Aqua TROLL® Instrument Tracks Saltwater Intrusion and Provides Real-Time Data and Event Notification

Conductivity measurements can be used as a surrogate for chloride concentration

Application

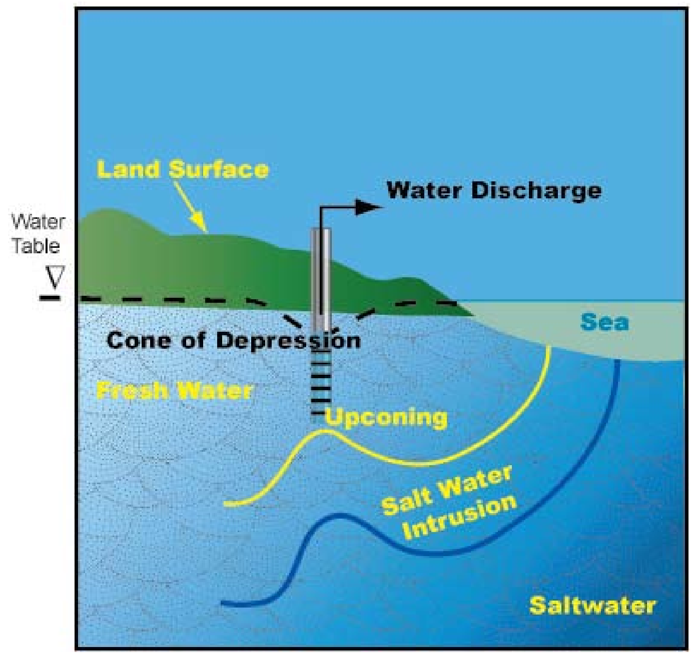
Saltwater intrusion, the movement of saline waters into freshwater aquifers, most commonly occurs along coastlines. Many coastal areas are monitoring saltwater intrusion due to growing populations, increasing agricultural and industrial needs, and expanding tourism. Saltwater intrusion decreases freshwater levels in an aquifer and can lead to abandonment of supply wells. Some prominent areas facing saltwater intrusion include the Mediterranean, the Middle East, Los Angeles and Orange Counties in California, and the Atlantic Coast of the United States.

Inland areas can also experience saltwater intrusion. Many deeper aquifers in the central part of the United States contain saline waters. Withdrawing water from overlying aquifers increases the potential for saltwater intrusion from below. For example, along the Mississippi River alluvial plain in Arkansas irrigation withdrawals from the Sparta aquifer have caused upward movement of saline water (Morris et al. 1986).

Understanding saltwater intrusion

Due to their close proximity to saltwater, coastal groundwater supplies, when overused, are vulnerable to chloride contamination. The secondary maximum contaminant level established by the U.S. Environmental Protection Agency (USEPA) for chloride in drinking water is 250 mg/L. Because of the high concentration of chloride in seawater, less than a 2 percent contribution of seawater mixed with fresh groundwater will raise the chloride concentration above the USEPA guideline (Barlow 2003).

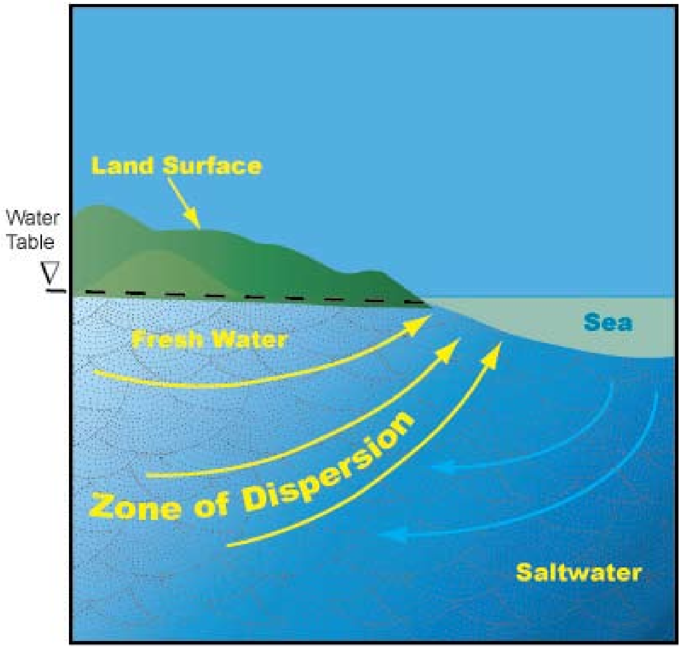
Less dense fresh water tends to flow on top of surrounding or underlying saline groundwater. Under natural conditions, freshwater moves toward the ocean and prevents saltwater from encroaching into coastal aquifers. Freshwater and saltwater zones of coastal aquifers are separated by a transition zone (zone of dispersion or zone of diffusion). In this zone, a gradation from fresh to saline water occurs.



