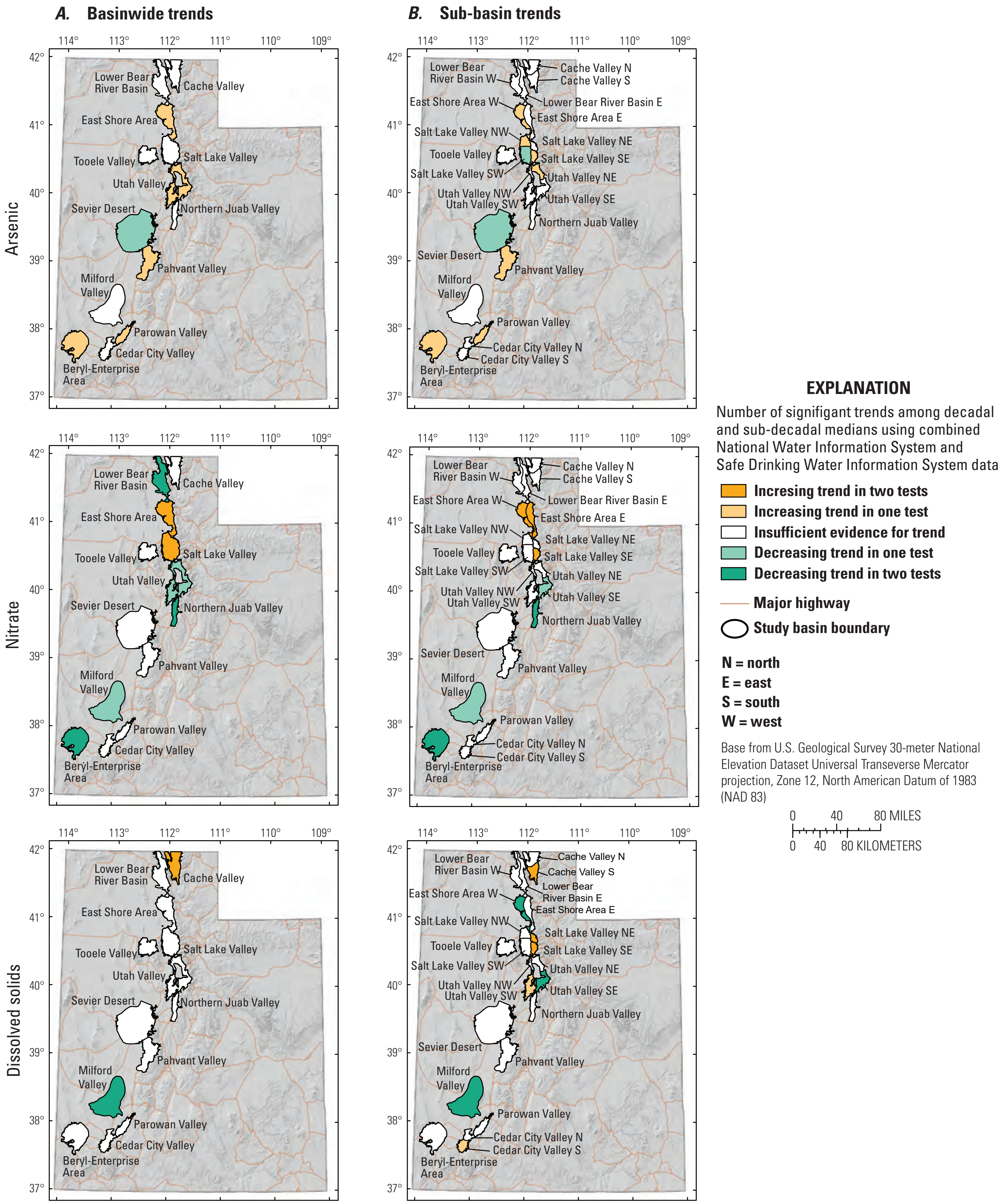


Figure 17. Spatial patterns of trends in arsenic, nitrate, and dissolved solids data from the National Water Information System and the Safe Drinking Water Information System in select basins and sub-basins of Utah.

Table 6. Nitrate trend test results for National Water Information System and Safe Drinking Water Information System data combined in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Basins										
Beryl-Enterprise Area	–1.00	–10	17	[1]0.027	–0.03	–0.72	–26	92	[1]0.009	–0.03
Cache Valley	0.70	7	16	0.130	0.01	0.33	12	92	0.251	0.01
Cedar City Valley	0.20	2	17	0.806	0.00	0.11	4	92	0.754	0.00
East Shore Area	1.00	10	17	[1]0.027	0.02	0.83	30	92	[1]0.002	0.02
Lower Bear River Basin	–0.90	–9	16	[1]0.043	–0.005	–0.47	–17	91	[1]0.093	–0.02
Milford Valley	–0.60	–6	17	0.221	–0.03	–0.50	–18	92	[1]0.076	–0.02
Northern Juab Valley	—	–10	17	[1]0.027	–0.08	–0.67	–24	92	[1]0.016	–0.06
Pahvant Valley	0.40	4	17	0.462	0.02	0.00	0	92	1.000	0.01
Parowan Valley	–0.20	–2	17	0.806	–0.02	–0.39	–14	92	0.175	–0.02
Salt Lake Valley	1.00	10	17	[1]0.027	0.01	0.56	20	90	[1]0.045	0.01
Sevier Desert	0.30	3	16	0.613	0.00	0.44	16	92	0.118	0.01
Tooele Valley	0.50	5	16	0.312	0.02	0.44	16	92	0.118	0.03
Utah Valley	–0.60	–6	17	0.221	–0.01	–0.50	–18	92	[1]0.076	–0.01
Sub-basins										
Cache Valley N	0.20	2	17	0.806	0.03	0.06	2	92	0.917	0.01
Cache Valley S	0.00	0	17	1.000	0.00	0.14	5	91	0.675	0.00
Cedar City Valley N	–0.40	–4	17	0.462	–0.01	–0.22	–8	92	0.466	–0.01
Cedar City Valley S	0.20	2	17	0.806	0.01	0.06	2	92	0.917	0.00
East Shore Area E	1.00	10	17	[1]0.027	0.01	0.72	26	92	[1]0.009	0.01
East Shore Area W	0.80	8	17	[1]0.086	0.02	0.69	25	91	[1]0.012	0.01
Lower Bear River Basin E	0.50	5	16	0.312	0.00	0.31	11	91	0.295	0.00
Lower Bear River Basin W	0.60	6	17	0.221	0.01	0.19	7	91	0.529	0.00
Salt Lake Valley NE	–0.60	–6	17	0.221	–0.02	–0.44	–16	92	0.118	–0.02
Salt Lake Valley NW	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley SE	1.00	10	17	[1]0.027	0.02	0.78	28	92	[1]0.005	0.02
Salt Lake Valley SW	0.60	6	17	0.221	0.01	0.03	1	91	1.000	0.00
Utah Valley NE	0.40	4	17	0.462	0.00	0.28	10	92	0.348	0.00
Utah Valley NW	—	—	—	—	—	0.33	2	9	0.734	0.04
Utah Valley SE	–0.80	–8	17	[1]0.086	–0.01	–0.33	–12	92	0.251	–0.01
Utah Valley SW	0.00	0	17	1.000	0.04	–0.21	–6	65	0.536	–0.04

[1] Significant value.

Table 7. Dissolved solids trend test results for National Water Information System and Safe Drinking Water Information System data combined in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: mg/L, milligrams per liter; —, no data; N, north; S, south; E, east; W, west; NE, northeast; NW, northwest; SE, southeast; SW, southwest]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Basins										
Beryl-Enterprise Area	–0.40	–4	17	0.462	–2	–0.28	–10	92	0.348	–1
Cache Valley	1.00	10	17	[1]0.027	1	0.89	32	92	[1]0.001	1
Cedar City Valley	0.60	6	17	0.221	2	0.25	9	88	0.395	3
East Shore Area	0.00	0	17	1.000	0	–0.17	–6	92	0.602	0
Lower Bear River Basin	–0.20	–2	17	0.806	–1	0.00	0	92	1.000	0
Milford Valley	–0.80	–8	17	[1]0.086	–5	–0.67	–24	92	[1]0.016	–4
Northern Juab Valley	–0.20	–2	17	0.806	–3	–0.43	–12	65	0.174	–6
Pahvant Valley	–0.40	–4	17	0.462	–2	–0.39	–14	92	0.175	–4
Parowan Valley	–0.40	–4	17	0.462	–1	–0.17	–6	92	0.602	–1
Salt Lake Valley	0.60	6	17	0.221	3	0.44	16	92	0.118	3
Sevier Desert	0.20	2	17	0.806	1	0.22	8	92	0.466	1
Tooele Valley	0.40	4	17	0.462	2	0.11	4	92	0.754	3
Utah Valley	–0.40	–4	17	0.462	–1	–0.22	–8	92	0.466	0
Sub-basins										
Cache Valley N	–0.10	—	16	1.000	0	–0.21	–6	65	0.536	–1
Cache Valley S	0.80	8	17	[1]0.086	1	0.83	30	92	[1]0.002	1
Cedar City Valley N	0.00	0	17	1.000	0	–0.17	–6	92	0.602	–1
Cedar City Valley S	0.60	6	17	0.221	4	0.56	20	92	[1]0.048	5
East Shore Area E	0.40	4	17	0.462	0	0.25	9	91	0.402	0
East Shore Area W	–1.00	–10	17	[1]0.027	–3	–0.56	–20	92	[1]0.048	–3
Lower Bear River Basin E	0.40	4	17	0.462	1	0.28	10	92	0.348	1
Lower Bear River Basin W	–0.40	–4	17	0.462	–1	–0.11	–4	92	0.754	–2
Salt Lake Valley NE	1.00	10	17	[1]0.027	4	0.67	24	92	[1]0.016	4
Salt Lake Valley NW	–0.40	–4	17	0.462	–34	–0.20	–3	28	0.707	–11
Salt Lake Valley SE	0.80	8	17	[1]0.086	4	0.78	28	92	[1]0.005	3
Salt Lake Valley SW	–0.60	–6	17	0.221	–2	–0.22	–8	92	0.466	–4
Utah Valley NE	0.40	4	17	0.462	1	0.22	8	92	0.466	1
Utah Valley NW	—	—	—	—	—	–0.67	–4	9	0.308	–18
Utah Valley SE	–1.00	–10	17	[1]0.027	–1	–0.50	–18	92	[1]0.076	–1
Utah Valley SW	0.80	8	17	0.086	7	0.21	6	65	0.536	5

[1] Significant value.

Dissolved solids trend results were similar to or smaller in magnitude than trends identified elsewhere using similar methods. Significant increases in dissolved solids median concentrations ranged from 1 to 7 mg/L per year and decreases in concentrations ranged from –1 to –5 mg/L per year. The rates of change were within the ranges of increases and decreases calculated in a range of well networks representing a range of land-use and principal aquifers across the U.S., where between 1988 and 2010 dissolved-solids concentrations increased between 1.3 and 33 mg/L per year and decreased between –1.7 and –7.5 mg/L per year (Lindsey and Rupert, 2012). For a comparison between trends from this study and in the southwestern U.S., a statistically significant increasing trend of 4.4 mg/L per year was identified in alluvial aquifers in the Upper Colorado River Basin, and no significant trends were identified in the Nevada Basin and Range basin-fill aquifers or the Rio Grande Aquifer System (Lindsey and Rupert, 2012). The period of record varies among all these studies, but the comparison is meant to give some general context for the slope of the trend line.

