Smart Groundwater Management:
Real-Time Nitrate Monitoring for Safe and Sustainable Water

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Abstract

Nitrate contamination in groundwater, particularly in agricultural regions, poses a critical challenge for drinking water safety. Elevated nitrate levels reduce blood oxygen-carrying capacity, presenting serious health risks (2, 3, 4), especially for children. Ensuring compliance with stringent drinking water guidelines requires accurate, continuous monitoring and proactive water management strategies (5, 6). Traditional nitrate monitoring methods, such as ion-selective electrode (ISE) sensors, often suffer from drift and cannot effectively compensate for interfering compounds (1). Reliance on grab sampling can create gaps in data and delay response to unexpected changes.

ABB's UviTec Nitrate Sensor overcomes these challenges by providing real-time, drift-free measurements using UV/VIS technology with automatic interference compensation. Combined with an automatic chemical cleaning system, it ensures reliable, low-maintenance operation. Continuous monitoring at key points including raw water intake, post-blending, pre- and post-treatment enables operators to optimise blending, improve treatment efficiency, and reduce operational costs. This paper presents a case study demonstrating how continuous nitrate monitoring supports utilities managing multiple groundwater wells to maintain finished water below regulatory limits while achieving operational efficiency and cost savings. Groundwater is a vital source in many Australian regions including WA, SA, inland NSW, QLD and NT,where real-time monitoring helps optimise resource management, protect public health, and ensure sustainable, efficient water operations (6, 7, 8, 9).

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1. Introduction

Groundwater sources are critical for drinking water supplies globally. In agricultural regions, elevated nitrate concentrations are common due to fertiliser runoff, animal waste, and natural geochemical processes (8, 9). Regulatory standards, such as the 10 mg/L NO_3-N limit in the U.S., require utilities to carefully manage water quality.

In Australia, the Australian Drinking Water Guidelines (ADWG) provide a health-based guideline for nitrate of 50 mg/L NO_3^- (approximately 11.5 mg/L as N) and a guideline of 3 mg/L for nitrite (5). These are not legally enforceable but serve as critical benchmarks for state and territory regulators and utilities. Typical reticulated supplies in Australia have nitrate concentrations well below guideline levels, commonly below 0.15 mg/L NO_3^-, though rural groundwater systems have been observed to have much higher levels (6, 8).

The high sensitivity of certain communities to nitrate underscores the importance of reliable monitoring systems (2, 3, 4). Aligning the outcomes of this New York State case study with Australian conditions, continuous nitrate monitoring can help groundwater utilities ensure compliance with guideline limits, optimise blending, detect deviations early, and safeguard public health.

Conventional monitoring methods, including grab sampling and ISE sensors, face limitations such as drift, delayed response, and inability to compensate for interferences (1). These shortcomings hinder timely operational decisions, affecting both water quality compliance and treatment efficiency. Continuous, real-time monitoring of nitrate provides actionable insights to manage multiple water sources, optimise blending, and detect sudden spikes in nitrate concentration.

The 2016 New York State case study demonstrates how ABB's UviTec Nitrate Sensor enabled reliable, automated monitoring at a groundwater well station, allowing operators to maintain safe water quality, optimize operations, and realize cost savings.

2. Methodology

2.1 Site and System Description

A groundwater utility in New York State, supplying water from hundreds of wells across a rural region, required real-time monitoring to ensure consistent compliance with drinking water regulations for nitrate. Within the network, some wells exhibited elevated nitrate concentrations while others remained low. To manage this variability, the utility employed a blending strategy mixing water from high and low nitrate wells to produce finished water with nitrate concentrations well below the regulatory limit of 10 mg/L NO_3-N. For additional safety and operational consistency, the blended water was typically maintained around 5 mg/L

Monitoring Period: April 2016 onwards

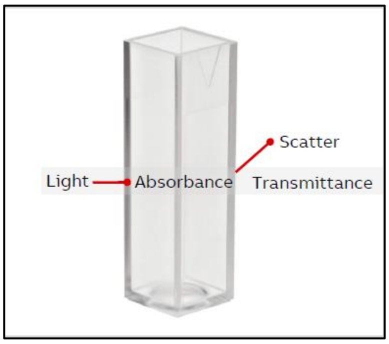
Analyser : ABB UviTec Nitrate Sensor and a competitor system