Vertical movement or upconing of saltwater

When groundwater pumping rates exceed the aquifer's ability to recharge and when pathways for natural recharge are reduced by urbanization, the transition zone moves inland, and saltwater is drawn toward the freshwater zones of an aquifer. Saltwater can contaminate freshwater aquifers when one or more of the following mechanisms occur:

- Lateral or horizontal intrusion occurs when excessive water withdrawals from an aquifer cause saline water from the coast to move inland.
- Vertical movement or upconing of saltwater can



Fresh water moves toward the ocean and prevents saltwater from encroaching into coastal aquifers.

occur near a discharge well when water moves toward the wellhead and saltwater in the deeper aquifers rises up.

- Cross-aquifer contamination can be caused by wells that are open to multiple aquifers or have casings that have been corroded or broken (Prinos et al. 2002).

Saltwater intrusion into an aquifer depends on many factors, including:

- Total rate of groundwater withdrawals compared to recharge rates
- Presence of freshwater drainage canals that lack salinity control structures
- Distance of stresses, such as wells and drainage canals, from the source(s) of saltwater intrusion
- The length of time that aquifer levels are lowered. For example, the South Florida Water Management District found that if water levels were lowered for more than six months, permanent inland movement of the saltwater interface occurred (Prinos et al. 2002).
- Fluctuations in tide stages
- Seasonal and annual variations in groundwater recharge and evapotranspiration rates
- Geologic structures and the distribution of hydraulic properties of an aquifer—presence of confining units can prevent saltwater intrusion
- Long-term changes in sea level and climate.

Determining chloride concentration

To determine chloride concentration, several analytical methods are available. Chloride ion-selective electrodes (ISEs) can be used to monitor chloride in the field. However, using an ISE for long-term deployment has several drawbacks, including the need for frequent recalibration. Instrument drift typically begins within hours of recalibration.

Titrimetric methods for determining chloride concentration are less precise than conductivity measurements (Farland 1975), are often time-consuming, and are not practical for continuous monitoring. Reagents for seawater analysis are hazardous (e.g., mercuric nitrate, silver nitrate) and require appropriate disposal. Interferences may require neutralization or elimination.

Ion chromatography is the preferred method for determining chloride because it is accurate, eliminates the use of hazardous reagents, distinguishes among halides, and provides a single instrumental technique for rapid, sequential measurement (Eaton et al. 2005, pp. 4-3, 4-70). However, unlike conductivity sensors, ion chromatography is not suitable for field applications or real-time monitoring.

Using conductivity as a surrogate for chloride offers advantages

According to the U.S. Geological Survey (USGS), no standard practice exists for defining the transition zone. However, the USGS typically characterizes the transition zone as having total dissolved solid (TDS) concentrations ranging from about 1,000 to 35,000 mg/L and chloride concentrations ranging from about 250 to 19,000 mg/L.

Chloride is the main constituent of seawater with an average concentration of 19,000 mg/L (Hem 1992). Due to the high concentration of chloride in seawater, the chloride concentration of groundwater samples is the most commonly used indicator of saltwater occurrence and intrusion into coastal aquifers.