Trends in Arsenic, Nitrate, and Dissolved Solids from Safe Drinking Water Information System Data

Evidence for trends in arsenic, nitrate, and dissolved-solids concentrations was identified using SDWIS data, which represents water from public-supply wells prior to any treatment. Increases in median arsenic concentrations between 0.06 and 0.1 µg/L per year were identified in in Cedar City Valley and Utah Valley (table 8; fig. 18). In Utah Valley, an increasing trend was identified in the northeast sub-basin. An increase of 0.16 µg/L per year also was identified in the Lower Bear River Basin West. In the Salt Lake Valley, median concentrations increased 0.02 µg/L per year in the Southeast sub-basin and decreased –0.17 µg/L per year in the Southwest sub-basin.

Increases in median nitrate concentrations between 0.01 and 0.06 mg/L per year were identified in the Beryl-Enterprise Area, East Shore Area, Salt Lake Valley, and Sevier Desert (table 9; fig. 18). In the East Shore Area, the western sub-basin had an increasing trend. In the Salt Lake Valley, the Southeast sub-basin had an increasing trend, whereas the Northeast sub-basin had a decreasing trend. Decreasing trends between –0.04 and –0.11 mg/L per year were identified in Northern Juab Valley and Pahvant Valley.

Increases in median dissolved-solids concentrations between 0.4 and 5 mg/L per year were identified in Cache Valley, East Shore Area, Milford Valley, and Sevier Desert (table 10; fig. 18). The Cache Valley South sub-basin had an increasing trend. The East Shore Area East sub-basin had increasing trends, whereas the western sub-basin had a decreasing trend. In the Salt Lake Valley and Utah Valley, no overall basin trends were identified. However, an increasing trend was identified in the Salt Lake Valley Southeast sub-basin, consistent with findings by Thiros and Spangler (2010). A decreasing trend was identified in Utah Valley Southeast. Decreases in median dissolved-solids concentrations between –16 and –19 mg/L per year were identified in Northern Juab Valley.

Increasing trends are more commonly identified in SDWIS data than combined NWIS and SDWIS data, particularly for nitrate and dissolved solids. Assuming that SDWIS data represent deeper wells and that increased concentrations are due to human impacts on groundwater, these results indicate that the deeper aquifers within study basins have been impacted by human activities. Generally, shallower aquifers are more susceptible to human activity at land surface, so changes to the deeper aquifers indicate that impacts are substantial.

Table 8. Arsenic trend test results for Safe Drinking Water Information System data in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: µg/L, micrograms per liter; —, no data; N, north; S, south; E, east; W, west; NE, northeast; SE, southeast; SW, southwest; NW, northwest]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
Basins										
Beryl-Enterprise Area	0.67	4	9	0.308	0.11	0.20	2	17	0.806	0.03
Cache Valley	–0.83	–5	8	0.149	–0.02	–0.43	–12	63	0.167	–0.03
Cedar City Valley	1.00	6	9	[1]0.089	0.10	0.54	15	64	[1]0.081	0.06
East Shore Area	0.33	2	9	0.734	0.00	0.10	1	16	1.000	0.00
Lower Bear River Basin	—	—	—	—	—	0.60	9	28	0.133	0.23
Milford Valley	0.40	4	17	0.462	0.10	0.05	1	44	1.000	0.08
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.20	2	17	0.806	0.03	0.07	2	65	0.902	0.02
Sevier Desert	–0.70	–7	16	0.130	–0.21	–0.17	–6	92	0.602	–0.07
Tooele Valley	—	—	—	—	—	–0.67	–4	9	0.308	–0.01
Utah Valley	—	—	—	—	—	0.71	15	42	[1]0.031	0.06
Sub-basins										
Cache Valley N	0.17	1	8	1.000	0.04	0.20	3	28	0.707	0.01
Cache Valley S	–0.33	–2	9	0.734	–0.03	–0.32	–9	64	0.319	–0.02
Cedar City Valley N	—	—	—	—	—	0.47	7	28	0.260	0.06
Cedar City Valley S	0.33	2	9	0.734	0.06	0.00	0	25	1.000	0.00
East Shore Area E	0.33	2	9	0.734	0.00	0.50	3	8	0.470	0.01
East Shore Area W	—	—	—	—	—	0.30	3	16	0.613	0.05
Lower Bear River Basin E	—	—	—	—	—	0.53	8	27	0.181	0.35
Lower Bear River Basin W	0.60	6	17	0.221	0.11	0.64	18	65	[1]0.035	0.16
Salt Lake Valley NE	—	—	—	—	—	0.30	3	16	0.613	0.02
Salt Lake Valley SE	—	—	—	—	—	0.90	9	16	[1]0.043	0.02
Salt Lake Valley SW	–0.40	–4	17	0.462	–0.23	–0.57	–16	65	[1]0.063	–0.17
Utah Valley NE	—	—	—	—	—	0.80	8	17	[1]0.086	0.11
Utah Valley NW	—	—	—	—	—	—	—	—	—	—
Utah Valley SE	—	—	—	—	—	–0.40	–6	25	0.314	–0.01
Utah Valley SW	0.67	4	9	0.308	0.24	0.47	7	28	0.260	0.10

[1] Significant value.

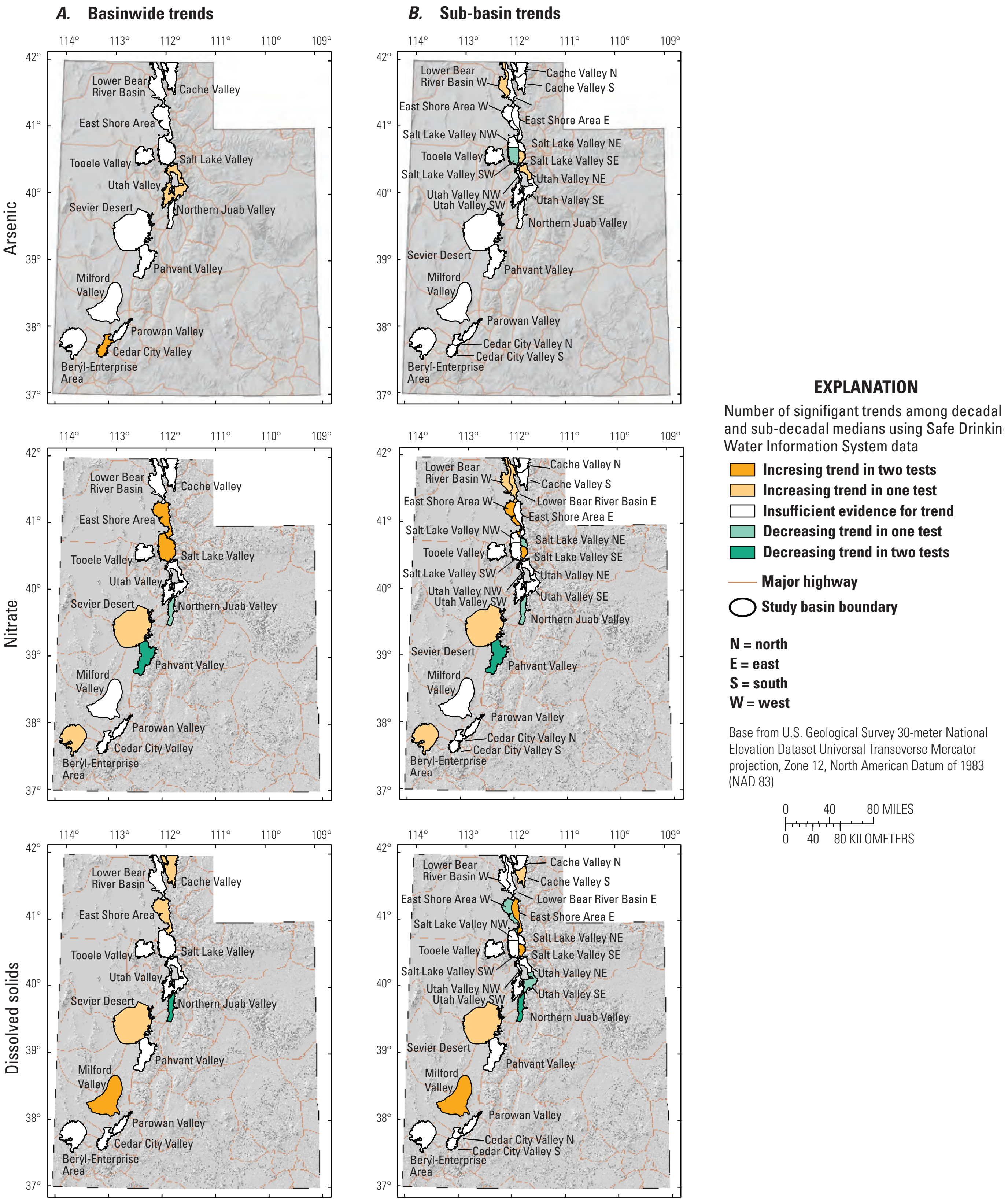


Figure 18. Spatial patterns of trends in arsenic, nitrate, and dissolved solids data from the Safe Drinking Water Information System in select basins and sub-basins of Utah.

Table 9. Nitrate trend test results for Safe Drinking Water Information System data in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; N, north; S, south; E, east; W, west; NE, northeast; SE, southeast; SW, southwest; NW, northwest; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Basins										
Beryl-Enterprise Area	0.67	4	9	0.308	0.05	0.64	18	65	[1]0.035	0.06
Cache Valley	0.60	6	17	0.221	0.02	0.28	10	92	0.348	0.01
Cedar City Valley	0.40	4	17	0.462	0.00	0.33	12	92	0.251	0.01
East Shore Area	0.80	8	17	[1]0.086	0.01	0.56	20	90	[1]0.045	0.01
Lower Bear River Basin	–0.20	–2	17	0.806	0.00	–0.03	—	91	1.000	0.00
Milford Valley	0.67	4	9	0.308	0.01	0.36	10	63	0.258	0.01
Northern Juab Valley	–0.80	–8	17	[1]0.086	–0.04	–0.44	–16	92	0.118	–0.04
Pahvant Valley	–0.80	–8	17	[1]0.086	–0.11	–0.58	–21	91	[1]0.036	–0.10
Parowan Valley	0.67	4	9	0.308	0.01	0.33	2	9	0.734	0.01
Salt Lake Valley	1.00	10	17	[1]0.027	0.01	0.72	26	92	[1]0.009	0.01
Sevier Desert	0.67	4	9	0.308	0.01	0.79	22	65	[1]0.009	0.01
Tooele Valley	0.60	6	17	0.221	0.00	0.39	14	90	0.171	0.01
Utah Valley	–0.20	–2	17	0.806	0.00	–0.11	–4	92	0.754	0.00
Sub-basins										
Cache Valley N	0.20	2	17	0.806	0.03	0.14	5	91	0.675	0.02
Cache Valley S	0.00	0	17	1.000	0.00	0.22	8	92	0.466	0.01
Cedar City Valley N	–0.40	–4	17	0.462	–0.01	–0.25	–9	91	0.402	–0.01
Cedar City Valley S	0.33	2	9	0.734	0.01	0.43	12	65	0.174	0.01
East Shore Area E	0.40	4	17	0.462	0.01	0.44	16	92	0.118	0.01
East Shore Area W	0.80	8	17	[1]0.086	0.01	0.69	25	91	[1]0.012	0.01
Lower Bear River Basin E	0.40	4	17	0.462	0.01	0.47	17	91	[1]0.093	0.01
Lower Bear River Basin W	0.80	8	17	[1]0.086	0.01	0.14	4	65	0.711	0.01
Salt Lake Valley NE	–0.80	–8	17	[1]0.086	–0.01	–0.36	–13	91	0.208	–0.02
Salt Lake Valley SE	1.00	10	17	[1]0.027	0.02	0.78	28	92	[1]0.005	0.02
Salt Lake Valley SW	0.20	2	17	0.806	0.00	0.33	12	92	0.251	0.01
Utah Valley NE	0.60	6	17	0.221	0.01	0.31	11	91	0.295	0.00
Utah Valley NW	—	—	—	—	—	0.33	2	9	0.734	0.05
Utah Valley SE	–0.60	–6	17	0.221	0.00	–0.39	–14	92	0.175	0.00
Utah Valley SW	—	—	—	—	—	0.20	2	17	0.806	0.00

[1] Significant value.