Installation Point: Before the treated water is pumped into the distribution network, key parameters such as pH, residual chlorine, and nitrate are continuously monitored (Figure 1). Real-time monitoring serves as a critical decision-making tool, delivering water quality data within minutes and enabling the utility to optimise blending of multiple wells without compromising the quality of the final supply. In contrast, reliance on third-party laboratory analysis for nitrate would introduce delays of several days, significantly limiting the utility's ability to adjust blending strategies in response to changing nitrate concentrations.

Figure 1: One of the many sites the utility extracts groundwater from. At this site, the water is drawn from three wells, one of which has a high concentration of nitrates, blended, chlorinated in Chem Building, and monitored for pH, residual chlorine and nitrates before being pumped to the consumers.

2.2 Analytical Approach

ABB's UviTec Nitrate Sensor utilises UV/VIS spectroscopy to provide continuous and accurate nitrate measurement, offering significant advantages over conventional monitoring techniques (1, 4). Nitrate ions exhibit strong absorption in the ultraviolet range, typically between 200-220 nm. The quantitative relationship between absorbance and concentration follows the Beer Lambert Law:



Absorbance (A) = a(λ)*b*c
a(λ) = absorptivity at a certain wavelength λ
b = path length
c = concentration

Figure 2: UV-Vis Principle

This relationship forms the foundation for UV/VIS nitrate measurement in ABB's UviTec sensor. By using reference wavelengths to compensate for organic and particulate interferences, the instrument ensures accurate determination of nitrate concentration in real time.
Common interferences such as organics, nitrite, iron(II), turbidity, and suspended solids are automatically compensated for by measurements at additional reference wavelengths in the UV-VIS spectrum where interfering compounds absorb but nitrates do not.