Specific conductance (SC) of groundwater can also be used to identify saltwater intrusion because it is a direct measure of TDS and salinity. SC also has been shown to be strongly correlated to chloride concentrations. Chloride, one of the main constituents of seawater and a charged ionic species, makes water conductive. As chloride concentrations increase, so does the solution's conductivity. A rather well-defined relationship exists for SC and chloride (Hem

Lee County Utilities (LCU) in southwest Florida is pioneering an ambitious Aquifer Storage and Recovery program. LCU will use self-powered Aqua TROLL® 200 Instruments to monitor and communicate well level and specific conductivity measurements by SCADA or cellular telemetry. A RuggedReader® Handheld PC with Win-Situ® Mobile Software allows operators to review and evaluate measurements onsite.

1992; Christensen et al. 1999), which implies a linear relationship between these two parameters.

The USGS notes that SC and chloride usually have a long and reliable analytical record and are useful for evaluating long-term trends. Using chloride concentration as an indicator of saltwater intrusion offers several advantages:

- Both SC and chloride are chemically and biologically conservative, or stable, water quality indicators and tracers.
- Chloride moves at about the same rate as the intruding seawater and is not retarded by the aquifer matrix (Roberts et al. 1986).
- Circulation of the chloride ion occurs largely through physical processes rather than chemical or biochemical processes (Hem 1992).

Chloride is least affected by movement away from the source and provides a true representation of contamination levels.

Developing a chloride-conductivity relationship

The conductivity sensor is a proven, stable method for measuring SC. Using conductivity as a surrogate for estimating chloride concentrations in seawater offers several advantages over currently available analytical methods. Conductivity sensors do not require hazardous reagents, have minimal maintenance and calibration requirements, and are not sensitive to drift, fouling, and other instabilities.

Using conductivity as a surrogate for chloride estimation and developing chloride-conductivity relationships provides more reliable and robust data sets and decreases manual data collection (Shingle Creek 2006). A surrogate is a sensor measurement that can be monitored continually and used to estimate concentrations of a certain water-quality parameters for which continual data are not available or not practical. Using surrogates decreases manual data collection and provides real-time information on a system's physical properties (Christensen et al. 1999).

Regression results can provide reasonable estimates for chloride in a given system (Hem 1992). An established regression equation may be used for all monitoring stations in an area (Cain 1987). Regression models can have disadvantages in that the predictive ability of the regression model is a function of the number and distribution of available measurements from the population being studied (Granato et al. 1999).

Monitoring chloride in real-time

Chloride-concentration profiles of several monitoring sites distributed along a coastline can determine changes in the transition zone and the degree of saltwater intrusion. Continuous, long-term monitoring of SC can alert water managers to a potential saltwater intrusion problem and upconing of saltwater resulting from aquifer withdrawals. Continuous chloride monitoring via SC can be used to:

- Understand the degree of saltwater intrusion
- Evaluate the relative quality or potability of water
- Monitor acute and chronic exposure levels in freshwater supplies
- Evaluate aquifer recharge and recovery operations
- Trace chloride in groundwater studies
- Conduct chloride profiling

The In-Situ® Inc. Aqua TROLL® 200 Instrument offers accuracy, reliability, and powerful remote monitoring capabilities for conductivity, salinity, total dissolved solids (TDS), water level, and temperature. The Aqua TROLL 200 typically requires no calibration. For saltwater intrusion monitoring programs and chloride monitoring networks, the Aqua TROLL 200 simplifies data collection and provides data that can be reliably correlated to

The Aqua TROLL 200 Instrument includes conductivity, level/pressure, and temperature sensors. The Aqua TROLL 100 Instrument includes conductivity and temperature sensors. Derived parameters available include actual conductivity, specific conductivity, salinity, total dissolved solids, resistivity, and density.

chloride concentration (see In-Situ white paper, *Verifying the Use of Specific Conductance as a Surrogate for Chloride in Seawater Matrices*).

With telemetry-ready options built into the instrument, you can download data from remote locations and deploy the instrument for long periods without the need for external power. The device's titanium housing safeguards against corrosion. With a TROLL® Link Telemetry System and the instrument's event mode, you can receive instant notification of spikes in freshwater aquifer conductivity due to penetration of saltwater. The event mode triggers the instrument to start logging and to alarm designated personnel.

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