Table 10. Dissolved solids trend test results for Safe Drinking Water Information System data in select basins and sub-basins in Utah between 1975 and 2015.

[Red indicates significant result. **Abbreviations**: mg/L, milligrams per liter; —, no data; N, north; S, south; E, east; W, west; NE, northeast; SE, southeast; SW, southwest; NW, northwest]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Basins										
Beryl-Enterprise Area	0.33	2	9	0.734	1	0.29	6	43	0.448	1
Cache Valley	0.40	4	17	0.462	0	0.50	18	92	[1]0.076	1
Cedar City Valley	0.60	6	17	0.221	3	0.33	12	92	0.251	2
East Shore Area	0.70	7	16	0.130	1	0.57	16	61	[1]0.054	0.4
Lower Bear River Basin	0.00	0	17	1.000	0	0.17	6	92	0.602	1
Milford Valley	1.00	10	17	[1]0.027	5	0.61	22	92	[1]0.029	5
Northern Juab Valley	–0.80	–8	17	[1]0.086	–16	–0.79	–22	65	[1]0.009	–19
Pahvant Valley	0.60	6	17	0.221	8	0.40	4	17	0.462	1
Parowan Valley	—	—	—	—	—	0.33	2	9	0.734	3
Salt Lake Valley	0.60	6	17	0.221	2	0.17	6	92	0.602	2
Sevier Desert	1.00	10	17	[1]0.027	2	0.50	14	65	0.108	2
Tooele Valley	0.00	0	17	1.000	0	0.00	0	65	1.000	0
Utah Valley	–0.30	–3	16	0.613	0	–0.08	–3	91	0.834	–0
Sub-basins										
Cache Valley N	–0.20	–2	17	0.806	0	–0.29	–8	65	0.386	–1
Cache Valley S	0.40	4	17	0.462	1	0.56	20	92	[1]0.048	1
Cedar City Valley N	0.40	4	17	0.462	1	0.17	6	92	0.602	2
Cedar City Valley S	0.33	2	9	0.734	5	0.29	6	43	0.448	4
East Shore Area E	0.80	8	17	[1]0.086	1	0.79	22	65	[1]0.009	1
East Shore Area W	–0.60	–6	17	0.221	–2	–0.57	–16	65	[1]0.063	–3
Lower Bear River Basin E	0.60	6	17	0.221	1	0.33	12	92	0.251	1
Lower Bear River Basin W	0.00	0	17	1.000	–1	0.05	1	44	1.000	1
Salt Lake Valley NE	0.60	6	17	0.221	3	0.39	14	92	0.175	2
Salt Lake Valley SE	0.80	8	17	0.086	3	0.83	30	92	[1]0.002	3
Salt Lake Valley SW	–0.60	–6	17	0.221	–7	–0.39	–14	92	0.175	–7
Utah Valley NE	0.20	2	17	[1]0.806	0	0.00	0	65	1.000	0
Utah Valley NW	—	—	—	—	—	—	—	—	—	—
Utah Valley SE	–0.60	–6	17	0.221	–1	–0.47	–17	91	[1]0.093	–2
Utah Valley SW	0.00	0	9	1.000	–1	—	—	—	—	—

[1] Significant value.

Linking Trends to Land-Use Change

Broad patterns in land use and land-use change, and related demographic and water-use patterns can be associated with water-quality changes. Although arsenic in groundwater is primarily naturally sourced, humans may influence aquifer geochemical conditions that mediate arsenic concentrations through activities that impact redox conditions and pH (Bexfield and others, 2011). Increasing trends also could be caused by the addition of deeper wells tapping into older groundwater that has had more time to interact with arsenic-bearing rocks in response to growing water demand. Humans can more directly influence arsenic, nitrate, and dissolved solids in groundwater by controlling their sources and practices that mediate loading (water-use practices such as artificial recharge, groundwater pumping, and well depths; Bexfield and others, 2011). Trends in nitrate and dissolved solids indicate that humans, through a range of activities, have impacted groundwater quality over time.

Generally, arsenic trends were not directly linked to land-use change taking place on land immediately surrounding wells. There were not enough data in many basins to do a trend analysis for some land-use change categories. There were fewer data from a fewer number of wells and from a shorter period of time available for each land-use change category in each basin (table 11). The median arsenic concentration over time in each basin for each land-use change category is shown in figure 19.

Basinwide, no significant arsenic trends were identified for wells experiencing any land-use change except a decreasing trend was identified at wells in the Salt Lake Valley where the land use changed from low use to urban (table 12). This decreasing trend may be explained by an increase over time in deeper wells (or samples from deeper wells) seeking cleaner water in response to the increased development or urbanization in areas where groundwater has lower arsenic concentrations. Trends were evaluated in shallow wells (depth less than 200 feet) to test this explanation; however, there were not enough data to identify significant trends in shallow wells experiencing a transition from low use to urban land. In the shallow wells where land use did not change, a significant decreasing trend was identified in the Salt Lake Valley and a significant increasing trend was identified in Utah Valley.

Generally, nitrate trends were not linked to land-use change at wells. There were insufficient data in many basins for many land-use change categories to do a trend test (table 13). The median concentration over time in each basin for each land-use change category is shown in figure 20. Nitrate trends were associated with land-use changes at wells in a few basins (table 14). For example, significant increasing trends were identified in the Cache Valley wells where land had changed from urban to production, presumably resulting from increased fertilizer application associated with agricultural production. However, in Cedar City, a significant positive trend in nitrate was identified among wells experiencing a transition from production to urban. This trend may be related to the timing and nature of the transition to urban land. Nitrate may have accumulated in aquifers from a history of production (fertilizer and manure associated with agriculture and livestock), leading to a positive trend that has been augmented by widespread use of septic systems accompanying development. Construction of sewer systems in and around Enoch began in 1994, although many households use septic systems as their primary means of wastewater disposal (Lowe and Wallace, 2001). Cedar City Valley also has naturally high nitrate concentrations (Lowe and Wallace, 2001). The percentage of land in each basin that has been converted from urban to production also is very low and so the results should be interpreted with caution. Significant increasing and decreasing nitrate trends were identified for wells where land use did not change.

When considering broader land-use change across a basin and the impacts on groundwater-quality trends, the results showing nitrate increases in more urban basins including the Salt Lake Valley and East Shore Area and decreases in other basins with more agricultural production may be counterintuitive. However, it is possible that the impacts of urbanization may have substantial effects on nitrate in groundwater through activities such as overfertilization of urban vegetation (for example, lawns and golf courses) or additional sources of nitrate including vehicles and industrial processes. In a nationwide study of decadal-scale changes in groundwater quality, Lindsey and Rupert (2012) reported a higher percentage of significant increases in nitrate concentrations in urban areas than agricultural areas, although they also reported large increases in nitrate concentrations in agricultural areas. Although agricultural activities are generally considered more important sources of nitrogen to hydrologic systems, the impacts of urban activities can be substantial as well. Further, if nitrate loading from agriculture has not changed substantially, nitrate concentrations would not be impacted.

Generally, dissolved solids trends were not linked to land-use change at wells. There were insufficient data in many basins for many land-use change categories to do a trend test (table 15). Among the different land-use change categories, the “no change” category has the most wells and samples. The median dissolved-solids concentration over time in each basin for each land-use change category is shown in figure 21.

Table 11. Number of wells; period of record; number of arsenic measurements; and minimum, maximum, and median arsenic concentration in each basin for each land-use change category.

[µg/L, micrograms per liter; —, no data]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (µg/L)	Maximum concentration (µg/L)	Median concentration (µg/L)
All wells									
Production to low use									
Beryl-Enterprise Area	1	2013	2013	1	0	0	2.8	2.8	—
Milford Valley	1	2011	2011	1	0	0	3.8	3.8	—
Sevier Desert	1	1979	1986	3	0	0	590	730	610
Urban to production									
Cache Valley	1	1989	2013	7	3	43	0.5	5	0.9
East Shore Area	1	1991	1991	1	1	100	5	5	—
Salt Lake Valley	3	1993	2009	10	0	0	5	21	14
Tooele Valley	1	2000	2000	1	0	0	1	1	—
Utah Valley	1	2003	2003	1	0	0	0.4	0.4	—
No change									
Beryl-Enterprise Area	21	1978	2015	81	10	12	0.04	95.7	4
Cache Valley	60	1975	2015	234	88	38	0.02	42.4	0.9
Cedar City Valley	40	1978	2015	144	38	26	0.1	15.7	2
East Shore Area	128	1976	2015	482	275	57	0.1	50	0.7
Lower Bear River Basin	77	1978	2015	342	108	32	0.1	106	2
Milford Valley	42	1978	2015	175	6	3	1	39	6.6
Northern Juab Valley	19	1978	2015	59	27	46	0.23	10	0.7
Pahvant Valley	59	1978	2015	111	17	15	0.21	19	2
Parowan Valley	15	1978	2015	48	6	13	0.5	11.3	3.8
Salt Lake Valley	332	1975	2015	1,443	421	29	0.005	360	1.7
Sevier Desert	74	1978	2015	209	20	10	0.08	730	7.5
Tooele Valley	101	1977	2015	348	80	23	0.005	206	1.6
Utah Valley	137	1977	2015	519	224	43	0.1	53	1
Production to urban									
Cache Valley	9	1979	2013	32	20	63	0.46	10	0.6
Cedar City Valley	1	1997	2014	6	4	67	0.5	5	—
East Shore Area	21	1978	2013	61	30	49	0.5	44	1
Lower Bear River Basin	1	1998	1998	1	0	0	95	95	—
Salt Lake Valley	51	1977	2015	206	54	26	0.3	99	4.4
Sevier Desert	1	1978	2008	11	0	0	10	28	12.2
Tooele Valley	7	1981	2013	24	4	17	0.6	7	2
Utah Valley	26	1978	2015	81	35	43	0.1	72.9	1
Low use to production									
Beryl-Enterprise Area	1	1987	2013	8	5	63	1	10	1
Cache Valley	4	1978	2015	20	5	25	0.5	17.3	5.6
Northern Juab Valley	2	2005	2012	4	0	0	0.19	1.3	—
Pahvant Valley	2	1985	2015	4	0	0	4	6.7	5.9
Parowan Valley	2	2007	2013	5	0	0	2.3	6	2.4
Salt Lake Valley	8	1978	2015	76	9	12	0.005	275	7
Sevier Desert	1	1980	2015	6	0	0	1.8	3	1.9

Table 11. Number of wells; period of record; number of arsenic measurements; and minimum, maximum, and median arsenic concentration in each basin for each land-use change category.—Continued