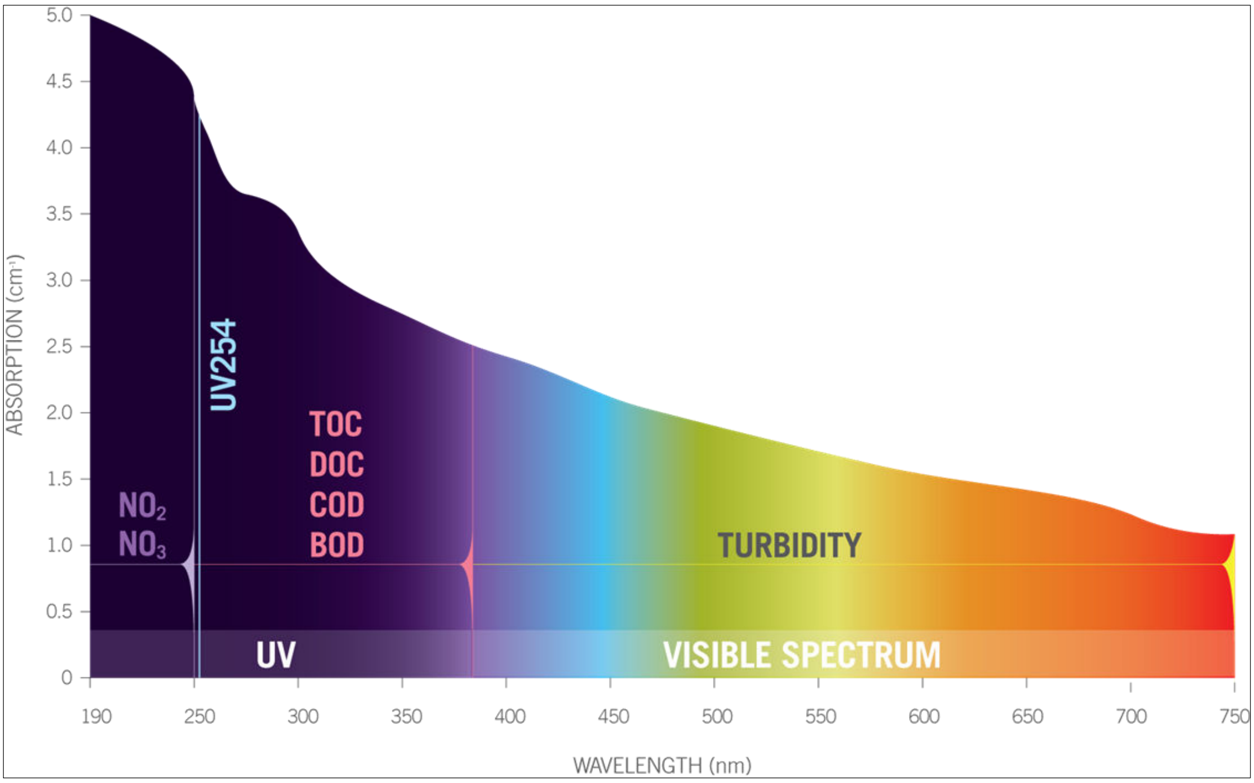


Figure 3: UV/VIS Spectrophotometric Principle for Nitrate Measurement

The sensor benefits from ABB's Split-Sense Pro technology, which compensates for lamp drift and fluctuations, providing accurate and stable output over time. To maintain long-term accuracy, the system employs automatic chemical cleaning that prevents fouling and eliminates drift, reducing the need for manual intervention.
The competitor system trialed also incorporated automatic cleaning however, it demonstrated persistent baseline drift due to less effective fouling prevention. The primary fouling mechanism in groundwater systems is mineral deposition, which is more effectively removed by chemical cleaning agents than by physical agitation methods (1). The UviTec platform supports both cleaning modes depending on site requirements.

2.3 Operational Procedure

The UviTec Nitrate Sensor was installed at the well station and integrated with the utility's data acquisition system. Water from high- and low-nitrate wells was blended in real time, guided by sensor readings. Data were used to optimise blending ratios, adjust treatment processes, and ensure compliance with regulatory limits (5).

3. Discussion

3.1 Key Challenges

3.1.1 Non-compliance Risk: Utilities must maintain nitrate below 10 mg/L NO_3-N (5). Sudden spikes from high-nitrate wells could jeopardize compliance.
3.1.2 Inaccurate Readings: Traditional sensors suffer from drift and interference, while grab sampling may miss transient events (1, 4).

3.2 Sensor Performance and Benefits

During the trial, ABB's UviTec Nitrate Sensor consistently provided reliable, drift-free measurements, ensuring confidence in data accuracy over an extended period. The automatic cleaning system prevented fouling and eliminated baseline drift issues observed in competing systems.

With real-time nitrate concentration data, operators were able to respond immediately when high-nitrate wells were brought online, enabling precise control of blending ratios to maintain finished water below regulatory limits (5). Continuous monitoring proved valuable for detecting short-term fluctuations and anomalies that would have been missed by traditional grab sampling, offering a more representative understanding of water quality and supporting proactive, rather than reactive, water management.

3.4 Observations from the Case Study

As illustrated in Figure 4, spikes in nitrate concentration were consistently observed during periods when high-nitrate wells were in operation. Both sensors detected these elevated levels, but the competitor system exhibited noticeable baseline drift throughout the monitoring period. A spike near the midpoint of the trial corresponds to the time when operators manually cleaned and recalibrated the competitor sensor. Although accuracy temporarily improved, the data began drifting again shortly after. The competitor system's baseline remained around 1 mg/L, while ABB's UviTec held a near-zero baseline. Considering typical nitrate peaks at 5 mg/L, the competitor's 1 mg/L offset represents a 20% baseline error, significantly distorting long-term data interpretation.

In contrast, ABB's system maintained a drift-free, chemical-free measurement throughout the entire trial. Its automatic cleaning mechanism effectively prevented fouling, ensuring continuous, trustworthy data that enabled the utility to maintain safe blending ratios below the 10 mg/L limit. Sensor maintained a steady baseline close to 0 mg/L and was able to accurately report nitrate events. This minimized the need for labor and time intensive equipment maintenance providing significant cost savings in rural areas where groundwater pumping sites were located up to a hundred miles apart.

