Nitrate

What is it?

Nitrate (NO_3) is a water-soluble molecule that forms when ammonia or other nitrogen rich sources combine with oxygenated water. The concentration of nitrate in water is often reported as "nitrate-N" which reflects only the mass of nitrogen in the nitrate (ignores the mass of oxygen). Nitrate levels in groundwater are below 2 ppm (as nitrate-N) where pollution sources are absent. Higher levels indicate a source of contamination such as agricultural or turf fertilizers, animal waste, septic systems or wastewater.

Flooded field after manure spreading. Nutrient application on agricultural fields accounts for 90% of nitrate in groundwater. *Photo*: *Marty Nessman, DNR.*

The health-based enforcement standard (ES) for nitrate-N in groundwater and the maximum contaminant level (MCL) for nitrate-N in public drinking water are both 10 ppm (WI NR 140.10, WI NR 809.11). Everyone should avoid long-term consumption of water containing nitrate above this level.

Infants below the age of 6 months who drink water containing nitrate in excess of the MCL are especially at risk, and could become seriously ill with a condition called methemoglobenemia or "blue-baby syndrome". This condition deprives the infant of oxygen and in extreme cases can cause death. The DHS has associated at least three cases of suspected blue-baby syndrome in Wisconsin with nitrate contaminated drinking water (Knobeloch et al., 2000). In children, there is also growing evidence of a correlation between nitrate and diabetes (Moltchanova et al., 2004; Parslow et al., 2007).

Birth defects have also been linked to nitrate exposure. Several epidemiological studies over the past decade have examined statistical links between nitrate exposure and neural tube birth defects (e.g., Brender et al., 2013). Some, but not all, of these studies have concluded there is a statistical correlation between maternal ingestion of nitrates in drinking water and birth defects. Further work, including a clear animal model, would be needed to conclusively demonstrate causation. Nonetheless, these studies collectively indicate an ongoing need for caution in addressing consumption of nitrates by pregnant women and support the continuation of private well testing programs for these women.

In the human body, nitrate can convert to nitrite (NO_2) and then to N-nitroso compounds (NOC's), which are some of the strongest known carcinogens. As a result, additional human health concerns related to nitrate contaminated drinking water include increased risk of non-Hodgkin's lymphoma (Ward et al., 1996), gastric cancer (Xu et al., 1992; Yang et al., 1998), and bladder and ovarian cancer in older women (Weyer et al., 2001).

Adverse environmental effects are also well documented. A number of studies have shown that nitrate can cause serious health issues and can lead to death in fishes, amphibians and aquatic invertebrates (Camargo et al., 1995; Marco et al., 1999; Crunkilton et al., 2000; Camargo et al., 2005; Smith et al., 2005; McGurk et al., 2006; Stelzer et al., 2010). This is significant because many baseflow-dominated streams (springs, groundwater-fed low-order streams) in agricultural watersheds in Wisconsin can exhibit elevated nitrate concentrations, at times exceeding 30 ppm.

Occurrence in Wisconsin

Nitrate is Wisconsin's most widespread groundwater contaminant. Nitrate contamination of groundwater is increasing in extent and severity in the state (Kraft, 2003; Kraft, 2004; Kraft et al., 2008; Saad, 2008). A 2012 survey of Wisconsin municipal water-supply systems found that 47 systems have had raw water samples that exceeded the nitrate-N MCL, up from just 14 systems in 1999. Increasing nitrate levels have been observed in an additional 74 municipal systems. Private water wells, which serve about one third of Wisconsin families, are at risk as well. Statewide, about 10% of private well samples exceed the MCL for nitrate-N, although one third of private well owners have never had their water tested for nitrate (Knobeloch et al., 2013; Schultz and Malecki, 2015). In agricultural areas, such as the highly cultivated regions in south-central Wisconsin, around 20%-30% of private well samples exceed the MCL (Mechenich, 2015). Nitrate concentrations are poised to further increase as nitrate pollution penetrates into deep aquifers and migrates farther from original source areas (Kraft et al., 2008).

Nitrate is Wisconsin's most widespread contaminant, yet 33% of private well owners have never had their water tested for it. *Photo*: *DNR*

To mitigate nitrate contamination, municipal systems surveyed in 2012 collectively spent over $32.5 million, up from $24 million in 2004. Excessive nitrate levels have also forced the installation of treatment systems or the replacement of wells at hundreds of other smaller public drinking water systems. Owners of nitrate-contaminated private wells do not qualify for well compensation funding unless the nitrate-N level in their well exceeds 40 ppm and the water is used for livestock. In order to establish a safe water supply, these private well owners may opt to replace an existing well with a deeper, better cased well or to connect to a nearby public water supply. Alternatively, they may choose to install a water treatment system or use bottled water. In a survey of 1,500 families in 1999, the DHS found that few took any action to reduce nitrate exposure (Schubert et al., 1999). Of those who did, most purchased bottled water for use by an infant or pregnant woman. More recently, it appears that some private well owners in rural Wisconsin are installing reverse osmosis filter systems at considerable cost to obtain safe drinking water (Schultz and Malecki, 2015).