[µg/L, micrograms per liter; —, no data]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (µg/L)	Maximum concentration (µg/L)	Median concentration (µg/L)
All wells—Continued									
Low use to production—Continued									
Tooele Valley	1	1997	2013	5	1	20	1	5	1.4
Utah Valley	10	1998	2015	22	1	5	0.5	18	2.6
Low use to urban									
Cedar City Valley	17	1979	2015	62	28	45	0.5	10	2
Lower Bear River Basin	2	1978	2010	13	8	62	0.5	7	0.6
Salt Lake Valley	18	1980	2015	79	15	19	0.5	155	6.5
Sevier Desert	1	2009	2013	2	0	0	12.4	14.3	—
Tooele Valley	15	1978	2013	43	23	53	0.2	10	0.6
Utah Valley	21	1978	2013	81	26	32	0.5	50	2
Wells less than 200 feet deep									
Urban to production									
Salt Lake Valley	2	1998	2008	3	0	0	5	11.3	5.1
No change									
Beryl-Enterprise Area	2	2005	2011	9	0	0	0.05	9.5	3.3
Cache Valley	9	1983	2015	26	9	35	0.55	13.1	0.7
Cedar City Valley	1	2007	2007	1	0	0	0.57	0.57	—
East Shore Area	10	1978	2015	33	15	45	0.5	22.8	1.3
Lower Bear River Basin	9	1985	2014	22	7	32	0.5	10	1.7
Milford Valley	2	2012	2015	2	0	0	2.9	20.5	—
Pahvant Valley	14	1985	2015	24	1	4	1	19	8.1
Parowan Valley	1	2005	2014	4	0	0	5.3	6.6	5.8
Salt Lake Valley	45	1980	2015	88	19	22	0.5	360	2.1
Sevier Desert	17	1979	2015	22	0	0	3.9	700	7.1
Tooele Valley	20	1991	2014	37	2	5	0.3	5.8	1.7
Utah Valley	19	1978	2015	35	1	3	0.5	12	1.8
Production to urban									
East Shore Area	1	1981	2008	8	8	100	0.5	5	—
Lower Bear River Basin	1	1998	1998	1	0	0	95	95	—
Salt Lake Valley	9	1981	2008	35	3	9	1	99	21
Tooele Valley	1	2000	2003	4	0	0	4.9	7	5.6
Utah Valley	1	2014	2014	1	0	0	5.9	5.9	—
Low use to production									
Cache Valley	1	2005	2015	10	0	0	5.6	8.2	6
Salt Lake Valley	4	1978	2015	18	2	11	1	275	6.4
Utah Valley	1	2008	2013	3	0	0	1	1.1	1
Low use to urban									
Salt Lake Valley	3	1991	2008	6	0	0	5	155	11.1
Tooele Valley	6	2001	2001	6	0	0	0.2	1.8	0.8
Utah Valley	4	1981	2005	12	7	58	0.5	5	0.6

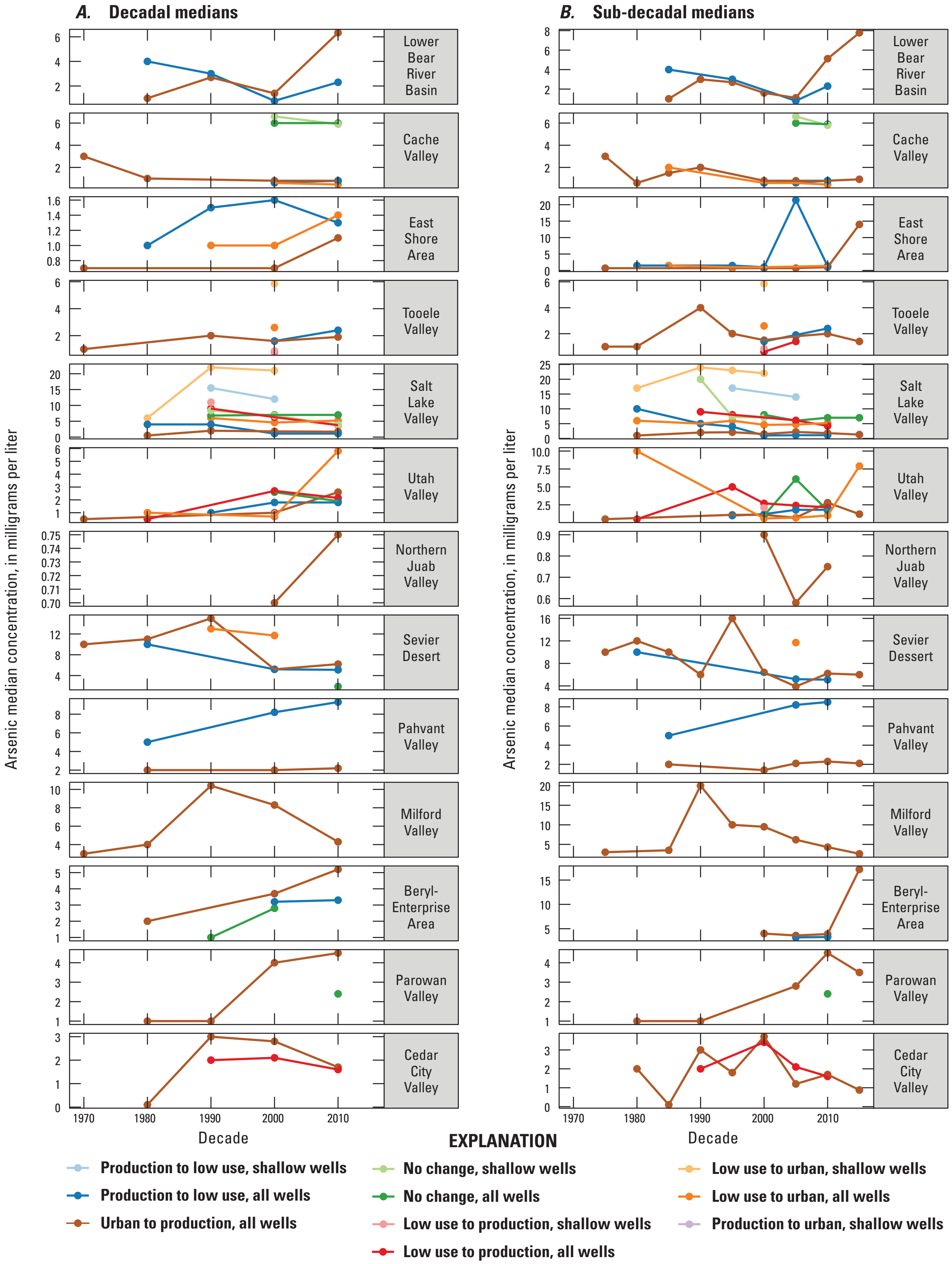


Figure 19. Decadal and sub-decadal median arsenic concentration in select *A*, basins and *B*, sub-basins by land-use change category in Utah.

Table 12. Trend test results for arsenic in basins for each land-use change category.

[Red indicates significant result. **Abbrebiations**: µg/L, micrograms per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
All wells										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	—	—	—	—	—	0.33	2	9	0.734	0.47
Cache Valley	–0.83	–5	8	0.149	–0.03	–0.18	–5	62	0.610	–0.02
Cedar City Valley	0.00	0	9	1.000	0.02	–0.21	–6	65	0.536	–0.02
East Shore Area	—	—	—	—	—	0.33	5	26	0.436	0.02
Lower Bear River Basin	0.67	4	9	0.308	0.17	0.43	9	44	0.230	0.16
Milford Valley	0.40	4	17	0.462	0.07	–0.21	–6	65	0.536	–0.22
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	0.40	4	17	0.462	0.01
Parowan Valley	0.83	5	8	0.149	0.13	0.70	7	16	0.130	0.09
Salt Lake Valley	0.00	0	9	1.000	0.02	0.05	1	44	1.000	0.01

Table 12. Trend test results for arsenic in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbrebiations**: µg/L, micrograms per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
All wells—Continued										
No change—Continued										
Sevier Desert	–0.20	–2	17	0.806	–0.13	–0.44	–16	90	0.114	–0.14
Tooele Valley	0.33	2	9	0.734	0.02	0.14	4	63	0.706	0.01
Utah Valley	—	—	—	—	—	0.60	9	28	0.133	0.02
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	–0.83	–5	8	0.149	–0.04
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	–0.17	—	8	1.000	0.00
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	–0.27	–4	27	0.566	–0.03
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	0.20	2	17	0.806	0.03
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	–0.17	—	8	1.000	–0.03
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	–0.33	–2	9	0.734	–0.06
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—

Table 12. Trend test results for arsenic in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbrebiations**: µg/L, micrograms per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
All wells—Continued										
Low use to urban—Continued										
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	–1.00	–10	17	[1]0.027	–0.20
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	–0.20	–2	17	0.806	–0.05
Wells less than 200 feet deep										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—

Table 12. Trend test results for arsenic in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbrebiations**: µg/L, micrograms per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
Wells less than 200 feet deep—Continued										
No change—Continued										
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	0.33	2	9	0.734	0.01	–0.10	—	16	1.000	0.00
Lower Bear River Basin	–0.67	–4	9	0.308	–0.08	–0.67	–4	9	0.308	–0.08
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	–0.67	–4	7	0.245	–0.12	–0.67	–10	27	[1]0.085	–0.29
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	1.00	6	9	[1]0.089	0.06
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0.00	0	9	1.000	0.03
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0.30	3	16	0.613	3.58
Sevier Desert	—	—	—	—	—	—	—	—	—	—

Table 12. Trend test results for arsenic in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbrebiations**: µg/L, micrograms per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (µg/L per year)	Tau	Score	Score variance	p-value	Slope (µg/L per year)
Wells less than 200 feet deep—Continued										
Low use to production—Continued										
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—

[1] Significant value.

Table 13. Number of wells; period of record; number of nitrate measurements; and minimum, maximum, and median nitrate concentration in each basin for each land-use change category.