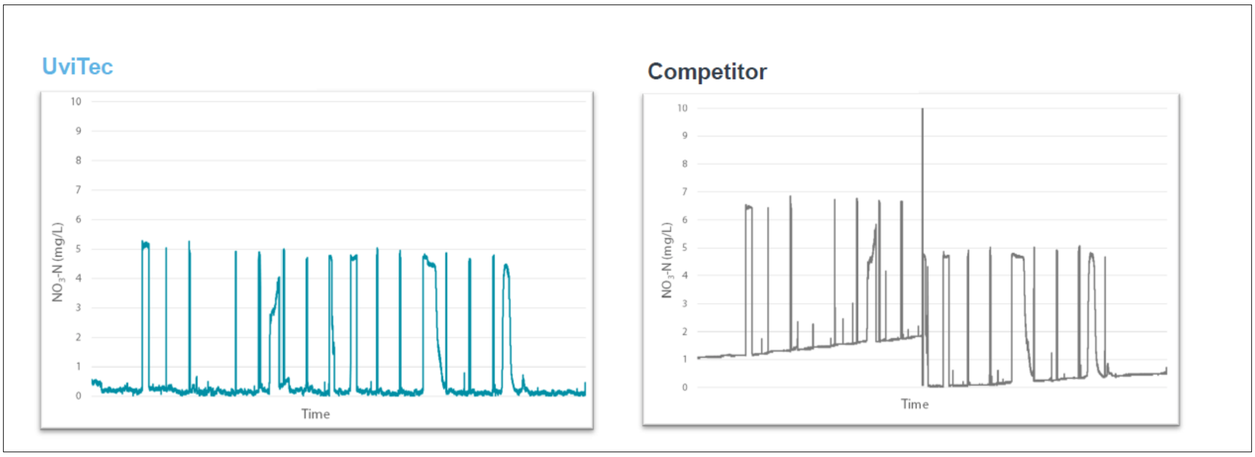


Figure 4: UviTec versus the leading competitor for nitrate analysis demonstrates our reliable long-term output without fouling and maintenance

3.5 Lessons Learned

Optical sensors are susceptible to fouling from minerals such as iron and manganese, which may be present in sufficiently high concentrations in the groundwater. Over time, the accuracy of the instrument is compromised unless there is regular cleaning. The trial demonstrated that automatic cleaning is as crucial as the sensor itself for maintaining long-term reliability. ABB Uvitec's nitrate sensors are complemented by an automatic cleaning system that takes care of mineral fouling without the need for manual work. Continuous monitoring supported proactive water management and compliance assurance. Integrating real-time data into operational decisions improved resource efficiency and reduced overall operational costs.

3.6 Treatment Efficiency and Additional Cost Savings

Monitoring nitrate in the influent and effluent of Ion Exchange and Reverse Osmosis systems can enable early detection of exhaustion, fouling, or breakthrough. This capability allows operators to optimize treatment cycles, thereby reducing chemical consumption and maintenance requirements while delivering measurable cost savings. In addition, continuous data provides confidence to adjust blending and treatment strategies proactively, which can help minimize operational risks and ensure that water quality consistently meet compliance targets.

4. Conclusion

The 2016 New York State groundwater case study clearly demonstrated that real-time nitrate monitoring using UV/VIS spectroscopy combined with automatic cleaning provides utilities with a powerful tool to safeguard drinking water quality. Continuous monitoring enabled operators to maintain finished water below regulatory limits while optimising blending of multiple wells for a safe, sustainable supply. The system improved treatment efficiency by reducing unnecessary chemical use and operational intervention, lowering overall costs. Most importantly, reliable, drift-free data gave operators greater confidence in decision-making compared with grab sampling or unstable sensors.These findings offer valuable lessons for groundwater utilities worldwide, particularly in Australia, where nitrate contamination from agriculture remains a persistent challenge (6, 7, 8, 9). By adopting continuous nitrate monitoring, Australian utilities can enhance water quality management, protect public health, and achieve more cost-effective and resilient operations.

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