GCC Agency Actions

Nitrate has always been a core concern for GCC agencies. Over 40 projects funded by the Wisconsin Groundwater Research and Monitoring Program (WGRMP) (10% of the total portfolio) have investigated the occurrence, transport, removal or management of nitrogen in Wisconsin. In addition, multiple sampling programs have been carried out by the DNR, DATCP and the WGNHS to characterize the extent of contamination.

Since the early 1990s, it has been well-accepted that around 90% of nitrogen inputs to groundwater in Wisconsin can be traced to agricultural sources including manure spreading and fertilizer application (Shaw, 1990). In addition to regular well sampling surveys, one of the key ways that DATCP assists in addressing this problem is by supporting the development of nutrient management plans (NMPs). These plans specify the amount and timing of all nutrient sources applied to a field as well as other best practices that both optimize economic input and reduce groundwater quality impacts. Approximately 31% of the agricultural land in Wisconsin is covered by an approved management plan (DATCP, 2015). Not all farms are required to have a nutrient management plan, but DATCP provides free resources and training for farmers to encourage total coverage across the state.

A concerning pattern in many areas has been the continued increase of nitrate levels in groundwater and streams even after reduced regional use of nitrogen-based fertilizers. Several recent studies by WGRMP-funded researchers illuminate possible reasons for this. For one, long groundwater travel distances in some geologic settings mean that it can take decades for nitrate to travel to streams and wells situated deep in thick aquifers, so it will take at least that long to see a response from more recent management changes (Kraft et al., 2008). Until then, increases in nitrate levels due to historical agricultural practices are likely. More concerning is the various studies which indicate that NMPs are questionably effective at reducing nitrate levels to below the MCL. Even in the best managed agricultural systems, over the long-term (7 years) nearly 20% of nitrogen fertilizer bypasses plants and is leached to groundwater, which makes it likely that groundwater concentrations of nitrate-N at or above the MCL will continue to be a concern for Wisconsin residents (Brye et al., 2001; Masarik, 2003; Norman, 2003). That said, there is still significant potential for improvement through increased adoption of NMPs. DATCP estimated that in 2007, over 200 million pounds of nitrogen were applied to agricultural lands in excess of UW recommendations, a number that could be substantially reduced with broader adoption of NMPs.

Exploring best nitrogen management practices in on agricultural fields is a key research priority for the GCC. *Photo*: DNR

The DNR began a program in 2012 to work with stakeholders on the "Wisconsin Safer Drinking Water Nitrate Initiative". This long-term program is targeted at reducing nitrate levels in groundwater by making the most efficient use of nitrogen in agricultural production. Activities in project areas include measuring all current nitrogen inputs and baseline groundwater nitrate levels, calculating agricultural input and production costs, determining and implementing best nitrogen management practices that optimize groundwater conditions and agricultural production efficiency, and measuring whether predicted results are achieved. Project areas include agricultural fields in Rock and Sauk Counties within watersheds where large numbers of public drinking water systems are approaching unsafe levels of nitrate contamination. DNR is currently working with stakeholders to determine and apply optimal nitrogen management systems to project areas. Monitoring of nitrogen inputs, groundwater nitrate levels, and production costs will continue and costs of nitrogen management will be compared to water treatment costs.

Future Work

Given the pervasiveness of nitrate contamination in groundwater and the seriousness of suspected human health impacts, there is a need for a better understanding of the health effects of high nitrate in drinking water. DHS will continue to monitor and review the literature on this topic, particularly with regards to links with birth defects.

Improved management strategies, technical tools, and incentives to promote efficient use of nitrogen are another top priority. The Wisconsin Safer Drinking Water Nitrate Initiative is designed to address many of these issues and will hopefully expand beyond the initial project areas in future years. Manure digesters are also emerging as an increasingly popular way to control nutrient fate and generate power.

Enhancing our ability to definitively link trends in groundwater nitrate levels to activities at individual locations is also the theme of three recently funded WGRMP projects. One study is designing a field based approach that captures the spatial and temporal variability of nitrate below agricultural fields of different soil textures. This project should help untangle variations in nitrate levels due to natural drivers and those due to management practices. Another study in Dane County will develop a numerical model that can be used to test the potential of alternate management strategies to reduce nitrate levels. A third study will investigate under what conditions microbes remove nitrate from water, which will help identify hotspots for nitrogen removal in streams across Wisconsin. Throughout all of this, continued groundwater monitoring is also needed to assess existing problem areas and identify emerging areas of concern.

Further Reading

DNR overview on nitrate in drinking water [link]

DNR overview on nutrient management planning [link]

DATCP overview on nutrient management [link]

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