[mg/L, miligrams per liter; —, no data]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells									
Production to low use									
Beryl-Enterprise Area	1	2013	2013	1	0	0	1.41	1.41	—
Cedar City Valley	2	1999	1999	2	0	0	0.25	0.39	—
Milford Valley	2	1975	2011	3	0	0	0.77	1.3	1.1
Parowan Valley	1	2013	2013	1	0	0	1.55	1.55	—
Sevier Desert	1	1981	1981	1	0	0	0.02	0.02	—
Tooele Valley	1	1999	1999	4	0	0	0.92	1.71	1.1
Urban to production									
Cache Valley	2	1989	2015	30	0	0	0.77	8.84	5.8
East Shore Area	3	1980	1991	3	0	0	0.6	1.5	0.73
Salt Lake Valley	3	1993	2009	62	1	2	0.2	7.6	4.2
Tooele Valley	1	2000	2000	1	0	0	0.83	0.83	—
Utah Valley	2	1981	2003	2	0	0	2.45	2.5	—

Table 13. Number of wells; period of record; number of nitrate measurements; and minimum, maximum, and median nitrate concentration in each basin for each land-use change category.—Continued

[mg/L, miligrams per liter; —, no data]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells—Continued									
No change									
Beryl-Enterprise Area	33	1975	2015	288	2	1	0.04	10	1.9
Cache Valley	79	1975	2015	636	34	5	0.01	18.85	1.3
Cedar City Valley	71	1975	2015	434	12	3	0.02	13.3	0.9
East Shore Area	175	1975	2015	1,521	182	12	0.01	18	1.1
Lower Bear River Basin	93	1975	2015	764	43	6	0.001	27.9	1
Milford Valley	53	1975	2015	374	23	6	0.01	40.3	0.75
Northern Juab Valley	38	1975	2015	195	1	1	0.01	42	3.15
Pahvant Valley	75	1975	2015	354	4	1	0.02	43.3	3.2
Parowan Valley	41	1975	2015	148	20	14	0.01	6.38	1.01
Salt Lake Valley	396	1975	2015	3,240	230	7	0.01	86	1.34
Sevier Desert	83	1975	2015	379	78	21	1.00E–06	22	0.36
Tooele Valley	188	1975	2015	841	12	1	0.02	36.9	1.83
Utah Valley	200	1975	2015	1,732	128	7	9.00E–04	46	0.85
Production to urban									
Cache Valley	11	1977	2015	110	3	3	0.05	8.9	0.8
Cedar City Valley	4	1995	2015	22	0	0	0.93	4.83	3.66
East Shore Area	33	1975	2015	206	29	14	0.01	3	0.45
Lower Bear River Basin	1	1998	1998	1	1	100	0.05	0.05	—
Salt Lake Valley	63	1976	2015	370	7	2	0.03	25	2.42
Sevier Desert	1	1978	2011	16	0	0	0.04	1.1	0.3
Tooele Valley	8	1981	2015	66	0	0	0.3	6.36	2.3
Utah Valley	53	1977	2015	315	12	4	0.01	15.4	1.63
Low use to production									
Beryl-Enterprise Area	1	1987	2015	17	0	0	2.06	5.8	3.81
Cache Valley	4	1976	2015	41	4	10	0.04	4.26	0.25
Cedar City Valley	3	1999	2000	3	0	0	0.521	3.28	2.45
Northern Juab Valley	2	1975	2012	13	0	0	1.68	6.4	5.3
Pahvant Valley	3	1979	2015	9	0	0	4.6	16	6.1
Parowan Valley	2	1979	2013	11	0	0	1.7	2.21	2
Salt Lake Valley	6	1978	2015	110	3	3	0.1	2.2	1
Sevier Desert	1	1976	2015	13	0	0	6	16	11.1
Tooele Valley	7	1994	2013	15	0	0	0.2	3.5	0.4
Utah Valley	15	1975	2015	49	2	4	0.1	32.5	1.6
Low use to urban									
Cache Valley	1	1991	1991	1	0	0	0.01	0.01	—
Cedar City Valley	27	1977	2015	259	3	1	0.035	19.5	1.1
East Shore Area	1	1984	1984	1	1	100	0.1	0.1	—
Lower Bear River Basin	2	1978	2015	44	1	2	0.01	3.5	1.65
Salt Lake Valley	18	1976	2015	152	21	14	0.01	9.16	1.3

Table 13. Number of wells; period of record; number of nitrate measurements; and minimum, maximum, and median nitrate concentration in each basin for each land-use change category.—Continued

[mg/L, miligrams per liter; —, no data]

Basin	Number of we lls	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells—Continued									
Low use to urban—Continued									
Sevier Desert	1	1998	2013	3	1	33	0.1	0.3	—
Tooele Valley	18	1977	2015	105	0	0	0.2	4.6	0.9
Utah Valley	27	1976	2015	246	11	4	0.01	23.14	0.4
Wells less than 200 feet deep									
Production to low use									
Tooele Valley	1	1999	1999	4	0	0	0.92	1.71	1.1
Urban to production									
Salt Lake Valley	2	1998	2008	3	0	0	2.74	3.47	3.06
No change									
Beryl-Enterprise Area	5	1975	2011	67	0	0	0.04	10	2.1
Cache Valley	13	1977	2015	55	6	11	0.02	6.66	0.9
Cedar City Valley	8	1977	2013	13	0	0	0.15	5.46	1.04
East Shore Area	14	1978	2014	55	10	18	0.01	18	0.7
Lower Bear River Basin	12	1979	2015	72	11	15	0.01	27.9	0.7
Milford Valley	3	1975	2015	16	0	0	0.597	5.69	1.1
Northern Juab Valley	6	1976	1998	16	0	0	1.1	9.3	2
Pahvant Valley	15	1975	2015	59	2	3	0.1	9.1	2.42
Parowan Valley	1	1986	2014	9	0	0	0.567	2.4	1.82
Salt Lake Valley	65	1976	2015	221	22	10	0.01	86	1.32
Sevier Desert	20	1977	2015	30	0	0	0.01	4.8	0.65
Tooele Valley	49	1979	2015	87	3	3	0.02	31	1.4
Utah Valley	30	1978	2015	61	18	30	0.02	6.19	0.8
Production to urban									
East Shore Area	4	1978	2015	32	2	6	0.1	2.6	0.53
Lower Bear River Basin	1	1998	1998	1	1	100	0.05	0.05	—
Salt Lake Valley	14	1977	2008	43	1	2	0.1	25	1.22
Tooele Valley	1	1999	2003	5	0	0	4.29	4.93	4.46
Utah Valley	5	1980	1981	5	0	0	0.14	3.1	1.5
Low use to production									
Cache Valley	1	1979	2015	19	1	5	0.1	0.26	0.133
Cedar City Valley	1	1999	1999	1	0	0	3.28	3.28	—
Salt Lake Valley	3	1978	2014	40	1	3	0.1	1.8	0.95
Tooele Valley	3	1994	1994	3	0	0	0.54	3.5	2.2
Utah Valley	1	2008	2013	3	0	0	1.88	1.94	1.88
Low use to urban									
Cedar City Valley	1	1999	1999	1	0	0	8.98	8.98	—
Salt Lake Valley	2	1993	2008	15	0	0	0.355	2	0.5
Tooele Valley	6	2001	2001	6	0	0	0.68	1.03	0.83
Utah Valley	7	1981	2008	31	6	19	0.05	1.8	0.2

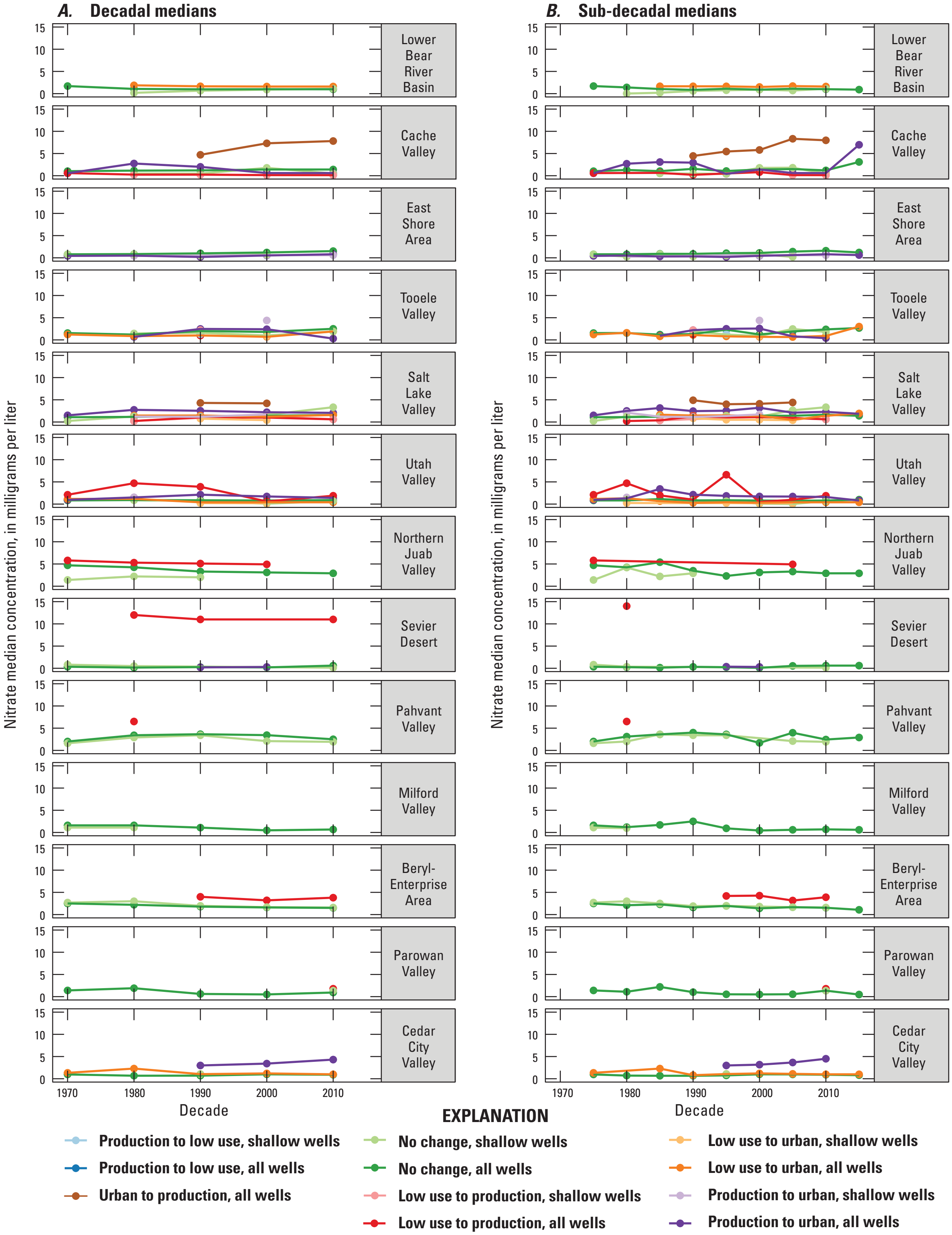


Figure 20. Decadal and sub-decadal median nitrate concentration in select *A*, basins and *B*, sub-basins by land-use change category in Utah.

Table 14. Trend test results for nitrate in basins for each land-use change category.

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	0.8	8	17	[1]0.086	0.19
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0	0	9	1.000	–0.01
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	–1.00	–10	17	[1]0.027	–0.03	–0.72	–26	92	[1]0.009	–0.03
Cache Valley	0.90	9	16	[1]0.043	0.01	0.50	18	92	[1]0.076	0.02
Cedar City Valley	0.20	2	17	0.806	0.00	0.19	7	91	0.529	0.00
East Shore Area	1.00	10	17	[1]0.027	0.02	0.83	30	92	[1]0.002	0.01
Lower Bear River Basin	–0.80	–8	17	[1]0.086	–0.01	–0.47	–17	91	[1]0.093	–0.01
Milford Valley	–0.70	–7	16	0.130	–0.03	–0.50	–18	92	[1]0.076	–0.03
Northern Juab Valley	–1.00	–10	17	[1]0.027	–0.05	–0.58	–21	91	[1]0.036	–0.05
Pahvant Valley	0.20	2	17	0.806	0.01	0.06	2	92	0.917	0.01
Parowan Valley	–0.40	–4	17	0.462	–0.02	–0.50	–18	92	[1]0.076	–0.02
Salt Lake Valley	1.00	10	17	[1]0.027	0.01	0.64	23	91	[1]0.021	0.01

Table 14. Trend test results for nitrate in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells—Continued										
No change—Continued										
Sevier Desert	0.20	2	17	0.806	0.00	0.31	11	91	0.295	0.01
Tooele Valley	0.60	6	17	0.221	0.02	0.50	18	92	[1]0.076	0.03
Utah Valley	0.00	0	17	1.000	0.00	–0.17	–6	90	0.598	0.00
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	–0.20	–2	17	0.806	–0.04	0.08	3	91	0.834	0.00
Cedar City Valley	—	—	—	—	—	1.00	6	9	[1]0.089	0.10
East Shore Area	0.60	6	17	0.221	0.01	0.44	16	92	0.118	0.01
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	–0.20	–2	17	0.806	–0.02	–0.11	–4	92	0.754	–0.01
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	–0.33	–2	9	0.734	–0.01	–0.20	–3	28	0.707	–0.02
Utah Valley	0.20	2	17	0.806	0.01	–0.28	–10	92	0.348	–0.02
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	–0.33	–2	9	0.734	–0.03
Cache Valley	–0.80	–8	17	[1]0.086	–0.01	–0.43	–9	44	0.230	–0.01
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	–1.00	–6	9	[1]0.089	–0.02	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.00	0	9	1.000	0.00	0.14	3	44	0.764	0.01
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	–0.40	–4	17	0.462	–0.07	–0.36	–10	65	0.266	–0.04
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	–0.60	–6	17	0.221	–0.01	–0.43	–12	65	0.174	–0.01
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	–1.00	–6	9	[1]0.089	–0.01	–0.33	–5	28	0.452	0.00
Milford Valley	—	—	—	—	—	—	—	—	—	—

Table 14. Trend test results for nitrate in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells—Continued										
Low use to urban—Continued										
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.33	2	9	0.734	0.00	–0.14	–3	44	0.764	–0.01
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	0.00	0	17	1.000	0.00	–0.19	–7	91	0.529	–0.01
Utah Valley	–0.30	–3	16	0.613	–0.02	–0.39	–14	92	0.175	–0.02
Wells less than 200 feet deep										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	–0.80	–8	17	[1]0.086	–0.03	–0.86	–24	65	[1]0.004	–0.04

Table 14. Trend test results for nitrate in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Wells less than 200 feet deep—Continued										
No change—Continued										
Cache Valley	0.17	1	8	1.000	0.00	0.27	4	27	0.566	0.01
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	–0.33	–2	9	0.734	0.00	–0.14	–3	44	0.764	0.00
Lower Bear River Basin	1.00	6	9	[1]0.089	0.03	0.81	17	44	[1]0.016	0.03
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	0.33	2	9	0.734	0.09
Pahvant Valley	0.00	0	17	1.000	0.00	0.00	0	43	1.000	0.00
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.80	8	17	[1]0.086	0.06	0.64	18	65	[1]0.035	0.07
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	0.33	2	9	0.734	0.02	0.00	0	17	1.000	0.02
Utah Valley	–0.67	–4	9	0.308	–0.01	–0.60	–9	28	0.133	–0.02
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	0.67	4	9	0.308	0.01	0.60	9	28	0.133	0.01
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0.00	0	17	1.000	0.00
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	–1.00	–6	9	[1]0.089	–0.004	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.33	2	9	0.734	0.02	0.33	2	9	0.734	0.03
Sevier Desert	—	—	—	—	—	—	—	—	—	—

Table 14. Trend test results for nitrate in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Wells less than 200 feet deep—Continued										
Low use to production—Continued										
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	–0.83	–5	8	0.149	–0.03
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	–1.00	–6	9	[1]0.089	–0.002

[1] Significant value.

Table 15. Number of wells; period of record; number of dissolved solids measurements; and minimum, maximum, and median dissolved-solids concentration in each basin for each land-use change category.

[mg/L, miligrams per liter; —, no data; NA, not applicable]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells									
Production to low use									
Beryl-Enterprise Area	1	2013	2013	1	0	0	281	281	—
Cedar City Valley	2	1999	1999	2	0	0	343	352	—
Milford Valley	2	1975	2011	3	0	0	436	3,320	3,230
Parowan Valley	1	2013	2013	1	0	0	267	267	—
Sevier Desert	2	1980	1986	3	0	0	378	2,200	1,840
Tooele Valley	3	1978	1999	6	0	0	674	3,360	957
Urban to production									
Cache Valley	2	1989	2013	10	0	0	304	448	358
East Shore Area	7	1980	1991	9	0	0	242	790	515
Salt Lake Valley	4	1980	2009	12	0	0	1,065	1,600	1,320
Tooele Valley	1	2000	2000	1	0	0	438	438	—
Utah Valley	2	1981	2003	2	0	0	260	353	—

Table 15. Number of wells; period of record; number of dissolved solids measurements; and minimum, maximum, and median dissolved-solids concentration in each basin for each land-use change category.—Continued

[mg/L, miligrams per liter; —, no data; NA, not applicable]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells—Continued									
No change									
Beryl-Enterprise Area	34	1975	2015	253	0	0	125	1,950	406
Cache Valley	73	1975	2015	273	0	0	150	1,986	290
Cedar City Valley	69	1975	2015	288	0	0	110	3,070	404
East Shore Area	204	1975	2015	835	0	0	28	4,000	300
Lower Bear River Basin	92	1975	2015	397	0	0	88	2,360	338
Milford Valley	55	1975	2015	367	0	0	156	10,200	456
Northern Juab Valley	38	1975	2015	151	0	0	18	2,940	810
Pahvant Valley	76	1975	2015	330	0	0	10	6,520	961
Parowan Valley	43	1975	2015	122	0	0	135	672	312
Salt Lake Valley	413	1975	2015	2,230	0	0	10	20,900	450
Sevier Desert	92	1975	2015	259	0	0	162	24,300	344
Tooele Valley	206	1975	2015	553	0	0	143	17,000	658
Utah Valley	211	1975	2015	791	0	0	55	2,560	313
Production to urban									
Cache Valley	9	1977	2015	41	0	0	174	535	286
Cedar City Valley	5	1977	2014	10	0	0	285	1,460	880
East Shore Area	36	1975	2013	113	0	0	112	2,460	258
Lower Bear River Basin	1	1998	1998	1	0	0	906	906	—
Salt Lake Valley	64	1976	2015	280	0	0	130	8,550	794
Sevier Desert	1	1978	2008	8	0	0	214	262	224
Tooele Valley	9	1978	2013	44	0	0	234	5,080	848
Utah Valley	55	1977	2015	142	0	0	131	1,390	312
Low use to production									
Beryl-Enterprise Area	1	1987	2013	8	0	0	336	723	430
Cache Valley	4	1977	2015	28	0	0	218	504	258
Cedar City Valley	3	1999	2000	3	0	0	369	1,790	761
Northern Juab Valley	2	1975	2012	14	0	0	299	746	698
Pahvant Valley	3	1979	2015	10	0	0	673	3,140	851
Parowan Valley	2	1979	2013	11	0	0	268	333	278
Salt Lake Valley	9	1978	2015	97	0	0	394	1,150	704
Sevier Desert	1	1976	2015	16	0	0	421	629	555
Tooele Valley	7	1978	2013	10	0	0	300	2,100	358
Utah Valley	14	1975	2015	41	0	0	206	1,230	581
Low use to urban									
Cedar City Valley	25	1977	2015	83	0	0	112	2,510	584
East Shore Area	1	1984	1984	1	0	0	2,960	2,960	—
Lower Bear River Basin	2	1978	2010	16	0	0	212	588	256
Salt Lake Valley	21	1976	2015	100	0	0	269	9,290	620

Table 15. Number of wells; period of record; number of dissolved solids measurements; and minimum, maximum, and median dissolved-solids concentration in each basin for each land-use change category.—Continued

[mg/L, miligrams per liter; —, no data; NA, not applicable]

Basin	Number of wells	Starting year	Ending year	Number of samples	Number of censored samples	Percent censored	Minimum concentration (mg/L)	Maximum concentration (mg/L)	Median concentration (mg/L)
All wells—Continued									
Low use to urban—Continued									
Tooele Valley	20	1977	2013	64	0	0	196	6,460	393
Utah Valley	27	1976	2013	107	0	0	96	1,290	278
Wells less than 200 feet deep									
Production to low use									
Tooele Valley	1	1999	1999	4	0	0	674	1,120	803
Urban to production									
Salt Lake Valley	2	1998	2008	3	0	0	1,140	1,240	1,230
No change									
Beryl-Enterprise Area	5	1975	2011	68	0	0	288	1,160	628
Cache Valley	13	1977	2015	36	0	0	162	539	311
Cedar City Valley	8	1977	2013	13	0	0	248	1,350	363
East Shore Area	17	1978	2015	44	0	0	152	4,000	267
Lower Bear River Basin	12	1977	2014	45	0	0	119	1,630	224
Milford Valley	3	1975	2015	19	0	0	376	1,080	551
Northern Juab Valley	6	1976	1998	18	0	0	399	1,070	629
Pahvant Valley	15	1975	2015	60	0	0	426	6,050	3,550
Parowan Valley	1	1986	2014	10	0	0	248	363	304
Salt Lake Valley	64	1976	2015	164	0	0	57	8,970	699
Sevier Desert	20	1977	2015	32	0	0	246	24,300	377
Tooele Valley	45	1978	2014	71	0	0	264	5,010	945
Utah Valley	33	1978	2015	71	0	0	91	2,560	326
Production to urban									
East Shore Area	4	1978	2008	12	0	0	112	613	172
Lower Bear River Basin	1	1998	1998	1	0	0	906	906	NA
Salt Lake Valley	14	1977	2008	49	0	0	390	2,630	528
Tooele Valley	2	1978	2003	7	0	0	557	1,070	963
Utah Valley	7	1980	2014	7	0	0	230	1,390	341
Low use to production									
Cache Valley	1	1979	2015	19	0	0	218	266	257
Cedar City Valley	1	1999	1999	1	0	0	761	761	NA
Salt Lake Valley	4	1978	2013	31	0	0	415	1,150	560
Tooele Valley	1	1978	1978	1	0	0	2,100	2,100	NA
Utah Valley	1	2008	2013	3	0	0	206	218	208
Low use to urban									
Cedar City Valley	1	1999	1999	1	0	0	735	735	NA
Salt Lake Valley	3	1991	2008	8	0	0	652	4,060	843
Tooele Valley	6	2001	2001	6	0	0	350	1,050	726
Utah Valley	7	1979	2005	29	0	0	114	479	232

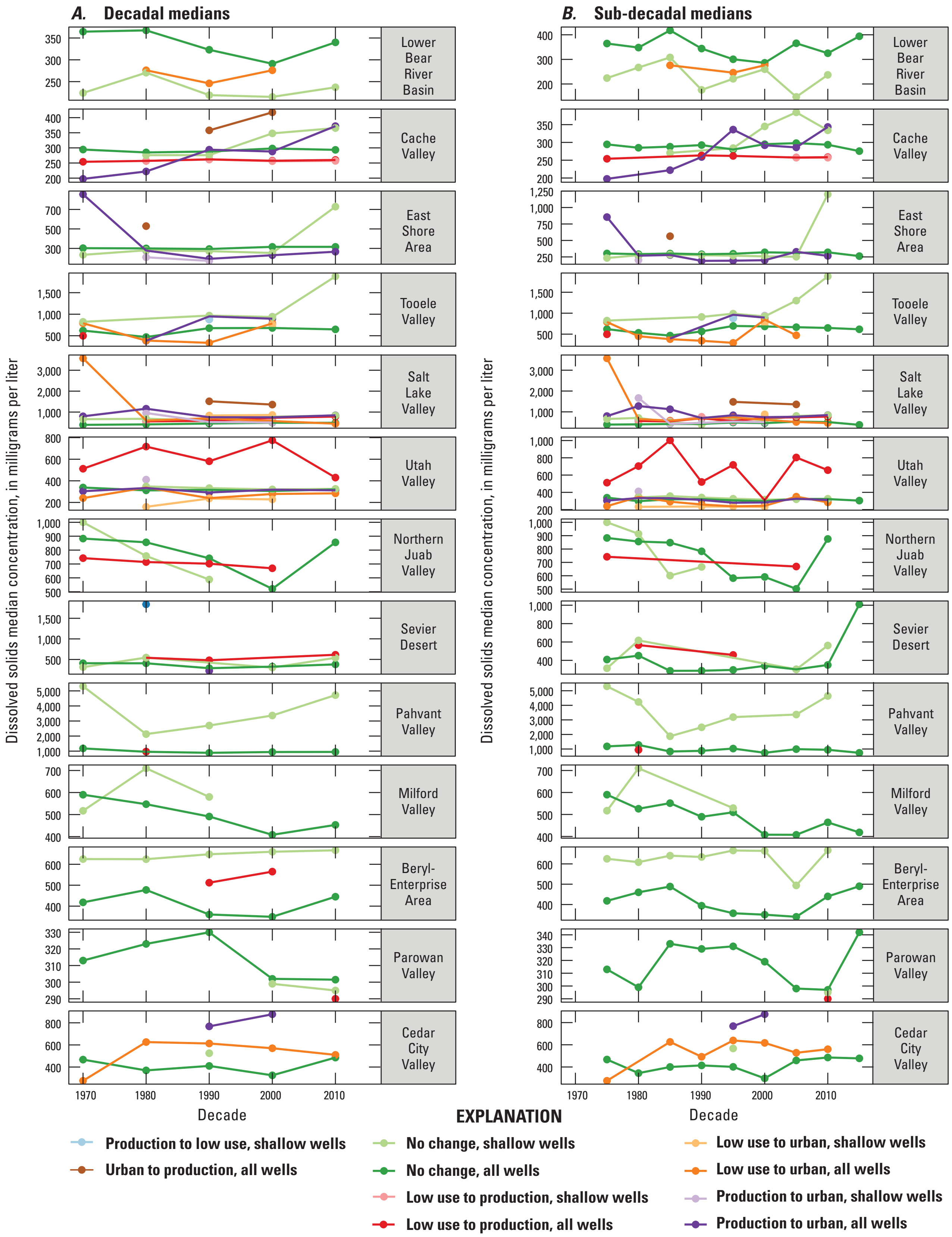


Figure 21. Decadal and sub-decadal median dissolved-solids concentration in select *A*, basins and *B*, sub-basins by land-use change category in Utah.

Dissolved solids trends were generally not associated with land-use change at a well except in a few areas (table 16). Significant increases in dissolved solids concentrations were identified in the Cache Valley wells experiencing a transition from production to urban land, and in the Salt Lake Valley wells experiencing a transition from low use to production. Wells in the Salt Lake Valley experiencing a transition from low use to urban had a significant decreasing trend, although this was not observed in the shallow subset of wells due to insufficient data and so it may be associated with an increase in deeper, cleaner wells to supply urban needs. In a nationwide study of decadal-scale changes in groundwater quality, Lindsey and Rupert (2012) reported more significant increases in dissolved-solids concentrations in urban areas than agricultural areas. Significant decreasing trends also were identified in the Northern Juab Valley wells associated with a transition from low use to production. However, these results represent two wells, which are likely not representative of more widespread water-quality conditions. Significant decreasing trends in Milford Valley and increasing trends in the Salt Lake Valley were identified among wells where land use did not change. Among shallow wells where land use did not change, increasing trends were identified in Beryl-Enterprise Area and Tooele Valley, and a decreasing trend was identified in Utah Valley.

These results highlight the complexity of the relationship between land use and arsenic, nitrate, and dissolved-solids concentrations, and trends that depend on a range of conditions at various spatial and temporal scales. Geologic and geochemical conditions are the most important factors affecting arsenic concentrations in groundwater (Bexfield and others, 2011). Groundwater redox condition, fertilizer application rates, and irrigation practices (Paul and others, 2007) likely all contribute to differences in nitrate concentrations among basins and over time. Fertilizer application rate and sprinkler irrigation have been reported to correlate positively with elevated nitrate concentrations, whereas reducing geochemical conditions have been reported to correlate negatively with elevated nitrate concentrations because of denitrification (Paul and others, 2007). Many of the processes that influence nitrate in groundwater apply to dissolved solids as well, although there are additional processes that control dissolved solids in groundwater. Recharge of surface water containing high dissolved-solids concentrations can increase groundwater concentrations. Surface water can have elevated dissolved solids due to runoff, wastewater discharge, spills, or mining and forestry activities. Groundwater interaction with aquifer material can result in increased dissolved-solids concentrations. For example, concentrations increase along flow paths in Utah Valley and Salt Lake Valley (Anning and others, 2007).

Although arsenic, nitrate, and dissolved solids trends were not generally associated with land-use changes at wells, land use and other human activities are still important drivers of groundwater conditions. Basinwide trends have been detected, despite a relatively small amount of basinwide land-use change. The indirect connection between water quality and land use at wells relates more to the nuanced effects of human activities, which can occur at different spatial and temporal scales, and effects at wells can be affected by travel time lags. Further, land use may not have to change for activity on the land to create impacts to groundwater. For example, building development can increase in an urban area, which may increase dissolved solids in urban runoff that eventually impacts groundwater. The land-use category did not change, but the activity may still impact groundwater. The data available on land-use change does not necessarily capture the distinctions of increased development or population density either.

Table 16. Trend test results for dissolved solids in basins for each land-use change category.

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	–0.20	–2	17	0.806	–1	–0.11	–4	92	0.754	–2
Cache Valley	0.20	2	17	0.806	0	0.00	0	92	1.000	0
Cedar City Valley	0.00	0	17	1.000	–1	0.33	12	92	0.251	3
East Shore Area	0.30	3	16	0.613	0	0.08	3	91	0.834	0
Lower Bear River Basin	–0.40	–4	17	0.462	–1	–0.11	–4	92	0.754	–1
Milford Valley	–0.80	–8	17	[1]0.086	–5	–0.67	–24	92	[1]0.016	–4
Northern Juab Valley	–0.60	–6	17	0.221	–5	–0.50	–14	65	0.108	–10
Pahvant Valley	–0.40	–4	17	0.462	–3	–0.44	–16	92	0.118	–7
Parowan Valley	–0.40	–4	17	0.462	0	–0.06	–2	92	0.917	0
Salt Lake Valley	0.80	8	17	[1]0.086	3	0.44	16	92	0.118	3

Table 16. Trend test results for dissolved solids in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells—Continued										
No change—Continued										
Sevier Desert	–0.40	–4	17	0.462	–1	0.28	10	92	0.348	1
Tooele Valley	0.40	4	17	0.462	1	0.17	6	92	0.602	2
Utah Valley	–0.20	–2	17	0.806	0	–0.08	–3	91	0.834	0
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	0.80	8	17	[1]0.086	4	0.71	15	44	[1]0.035	4
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	–0.40	–4	17	0.462	–5	–0.14	–4	65	0.711	–2
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	–0.20	–2	17	0.806	–1	–0.14	–4	65	0.711	–4
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	0.00	0	17	1.000	0	–0.21	–6	65	0.536	0
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	0.60	6	17	0.221	0	0.00	0	17	1.000	0
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	–6	9	[1]0.089	–2	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	1.00	6	9	[1]0.089	8	0.71	15	44	[1]0.035	7
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	0.00	0	17	1.000	0	0.07	2	65	0.902	1
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	–0.20	–2	17	0.806	–2	0.14	3	44	0.764	2
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—

Table 16. Trend test results for dissolved solids in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
All wells—Continued										
Low use to urban—Continued										
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	–0.80	–8	17	[1]0.086	–13	–0.57	–16	65	[1]0.063	–12
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	–0.33	–2	9	0.734	–3	–0.14	–3	44	0.764	–9
Utah Valley	0.20	2	17	0.806	1	0.07	2	65	0.902	0
Wells less than 200 feet deep										
Production to low use										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Urban to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
No change										
Beryl-Enterprise Area	0.80	8	17	[1]0.086	1	0.36	10	65	0.266	1

Table 16. Trend test results for dissolved solids in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Wells less than 200 feet deep—Continued										
No change—Continued										
Cache Valley	0.83	5	8	0.149	3	0.60	6	17	0.221	4
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	0.40	4	17	0.462	3	0.04	1	64	1.000	0
Lower Bear River Basin	–0.20	–2	17	0.806	0	–0.21	–6	65	0.536	–1
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	–0.67	–4	9	0.308	–24
Pahvant Valley	0.20	2	17	0.806	59	0.05	1	44	1.000	14
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	0.60	6	17	0.221	5	0.36	10	65	0.266	6
Sevier Desert	0.00	0	9	1.000	3	0.00	0	9	1.000	3
Tooele Valley	0.67	4	9	0.308	17	0.87	13	28	[1]0.024	26
Utah Valley	–0.67	–4	9	0.308	–1.00	–0.62	–13	44	[1]0.072	—
Production to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0.00	0	17	1.000	–1
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to production										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	–0.17	–1.00	8	1.000	0	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	0.30	3	16	0.613	4
Sevier Desert	—	—	—	—	—	—	—	—	—	—

Table 16. Trend test results for dissolved solids in basins for each land-use change category.—Continued

[Red indicates significant result. **Abbreviations**: mg/L, miligrams per liter; —, no data]

Basin	Decadal medians					Sub-decadal medians				
	Tau	Score	Score variance	p-value	Slope (mg/L per year)	Tau	Score	Score variance	p-value	Slope (mg/L per year)
Wells less than 200 feet deep—Continued										
Low use to production—Continued										
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	—	—	—	—	—
Low use to urban										
Beryl-Enterprise Area	—	—	—	—	—	—	—	—	—	—
Cache Valley	—	—	—	—	—	—	—	—	—	—
Cedar City Valley	—	—	—	—	—	—	—	—	—	—
East Shore Area	—	—	—	—	—	—	—	—	—	—
Lower Bear River Basin	—	—	—	—	—	—	—	—	—	—
Milford Valley	—	—	—	—	—	—	—	—	—	—
Northern Juab Valley	—	—	—	—	—	—	—	—	—	—
Pahvant Valley	—	—	—	—	—	—	—	—	—	—
Parowan Valley	—	—	—	—	—	—	—	—	—	—
Salt Lake Valley	—	—	—	—	—	—	—	—	—	—
Sevier Desert	—	—	—	—	—	—	—	—	—	—
Tooele Valley	—	—	—	—	—	—	—	—	—	—
Utah Valley	—	—	—	—	—	–0.17	–1.00	8	1.000	0

[1] Significant value.

Trends Across Analytes and Land-Use Change

Trends across multiple analytes can indicate basinwide changes to the hydrologic system. In comparing the total number of trends (using decadal and sub-decadal medians from combined NWIS and SDWIS data) in each basin across analytes, the water quality in several basins has changed more (fig. 22*A*). Basins with three significant trends across all analytes include the Beryl-Enterprise Area, East Shore Area, and Milford Valley. In the Beryl-Enterprise Area, concentrations of arsenic increased, whereas concentrations of nitrate decreased. In the East Shore Area, concentrations of arsenic and nitrate increased. In Milford Valley, concentrations of nitrate and dissolved solids decreased. Cache Valley, Lower Bear River Basin, Northern Juab Valley, and Salt Lake Valley each had two significant trends, although they were for a single analyte in each basin. This gives increased confidence in the trend result for the particular analyte but does not indicate that trends in other constituents are linked. Utah Valley had two trends across two analytes. The other basins had between zero and one significant arsenic trend.

The East Shore Area, Cache Valley, and Salt Lake Valley had the most increasing trends. The number of increasing trends in a basin can be related to basinwide land use and land-use change patterns, although land-use change is relatively limited. Change occurring in more than 20 percent of a basin area only occurred in the Salt Lake Valley (25 percent), Utah Valley (24 percent), and East Shore Area (20 percent). In basins with the most land-use change, the highest percentage of land changed from production to urban. The total number of increasing trends were correlated with transitions from production to urban land (Pearson correlation coefficient equals 0.77, p-value equals 0.04). However, the limited area of land-use change in many basins reduces confidence in results. Some basins that experienced the most increasing trends such as the East Shore Area and Salt Lake Valley also are where most of the state's population lives and where much of the population growth has occurred. These basins also had substantial areas of agriculture, which may account for the increasing nitrate trends in these basins. The absence of trends in some analytes in some basins may be related to the small amount of land-use change in those basins. For example, there was no nitrate trend in Cache Valley, where about 4 percent of the land had been converted from production to urban and another 4 percent had been converted from low use to production, and effectively replaced the production land lost to urban land. Land use, land-use change, and population all influence water-use practices as well, which can impact water and solute movement through the subsurface.

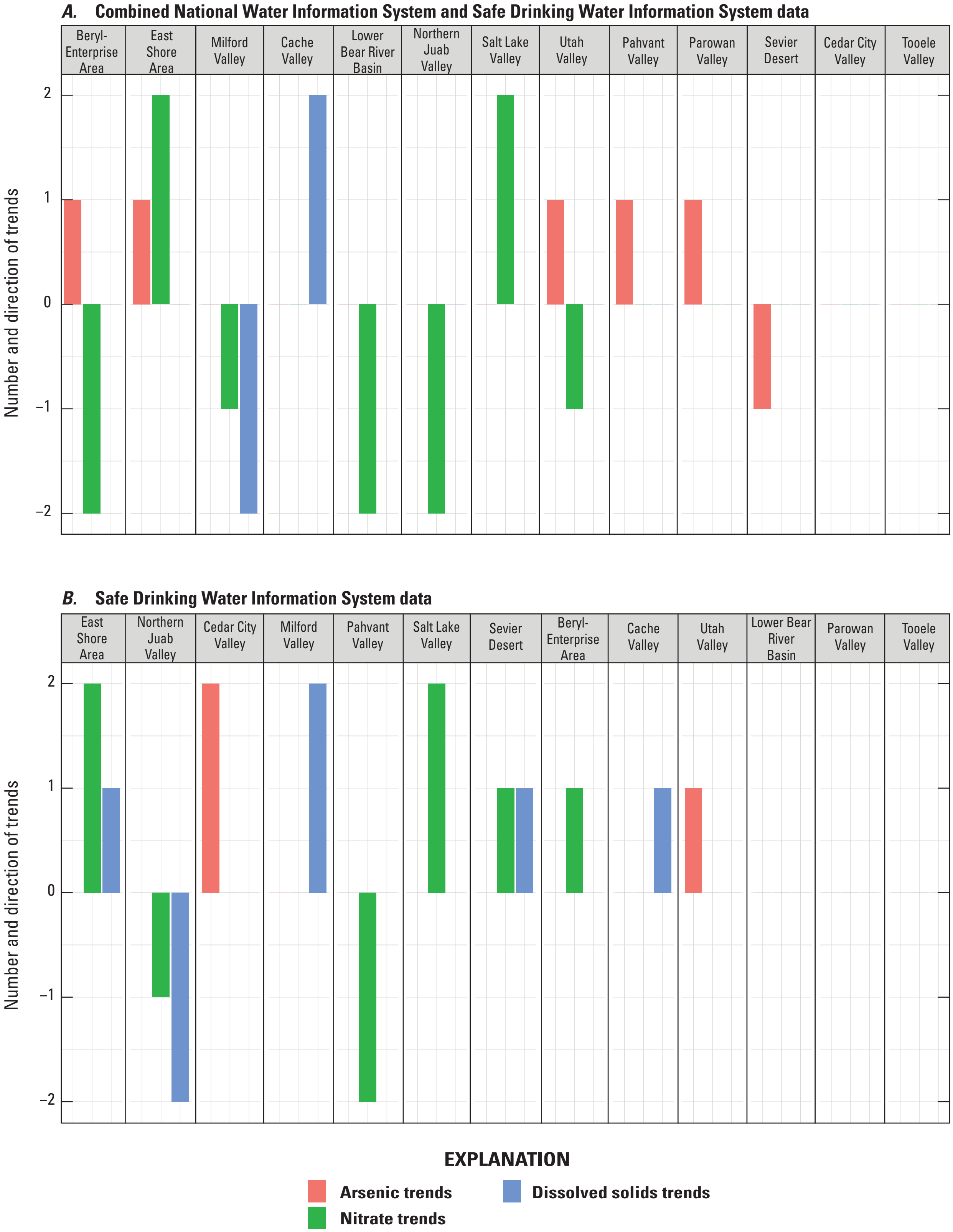


Figure 22. Number and direction of trends for each analyte in each basin for the *A*, National Water Information System and Safe Drinking Water Information System data combined and the *B*, Safe Drinking Water Information System data.

The activity within a basin appears to determine the number and direction of trends more than geographic location, which favors human drivers of trends over natural drivers. Basins proximal to each other with similar geologic conditions, such as the East Shore Area and Lower Bear River Basin had substantially different trend behavior. These basins have similar geologic histories and climate conditions (Bjorklund and McGreevy, 1974; Clark and others, 1990). Both basins lie adjacent to the Great Salt Lake and formed through normal faulting along the Wasatch Fault. Subsequent erosion of the uplifted mountains deposited sediment in the basins and rising and falling of Lake Bonneville further modified sediment deposition and erosion as well as groundwater quality. These basins have a similar temperate and arid climate and similar amounts of precipitations and temperatures. Precipitation in both basins increases significantly in the mountains, which feeds streams and groundwater recharge. Despite these similarities, increasing trends in arsenic and nitrate occurred in the East Shore Area, whereas nitrate decreased in the Lower Bear River Basin. Some of these patterns may be explained by population and land use. The East Shore Area spans Davis and Weber Counties, which had a combined population in 2010 of more than 500,000 people, whereas Box Elder County had almost 50,000 people, of which the Lower Bear River Basin is less than one-fourth of the area (U.S. Census Bureau, 2019). The rate of population growth is estimated to be greater in Weber and Davis counties (10 and 15 percent, respectively) compared to Box Elder County (10 percent) from 2010 to 2018 (U.S. Census Bureau, 2019). The East Shore Area had more urban area, whereas the Lower Bear River Basin had more production (agricultural) land in 1974 and 2012 (Falcone, 2015). The East Shore Area also experienced land-use change across a greater area (20 percent) than the Lower Bear River Basin (5 percent). Further, the East Shore Area had more land converted from production to urban land over this period (13 percent compared to 1 percent in the Lower Bear River Basin).

In comparing the total number of trends using decadal and sub-decadal medians from SDWIS data in each basin across analytes, the water quality in several basins changed the most in the East Shore Area and Northern Juab Valley (three trends in each basin, fig. 22*B*). There were more increasing trends than decreasing trends for all analytes, and increasing trends among SDWIS data were more common than among NWIS and SDWIS data combined. Only Northern Juab Valley and Pahvant Valley had any decreasing trends in data from public-supply wells.

Summary

The U.S. Geological Survey, in cooperation with the Utah Department of Environmental Quality, Division of Water Quality, studied trends in arsenic, nitrate, and dissolved-solids concentrations in basins throughout Utah that have experienced substantial groundwater development. The significance and magnitude of decadal and sub-decadal (5-year) scale trends was determined using data from the National Water Information System (NWIS) and Safe Drinking Water Information System (SDWIS) datasets combined, and from the SDWIS dataset independently. Spatial variation in temporal trends and the relationship to land-use change were evaluated. Additionally, spatial patterns in concentrations and regulatory exceedances of arsenic, nitrate, dissolved solids, and other inorganic contaminants were assessed.

Data stored in the NWIS and SDWIS databases represent water samples taken at different kinds of wells; SDWIS data represent drinking water (before treatment) and NWIS data represent water used for a broader range of purposes. Trends in each basin were tested using SDWIS data separately to identify changes in water that will eventually be used for drinking water. However, combining the datasets increased the number of samples for trend analysis and captured a more complete picture of the overall water-quality conditions within a basin. Decadal and sub-decadal medians were calculated to increase the number of medians available for analysis. Although this more frequent calculation often provided enough medians for trend analysis, it also introduced increased variability in median concentrations over time that could obscure trend identification, particularly with the Mann-Kendall trend test, which identifies monotonic changes.

Changes in decadal and sub-decadal median arsenic, nitrate, and dissolved-solids concentrations over time occurred throughout the basins in this study. Significant trends in arsenic were identified in the Beryl-Enterprise Area, East Shore Area, Utah Valley, Pahvant Valley, Parowan Valley, and Sevier Desert. Rates of median-concentration change ranged between decreases of –0.24 microgram per liter (ug/L) per year and increases of 0.48 ug/L per year across basins and sub-basins. Significant nitrate trends were identified in the Beryl-Enterprise Area, East Shore Area, Milford Valley, Lower Bear River Basin, Northern Juab Valley, Salt Lake Valley, and Utah Valley. Rates of median-concentration change ranged between decreases of –0.08 milligrams per liter (mg/L) per year and increases of 0.02 mg/L per year across basins and sub-basins. More basins had decreasing trends than increasing trends in nitrate. Significant trends in dissolved solids were identified in Milford Valley, Cache Valley, and parts of the East Shore Area, Salt Lake Valley, and Utah Valley. Rates of median-concentration change ranged between decreases of –5 mg/L per year and increases of 7 mg/L per year across basins and sub-basins. Changes within sub-basins can drive or be obscured by inclusion of data from a larger basin. The rates of change for nitrate and dissolved solids were below or similar to rates of change observed nationwide and in the southwestern United States. The similarity between rates of change in Utah and Central Valley, California, is noteworthy in that nitrogen fertilizer application rates and population were substantially higher in the Central Valley.

Public-supply wells experienced a number of increasing trends, particularly for nitrate and dissolved solids. Many of the basins experienced trends in similar direction for nitrate and dissolved solids. The Salt Lake Valley Southeast experienced increases in arsenic, nitrate, and dissolved solids. Increasing trends were more common among data from public-supply wells than among data from all well types combined.

Broad land-use change, as well as population growth, was associated with water-quality changes over time, and land-use change at wells was more loosely associated with trends. However, this was in part affected by a lack of data from wells experiencing different kinds of land-use change. Information about land-use change provided insight into drivers of water-quality changes. Land-use changes directly at wells were only one component of the range of factors that impacted water quality at a well, including land and water use over a larger area surrounding and up-gradient from the well, rates and direction of groundwater movement, and geologic and hydrologic conditions. The controls on groundwater quality were complex and included spatial and temporal variability in the local hydrology, land use, and other human activities. Increasing trends identified in this report occurred in areas that had experienced land-use change, population growth and associated development, and substantial groundwater use. Basins where concentrations of arsenic, nitrate, or dissolved-solids concentrations increased represent areas of potential concern, whereas basins where concentrations decreased represent areas where improvements occurred. Human activity has impacted groundwater quality in Utah, and may continue to do so as the state's population continues to grow.

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